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Polychaete/amphipod ratio revisited

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Abstract

In this paper, we reexamine the opportunistic polychaete/amphipod ratio, modifying it to allow estuarine and coastal communities to be divided into the five classes suggested by the European Water Framework Directive (WFD). The resulting biological index, called the BOPA index, considers the total number of individuals collected in the samples, the frequency of opportunistic polychaetes, and the frequency of amphipods (except the genus *Jassa*). After comparing this new index to AMBI and BENTIX, two other indices that have been proposed in the literature, we tested it in two situations involving soft-bottom communities in the English Channel (Bay of Morlaix and Bay of Seine). Our results show that the BOPA index is simple to use. Amphipods and opportunistic polychaetes (21 species, nine genus and two families from the AZTI list for a total of 3459 taxa) are easy to identify, providing that both the number of these organisms in a sample and the total number of individuals collected (independent of the sampling surface) is known. The BOPA is appropriate for use in the poorest communities whose total number of individuals exceeds 20 individuals.

Keywords: Benthic indicators; Opportunistic polychaetes; Amphipods; BOPA index; AMBI; BENTIX; English Channel

1. Introduction

The implementation of the European Water Framework Directive (WFD, 2000/06/EC) has provoked a huge debate about the use of benthic bio-indicators and indices to determine the quality of European coastal and estuarine (transitional) water masses, according to Ecological Quality Status (EcoQ) (see Borja et al., 2000, 2003, 2004a,b; Borja and Heinrich, 2005; Simboura and Zenetos, 2002; Simboura, 2004; Simboura et al., 2005). Two of the more recent quality indices—AMBI (AZTI, Borja et al., 2000) and BENTIX (Simboura and Zenetos, 2002)—require classifying soft benthic species into previously defined ecological groups (see Pearson and Rosenberg, 1978; Grall and Glémarec, 1997) as well as knowing the respective proportion of these different groups in the communities (or samples). In fact, all of the recent indices require knowledge of the relative abundances of sensitive species faced with increased organic sedimentary matter and those of the non-sensitive opportunistic species—resistant, indifferent or favored—that proliferate in such organically enriched sedimentary matter. Among the sensitive species, crustaceans, especially amphipods, form a particularly sensitive zoological group, not only to significant increases in organic matter but also to increases in other kinds of pollution including metals and hydrocarbons (Dauvin, 1987, 1998). Several families, such as Ampeliscidae, Pontoporeidae, Melitidae and Gammaridae, are greatly affected by hydrocarbons and can disappear completely given a large oil spill, for example (Dauvin, 1987, 1998, 2000).

In an earlier paper, Gomez Gesteira and Dauvin (2000) tested a variety of species ratios (polychaetes/crustaceans, opportunistic polychaetes/crustaceans, and opportunistic polychaetes/amphipods) in an effort to identify the most efficient abundances ratio for determining the impact of oil spills on soft-bottom communities. According to their results, the most efficient ratio was $\log[(\text{opportunistic polychaetes}/(\text{amphipods}+1))+1]$, which varied from $\leqslant 1$, given a relative absence of pollution, to >1 in stations

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subjected to high levels of pollution, where the amphipods disappeared completely. Similar research has been done to identify the effects of pollution on the meiobenthos, with Raffaelli and Mason (1981) suggesting the use of a nematode/copepod ratio (N/C ratio).

Nikitik and Robinson (2003) used the opportunistic polychaete/amphipod ratio as an indicator when studying the effects of the 'Sea Empress' oil spill in the Milford Haven waterway (UK). However, they used the formula log[opportunistic polychaetes/(amphipods + 1)], without the additional +1 in the calculation of the ratio. Therefore, the ratio sometimes produces negative values. This variation was probably due to a certain ambiguity in the original publication (Gomez Gesteira and Dauvin, 2000) with regard to the +1 used to prevent a total absence of amphipods and the other +1 used to prevent a total absence of opportunistic polychaetes. This opportunistic polychaete/amphipod ratio produces results that vary between a minimum value of 0 and a maximum value that can exceed 10.

In this paper, we propose to reexamine the opportunistic polychaete/amphipod ratio, modifying it so that it can be used to assign estuarine and coastal communities to the five EcoQ (ECOlogical Quality Status) classes suggested by the WFD: *high* for unpolluted sites, *good* for slightly polluted sites, *moderate* for moderately polluted sites, *poor* for heavily polluted sites, and *bad* for extremely polluted or azoic sites. We compared this modified ratio, called the benthic opportunistic polychaetes amphipods index (BOPA), to the recently proposed AMBI (Borja et al., 2000) and BENTIX (Simboura and Zenetos, 2002) indices, which are based on a theoretical model of successive species, ranked according to their sensitivity to a gradient of organic pollution. The ecological status of an area is not only lied at the organic matter content. We then tested our BOPA index by studying the ecological quality of several soft-bottom communities in the English Channel, one of which had been subjected to hydrocarbon pollution, while others had been subjected heavy river discharge.

