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Assessing eutrophication in the Portuguese continental Exclusive Economic Zone within the European Marine Strategy Framework Directive

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ABSTRACT

This study reports the state and causes of eutrophication in the Portuguese continental Exclusive Economic Zone (EEZ), during a 14-year period (1995–2008), following the European Marine Strategy Framework Directive (MSFD) and using the trophic index TRIX for an integrated evaluation of indicators of eutrophication, and identifies areas where monitoring is needed to improve the eutrophication assessment. A non-continuous dataset for the 8 indicators specified by the MSFD for eutrophication assessment was used, including published and grey data. Eutrophication indicators were validated and thresholds reviewed, considering regional differences. The diatom:flagellate ratio was found a poor indicator of eutrophication as shifts in the diatom:flagellate ratio naturally occur associated with alternating water column turbulence and upwelling, and stratification, and therefore, could not be associated with anthropogenic nutrient enrichment effects. Assessment areas were, as a whole, classified as non-problem areas concerning eutrophication. Although nutrient enrichment was observed in coastal waters, related to river plume influence, nutrient enrichment direct and indirect effects were generally not detectable, possibly due to water column dispersion and mixing processes. Only occasionally, mild eutrophication was found in specific areas under the influence of major river (Douro, Vouga and Guadiana) plumes, associated with high nutrient and phytoplankton biomass levels and seagrass decline, which indicates the need for directed monitoring on eutrophication in those areas.

1. Introduction

Eutrophication, defined as "the enrichment of water by nutrients, especially compounds of nitrogen (N) and/or phosphorus (P) causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned" (Ferreira et al., 2010), has been one of the most important causes of water quality impairment and a major threat to the health of estuarine, coastal and marine ecosystems, for more than four decades (Ryther and Dunstan, 1971; Nixon, 1995; Bachmann et al., 2006; Howarth et al., 2011). The increasing number of areas worldwide experiencing symptoms of eutrophication stresses the global scale of the problem (OSPAR, 2003; Bricker et al., 2007; Selman et al., 2008). Approximately 65% of Europe's Atlantic coast displays signs of eutrophication. Human activity in coastal areas has greatly accelerated the rate and the extent of eutrophication through N and P overloading (Nixon, 1995; Rabalais, 2002), triggered by point discharges (e.g. municipal and industrial effluents) and diffuse input (e.g. agricultural leaching and run-off, and atmospheric deposition) into the coastal and marine environment (Carpenter et al., 1998). Consequences of eutrophication are oxygen deficiency in bottom waters, occurrence of harmful algal blooms, benthic organism death, declines in seagrasses, and changes of biodiversity (Riegman, 1995; Smith et al., 1999; Cloern, 2001; Glibert et al., 2005). These environmental damaging events compromise the sustainable provision of services and goods by coastal and marine ecosystems (Liquete et al., 2013). According to Costanza et al. (1997) and Martinez et al. (2007), the oceans and mainly the coastal zone contribute to around 60% of the total economic value of the biosphere. Landscape, recreation activities, fish and shellfish are only a few of the services and goods threatened by eutrophication in coastal and marine areas, with dramatic impact

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on the coastal communities' subsistence and on the economy of the countries. Human-induced eutrophication can be minimized through management measures that include the reduction in nitrogen (N) and phosphate (P) loadings to coastal waters (Kemp and Goldman, 2008). However, these actions might not result into immediate recovery towards a more pristine state because eutrophication in coastal ecosystems shows various patterns of spatial inshore-offshore and along shore gradients, have intrinsic large interannual variability in both intensity and extension, particularly in areas under direct influence of major rivers (Rinaldi and Montanari, 1988; Riisgard et al., 1996). Moreover, released nutrients in these coastal marine areas may be diluted and dissipated through tidal action, currents, weather and wind conditions, and also rapid uptake by marine plants (Glibert and Goldman, 1981; Wheeler et al., 1982; Vollenweider et al., 1998), and therefore, direct measurement of water column N and P concentrations alone to estimate over-enrichment has been found useless (Lee et al., 2004). An integrated evaluation of indicators of eutrophication, particularly in the over-enrichment early stages, also including oxygen saturation and plant biomass, is thus critical for effective eutrophication assessment and management. In fact, the multidimensional nature of eutrophication means that no single variable is representative of the eutrophication status. More robust trophic state criteria or indices using multivariate approaches have been proposed, mostly for lakes (Carlson, 1977; Walker, 1979; Aizaki et al., 1981; Xu et al., 2001). The trophic state index (TSI) based on several physical, chemical and biological indicators, particularly the Carlson-type TSI, offers a suitable and acceptable method which has been widely used to evaluate lake eutrophication (Carlson, 1977). Direct transfer of limnological models unmodified to marine conditions, however, is largely inappropriate because gradients in lakes are usually modest, and limnological trophic criteria intend to characterize lakes in their entirety. The development of a trophic index (TRIX), suitably adapted to marine water features, based on Carlson's TSI, was created by Vollenweider et al. (1998), allowing to synthesize key data into a simple numeric expression to make information comparable over a wide range of spatial and temporal trophic situations. The use of this marine water adapted trophic index will greatly improve eutrophication assessments and increase the feasibility of marine ecosystem management planning.

