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'The past is the future of the present': Learning from long-time series of marine monitoring☆

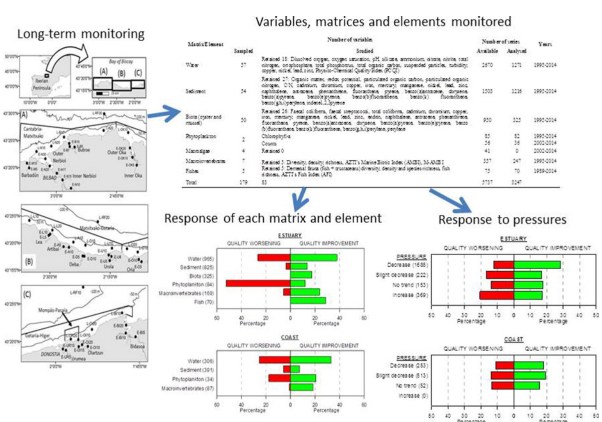
Ángel Borja *, Guillem Chust, José G. Rodríguez, Juan Bald, Mª. Jesús Belzunce-Segarra, Javier Franco, Joxe Mikel Garmendia, Joana Larreta, Iratxe Menchaca, Iñigo Muxika, Oihana Solaun, Marta Revilla, Ainhize Uriarte, Victoriano Valencia, Izaskun Zorita

AZTI, Marine Research Division, Herrera Kaia Portualdea s/n, 20110 Pasaia, Spain

HIGHLIGHTS

- Long-term monitoring data used to assess the responsiveness of 83 variables
- Both human pressures and management actions were investigated.
- 3247 series of data analysed to detect trends of improvement and worsening in quality
- Management actions resulted in positive effects in the environment

GRAPHICAL ABSTRACT



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D. Barcelo

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ABSTRACT

Using a long-term (1995–2014) monitoring network, from 51 sampling stations in estuaries and coasts of the Basque Country (Bay of Biscay), the objective of this investigation was to assess the responsiveness of 83 variables in water (18), sediments (27), biota (26), phytoplankton (2), macroinvertebrates (5) and fishes (5) to different human pressures and management actions. We used a total of 3247 series of data to analyse trends of improvement and worsening in quality. In a high percentage of the cases, the management actions taken have resulted in positive effects in the environment, as shown by the trend analysis in this investigation. Overall, much more trends of improvement than of worsening have been observed; this is true for almost all the media and biological components studied, with the exception of phytoplankton; and it applies as well to almost all the stations and water bodies, with the exception of those corresponding to areas with water treatment pending of accomplishment. In estuaries with decreasing human pressures during the period, the percentage of series showing quality improvement was higher (approx. 30%) than those showing worsening of quality (12%). Moreover, in those water bodies showing an increase of pressure, variables which can be considered indicators of anthropogenic effects showed negative trends (quality worsening). On the other hand, some of the variables analysed were more affected by natural variability than by changes in pressures. That was the case of silicate, nitrate and suspended

☆ Japanese proverb.

* Corresponding author.
E-mail address: aborja@azti.es (Á. Borja).

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solids, which followed trends correlated to salinity, which, in turn, was related to the rainfall regime during the study period.

1. Introduction

Despite the need to understand the interactions between natural variability and human effects in the marine realm, disentangling the combined effects that natural variability and anthropogenic pressures (or the management actions to reduce them) produce in marine systems is always a difficult task (Elliott and Quintino, 2007).

On the basis of marine monitoring, there is the need of understanding the history of how humans have interacted with the rest of nature, to clarify the options for managing our increasingly interconnected global system; as such, if we can adequately understand the past, we can use that understanding to influence our decisions and to create a better, more sustainable and desirable future (Costanza et al., 2009).

Hence, marine monitoring includes the rigorous sampling of different physical, chemical and biological ecosystem components for a well-defined purpose and against a well-defined end-point (McLusky and Elliott, 2004; Borja and Elliott, 2013). That aim may be the detection of a trend or the non-compliance with a threshold, standard, or baseline, thus leading to a well-defined policy or management action (De Jonge et al., 2006). In this way, marine legislation worldwide requires adequate and rigorous monitoring at different spatial and temporal scales, including different ecosystem components and media (Borja et al., 2008).

Examples of successful long-term monitoring networks, including multiple ecosystem components, can be found elsewhere, such as in the United Kingdom (Southward et al., 1995), Chesapeake Bay (Boesch, 2000), Southern California (Stein and Cadien, 2009), Australia (Addison et al., 2015), or the Baltic Sea (Andersen et al., 2015). Each of these monitoring networks can have different objectives (in fact, Elliott (2011) identified 10 different types of monitoring). However, taking into account the high amount of money invested in past 30 years in reducing pollutants discharged into the sea, in Europe and USA (Stein and Cadien, 2009), some management effectiveness evaluation is needed (Addison et al., 2015).