2. Materials and methods

2.1. Indices used

The proportions of the five ecological groups (EG) provided by the AZTI laboratory's regularly updated list (October 2005; www.azti.es) were used to calculate the AMBI index (Borja et al., 2000; Borja and Muxika, 2005):

$$\text{AMBI} = 0\text{EG}_1 + 1.5\text{EG}_2 + 3\text{EG}_3 + 4.5\text{EG}_4 + 6\text{EG}_5$$

These EG are ranked according to their sensitivity to an increasing stress gradient: EG_1 (species very sensitive to organic matter enrichment), EG_2 (species indifferent to enrichment), EG_3 (species tolerant to excess organic matter enrichment), EG_4 (second-order opportunistic species favored by excess organic matter enrichment) and EG_5 (first-order opportunistic species favored by excess organic enrichment). The results of the AMBI calculation can vary between 0 (high ecological status) and 7 (bad ecological status) (Borja et al., 2003).

To calculate the BENTIX index (Simboura and Zenetos, 2002), the same groups were used, but were proportioned differently. EG_1 and EG_2 were placed in one group G_I, and EG_3, EG_4, and EG_5 were placed in a second group G_{II}, and the calculation was $\text{BENTIX} = 6G_I + 2G_{II}$. The results for the BENTIX index can either be equal to 0 (bad ecological status) or can vary between 2 (poor ecological status) and 6 (high ecological status).

Both the AMBI and BENTIX indices require a major taxonomic classification effort, which is contrary to the principle of "taxonomic sufficiency" (Ellis, 1985; Dauvin et al., 2003) that recommends reducing the classification effort by considering only those taxonomic categories higher than species when appropriate. Clearly, identifying amphipods to the species level is not necessary when calculating AMBI or BENTIX since all of these organisms have the same sensitivity to increased organic matter, with the exception of one genus (*Jassa*). In fact, excepting *Jassa*, all amphipods belong to AZTI's EG_1 group, and all opportunistic polychaetes belong to the groups EG_4 and EG_5 (see www.azti.es). Thus, in accordance with the taxonomic sufficiency principle, we propose to exploit the opportunistic polychaete/amphipod ratio to determine ecological quality, using relative frequencies ([0; 1]) rather than abundances ([0; +∞[) in order to define the limits of the index.

Our new index, the *benthic opportunistic polychaetes amphipods index* is written:

$$\text{BOPA index} = \log\left(\frac{f_P}{f_A + 1} + 1\right),$$

where f_P is the opportunistic polychaete frequency (ratio of the total number of opportunistic polychaete individuals to the total number of individuals in the sample); f_A, the amphipod frequency (ratio of the total number of amphipod individuals excluding the opportunistic *Jassa* amphipods to the total number of individuals in the sample); and $f_P + f_A \leqslant 1$. The two "+1" terms (without unit) in the equation are needed in order (1) to allow the division operation to be completed even when f_A is null, and (2) to prevent the eventuality that a log of zero (which does not exist) would need to be calculated if f_P is null. The BOPA index is null only when there are no opportunistic polychaetes, indicating an area with a very low amount of organic matter. The index is low when the environment is good, with few opportunistic species; and it increases as increasing organic matter degrades the environment. Its value can vary between 0 (when $f_P = 0$) and log 2 (ca. 0.30103, when $f_A = 0$) because:

$$f_P = [0; 1] \quad \text{and} \quad f_A = [0; 1]$$
$$(f_A + 1) = [1; 2]$$
$$\frac{f_P}{f_A + 1} = [0; 1]$$
$$\left(\frac{f_P}{f_A + 1} + 1\right) = [1; 2]$$
$$\text{BOPA index} = [0; \log 2]$$

The frequency f_X of other species (ratio of the total number of individuals belonging to other species, including the amphipods of the *Jassa* genus, to the total number of individuals in the sample) can be taken into account using the following equations:

$$f_A + f_P + f_X = 1 \quad \text{with } f_X = [0; 1]$$

If the BOPA index is represented as a function of f_A and f_P, then the value of the BOPA index is constant for all couples (f_A;f_P) that resolve the equation $f_P = (f_A + 1)(10^{BOPA} - 1)$. The endpoints of this curve are $f_A = 0$ and $f_P = 10^{BOPA} - 1$, when $f_A = 0$ (e.g. $f_P + f_X = 1$), and $f_A = \frac{2}{10^{BOPA}} - 1$ and $f_P = 2 - \frac{2}{10^{BOPA}}$, when $f_P + f_A = 1$ (e.g. $f_X = 0$).

2.2. Data application

The BOPA index was developed for and applied to the soft-bottom communities in the English Channel. In this paper, we examine results of three studies on different assemblages of the *Abra alba* muddy fine sand community: (1) a temporal study conducted in the Bay of Morlaix (area A in Fig. 1); (2) a study of spatial distribution in the Bay of Veys (area B in Fig. 1); and (3) a study of ecological quality in two transects (west/east and north/south) in the Bay of Seine (areas C and D in Fig. 1). A *Macoma balthica* community was also sampled in the Seine estuary, and coarse and medium communities were also sampled in the Bay of Seine.

