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Trophic status and meiofauna biodiversity in the Northern Adriatic Sea: Insights for the assessment of good environmental status

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A B S T R A C T

The Descriptor 5 (Eutrophication) of the EU Marine Strategy Framework Directive aims at preventing the negative effects of eutrophication. However, in coastal systems all indicators based on water column parameters fail in identifying the trophic status and its effects on biodiversity and ecosystem functioning. We investigated benthic trophic status, in terms of sedimentary organic matter quantity, composition and quality, along with meiofaunal abundance, richness of taxa and community composition in three coastal sites (N Adriatic Sea) affected by different levels of anthropogenic stressors. We show that, on the basis of organic matter quantity and composition, the investigated areas can be classified from oligo-to mesotrophic, whereas using meiofauna as a descriptor, their environmental quality ranged from sufficient to moderately impacted. Our results show that the benthic trophic status based on organic matter variables, is not sufficient to provide a sound assessment of the environmental quality in marine coastal ecosystems. However, data reported here indicate that the integration of the meiofaunal variable allows providing robust assessments of the marine environmental status.

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1. Introduction

Marine ecosystems worldwide are experiencing impacts of unprecedented intensity and frequency generated by the synergistic effects of multiple stressors (Claudet and Fraschetti, 2010): these are causing severe changes in oceans' biodiversity, assemblage structure, organization and functioning (Worm et al., 2006). Marine ecosystems are characterized by complex internal dynamics and can show rapid and non-linear responses to multiple stressors (DeYoung et al., 2008). These features limit our capability to predict the trajectories of change of marine ecosystems in different scenarios of socio-economic development and climate change (Pastres and Solidoro, 2012).

Eutrophication, i.e., the enhanced primary production stimulated by large inputs of nutrients, is almost ubiquitous in oceans worldwide, and in the last 50 years has caused large and severe alterations of many coastal regions (Cloern, 2001; Pinckney et al., 2001). As a consequence, during the last decades, ecologists have developed tools and indicators to asses background levels of trophic status of marine coastal environments (Dell'Anno et al., 2002; Pusceddu et al., 2009). In this regard, the assessment of the trophic status of marine coastal ecosystems has been historically based on measurements of the main elements (e.g., inorganic and organic N and P), molecules (organic matter, chlorophyll-a concentrations) used as surrogates of biomass in the water column (Coelho et al., 2007) and combinations of biotic and abiotic variables (e.g. Vollenweider et al., 1998). However, changes in the trophic status of a given marine ecosystem are not only associated with increases in primary production levels, and can exert consequences at different hierarchical levels of ecosystem organization (Lotze et al., 2006). For example, increased levels of primary production can also be associated with the accumulation of large amounts of detrital (i.e. non-living) organic material, with associated changes in the biochemical composition and bioavailability of food for heterotrophs (Pusceddu et al., 2009). Moreover, in shallow marine ecosystems, where hydrodynamic forcing can modify the structure and biology of the water column at very short-time intervals (e.g. from minutes to hours), the assessment of trophic status using only variables measured in the water column can lead to misleading classifications (Izzo et al., 1997; Dell'Anno et al., 2002). In this regard, marine sediments underlying shallow waters can be considered a sort of "recorder" of the biological processes that occur in the overlying water column (Dell'Anno et al., 2002). Accordingly, the

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trophic status of marine coastal environments has been recently assessed using the quantity and biochemical composition of sedimentary organic matter (Pusceddu et al., 2007a, 2009, 2011). This approach can be even profitably applied also to the deep sea, lacking primary production (Bianchelli et al., 2008; Pusceddu et al., 2010).

Natural and anthropogenic changes in the benthic trophic status, in terms of organic matter quantity and biochemical composition, can in turn exert consequences on the composition and structure of the benthic communities (Pusceddu et al., 2011; Foti et al., 2014). In this regard, meiofauna, due to their strong sensitivity to environmental disturbances, high abundance, lack of pelagic larval dispersion and the short life cycles, have recently acquired the rank of a "wide spectrum" tool in marine environmental monitoring (Heip et al., 1985; Semprucci et al., 2015a). Indeed, meiofauna have become a common tool to assess the effects of various sources of disturbance on the marine environment (Danovaro et al., 2000; Austen and Widdicombe, 2006; De Troch et al., 2006; Semprucci et al., 2015b,c), and, in particular, to assess the impacts of benthic eutrophication (Pusceddu et al., 2007b; Mirto et al., 2014).

