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Twenty years of application of Polychaete/Amphipod ratios to assess diverse human pressures in estuarine and coastal marine environments: A review

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ABSTRACT

Benthic indices based on the Polychaetes/Amphipods (P/A) ratio have been proposed to assess the environmental quality status of ecosystems in estuarine and coastal waters. Although the methods used to calculate these indices (essentially BOPA and BO2A) have been revised over the past two decades, the underlying approach corresponds to the contrasted responses of two benthic invertebrate groups to pollution, with polychaetes as tolerant/opportunistic species and amphipods as sensitive taxa. The Polychaetes/Amphipods ratio has been tested for monitoring major changes in benthic communities in response to a wide variety of different human pressures in estuarine and coastal environments (oil spills, urban sewage outfalls, enrichment in organic matter, etc.) and is used in 23 countries mainly in Europe, but also in Africa, Asia, Oceania and South America. This paper reviews the use of the P/A ratio (79 documents) in relation to a large panel of human activities, in transitional (estuaries and lagoons) and coastal waters. In some studies, BOPA and BO2A indices based on P/A ratios were selected in certain regions of Spain and Gibraltar to assess the quality of water bodies according to the Water Framework Directive. Moreover, most of these studies do not meet the necessary conditions for application of the indices. As a result, comparisons between P/A ratios and other benthic indices are inappropriate when assessing ecological quality status, which therefore reinforces the need to apply P/A ratios with precaution.

1. Introduction

Forty year ago in March 1978, the tanker Amoco Cadiz was wrecked on the North Brittany coast 60 km west of the Bay of Morlaix (western part of the English Channel). This accident generated one of the most severe oil spills in Europe, with the release of 223,000 t of hydrocarbon into the sea in less than two weeks (Cabioch et al., 1978; Dauvin, 1987, 1998, 2000). One year before the oil spill, surveys were carried out on two muddy fine sand subtidal benthic communities, highlighting the potentially high sensitivity of amphipods to hydrocarbon pollution (Dauvin, 1982, 1998, 2000). The disappearance of the dominant amphipods of the genus *Ampelisca* from the fine sand Pierre Noire community (which represented 80% of the total abundance ~ 40,000 ind.m^2 in summer 1997) was one of the main impacts of the spill on the benthic communities (Cabioch et al., 1978; Dauvin, 1987). Conversely, the polychaetes showed very little changes just after the spill, with a moderate Cirratulidae peak during the autumn of 1978, then four and six year later respectively during summer 1982 and 1984, very high abundances (> 30,000 ind.m^2) of the Spionidae *Pseudopolydora pulchra* (Carazzi, 1893) occurred (Dauvin, 1998).

Again, the impact of the "Aegean Sea" oil spill along the northern coast of Galicia, Spain, led to the disappearance of amphipods including *Ampelisca* species in the more polluted stations in the Ria de Ares and Betanzos, in the eastern part of La Coruna (Gomez Gesteira and Dauvin, 2000, 2005; Gomez Gesteira et al., 2003). At the same stations, there was no change or even an increase of polychaete species (Gomez Gesteira and Dauvin, 2005).

Several studies have shown the great sensitivity of the amphipods to hydrocarbons compared to other groups of invertebrates, including polychaetes, either in the laboratory or in the natural environment due to pollution by hydrocarbons (see Dauvin, 1987; Nikitik and Robinson, 2003). Oil spills due to tanker accidents in the Baltic Sea ("Palva", "Tsesis and "Antonio Gramsci"), in the South Atlantic ("Esso Essen"), in Florida and along the eastern coast of the United States, as well as coming from the "Amoco Cadiz" in the western part of the English Channel (Dauvin, 1987) or, more recently, the "Aegean Sea" in Galicia, Spain (Gomez Gesteira and Dauvin, 2000) or the 'Sea Empress' at Milford Haven (Wales, UK) (Nikitik and Robinson, 2003), have confirmed the high sensitivity of amphipods to accidental oil spill pollution.

