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Viewpoint

Benthic indicators: From subjectivity to objectivity – Where is the line?

Jean-Claude Dauvin [a,*], Gérard Bellan [b], Denise Bellan-Santini [b]

[a] Université de Lille 1, CNRS UMR 8187 LOG, Station Marine de Wimereux, 28 Avenue Maréchal Foch, B.P. 80, F-62930 Wimereux, France
[b] Centre d'Océanologie de Marseille, UMR CNRS DIMAR 6540, Université de la Méditerranée, Station Marine d'Endoume, Rue Batterie des Lions, F-13007 Marseille, France

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ABSTRACT

Over the last few years, the interest in using benthic indicators to assess marine environments has increased dramatically after a rather long period of relative stagnation, mostly due to the need to assess the status of coastal marine waters required by North American and European regulations. Numerous papers on this topic have been published in the domain of ecology, using a variety of different terms to refer to two categories of information: benthic species and the status of benthic communities. Nowadays, the abundant literature on these two categories makes it possible to comment on (1) the definition of the different terms used by benthic researchers, (2) the current increase of papers of rising complexity about benthic indicators, and (3) the subjectivity and objectivity involved in using benthic indicators. Faced with the increase in the number of methods, we recommend pragmatism and thus the transfer of simple methods to the research consultancies that are responsible for assessing benthic quality in numerous impact studies. Using certain procedures, such as the "sentinel species", the best professional judgement (BPJ) and taxonomic sufficiency (TS), should clearly be encouraged.

1. Introduction

Managing the quality of estuarine and coastal waters is a challenge for western countries, such as those in North America and Europe. The United States' Clean Water Act (CWA), published in 1972 as part of the Federal Water Pollution Control Amendments, and the European Union's Water Framework Directive (WFD), published in 2000, both defined clearly the objectives of these legislations. They notably encourage the improvement of water quality in the future to insure both the use of coastal waters for recreative activities and for the harvest and/or cultivation of seafood, such as mussels, oysters and clams. Water quality can be determined by analysing the chemicals present in the water (e.g., oxygen content, metallic and organic pollutants, nutrients) or using biological indicators (also called bio-indicators) as surrogates to indicate the quality of the water in which they are present.

Among these bio-indicators, there are five biological compartments retained in the WFD: phytoplankton, macroalgae, angiosperms, macrozoobenthos and fish (Leonardsson et al., 2009; Rosenberg et al., 2004). However, surprisingly, some biological components were not selected for the WFD (e.g., zooplankton) in spite of their abundance in the water column. Zooplankton is a good indicator of the evolution of the sea surface temperature. For example, over the three last decades, the North Atlantic has experienced a northern migration of warm temperate species into the North Sea and a migration of boreal species into the Arctic (Beaugrand, 2003). The plankton as a whole is seriously affected in confined areas, such as harbours (Patriti, 1984). In the open sea, even in areas that are severely impacted by industrial or domestic effluents, the plankton progressively return to a more normal composition as they get farther away from the disturbance (Patriti, 1982, 1984). Equally surprising was the exclusion of certain meiobenthic groups (e.g., foraminifera, harpacticoid copepods or nematodes), known to indicate changes in salinity and climate clearly. Due to the sensibility of copepods and foraminifera to oil spills, these are a good choice as bio-indicators for pollution of the marine environment (Mojtahid et al., 2008; Raffaelli and Mason, 1981).

The study of the Los Angeles and Long Beach harbours five decades ago was based on the benthic populations in these harbours and is generally considered as a cornerstone for the use of biological indicators and animal communities to describe polluted marine environments (Reish, 1959). Over the last few years, the interest in using benthic indicators to assess marine environments has increased dramatically after a rather long period of relative stagnation, although paradoxically there is now a lack of qualified systematists needed to acquire the necessary knowledge to build and validate these indicators and indices. This increasing interest is mostly due to the need for new tools for assessing the status of marine waters, which is required by regulations like the CWA and the WFD.

In this context, a certain number of new indicators and indices have been proposed. Most of the pollution indices have been created based on "subjective" or "objective" biological indicators.

* Corresponding author. Tel.: +33 3 21 99 29 20; fax: +33 3 21 99 29 01.
E-mail address: jean-claude.dauvin@univ-lille1.fr (J.-C. Dauvin).

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This has led the European scientific community to see the advantages of developing biological indicators and indices based on the macrobenthos compartment. Still, the first interest in the macrobenthic organisms as indicator species dates back several decades for the North American and European scientific communities. It is no longer contested that macrobenthic organisms as indicators have many advantages: they are relatively non-mobile and therefore useful for studying the local effects of physical and chemical perturbations; some of these species are long-lived; their taxonomy and their quantitative sampling is relatively easy; and there is extensive literature on their distribution in specific environments and on the effect of the various stresses that these organisms could encounter (Borja et al., 2008).