2.2.1. Bay of Morlaix

During a 20-year survey (1977–1996) of the soft-bottom communities in the Bay of Morlaix (Brittany, Western English Channel), the macrozoobenthos was sampled at two sites (Pierre Noire: 137 data elements and Rivière de Morlaix: 97 data elements) with either a Smith McIntyre grab or a Hamon grab (1 m^2) and sieved on a 1 mm circular mesh (see Dauvin, 1998, 2000; Gomez Gesteira and Dauvin, 2000, for more information about the principal characteristics of both sites and the sampling conditions). Pierre Noire is an *A. alba–Hyalinoecia bilineata* fine sand macrobenthic community. While Rivière de Morlaix is an *A. alba–Melinna palmata* muddy fine sand community. Both sites were polluted by hydrocarbons from the Amoco Cadiz wreck in April 1978. But the spill's impact was more pronounced at Pierre Noire where amphipods of the genus *Ampelisca* had dominated prior to the spill (Dauvin, 1987). These amphipods disappeared in April 1978 just after the sediment was contaminated by hydrocarbons, and the recolonisation of the destroyed population took 10 years. Though a small number of amphipods did disappear from the Rivière de Morlaix site, which before the spill had been dominated by polychaetes, particularly by *M. palmata* and *Chaetozone setosa* in such estuarine environment with high level of organic matter in natural condition (see Dauvin, 2006), the impact of the spill was insignificant (Dauvin, 2000). Members of the dominant polychaetes species influenced the dynamics of the community.

2.2.2. Bay of Veys

The spatial distribution of the *A. alba* muddy fine sand community in 47 common sites in the Bay of Veys (western English Channel) was investigated in March and October of 1997. The fauna was sampled with a Hamon grab and sieved on a 2 mm circular mesh (Dauvin et al., 2004). The size of the meshes was not the same that in the previous case (Section 2.2.1), but it was without effect on the results (Dauvin et al., 2006) because we use frequencies: the proportions of each category of organisms—opportunistic polychaetes, amphipods (except *Jassa*) and others species—not sampled on a 2 mm mesh compared to on a 1 mm mesh can be probably the same.

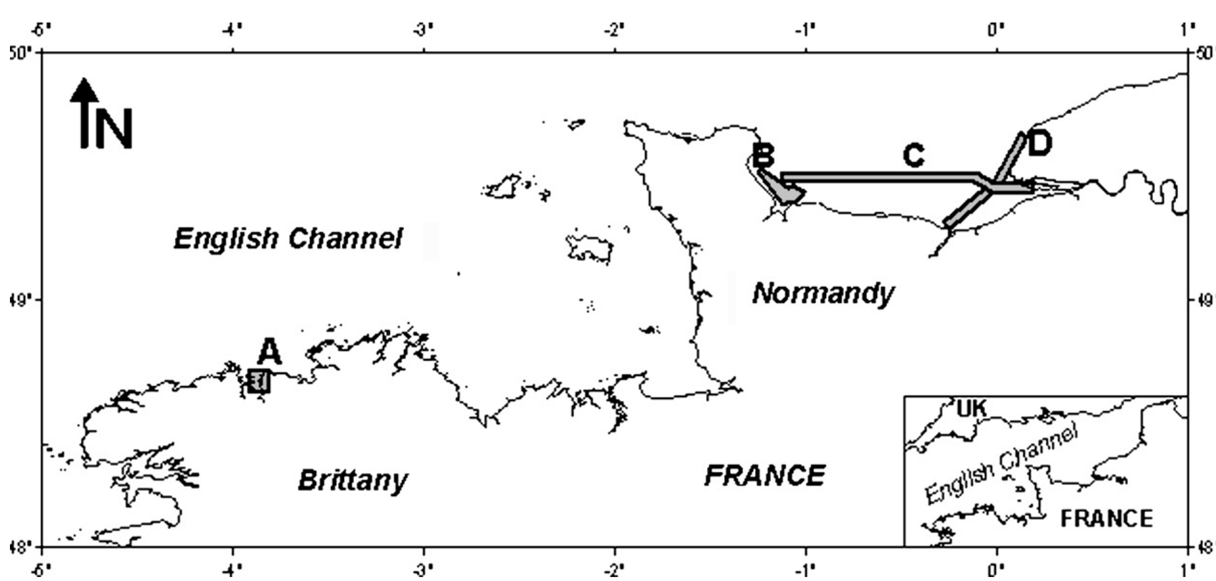

Fig. 1. Location of the areas studied (A, B, C, and D) in the English Channel.

2.2.3. Bay of Seine

Ecological measurements were taken in two transects:

(a) A west–east transect from the Bay of Seine to the polyhaline zone (salinity > 20) in the Seine estuary (area C in Fig. 1) during the pre-recruitment period of the macrobenthos (March–May). The macrofauna at 23 sites was sampled with a Hamon grab and sieved on a 2 mm circular mesh. The 15 sites nearest to the Seine estuary—including sites in a *Macoma balthica* muddy community and in an *A. alba–Pectinaria koreni* muddy fine sand community—were examined in March 1996 (Thiébaut et al., 1997). In May 1999, eight other sites were sampled, these in a coarse sand and sandy coarse gravel community and an *Ophelia borealis* medium to fine sand community (Ghertsos, 2002).

(b) A north–south transect offshore of the mouth of the Seine estuary (area D) in March 1991. A total of 19 sites in an *A. alba–P. koreni* muddy fine sand community and in a *A. alba* heterogeneous muddy community were sampled; site location ranged from the Orne River in the south to Antifer Harbour in the north (Thiébaut et al., 1997). Samples were taken using a Hamon grab and were sieved on a 2 mm circular mesh.

