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Methods of eutrophication assessment in the context of the water framework directive: Examples from the Eastern Mediterranean coastal areas

Alexandra Pavlidou [a,*], Nomiki Simboura [a], Eleni Rousselaki [a], Manolis Tsapakis [b], Kalliopi Pagou [a], Paraskevi Drakopoulou [a], Georgia Assimakopoulou [a], Harilaos Kontoyiannis [a], Panayotis Panayotidis [a]

[a] Institute of Oceanography, Hellenic Centre for Marine Research, 46.7 km Athens-Sounio Avenue, Mavro Lithari, PO Box 712, 19013 Anavissos, Attika, Greece
[b] Institute of Oceanography, Hellenic Centre for Marine Research, PO Box 2214, 71003 Heraklion, Greece

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ABSTRACT

A set of methodological tools were tested in order to assess the eutrophication quality of selected coastal areas in Eastern Mediterranean Sea, Greece, in the context of the Water Framework Directive under various anthropogenic pressures. Three, five-step tools, namely, TRIX, chlorophyll-a (chl-a) biomass classification scheme, and eutrophication index (E.I.) were applied in oligotrophic waters for (a) the whole water column and (b) the euphotic zone. The relationship among the eutrophication assessment indices and the ecological quality status (EcoQ) assessment indices for benthic macroinvertebrates (BENTIX index) and macroalgae (ecological evaluation index-EEIc) was also explored. Agricultural activities and mariculture are the pressures mostly related to the eutrophication assessment of the selected Greek coastal water bodies. Chl-a proved to be the criterion with the best overall correlation with the EcoQ indices, while TRIX with the lowest. Moreover, among the eutrophication indices, E.I. showed better overall agreement with BENTIX showing that probably it reflects the indirect relation of macroinvertebrates with water eutrophication in a better way. Among the eutrophication indices used, TRIX rather overestimated the eutrophication status of the selected coastal areas. The first stage of eutrophication was reflected more efficiently using E.I. than TRIX, but E.I. seems to be a rather sensitive index. A future modification of the high to good boundary of E.I. may be needed in order to demonstrate the high status of the relatively undisturbed Greek coastal sites.

1. Introduction

Coastal marine environments are usually influenced by human-induced and natural pressures, which may alter their functioning, and finally contribute to ecosystem degradation and pollution problems (Jickells, 2005; Aubry and Elliott, 2006; Borja et al., 2010). The legislation developed and applied worldwide includes restoration of degraded aquatic habitats as one of the primary goals and require suitable methods to assess their quality in relation to anthropogenic impacts on marine ecosystems using various elements of the ecosystem (Borja et al., 2008, 2011, 2012; Ferreira et al., 2011). In Europe, the umbrella regulations for addressing the ecological quality of the water systems are the Water Framework Directive (WFD; 2000/60/EC), for lakes, rivers, transitional (estuaries and lagoons) and coastal waters, and the Marine Strategy Framework Directive (MSFD; 2008/56/EC) for all marine waters (Van Hoey et al., 2010). An informative work by Borja et al., (2010) presents a system of applying the experience gained from the WFD to implement the MSFD. This work outlines the points of overlap and conflict between the two directives and is regarding the WFD as a 'deconstructing structural approach' whereas the MSFD is a 'holistic functional approach', i.e. the WFD has split the ecosystem into several biological quality elements (BQEs) and evaluates them individually before combining them and attempting to determine the overall condition. The other elements (hydromorphological and physicochemical) are only used to support the BQEs.

In contrast the MSFD focuses on the set of 11 descriptors with several indicators covering the ecological, physical, chemical and anthropogenic components of the ecosystem that need to be integrated at the indicator and descriptor levels (Van Hoey et al., 2010). These 11 descriptors together summarize the way in which the whole system functions. Moreover, MSFD has established a framework for the development of strategies designed to achieve good environmental status (GEnS), which takes into account the structure, function, and processes of the marine ecosystems together with natural physiographic, geographic, and climatic factors, as well as physicochemical conditions including those

* Corresponding author. Fax: +30 2291076347.
E-mail address: aleka@hcmr.gr (A. Pavlidou).

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resulting from human activities in the area concerned (Borja and Collins, 2009).

The ecological quality status (EcoQ) within the WFD and the environmental status (ES) within the MSFD should be harmonized and the two directives should be fully and seamlessly integrated (Borja et al., 2010). To this respect, intercalibrated indices which are used under the WFD can also assess the ES within the MSFD in the respective interlinked criteria or indicators. Such an approach addressing interlinking quality elements' indicators and descriptors of both directives has been applied in several cases i.e. the Basque country (Borja et al., 2011) and Greece (Simboura et al., 2015). The intercalibrated and interlinked indicators used in the present work are the chlorophyll-a (chl-a) biomass (pertaining to eutrophication descriptor 5) and the benthic and macroalgae indices (pertaining to biodiversity and sea floor integrity descriptors, namely, D1 and D6, respectively).