The Northern Adriatic Sea has been for a long time considered among the most productive and, at the same time, most environmentally compromised basins of the Mediterranean Sea (Micheli et al., 2013). In the last 30 years, the Adriatic Sea has experienced large changes in the trophic regime, structure and organization of pelagic and benthic communities also in response to current climate shifts (Kamburska and Fonda Umani, 2006; Danovaro et al., 2009; Conversi et al., 2010; Mozetič et al., 2012; Giani et al., 2012; Di Camillo and Cerrano, 2015). Nevertheless, within this basin there are still areas characterized by relatively low levels of anthropogenic impact, deserving attention for their conservation (Micheli et al., 2013).

In this framework, our aim was to investigate the reliability of previously tested variables in describing the benthic biodiversity response to variations in sedimentary organic matter quantity and biochemical composition under different levels of environmental impairment, in the Adriatic Sea coastal ecosystems. To cope with this aim, we analysed temporal variations in the quantity and biochemical composition of sedimentary organic matter (OM) and the abundance and community structure of meiofauna under three different putative levels of anthropogenic impact along the Italian coasts of the Northern Adriatic Sea. More specifically, we tested the null hypothesis by which benthic trophic status and meiofaunal communities (in terms of abundance and taxonomic composition) do not vary among sampling times and sites characterized by the presence of different levels of environmental impairment.

2. Materials and methods

2.1. Study areas and sampling

Samples were collected in the Northern Adriatic Sea, from three coastal sites: Senigallia, Falconara and Portonovo, located at 4–12 m water depths (Fig. 1) and selected as representative of three different levels and types of environmental impairment. Senigallia, located 3 km from the coast (43°45′30″N, 13°13′00′E) is subjected to commercial and touristic maritime traffic throughout the year and receives seasonally riverine inputs from the nearby Misa river. Falconara, located at about 0.6 km from the coast (43°39′00″N, 13°22′00″E) receives the inputs from the Esino river estuary and shows the presence of a petrochemical industry (refinery) located ca 1 km apart. According to the report on the quality status of coastal marine water bodies for the period 2010–2012, drawn up by the Regional Agency for the Environmental Protection of Marche

Fig. 1. Location of the sampling sites (Senigallia, Falconara and Portonovo) in the Northern Adriatic Sea. (The red dot indicates the study area). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

region (ARPAM), the ecological status for all the investigated sites was classified as "Sufficient" (see for details the report available at: http://www.arpa.marche.it/images/PUBBLICAZIONI/marino_costieri_2010-2012.pdf).

Portonovo, located ca 4.5 km apart from the coast (43°36′12″N, 13°36′42″E), is affected during the summer season by tourism and maritime traffic, and, because of its ecological peculiarity, is included within a Site of Community Importance (Natura 2000, site code IT5320006).

Sediment samples were collected by means of a Van Veen grab (sampling surface 0.15 m^2), on monthly basis from October 2011 to September 2012 (except for April and August 2012), on board of the R/V Actea. To cope with the possible bias raised by using the Van Veen grab, which may produce leaking of interstitial water during recovery, we collected samples only from deployments in which the grab resulted completely watertight. Sediment sub-samples for the subsequent analyses of organic matter (OM) and meiofauna were collected from three independent deployments of the grab by means of plexiglass corers (internal diameter 3.6 cm). Once on board, the top first 2 cm from each sediment core (three for OM and three for meiofauna) were sliced and kept at *in situ* temperature until brought to the laboratory. Analyses were carried out on the top 2-cm sediment layer since the concentration of sedimentary OM compounds as well as organisms belonging to meiofauna are typically higher in the first top centimeters of the sediments. In the laboratory, sediment samples dedicated to the analysis of organic matter were stored at −20 °C until analysis (usually within two weeks), whereas samples for meiofauna analyses were preserved with formalin (final concentration 4% in sea water filtered on a 20 μm mesh) and stained with Rose Bengal (0.5 g L^{-1}) until further treatment as described below, according to Danovaro (2010).

2.2. Grain size

Aliquots of sediment were treated with 10% hydrogenperoxide in a large beaker for 24–48 h and dried in the oven at 60 °C for an additional 24 h. The sediment was then sieved through a 63-μm sieve and the two fractions (sands >63 μm and mud <63 μm) weighed (±0.1 mg) and expressed as percentage of the initial total dry weight (Pusceddu et al., 2010).