3. Results

3.1. Calibration of the index

To define the five EcoQ classes as proposed by the WFD, we compared the BOPA index with the limits proposed for AMBI and BENTIX. The ecological groups were defined as follows:

$$EG_1 = f_A + \alpha_1 f_X$$

$$EG_2 = \alpha_2 f_X$$

$$EG_3 = \alpha_3 f_X$$

$$EG_4 = \alpha_4 f_X + \alpha_6 f_P$$

$$EG_5 = \alpha_5 f_X + \alpha_7 f_P$$

$$G_I = EG_1 + EG_2 = f_A + (\alpha_1 + \alpha_2) f_X$$

$$G_{II} = EG_3 + EG_4 + EG_5 = f_P + (\alpha_3 + \alpha_4 + \alpha_5) f_X$$

where α_1–α_5 are the proportions ([0; 1]) of f_X in each ecological group ($\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 = 1$), and α_6 and α_7 are the proportions of f_P in EG_4 and EG_5 respectively ($\alpha_6 + \alpha_7 = 1$). Other than *Jassa*, which is included in f_X, all amphipods are considered to be part of EG_1. The values of α_1–α_5 cannot be known due to the application of the

Table 1
Example of calculation of BOPA index, AMBI and BENTIX with macrofauna sampled in one site from the Bay of Veys

<table>
<tr><th>Species and Ecological groups</th><th>Abundances</th><th>BOPA variables</th><th>AMBI variables</th><th>BENTIX variables</th><th>EG in f_X</th><th>EG in f_P</th></tr>
<tr><td>Chaetozone setosa
(opportunistic Polychaeta) EG_4/G_{II}</td><td>2 ind.m^{-2}</td><td rowspan="2">f_P = 4/52
f_P = 0.077</td><td rowspan="2">EG_4 = 4/52
EG_4 = 0.077</td><td rowspan="3">G_{II} = 10/52
G_{II} = 0.192</td><td rowspan="2"></td><td rowspan="2">α_6 = 4/4
α_6 = 1</td></tr>
<tr><td>Cirriformia tentaculata
(opportunistic Polychaeta) EG_4/G_{II}</td><td>2 ind.m^{-2}</td></tr>
<tr><td>Carcinus maenas
(Crustacea non Amphipoda) EG_3/G_{II}</td><td>6 ind.m^{-2}</td><td rowspan="7">f_X = 34/52
f_X = 0.654</td><td>EG_3 = 6/52
EG_3 = 0.115</td><td>α_3 = 6/34
α_3 = 0.176</td><td rowspan="8"></td></tr>
<tr><td>Diogenes pugilator
(Crustacea non Amphipoda) EG_2/G_I</td><td>2 ind.m^{-2}</td><td rowspan="5">EG_2 = 22/52
EG_2 = 0.423</td><td rowspan="7">G_I = 42/52
GI = 0.808</td><td rowspan="5">α_2 = 22/34
α_2 = 0.647</td></tr>
<tr><td>Amphiura brachiata
(Ophiuroidea) EG_2/G_I</td><td>8 ind.m^{-2}</td></tr>
<tr><td>Autolytus sp.
(non opportunistic Polychaeta) EG_2/G_I</td><td>2 ind.m^{-2}</td></tr>
<tr><td>Nephtys hombergii
(non opportunistic Polychaeta) EG_2/G_I</td><td>6 ind.m^{-2}</td></tr>
<tr><td>Sigalion mathildae
(non opportunistic Polychaeta) EG_2/G_I</td><td>4 ind.m^{-2}</td></tr>
<tr><td>Magelona mirabilis
(non opportunistic Polychaeta) EG_1/G_I</td><td>6 ind.m^{-2}</td><td rowspan="2">EG_1 = 20/52
EG_1 = 0.385</td><td>α_1 = 6/34
α_1 = 0.176</td></tr>
<tr><td>Bathyporeia gracilis
(Crustacea Amphipoda) EG_1/G_I</td><td>14 ind.m^{-2}</td><td>f_A = 14/52
f_A = 0.269</td><td></td></tr>
<tr><td>SUM =</td><td>52 ind.m^{-2}</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
</table>

See text for the names of the variables and proportions.
BOPA index = log((0.077/1.269) + 1).
BOPA index = 0.026 (high status).
AMBI = 1.5 × 0.423 + 3 × 0.115 + 4.5 × 0.077.
AMBI = 1.33 (good status).
BENTIX = 6 × 0.808 + 2 × 0.192.
BENTIX = 5.23 (high status).
NB: α_4, α_5 and α_7 = 0.

principle of "taxonomic sufficiency". A real example, where the determination was made at the level species, is provided in Table 1 to facilitate the demonstration. To calculate the BOPA index, the AMBI and BENTIX equations must be solved using our variables (e.g., the frequencies f_A, f_P and f_X) and not the proportions of the ecological groups EG_1–EG_5 and G_I and G_{II}, as in original equations. Thus, it is necessary to continue the demonstration for the particular case of $f_X = 0$ (e.g., $f_P + f_A = 1$) so that the α_1–α_5 values no longer intervene.

