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Ecological quality scales based on phytoplankton for the implementation of Water Framework Directive in the Eastern Mediterranean

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ABSTRACT

Structural changes of phytoplankton communities, often expressed through ecological indices, constitute one of the metrics for the implementation of the European Water Framework Directive (WFD). In the current study a thorough analysis of the efficiency of 22 ecological indices was performed and a small number was selected for the development of five-level water quality scales (High, Good, Moderate, Poor, and Bad). The analysis was performed on simulated communities free of the noise of field communities due to uncontrolled factors or stochastic processes. Two criteria were set for the sensitivity of indices, namely their monotonicity and linearity across the studied eutrophication spectrum. The whole procedure was based on the development of a five-level quality assessment scheme based on phytoplankton abundance. Among the indices tested, the Menhinick diversity index and three indices of evenness were the most efficient, showing consistency (monotonic behavior) and linearity and were therefore used for the development of quality scales for the WFD. An Integrated Phytoplankton Index (IPI) based on three phytoplankton metrics, chlorophyll a, abundance, and diversity is also proposed. The efficiency of these indices was evaluated for a number of sites in the Aegean, already classified in the past by various methods based on nutrient concentrations or phytoplankton data. The results indicate that the various phytoplankton metrics (chlorophyll a, abundance, and diversity) assessed or proposed in the current study, carry their own information showing differences in the final classification of areas. Therefore the establishment of synthetic indices as the IPI seems to be advantageous for the integrated assessment of coastal water quality in the framework of European policies as the WFD.

1. Introduction

Surface waters including streams, rivers, lakes, estuaries, and coastal waters are under increasing ecological stress due to anthropogenic activities worldwide (UNEP, 1999), leading to the enforcement of major environmental policies, including the US Federal Water Pollution Control Act (2008), the US Oceans Act (2000), the European Water Framework Directive 2000/60 (EC, 2000), and the European Marine Strategy (EC, 2008). The implementation of the Water Framework Directive (WFD) in particular, both regionally and nationally, assumes the development of a five-level water quality classification scheme (High, Good, Moderate, Poor, and Bad) with the environmental objective to achieve good surface water status for all European waters by 2015 (EC, 2000). The levels are defined using the Ecological Quality Ratio (EQR) for a number of biological and chemical quality elements. Among the key biological elements specified for coastal waters, the only planktic element referred to in the WFD is phytoplankton. Phytoplankton is an efficient indicator of changes in nutrient loads, but is also effective in evaluating responses to many other environmental stressors, due to its fast population response to changes in water quality, hydrology or climate (Domingues et al., 2008). According to the European Directive (EC, 2000), phytoplankton metrics that are fundamental in defining and classifying the ecological status of surface waters are biomass (as chl a), community changes (composition and species abundance), and increase in the frequency and intensity of blooms.

Phytoplankton has been considered as a water quality key-element in many studies for coastal ecosystems. A synthetic approach for water quality assessment in the Atlantic Ecoregion (Basque country), involved the development of an integrated index based on chlorophyll a, phytoplankton total abundance (when exceeding 10^7 cells/L), and abundance of harmful phytoplankton species (Borja et al., 2004; Revilla et al., 2009; Vincent et al., 2002). For the North Sea and the Atlantic Ecoregions (British coastal waters), Devlin et al. (2007) developed an Integrated Phytoplankton Index taking into account phytoplankton biomass (as chl a), the frequency of elevated phytoplankton counts (individual species

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and total cell counts), and seasonal progression of functional groups. Regarding the coastal waters of the Eastern Mediterranean Ecoregion, one of the most oligotrophic marine environments around the world (Krom et al., 1991), chlorophyll a is the only parameter taken into consideration so far for WFD implementation (Simboura et al., 2005). The limits set by these authors are below 0.10 μg/L of chl a for High water quality, 0.10–0.40 for Good, 0.40–0.60 for Moderate, 0.60–2.21 for Poor and above 2.21 for Bad water quality. Chlorophyll concentrations represent a simple and integrative measure of the phytoplankton community response to nutrient enrichment or succession (Devlin et al., 2007; Harding, 1994). However, community structure (i.e. the distribution of individuals to species) conveys different information by also considering heterotrophic species that are not represented in chlorophyll measurements (Domingues et al., 2008). Moreover, previous studies have demonstrated that an increase in chlorophyll a due to eutrophication is always accompanied by changes in phytoplankton community structure in terms of total abundance, species richness, and evenness (Tsirtsis and Karydis, 1998; Tsirtsis et al., 2008). For phytoplankton abundance, a four-level classification system was developed in the past for Eastern Mediterranean coastal waters (Kitsiou and Karydis, 2000). The limits set were <4160 cells/L for oligotrophy, 4160–31,399 cells/L for lower mesotrophy, 31,400–188,333 cells/L for higher mesotrophy, and >188,334 cells/L for eutrophication. However this scale has not been adjusted so far to the five-level system required by the WFD.

