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The derivation, performance and role of univariate and multivariate indicators of benthic change: Case studies at differing spatial scales

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Abstract

In Europe there is an extensive history of the derivation and use of benthic indicators which parallels similar developments in North America and elsewhere. Most recently, this has increased because major European Union Directives require that indicators of marine benthic change are used to confirm good ecological status quality (as in the Water Framework Directive) and favourable conservation status (as in the Habitats and Species Directive). Furthermore, these indicators have to fit within the current philosophy of the Ecosystem Approach requiring the development and use of Ecological Quality Objectives and Standards. Despite this, comparisons of families of indicators derived by differing methods have not been carried out such that the robust nature of the indicators on differing spatial scales and under differing benthic conditions has not been rigorously assessed. Using case studies from the Portuguese coasts and estuaries, this paper compares and contrasts univariate and multivariate macrobenthic indicators to quantify comparisons of change. The studies indicate the relative value of those indicators at contrasting spatial scales, e.g. in the transition from small areas around coastal submarine outfalls, to the local and regional estuarine and coastal scale. The analysis indicates the difficulties of deriving and using qualitative and quantitative indicators from benthic communities in stable, and in moderately and highly variable environmental conditions in estuarine, coastal and open sea habitats. In some areas, the variability in the indicators and indices within a station and site is as large as that between stations and sites. For those areas studied, there is an adequate quality and quantity of benthic data available for making management decisions but this is unlikely to be the case for all areas. Similarly, the interrogation of the methods shows that while their use and interpretation rely on a good understanding of the biology of the individual species and their responses to physical and polluting stress, that understanding is not yet available for many of the species. Most notably, while the indices and integrative indicators are becoming increasingly sophisticated, many are still dependent on the Pearson–Rosenberg model for organic enrichment hence they require to be validated for physical disturbance and for chemical pollution. Because of these features, the outcome of the analysis has repercussions for the management of coastal and estuarine areas. Although the present study indicates the value of indicators of benthic change for making management decisions at the various scales, further validation is required especially, for example, where one indicator over-estimates the ecological status for poor areas and underestimates it for good areas.

Keywords: Benthos; Coastal shelf; Estuaries; Indicators; Indices; Organic enrichment; Water framework directive

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1. Introduction

The detection of change in marine and estuarine ecosystems against accepted baselines is a fundamental tenet of estuarine and marine management. Once a change has been detected then management responses are required to address the cause of the change. Many estuarine and coastal management initiatives worldwide, e.g. in North America, Europe and Australia, are required to derive and use environmental quality indices, e.g. the implementation of the European Water Framework Directive (European Commission, 2000) and the US Clean Water Act (Gibson et al., 2000; USEPA, 2002). Those indices are then required to test for departure from a reference or control situation. Thus, there is an increasing need to link indicators to monitoring sensu stricto, i.e. in which change is judged against an a priori derived standard/threshold/reference condition/critical value (McLusky and Elliott, 2004). The results from the use of those indicators then have to be incorporated into management decisions (Fig. 1).

Macrobenthic marine invertebrates have a fundamental role on sediment processes, predator–prey relationships and as bioengineers, and usually have well-defined responses to environmental change, especially those stressors which influence the sediment structure, its chemistry and quality. Because of this, macrobenthic studies have achieved a fundamental role in estuarine and marine impact assessment and marine management (e.g. McLusky and Elliott, 2004). Given the inherent ability of the benthos to integrate sediment quality, many environmental indicators and indices are based on marine macrobenthos. Consequently a large number of techniques have developed to show the degree and nature of the environmental change (Warwick and Clarke, 1991; Elliott, 1994). There is also the advantage that there is a good conceptual understanding of temporal and spatial benthic population and community dynamics in relation to certain types of environmental disturbances, especially organic enrichment (e.g., Pearson and Rosenberg, 1978; Rhoads and Germano, 1986). These, in turn, have produced a large suite of numerical methods which describe environmental change and allow deviation from normal conditions to be quantified (e.g., Elliott, 1994; Borja et al., 2000; Rosenberg et al., 2004). These techniques include graphical, univariate and multivariate statistics and other numerical methods for presenting, describing and interpreting change. However, there is the continued need to question the underlying basis of these paradigms, and to determine the performance and sensitivity of those indices and other numerical models. This is especially so if there is an increasing uncritical use of the indices against stressors for which the indicators were not originally developed.

Biological indices and indicators have been created which summarise ecological status and ecological quality. This study aims to test and validate a suite of those biological indices and indicators, and thus to determine their sensitivity and behaviour, under differing benthic conditions. In particular, there is the need to indicate and explore the management decisions arrived at as the consequence of the output of the benthic analyses. For example, if one index indicated that an area was more polluted than that shown by another index, this result may have financial repercussions following a demand for greater waste treatment.

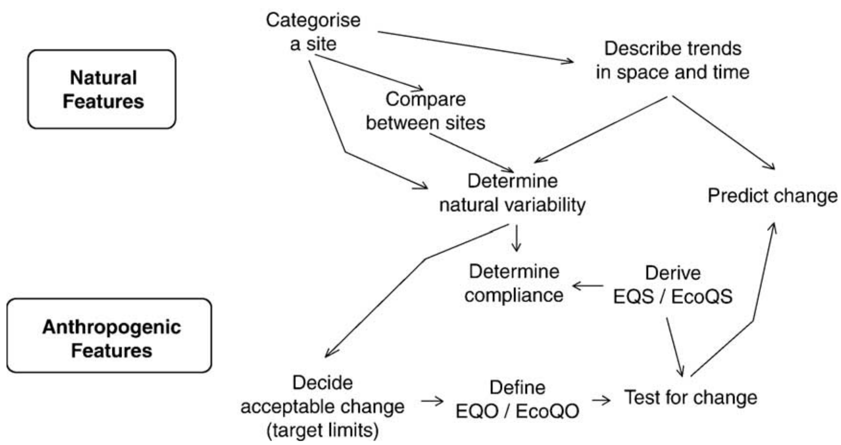

Fig. 1. Schematic representation of the analysis and interpretation of biotic-related information within the establishment and assessment of environmental and ecological quality objectives and standards. EQO — Environmental Quality Objectives; EcoQO — Ecological Quality Objectives; EQS — Environmental Quality Standards; EcoQS — Ecological Quality Standards (from Elliott and Hemingway, 2002).