For the case ($f_X = 0$), $AMBI = 0 \times f_A + 4.5 \times \alpha_6 f_P + 6 \times \alpha_7 f_P$, where $\alpha_6 = [0; 1]$ and $\alpha_7 = [0; 1]$. Consequently, $4.5 f_P \leqslant AMBI \leqslant 6 f_P$. Using the limits of AMBI proposed by Borja et al. (2004a), it is possible to calculate the corresponding f_P values. f_A is then obtained by subtracting f_P from 1 ($f_A = 1 - f_P$). The BOPA index can then be calculated using these new values (shown in Table 2). When $f_X = 0$, the intervals overlap; however, since in the samples f_X is generally greater than 0 and $f_P + f_A$ is generally less than 1, the smallest values can be used as limits given that if f_X increases, then f_P (the highest coefficient in the AMBI formula) decreases. When opportunistic polychaetes are rare, the environmental status rating is always considered to be high (Fig. 2).

The same type of calculation that was done for AMBI was then carried out using the BENTIX limits proposed by Simboura and Zenetos (2002) (see Table 3). If $f_P + f_A = 1$, then $BENTIX = 6f_A + 2f_P$. Thus, $BENTIX = 6f_A + 2(1 - f_A) = 2 + 4f_A$ or $BENTIX = 6(1 - f_P) + 2f_P = 6 - 4f_P$. Using the BENTIX limits, only four groups can be obtained for the BOPA index if $f_P + f_A = 1$, because a bad EcoQ is not possible with this index (a bad BENTIX EcoQ corresponds to an azoic system ($f_A + f_P + f_X = 0$)). Since the WFD requires five EcoQ classes, the BOPA index limits obtained with AMBI are a better choice.

Since frequencies are used to calculate the BOPA index instead of total abundance values, the opportunistic polychaete/amphipod ratio is interpreted in terms of the frequency, which can affect the EcoQ rating. For an identical ratio, the presence of opportunistic polychaetes will be seen to reflect a more disturbed situation if their frequency is higher (e.g., if opportunistic polychaetes and amphipods represent a larger part of the sample). For example, given 250 opportunistic polychaetes/m^2,

Table 2
Theoretical variations of f_P (opportunistic polychaete frequency), f_A (amphipod frequency, except *Jassa*) and the BOPA index, given the limits of the AMBI index, for the five EcoQ if $f_P + f_A = 1$

High	$0.0 < AMBI \leqslant 1.2$	$0.00 \leqslant f_P \leqslant 0.27$	$0.73 \leqslant f_A \leqslant 1.00$	$0.00000 \leqslant BOPA \leqslant 0.06298$
Good	$1.2 < AMBI \leqslant 3.3$	$0.20 < f_P \leqslant 0.73$	$0.27 \leqslant f_A < 0.80$	$0.04576 < BOPA \leqslant 0.19723$
Moderate	$3.3 < AMBI \leqslant 4.3$	$0.55 < f_P \leqslant 0.96$	$0.04 \leqslant f_A < 0.45$	$0.13966 < BOPA \leqslant 0.28400$
Poor	$4.3 < AMBI \leqslant 5.5$	$0.72 < f_P \leqslant 1.00$	$0.00 \leqslant f_A < 0.28$	$0.19382 < BOPA \leqslant 0.30103$
Bad	$5.5 < AMBI \leqslant 7.0$	$0.92 < f_P \leqslant 1.00$	$0.00 \leqslant f_A < 0.08$	$0.26761 < BOPA \leqslant 0.30103$