Based on the application of the Nematodes/copepods ratio as an indicator of the response of meiofauna to oil pollution, Gomez Gesteira

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and Dauvin (2000) proposed using $\log_{10}$ of the ratio between the opportunistic polychaete abundance and the amphipod abundance + 1 as an index to identify the impact of oil spills on benthic soft-bottom communities.

At the beginning of the years 2000, the implementation of the European Water Framework Directive (WFD) was a famous opportunity for marine ecologists to propose new indicators to assess the water quality in transitional and coastal environments (Borja et al., 2000, 2012, 2015; Borja and Muxika, 2005; Blanchet et al., 2008, 2015; Pinto et al., 2009; Boon et al., 2011; Birk et al., 2012; see also the special issue of Marine Pollution Bulletin, 55: implementation of the Water Framework Directive in European Marine Waters). Nevertheless, the response of benthic species to human pressures and the associated organic enrichment started to be felt by the late 1950s, and the WFD marked a new era in the development and proposition of benthic indices (Dauvin et al., 2007; Pinto et al., 2009; Dauvin et al., 2010; Borja et al., 2012; Birk et al., 2012).

Several studies have focused on discussing the advantages and disadvantages of the suggested indices, while ranking their efficiency for detecting the different impacts of human pressures in transitional and coastal marine waters under the WFD (see Pinto et al., 2009; Boon et al., 2011; Birk et al., 2012; Borja et al., 2012, 2015; Rombouts et al., 2013; Martinez-Haro et al., 2015). Moreover, in a recent paper, Borja et al. (2015) reported that, out of 35 suggested indices, only a few have been adopted by the scientific community, with some being selected by European countries as indices suitable to qualify the ecological status of transitional and coastal water bodies. Among these indices, the most commonly employed are AMBI (Borja et al., 2000; Borja and Muxika, 2005), BENTIX (Simboura and Zenetos, 2002), BQI (Rosenberg et al., 2004), BOPA/BO2A (Dauvin and Ruellet, 2007, 2009), and M-AMBI (Muxika et al., 2007).

Two decades after the first use of the Polychaetes/Amphipods ratio, the main aim of this paper is to review the existing literature concerning this indicator, i.e. estuarine and marine coastal zones subject to human activities and pressures.

2. History of the Polychaetes/Amphipods ratio

The BOPA index (Benthic Opportunistic Polychaetes Amphipods ratio; Dauvin and Ruellet, 2007) was originally calibrated using the AMBI index and the five classes of the WFD. This index is based on two paradigms: 1) the taxonomic sufficiency principle, and 2) the principle of antagonism between sensitive species (amphipods) and opportunistic species (polychaetes). Opportunistic polychaetes were known to be resistant, indifferent or favoured by organically enriched sedimentary matter, whereas amphipods were highly sensitive to contaminated sediments compared to other benthic macro-invertebrates. In the initial formulation, the species of the amphipod genus *Jassa* Leach (Corophiida: Ischyroceridae) were not counted as sensitive species because they were considered in Ecological Group IV (second order of opportunists) in the AZTI list (www.azti.es). The calculation of the BOPA index was independent of the sampling protocol used, i.e. mesh size and surface units for expressing abundances.

After the initial BOPA proposition, Dauvin and Ruellet (2009) proposed adding the Clittellata (i.e., Hirudinea and Oligochaeta) to the opportunistic polychaeta in order to adapt the BOPA index for application to the freshwater zones of transitional waters, thus creating the Benthic Opportunistic Annelida Amphipods index (BO2A). As the Clitellata are generally absent or weakly represented in coastal sediments, the BO2A and BOPA values are strictly identical or very similar.

The BOPA/BO2A index has been applied in different studies during the years 2000 (Table 1). Nevertheless, several authors have stressed that this efficiency is limited by an apparent overestimation of the ecological quality status (EcoQS) compared to the EcoQS ranking given by other indices, mainly AMBI, M-AMBI and BENTIX. For this reason, the EcoQS thresholds of the indices have been modified to produce the same, or at least similar, results for the assessment of the same area. This was performed by again calibrating the EcoQS classifications given by BO2A against the AMBI classifications (de-la-Ossa-Carretero and Dauvin, 2010). These new thresholds led to a smaller number of EcoQS classifications with high and good status, which increased the conformity of the BOPA results with those produced by AMBI, thus resulting in a better agreement in Mediterranean coastal waters and in French Atlantic transitional waters (de-la-Ossa-Carretero and Dauvin, 2010).