Most of the studies have been done on soft-bottom communities; however, some researchers have used the hard-bottom epifauna, and some progress has recently been made in the use of hard-bottom fauna, especially vagile fauna, as indicators of water quality (Bevilacqua et al., 2009), following precursor studies in the 1960s and 1970s (see Bellan-Santini, 1969, 1980). Most of the authors in the literature have developed water quality indicator/s and index/indices to indicate the responses of the fauna to a pollution gradient, with the disappearance of sensitive species in polluted area, the increase in the abundance of certain resistant species in moderately polluted areas, and the survival and even the proliferation of opportunistic species in the more polluted zones. In the most polluted zone, no macrofauna resists.

The above developments were greatly inspired by the idea of macrobenthos succession (Pearson and Rosenberg, 1978) with respect to organic enrichment and pollution of the marine environment. Pearson and Rosenberg's paper is probably the most cited by the scientists working on benthos (>14,000 citations; R. Rosenberg, personal communication). In fact, it was the source of most of the discussions and the proposed indicators and indices used in soft-bottom macrobenthic communities. The success of Pearson & Rosenberg's idea is also certainly due to the fact that, during the decades preceding their paper, a real corpus of knowledge and basic data had been acquired, particularly in Europe, corpus to which Pearson and Rosenberg referred in their paper.

The objective of this *Viewpoint* is to provide our take on (1) the definition of the different terms used by benthic researchers, (2) the current increase of papers of rising complexity about benthic indicators, and (3) the subjectivity and objectivity involved in using benthic indicators. In this paper, we comment mostly on the coastal soft-bottom communities, and we do not discuss the reference status for benthic communities.

2. Definition of terms used in publications

Many papers have been published in the domain of ecology using different terms for qualifying benthic species and the status of benthic communities [mainly "Ecological Quality Status" (EcoQS)].

2.1. Terms used to qualify benthic species

- A "*sensitive species*" is a species that can only survive within a narrow range of environmental conditions and disappear from polluted areas and zones undergoing environmental change (i.e., climate or habitat changes).
- A "*tolerant species*" means a species that is not sensitive to a particular stress and/or pollution.
- An "*opportunistic species*" is a species that can quickly exploit new resources or ecological niches as they become available. For example, the species can rapidly colonize a new environment. These species are characterised by early reproduction, high reproduction rates, rapid development, small body size and an uncertain adult survival rate.
- A "*characteristic species*" means a species linked to a particular biocenotic structure referred to as a "community", a "biotic assemblage" or a "biocenosis".
- A "*sentinel species*" is a particular species which by its presence or its relative abundance "warns" an observer about possible imbalances in the surrounding environment and/or alterations of the community functions.
- An "*indicative species*", or an "*indicator species*" (in our opinion, the nearest equivalent term), will signal the presence of a particular factor, either biotic or more often abiotic, within a given environment. These "*indicative species*" intervene in a community's functions rather than in its structure. For example, a species may indicate an environmental condition, such as a pollution, species competition or climate change. "*Indicative species*" or "*indicator species*" are among the most sensitive species in a region and sometimes act as an early warning system for monitoring biologists. Sometimes, the term "*pollution indicator species*" is used for species that increase with the amount of organic matter.
- An "*indifferent species*" is a species with no real affinity for any particular community and which shows no response to pollution. In fact, based on the personal observations of one of the authors of this *Viewpoint* (Gérard Bellan), "*indifferent species*" are rarely found in the most polluted or the most degraded areas, where only the opportunistic polychaetes *Capitella capitata* and *Scolelepis fuliginosa* survive. Though, according to the purists, "*indifferent species*" do not form a real community, but rather a gathering of a given species. These species are not necessarily rare, and they have frequently been considered to have a "*large ecological valence*".

2.2. Terms used to qualify the EcoQS of benthic communities

"*Index/Indices*" is a generic term used in a very large range of scientific domains, from marine biology to sociology to economics. It corresponds mainly to a numerical scale used to compare one variable to another or to a reference number, a value or a ratio (a value on a measurement scale) derived from a series of observed facts. It can reveal relative changes over time.

"*Biotic Index/Indices*" is a term used to give a status report about a particular environment by indicating the types of organisms that are in it. It is often used to assess the quality of an environment. It generally ranges from a minimum value to a maximum value and permits to classify the status of an environment compared to a reference status.

The term '*Indicator*' is used often in ecology and environmental planning but also in a large variety of other domains ranging from economics to sociology and political science. Although it is often used ambiguously and in different contexts, a systematic overview of the existing definitions of the term has not yet been compiled. Recently, Heink and Kowarik (2010) reviewed the different uses and definitions of the term "*indicator*" in ecology and environmental planning. These authors differentiate three categories used to define indicators, "*namely measures* (e.g., *species richness*), *components* (e.g., *a certain taxon*), *and values and measurement results* (e.g., *a vegetation cover of 50% in the understorey*)." Furthermore, they make a distinction between descriptive and normative indicators, with hybrid indicators being those that can be used both descriptively and normatively. They also proposed to retain the OECD definition (2003): "*an indicator in ecology is a component or a measure of environmentally relevant phenomena used to depict or evaluate environmental conditions or changes or to set environmental goals. Environmentally relevant phenomena are pressures, states, and responses*".

"*Biological indicators*", or "*bio-indicators*", are detectors that reveal the existence of complex conditions resulting from a group