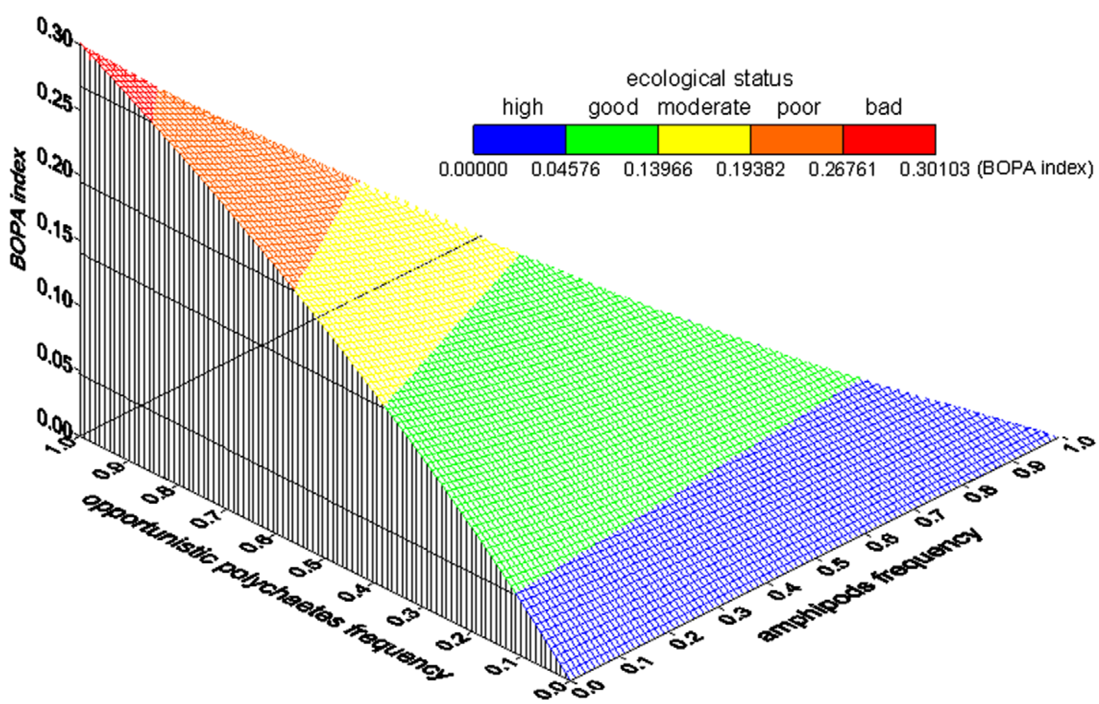

Fig. 2. Variations of the BOPA index according to f_P and f_A ($f_P + f_A + f_X = 1$). Colors correspond to those of the EcoQs (f_P = opportunistic polychaete frequency, f_A = amphipod frequency, except *Jassa*, f_X = other species frequency, *Jassa* included).

Table 3
Theoretical variations of f_P (opportunistic polychaete frequency), f_A (amphipod frequency, except *Jassa*) and the BOPA index, given the limits of the BENTIX index, for the five EcoQ if $f_P + f_A = 1$

High	$4.5 \leqslant$ BENTIX $\leqslant 6.0$	$0.000 \leqslant f_P \leqslant 0.375$	$0.627 \leqslant f_A \leqslant 1.000$	$0.00000 \leqslant$ BOPA $\leqslant 0.09018$
Good	$3.5 \leqslant$ BENTIX < 4.5	$0.375 < f_P \leqslant 0.625$	$0.375 \leqslant f_A < 0.625$	$0.09018 <$ BOPA $\leqslant 0.16273$
Moderate	$2.5 \leqslant$ BENTIX < 3.5	$0.625 < f_P \leqslant 0.875$	$0.125 \leqslant f_A < 0.375$	$0.16273 <$ BOPA $\leqslant 0.24988$
Poor	$2.0 \leqslant$ BENTIX < 2.5	$0.875 < f_P \leqslant 1.000$	$0.000 \leqslant f_A < 0.125$	$0.24988 <$ BOPA $\leqslant 0.30103$
Bad	BENTIX = 0.0	$f_P = 1.5$	$f_A = -0.5$	Impossible

20 amphipods/m^2 and no other individuals, the index value is 0.27 (bad); however, the same 250–20 ratio in the presence of other individuals, such as 5000 molluscs/m^2, would yield an index value of 0.02 (high). In the second case, opportunistic polychaetes are not considered abundant (ca. 5%) and so do not indicate a degraded situation.

3.2. Changes of the Bay of Morlaix macrobenthic communities over time

At the beginning of the sampling in the Bay of Morlaix—before the Amoco Cadiz wreck—the BOPA index values are different for the two sites (Fig. 3). The poor ecological status at Rivière de Morlaix (BOPA index = 0.26 on 1 August 1977) contrasts with the high ecological status at Pierre Noire (BOPA index = 0.01 on the same date), and the presence of *C. setosa*, an opportunistic polychaete that dominates the latter sample (more than 81% of the total abundance: 4186 ind m^{-2}), explains this difference.

At Pierre Noire, the BOPA index values increase just after the oil spill in that area, reflecting a decrease in amphipod abundance and frequency. A local index maximum (0.11) can be observed for autumn 1978, only six months after the spill, despite the overall good quality of the environment. For the other 19 years of the survey, the changes in the BOPA index values show two main patterns. During the first decade after the spill (1979–1987), higher values are obtained for the summer than for the winter, with two periods of moderate (1984) or poor (1982) ecological status related to a summer peak of *Pseudopolydora pulchra* at Pierre Noire. During the last decade (1988–1996), however, the BOPA values are low again and the EcoQ status is high, probably due to the recovery of the amphipods that originally dominated the community, particularly the *Ampelisca* (Dauvin, 1987, 1998).

According to the BOPA index values for two-thirds of the 19 years, moderate and poor EcoQ dominated at Rivière de Morlaix, probably due to a high abundance of *C. setosa*. With the exception of March 1981, from the moment of the Amoco Cadiz oil spill in 1978 until the end of 1982, four years after the spill, EcoQ are consistently moderate and/or poor. For the other 15 years of the survey, the BOPA index values indicate a more variable status, ranging from high in the winter/spring 1983, 1985, 1990, and 1995, to good status especially from July 1985 to July 1986 and in 1996 (the last year of the survey). These changes were due to the recovery of the impacted amphipod population (which, like at the Pierre Noire site, disappeared in 1978) and the high recruitment of *C. setosa* in certain years (e.g., 1987). In summary, the BOPA values for the Rivière de Morlaix site indicate the very strong dominance of opportunistic polychaetes, such as *C. setosa* and *P. pulchra*, no doubt due to the high concentration of organic matter in the sediment in an estuary sedimentation zone (Dauvin, 2000).