To analyse this effectiveness, long-term trend assessment is needed to determine: (i) how human activities are adversely affecting water-quality conditions; (ii) when management intervention is required to conserve water uses; and (iii) the efficacy of such management actions (MacDonald et al., 2009). In addition, we need to understand also the potential interactions between natural environmental variability and human intervention, and their implications in management (Borja et al., 2013).

Some authors (i.e. MacDonald et al., 2009; Clark et al., 2010) have proposed systematic and sequential ecosystem-based processes to ensure that those long-term monitoring programs will provide information critical to make informed decisions regarding management of marine ecosystems. After Clark et al. (2010), this sequence includes: (i) identification of water-quality issues; (ii) development of a conceptual model for the system; (iii) setting ecosystem goals, objectives and indicators; (iv) design of monitoring programs; (v) verification of the sampling design; (vi) implementation of status and trends; (vii) evaluation, interpretation and reporting of monitoring data; and, (viii) application of monitoring program results in decision making.

Marine monitoring is expensive and time consuming (Stein and Cadien, 2009; Karydis and Kitsiou, 2013). Hence, some countries are trying to reduce costs in times of economic crisis (Borja and Elliott, 2013). Systematic and sequential approaches, such as that described above, can contribute to make monitoring effective and efficient, and can inform the development of other similar monitoring programs (Levine et al., 2014). As such, regular evaluation of long-term monitoring programs is an important part of the monitoring process (Lindenmayer and Likens, 2009), resulting in minimizing the cost of oversampling for too long a time (Levine et al., 2014).

Despite the fact that there are numerous investigations analysing the cost-effectiveness of monitoring networks and their responsiveness to human pressures and management actions (e.g. de Jonge et al., 2006; Stein and Cadien, 2009; Clark et al., 2010; Abramic et al., 2014; Levine et al., 2014; Addison et al., 2015), to our knowledge there are no studies on the most (or less) responsive variables, media (e.g. water, sediment), and biological components (e.g. phytoplankton, macroalgae, macroinvertebrates, fishes) to human pressures and management actions, in the marine system.

Taking this into account, the objective of this investigation is to assess the abovementioned responsiveness using a long-term (1995–2014) monitoring network, with many ecosystem components, from the Basque Country (Bay of Biscay), testing the response of many variables to different pressures and water treatment histories, within estuarine and coastal systems. Our hypothesis is that the management measures taken in the area in the last 20 years have resulted in an improvement of the quality, reflected by the several ecosystem components investigated.

2. Methods

2.1. Description of the study area and the monitoring network

The study area is located in the South-eastern part of the Bay of Biscay (North-east Atlantic) (Fig. 1). It has a narrow continental shelf (between 7 and 20 km). The coast is mountainous, with cliffs (20–150 m high), which extend over 70% of the 150 km of the coastal area (the remainder are beaches or low coast). It is a temperate sea (annual range of temperatures, at the surface: 11°–23 °C), with high wave exposure (in winter, waves can reach 15 m), due to its long (>4000 km) fetch. The area is mesotidal, with mean tidal range of 1.5 m at neap tides and 4 m at spring tides; the maximum annual tidal range exceeds 4.5 m. There are small rivers (mean flow range: 2–36 $m^3 s^{-1}$) flowing into 12 small estuaries (length between 2 and 22 km). Additional details about the area can be found in Borja and Collins (2004).

The Basque Water Agency has monitored the Basque coastal and estuarine quality since January 1995 (Borja et al., 2009a). The monitoring network comprises sampling of both physico-chemical (water, sediment and biota) and biological components (phytoplankton, macroalgae, macroinvertebrates and fishes). The monitoring series data include 32 coastal and estuarine stations sampled, from 1995 to 2014, with 19 additional stations sampled since 2002. From these 51 stations, 48 are distributed among the 18 water bodies (management units) of the Basque Country (14 estuarine and 4 coastal), and 3 are considered as reference coastal stations (L-RF, in Fig. 1). As such, they constitute a monitoring network reporting to different European directives (mainly the Water Framework Directive, WFD, 2000/60/EC) and serve to take managerial decisions to reduce or remove human pressures affecting the ecological status of these aquatic systems. These decisions are taken at the level of the management units, which are discrete and significant elements of a water body, showing similar level of human pressures, after the WFD. Also, this network serves to study the natural environmental variability over the area. In the case of fish communities,