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New methodology for analysing and increasing the cost-efficiency of environmental monitoring networks

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ABSTRACT

This study focuses on the coastal monitoring network established in the scope of WFD implementation. The objective of this network was to provide an ecological assessment of Valencian coastal waters. After three years, sufficient data had been collected to enable us to analyse and explore ways to increase the network's efficiency.

A methodology was developed to select the best subset of sampling stations to be surveyed. This method was approached from the perspective of an inter-observer variability problem. In order to compare the concordance between the k-observers and the reference observer, two measures were considered: euclidean distance, and interclass correlation coefficient.

The obtained results confirm that the current network can be reduced by over 50% and still guarantee accurate results. This methodology (not limited by indicators, geographically, or by type of water body) could be applied to different environmental monitoring networks and could significantly decrease the efforts and costs required by the WFD.

1. Introduction

The Water Framework Directive 2000/60/EC (WFD) introduced new advanced policy guidelines for the management of inland and coastal waters in the European Union. Among its environmental objectivities, the WFD indicates that good ecological status (GES), which is the essence of the WFD, should be achieved by 2015 European Commission (2000). Consequently, numerous methodologies have been proposed in recent years to assess the ecological status of coastal water bodies, within the framework of the WFD (for details, see Birk et al., 2012; Borja et al., 2004; Borja, 2005; Quintino et al., 2006). Successful implementation of the WFD requires accurate quality assessment of all water bodies (Allan et al., 2006). By monitoring the changes in water quality we can observe, assess, and correct long term trends in water quality degradation from anthropogenic sources (Bierman et al., 2009). Different systems are available to assess coastal water bodies, however, the use of ecological indicators is currently considered to be the most suitable system. Ecological indicators supply information about the state of the ecosystem and, if chosen accurately, reflect the changes in environmental quality (Blandin, 1986; Dauer, 1993; Moreno et al., 2011). For coastal waters, the WFD established systems of organisms (biological quality elements) that should be taken into consideration, such as phytoplankton, macroalgae, angiosperms and benthic invertebrates.

The design and optimisation of monitoring programmes are rigorously constrained by the financial and human resources allocated to monitoring activities (Allan et al., 2006). However, the precision and reliability of the classification framework are also crucial elements for decision-makers when investing human and financial resources in improving the ecological quality of water bodies (Carstensen, 2007). If an appropriate monitoring strategy were to be applied, financial and human costs could be significantly reduced. Before establishing a monitoring programme and related strategy, the requirements of water bodies must be recognised so they can be properly observed and assessed. Due to the

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lack of environmental information, this task must be performed by experts in most cases.

Nevertheless, environmental monitoring should be a dynamic process and, at some point, an analysis needs to be carried out as to whether the previously chosen strategy, based on expert judgment, is appropriate. The analysis should study whether the surveyed water bodies are spatially covered by a suitable number of sampling stations and whether the information obtained overlaps or is insufficient for accurate assessment. The spatial coverage of water body sampling stations should be analysed alongside sampling frequency, but the latter should only be carried out if the number of campaigns significantly exceeds WFD requirements (Abramic et al., 2012). The monitoring efforts required to ensure precise assessment of a water body's ecological status are significantly higher than those proposed by the WFD (Carstensen, 2007). The monitoring frequency required by the WFD is inconsistent in terms of natural spatial and temporal variability, management actions, and decision-making (De Jonge et al., 2006). Sampling strategies for biological elements require further development if they are to meet the real needs (not only the requirements) of the WFD and address seasonal and spatial variations in particular (Irvine, 2004).

Andersen (2006) proposes a survey strategy based on a reasonable and cost-effective approach; monitoring networks should be stratified and based on two types of stations: (i) intensive stations in areas where many indicators are monitored on a highly frequent basis and (ii) mapping stations, where few indicators are monitored on a less frequent basis. This kind of stratification was used in the HELCOM COMBINE Programme (HELCOM, 2003), and in the Danish National Marine Monitoring and Assessment Programme 2003–2009 (Conley et al., 2002; Carstensen et al., 2006). This approach can be applied to an integrated monitoring programme, as well as to single indicator monitoring. Stratification of water bodies with intensive and low frequency spatial coverage could be applied to provide accurate environmental information and decrease the financial costs of monitoring.