3.3. Spatial distribution pattern in the Bay of Veys

The first sampling in the Bay of Veys was carried out in March 1997 (i.e., before the recruitment period of most of the macrobenthic species) and the second in October 1997 (i.e., after the spring–summer recruitment period) (Dauvin et al., 2004). Total abundance increased by 30% between the two periods, indicating the settlement of juveniles between March and October. Only three sites had a total abundance lower than 50 ind m^{-2} in March, with only two in October; however, total abundances were moderate everywhere, exceeding 1000 ind m^{-2} in only few sites. On the other hand, the frequencies of amphipods and opportunistic polychaetes were generally low in such communities, which are dominated by echinoderms, such as *Echinocardium cordatum*, *Acrocnida brachiata* and *Thyone fusus*; molluscs, such as *A. alba* and *Crepidula fornicata*; and polychaetes, such as *Lanice conchilega*, *P. koreni* and *Owenia fusiformis*. Consequently, all sites qualified for high ecological status, except two in March and one in October, which only attained good status (Fig. 4). One of the sites, located in the southern part of the Bay of Veys, was "good" in both March and October. The other, close to Lestre along the eastern coast of Cotentin, was "good" only in March.

3.4. Transects in the Bay of Seine

Two transects were selected for sampling. The first one (C in Fig. 1) begins east of Cotentin and ends at the Seine estuary in the polyhaline zone of the estuary ($S > 20$) in the west. Densities were low: 16 sites have a total abundance of $\leqslant$100 ind m^{-2}. Amphipods and opportunistic polychaetes were rare: only three sites attained 1 amphipod m^{-2}, while the others had none; six sites had opportunistic polychaetes with a maximum of 6 ind m^{-2}. Consequently, all sites qualified for high EcoQ status (Fig. 5), except one, located close

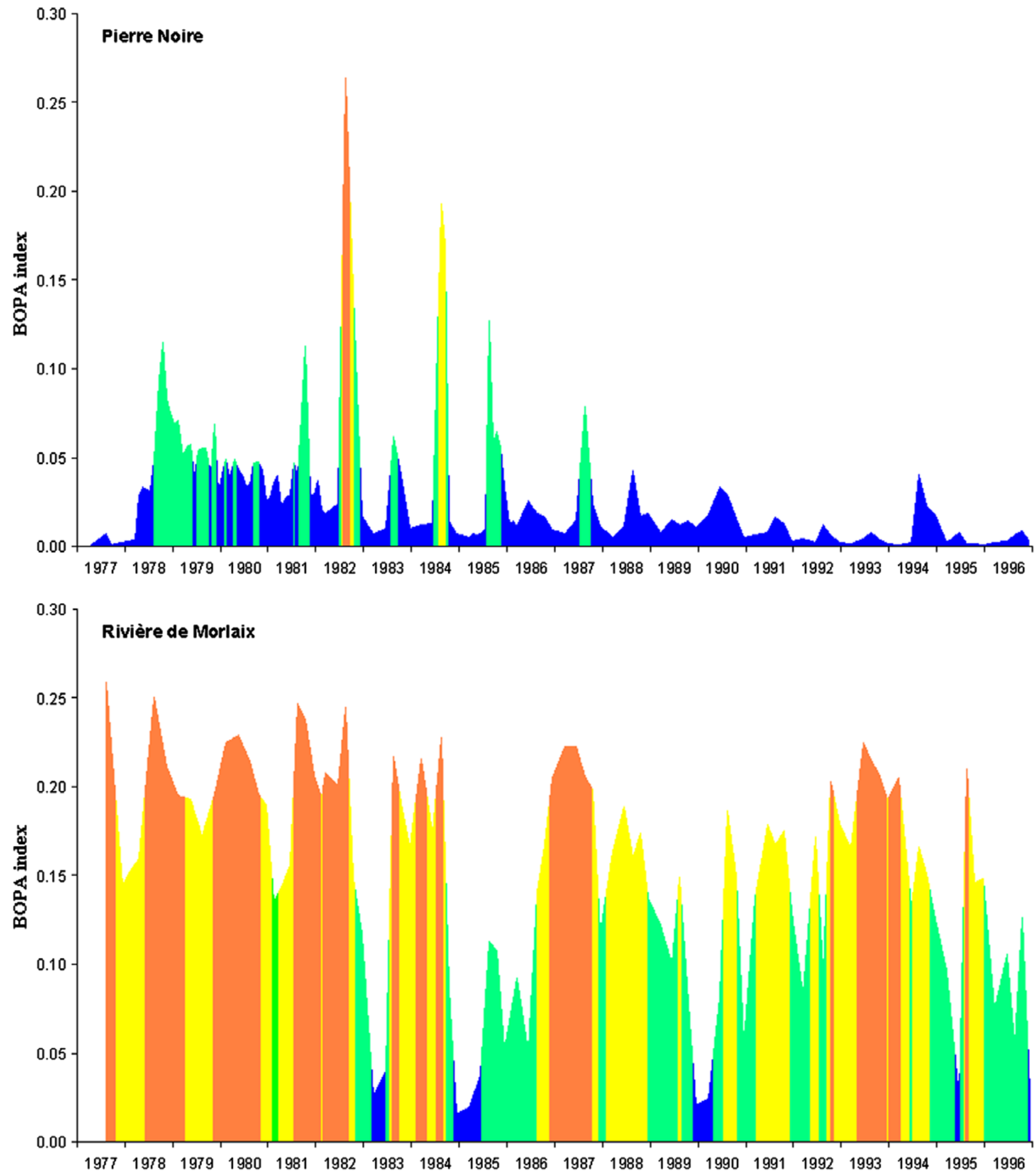

Fig. 3. Changes in the BOPA index over time (from 1977 to 1996) in the Bay of Morlaix (Western part of the English Channel) at two sites: Pierre Noire and Rivière de Morlaix. Colors correspond to those of the EcoQs: blue for high, green for good, yellow for moderate and orange for poor. (There was no "bad" status rating.)

to Le Havre Harbour, which only qualified for good status. All sites whose BOPA index is not null are near to the coast.