Changes in community structure are often quantified through a number of indices which constitute popular tools in studies associated with community ecology and disturbance (Washington, 1984). The most important advantages provided by indices are the ability for direct comparisons between communities that have few or no species in common and the easiness of their application and interpretation (Magurran, 2004). Alternative methods to taxonomic-based indicators related to body size, abundance distribution among functional groups, functional diversity, and productivity descriptors have been found suitable for other biological quality elements (Mouillot et al., 2006). However, for phytoplankton, productivity and species-abundance data are considered so far the most effective means to explore changes in community structure (Mouillot et al., 2006). In the framework of new policies for water quality assessment, investigators should retain a parsimonious approach, assessing the suitability of existing indices rather than developing new ones (Borja and Dauer, 2008; Diaz et al., 2004). In addition, the evaluation of water quality status should ideally incorporate suitable multimetric indices (Borja and Dauer, 2008; Diaz et al., 2004; Domingues et al., 2008) taking into consideration as many of the fundamental attributes of phytoplankton as possible (i.e. biomass, community structure, and frequency of blooms).

An important shortcoming in the development process of water quality assessment schemes is the inherent noise or variability of field data associated with seasonality, hydrodynamic circulation, grazing, and patchiness (Karydis, 1996) or stochastic processes (Mouillot and Lepretre, 2000). This variability masks and distorts the information associated with a particular stressor or process of interest (Karydis, 1992) and therefore is considered as undesirable, especially in water quality assessment schemes which are often based on annual means. An alternative approach in the assessment of water quality can be based on the use of simulated communities (Boyle et al., 1990; Mouillot and Wilson, 2002) that retain the main structural characteristics of natural communities. The elimination of noise in the simulated communities reveals the signal, and therefore supports the quantification of the community response to environmental stressors. Previous studies have demonstrated that phytoplankton communities can be successfully modeled using statistical distributions such as the lognormal and log series (Tsirtsis et al., 2008) along a wide spectrum of productivity, from oligotrophy to eutrophication, characteristic of Eastern Mediterranean coastal waters.

The present study aims to assess the sensitivity of 22 ecological indices of phytoplankton diversity to efficiently detect eutrophic trends in Eastern Mediterranean coastal waters, and thus their applicability in the Water Framework Directive. The development and use of simulated phytoplankton communities covering a wide and continuous eutrophication spectrum enabled (a) the unbiased examination of the sensitivity (monotonicity and linearity) of the indices and (b) the development of coastal water quality classification scales using selected indices. Moreover a new, integrated index of water quality was developed taking into account three of the metrics proposed by the European Directive for phytoplankton, which is chlorophyll a, abundance, and community structure. The proposed classification schemes are finally evaluated with an extensive validation dataset from coastal areas of the Aegean Sea.

2. Methodology

2.1. Field data

Available datasets from coastal areas of the Aegean Sea, Eastern Mediterranean were used to develop the proposed water quality classification schemes and assess their efficiency. Detailed information on the datasets, as well as previous assessment of the water quality of the coastal areas under consideration, is provided in Spatharis et al. (2008). For each dataset, information on chlorophyll a, nutrients, and species abundances existed on a monthly basis covering a full annual cycle and a total number of 816 samples was available for analysis. The areas under consideration cover a wide range of biomass (chl a in the range 0.01–8.80 μg/L and phytoplankton abundance from 960 to 9,905,980 cells/L), mainly affected by anthropogenic activities (agriculture, urbanization, tourism) in the coastal zone. Summary statistics for chlorophyll a and nutrient concentrations are given in Table 1. More eutrophic areas according to previous assessments based on chl a and/or nutrient concentrations are the Inner Saronikos (Ignatiades et al., 1992; Karydis, 1996), the Kalloni Gulf (Spatharis et al., 2007a,b), the Mytilene port (Tsirtsis, 1995) and the Rhodos ports (Stefanou et al., 2000), whereas outer Saronikos (Ignatiades et al., 1992; Karydis, 1996) and the Gera Gulf (Arhonditsis et al., 2000) are considered as mesotrophic. Mytilene strait (Tsirtsis, 1995), Rhodos coastal (Stefanou et al., 2000) and Rhodos offshore (Vounatsou and Karydis, 1991) are characteristic of oligotrophy. Rhodos offshore waters in particular, located northwestern of the Island of Rhodos, Greece, are typical of the pristine undisturbed marine environment of the Eastern Mediterranean (Vounatsou and Karydis, 1991). Therefore, this site has been extensively used in the past to express reference conditions when developing water quality assessment scales for the Aegean Sea

Table 1
Dataset information and mean annual values of chlorophyll a (μg/L) and dissolved nutrient concentrations (μM) for the coastal areas in the Aegean Sea.

Site	Stations	Samples	Chl a	DIP	DIN
Rhodos offshore	R1–R5	145	0.10	0.002	0.064
Rhodos coastal	RH1–2 & 6–10	84	0.10	0.002	0.083
Mytilene strait	M2	67	0.33	0.002	0.122
Rhodos ports	RH3–RH5	36	0.44	0.002	0.293
Gera Gulf	GG3–GG8	89	0.84	0.007	0.053
Outer Saronikos Gulf	S3–S9	168	0.63	0.004	0.148
Mytilene port	M1	39	1.01	0.003	0.166
Kalloni Gulf	K3–K8	140	1.19	0.003	0.301
Inner Saronikos Gulf	S1, S2	48	1.65	0.020	0.354