When alluding to water bodies that may not comply with environmental objectives, the WFD states that in order to limit monitoring costs during recovery, only the biological parameters that are most sensitive to environmental pressure(s) need to be monitored (Marchetto et al., 2009). Phytoplankton has been selected for this quality assessment, as it can respond to nutrient enrichment and is a fundamental actor in global biogeochemical processes. Nutrient enrichment is one of the most important environmental pressures in European transitional (estuarine) and coastal marine waters (OSPAR, 2003; Domingues et al., 2008). Additionally, phytoplankton affects turbidity, oxygen, and the total productivity of the system (Los and Wijsman, 2007). Phytoplankton reacts directly to environmental pressure through changes in its biomass and species composition (Reynolds, 2002), and its growth cycle is shorter than other bio-indicators, which allows for a faster response.

Monitoring phytoplankton composition (and recounts) requires significant human and financial efforts. However, most methods for the assessment of ecological quality based on phytoplankton are not developed specifically to fulfil the requirements of the WFD, but instead to detect the presence of toxic algae and phytoplankton blooms (Vincent et al., 2002; Borja, 2005). These methods should be taken into consideration, should be well analysed, and, if possible, applied, but it is important to bear in mind that there is insufficient funding to measure and monitor everything. De Jonge et al. (2006) stated the need to achieve cost-effective monitoring and thus to rely on surrogates for detecting environmental change.

Chlorophyll *a* is widely used as a measure of phytoplankton biomass, and was selected early in the WFD harmonisation process as a key indicator of the ecological impact of eutrophication in lakes (Solheim et al., 2008; Søndergaard et al., 2011), and transitional and coastal waters (Domingues et al., 2008; Giordani et al., 2009; Carletti and Heiskanen, 2009). The usage of chlorophyll *a* as a surrogate indicator for phytoplankton biomass was one of the first cost- and time-effective measures in WFD environmental monitoring to be widely implemented.

This article deals with a monitoring network which was established in the scope of the WFD and is part of the integrated monitoring programme for Valencian coastal waters. A significant amount of environmental information is currently available, consisting of over 2500 samples obtained during a three-year monitoring period. The study analyses the efficiency of the current environmental monitoring network and worked on a new design by reducing the number of active sampling stations whilst obtaining the same results, but with less human and financial investment.

Based on the results, this new methodology could be applied to other monitoring networks to make them more efficient and reduce the financial costs of environmental monitoring.

2. Material and methods

2.1. Phytoplankton monitoring network, sampling and laboratory analysis

The autonomous Valencian Region is located on the east coast of Spain. There are only two major rivers: the Segura, in the province of Alicante, and the Júcar, in the province of Valencia. Both are subject to very intense anthropogenic regulation for cities, industries, and agricultural use (see Fig. 1).

Sample station locations are normally chosen according to their continental water influence (rivers, gullies, ground waters…) and well-known anthropogenic impacts (sea outfalls, geomorphological coastal changes), ensuring that the indicators used for assessing ecological status are not biased by their location (Carstensen, 2007).

The surveyed network takes an inshore water sample at each monitoring station. Each water sample is taken at a depth of 10 cm, in the surf zone, but before the wave collapsing area (to avoid sediment resuspension that can affect biochemical water quality). Taking the water samples inshore makes the survey easier and more efficient, as there is no need to use a vessel. Each water sample is placed in a two-litre, high-density polyethylene bottle. After water sampling, all samples are temporarily stored at low temperature in a portable refrigerator, during the day of the campaign. This temporary storage never exceeds 12 h before the

Fig. 1. The autonomous Valencian Region is located on the east coast of Spain.