To assess the impact of offshore oil and gas production on benthic fauna along the Norwegian continental shelf, Andrade and Renaud (2011) proposed a simple Polychaetes/Amphipods ratio and showed that it decreased along a gradient from the production stations towards the less impacted stations.

Recently, Aguado-Giménez et al. (2015) proposed a BOPA-FF including the opportunistic polychaete families considered in the BOPA/BO2A indices, i.e. Capitellidae, Cirratulidae; Dorvilleidae, Pectinariidae, and Spionidae, plus also other polychaete families tolerant to influence from fish farming, i.e. Glyceridae, Nereididae and Oweniidae.

Finally, Dauvin et al. (2016) tested two new formulations of the Polychaetes/Amphipods ratio to assess the EcoQs of soft-bottom communities: these ratios were based on BPOFA (Benthic Polychaete Opportunistic Families Amphipods) and BPA (Benthic Polychaetes Amphipods). Both the BPOFA and BPA indices consider the frequency of all amphipods including the genus *Jassa*. These authors showed that BPOFA yields very similar EcoQs to the results obtained from BO2A and, additionally, the former ratio could be accepted as a surrogate of the BO2A index. As such, BPOFA represents a simple and effective benthic indicator for assessing the ecological status of coastal water masses.

In Dauvin et al. (2016), BPOFA is calculated in the same way as BOPA, while BO2A is taken as equal to $\log_{10}[(fpof/fa + 1) + 1]$, where fpof is the frequency of opportunistic polychaete families (i.e. Capitellidae, Cirratulidae, Dorvilleidae, Pectinariidae and Spionidae) and fa is the frequency of all amphipods including *Jassa*. The thresholds of the five classes of the WFD are calibrated within the same limits as those used for BO2A (Table 2). As the computation of BOPA and BO2A is not recommended for samples containing ≤ 20 individuals (Dauvin and Ruellet, 2007, 2009), the same minimum number of individuals in a sample was recommended for BPOFA.

3. Review of the use of Polychaete/Amphipod ratios

Table 1 lists seventy-nine studies from the literature, mainly including articles in peer-reviewed journals, as well as PhD theses and reports, which make use of the ratios between polychaetes and amphipods. Most of these studies were published in two journals: Marine Pollution Bulletin (25 articles) and Ecological Indicators (19 articles). Most of the articles cited in Table 1 refer to the BOPA ratio, with some using BO2A, and six mention only a simple ratio between the relative abundances of polychaetes and amphipods. The Polychaetes/Amphipods ratios (mainly BOPA and to a lesser extent BO2A) have been used in Europe for the development and implementation of the WFD, essentially for coastal but also for transitional waters (Atlantic Ocean estuaries and Mediterranean lagoons) (Fig. 1). These studies come from twelve Europeans countries: Norway, Germany, the United Kingdom (England, Wales and Scotland), Ireland (Galway Bay), France (English Channel, Atlantic coast, Mediterranean Sea), Spain (Atlantic coast of Galicia, Andalusia and along the Mediterranean coast), Portugal, Italy (Tyrrhenian and Adriatic seas), Slovenia, Malta, Cyprus, and Greece (Adriatic and Aegean seas). Benthic studies based on Polychaetes/Amphipods ratios have also been carried out in North Africa (Morocco, Algeria and Tunisia), South America (Brazil), Asia: Turkey (Marmara Sea), Iran (Persian Gulf and Caspian Sea), Arabia (Arabian-Persian Gulf), India (Arabian Sea and Bengal Gulf), China (Yellow Sea), Korea (Yellow Sea), and the Pacific Ocean (New Zealand) (Fig. 2). Twenty-