In Europe, conventions and legislation, and more recently the Marine Strategy Framework Directive (MSFW, European Commission, 2008) have been developed to improve water quality. The MSFD establishes a framework to support marine strategies aiming to prevent deterioration or restore adversely affected marine areas, and to prevent and reduce inputs in the marine environment, to achieve or maintain Good Environmental Status (GES) by 2020, within the European Union (EU) Exclusive Economic Zone (EEZ). The directive explicitly considers eutrophication among the water quality descriptors, providing practical guidelines and methodologies (European Commission, 2008; Ferreira et al., 2011) that may be used for coastal and marine eutrophication assessment, to ensure that the specificity of each EU marine region or subregion is taken into consideration. As an EU member state, Portugal is committed to apply the integrated ecosystem-based approach provided by the MSFD, giving priority to the attainment of "good environmental status" through the assessment of the environmental descriptors, including eutrophication (Descriptor 5).

The Portuguese EEZ comprises three large areas associated with the Azores and Madeira archipelagos and the Portuguese continental EEZ which is the focus of the present work. This area in particular is part of the North-east Atlantic Ocean marine region included in the target areas defined by the MSFD, and was classified as Non-Problem Area, according to the national initial assessment report (MAMAOT, 2012) for the application of the Directive in Portugal. This study presents the outcome of a second application of the MSFD to the Portuguese continental EEZ, using an extended dataset to support a more complete coverage of coastal areas affected by river plumes of major rivers and submarine outfalls. A thorough review was undertaken of the thresholds applied for each of the Assessment Criteria, considering regional differences. The present assessment follows the MSFD recommendations as closely as possible in the light of the characteristics of Portuguese waters, but taking account of lessons learned from the first application and our developing understanding of overall ecological status. Here we hypothesize that fluctuations in eutrophication in the Portuguese continental EZZ are triggered by the seasonality of the hydrodynamic regime (e.g. river runoff) and by geographic specificities. We have employed methods that were considered to be more accurate and improve the quality of the assessment and evaluated the trophic status and water quality, following MSFD indications and also by using the trophic index TRIX.

This study investigates effective and reliable eutrophication indicators for open coastal areas, reports the trophic status and causes of eutrophication in the Portuguese continental EEZ, and identifies areas where an increased monitoring effort is needed to improve the assessment, within the scope of the MSFD. A non-continuous dataset over a 14-year period (1995–2008) for the 8 indicators specified by the MSFD for the assessment of eutrophication is presented, by gathering both published and grey data. A comprehensive assessment of eutrophication for the Portuguese continental ZEE has never been published, and therefore the results herein presented should be significantly important, at international, national and regional levels, and definitely to an integrated overview of eutrophication worldwide.

2. Materials and methods

2.1. Assessment areas

The Portuguese continental EEZ comprises 327 667 km^2 (Fig. 1) corresponding to 19% of the total Portuguese EEZ area, one of the largest in Europe. Its geography can be briefly summarized as a continental margin divided into subregions by the occurrence of seamounts, submarine canyons and abyssal plains. The shelf break occurs at depths of around 150 m throughout the region, with steep slopes in the northwest and south coasts and gentle slopes down to 1000 m off the southwest coast. From the oceanographic point of view, the main distinctive characteristics are a strong seasonal and interannual variability on the hydrology and circulation of the upper layers (0–200 m), and the influence of the Mediterranean outflow on the water mass characteristics at depths around 1000 m, also impacting the upper-layer dynamics through its interaction with the Azores Current (Peliz et al., 2007; Kida et al., 2008). A large fraction of this variability is forced by the winds and fresh water input from river runoff that change at seasonal and interannual time-scales.

At the seasonal timescale, the fluctuations are driven by the alternation between the summer northerly winds (responsible for a coastal upwelling current system along the west coast) and low precipitation regime, and the more variable winter winds with events of strong southerly winds and high precipitation (Wooster et al., 1976; Fiúza et al., 1982). In summer, coastal upwelling jets bring cold and nutrient rich subsurface waters to the surface and promote the export of shelf waters rich in organic matter into offshore oligotrophic waters (Fiuza, 1983; Haynes et al., 1993; Álvarez-Salgado et al., 2007). During winter, the river runoff is responsible for the formation of low salinity plumes, still traceable in summer, especially in the northern coast, where a higher number of coastal water bodies can be found in comparison with the remaining coastal areas