Regarding the eutrophication, the WFD intends to improve the ecological status, including eutrophication status, of all European surface waters of which many are considered to be eutrophic (European Environment Agency, 2001, 2003). However, according to Andersen et al. (2006), the WFD does not explicitly consider eutrophication because the treatment of eutrophication is indirect with the boundary between good and moderate ecological status being defined as an environmental management objective. Consequently, the need for a common understanding and definition of eutrophication, as well as, the need for stronger coordination between directives dealing directly or indirectly with eutrophication has been emerged (Andersen et al., 2006; Ferreira et al., 2011). It is important to point out that the WFD is a dynamic directive and permits further incorporation of new methodologies, or improvements of those already applied (Revilla et al., 2009). On the other hand, MSFD takes a functional approach to eutrophication establishing it as one of the 11 holistic quality descriptors, namely, descriptor 5 (MSFD; 2008/56/EC; Ferreira et al., 2011). This is important because eutrophication problems have been reported from a wide variety of coastal ecosystems (Justic et al., 2005; O' Higgins and Gilbert, 2014).

The guidance for the descriptor 5 (D5) defines that most eutrophication assessment methods recognize that the immediate biological response is increased primary production reflected as chl-a and/or macroalgal abundance (Ferreira et al., 2010). These are "direct effects" or "primary symptoms" and indicate the first stages of eutrophication. "Indirect effects" or "secondary symptoms" such as low dissolved oxygen (DO), losses of submerged aquatic vegetation (SAV), changes in macrozoobenthic species composition, and occurrences of nuisance and toxic blooms indicate more advanced problems.

Various methods have been developed in the EU to assess eutrophication in order to fulfill requirements of legislation designed to monitor and protect coastal water bodies from degradation. Some methods use only chl-a concentrations, while in others chl-a concentrations are combined with other parameters to give a more integral picture of eutrophication (Borja et al., 2012). However, in many cases the various methods give different assessment results in terms of classes when they are applied to the same water body. In such cases, we have to decide which method is more efficient and representative of the condition in determining the eutrophication status (Borja et al., 2012).

The Eastern Mediterranean Sea has always been considered as one of the most oligotrophic areas in the world with extremely low nutrient concentrations, 12 times lower than the Atlantic Ocean (Pavlidou and Souvermezoglou, 2006; Krom et al., 2010). Despite the oligotrophic character of the Mediterranean Sea, elevated nutrient concentration indicates coastal eutrophication problems because several coastal areas undergo intense and continuous environmental pressure derived from a number of driving forces such as urbanization, industrialization, changes in land use, tourism development, aquaculture development, climate change, and others (Pavlidou and Souvermezoglou, 2006; UNEP, 2007; Halpern et al., 2007; Karydis and Kitsiou, 2013; Aguilar et al., 2014; Levin et al., 2014; Newton et al., 2014). In Greece, more than 80% of the industrial activities and 90% of tourism activities are located along the coastline (Anagnostou et al., 2005). Athens and Thessaloniki, the two biggest cities of Greece, exceeding 4 and 1 million people, respectively, are also located on the coastal zone and influence the functioning of Saronikos and Thermaikos ecosystems, in the central and northwestern Aegean Sea, respectively (Anagnostou et al., 2005; Karageorgis et al., 2005; Konstantinou et al., 2012; Pavlidou et al., 2014).

This study was conducted in selected coastal areas of Greece, influenced by the human activities and which are subjected to different types of pressure. The eutrophication status of these areas was studied using different indicators and different methodological approaches in the context of WFD. The WFD tries to combine both aspects of pressures and biological elements (water and benthic) into a sole ecological status. In these terms, results of the eutrophication status of the coastal water bodies were juxtaposed and compared to the benthic indices results.

The objectives of this work are (i) to identify, evaluate, and map the different types of pressures affecting each area; (ii) to assess the eutrophication status of the studied coastal areas based on three different assessment principles and methods usually applied in Greek ecosystems; (iii) to compare the resulting classifications and evaluate them; (iv) to compare the eutrophication status with the benthic status of the coastal areas and investigate whether there is a good link between them or not.

2. Materials and methods

2.1. Monitoring program

WFD requires that EU member states must regularly monitor and report on the condition of the coastal water bodies within their jurisdiction (Ferreira et al., 2007). However, reviewing the objectives and requirements of marine water quality monitoring, Karydis and Kitsiou (2013) highlighted the scarcity of the marine monitoring programs.

A national monitoring program for coastal waters is undertaken and run by the Hellenic Centre for Marine Research (HCMR) in Greece (Simboura et al., 2015). The monitoring network has been designed for the implementation of WFD in coastal waters and is delegated by the Greek water management authorities. The Greek authorities report annually on the water quality status to the European Environment Agency providing data sets of physical characteristics and concentrations of inorganic and organic nutrient, organic matter, chl-a, macroalgae and macroinvertebrates and hazardous substances together with the characterization of the main pressures and impacts from human and other activities at each monitoring station, according to Annex V of WFD 2000/60/EC (Anonymous, 2012).

For this study, we have used data from 27 coastal monitoring stations located in 15 water bodies of Greece which are subjected to different types of anthropogenic pressures. Among them, the station in Limnos Island in the Aegean Sea receives very minor anthropogenic pressures (Fig. 1; Table 1; see Section 2.2). In this work, we used data from five sampling periods during 2012–2014 (March–April 2012; November 2012; March–April 2013; November 2013; March–April 2014).

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