The second transect (D in Fig. 1) begins at the Orne River towards the southern end of the Bay and ends in Antifer Harbour to the north, thus crossing the mouth of the Seine estuary. The EcoQ rating is good near the Orne river and in the middle of the transect where the Seine river discharge is at its maximum, but high in the sites nearer to Antifer Harbour (Fig. 5).

4. Discussion

4.1. Utility of BOPA index

Tools for defining the ecological status of bodies of water must be developed in order to apply the Water Framework Directive (WFD). Benthic invertebrate fauna, along with phytoplankton, macroscopic algae, angiosperms and ichtyofauna, is one of the five biological elements that are examined to determine the quality of

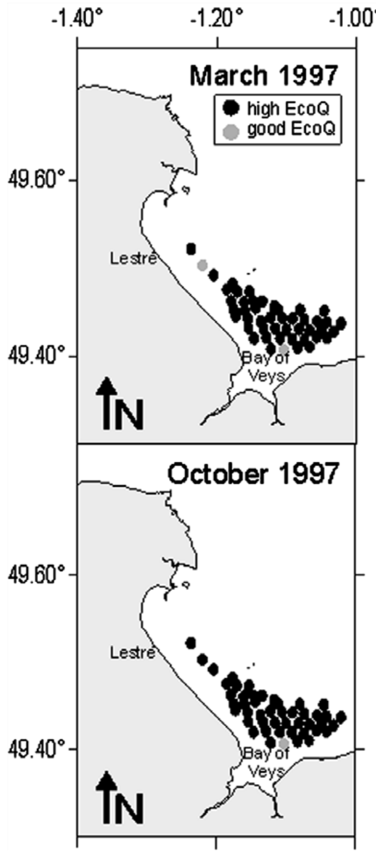

Fig. 4. Spatial distribution according to the BOPA index in March and October 1997 in the Bay of Veys (Bay of Seine, Eastern part of the English Channel).

transitional waters. Given this context, two indices based on the organisms have been developed and adapted to the objectives of the WFD: AMBI (Borja et al., 2000) for most regions and BENTIX specifically for the Mediterranean Sea (Simboura and Zenetos, 2002). These indices were the first to transcribe old concepts (the succession of ecological groups along a gradient of sedimentary organic matter) into mathematical language.

AMBI, BENTIX and the opportunistic polychaete/amphipod ratio are based on ecological groups. AMBI uses five groups, while BENTIX uses only two (formally three including two with the same coefficient), consequently minimizing the taxa classification errors possible with AMBI. But BENTIX, like AMBI, requires a lot of work to correctly identify and classify the different taxa. The BOPA index is easier to use than both AMBI and BENTIX because the need for taxonomic knowledge is reduced. It is only necessary to recognize amphipods and a reduced list of opportunistic polychaetes and to distinguish the *Jassa* amphipods from the others. According to the October 2005 inventory made available by the AZTI research (www.azti.es) team, the list of opportunistic polychaetes contains two families (Capitellidae and Cirratulidae), nine genus (*Cossura*, *Laeonereis*, *Ophryotrocha*, *Paraprionospio*, *Polycirrus*, *Polydora*, *Prionospio*, *Pseudopolydora* and *Rhaphidrilus*) and 21 species (*Chloeia rosea*, *C. venusta*, *Dipolydora caulleryi*, *D. coeca*, *D. flava*, *D. giardi*, *D. quadrilobata*, *D. socialis*, *Ficopomatus enigmaticus*, *Glycera alba*, *Leitoscoloplos mammosus*, *Malacoceros fuliginosus*, *Neanthes caudata*, *N. irrorata*, *Parougia caeca*, *Pholoe inornata*, *Phyllodoce (Anaitides) groenlandica*, *Schistomeringos rudolphii*, *Scolelepis tridentata*, *Sigambra parva* and *S. tentaculata*).

Diaz et al. (2003) reproached the scientific community for a "tautological development of new indices" that are ultimately futile since other indices already exist and function correctly. However, the BOPA index is not really a new index. It is more a necessary improvement of the opportunistic polychaete/amphipod ratio suggested by Gomez Gesteira and Dauvin (2000) for monitoring the impact of a pollution incident on soft-bottom macrobenthic communities. Replacing its predecessor, it does not duplicate the available methods.

The opportunistic polychaete/amphipod ratio has proven its effectiveness (Gomez Gesteira and Dauvin, 2000; Nikitik and Robinson, 2003), but a modification of its calculation mode was necessary to make it conform to the required WFD five ecological classes. Although this adaptation does impose certain limits on the index, our use of frequencies rather than abundances allows the ratio to be used to assign five EcoQ statuses. We do not dispute the effectiveness of AMBI or BENTIX. The proof is that we use the AMBI limits to calibrate those of the BOPA index. However, the principle of "taxonomic sufficiency" (Ellis, 1985; Dauvin et al., 2003; Dauvin, 2005) that is incorpo-

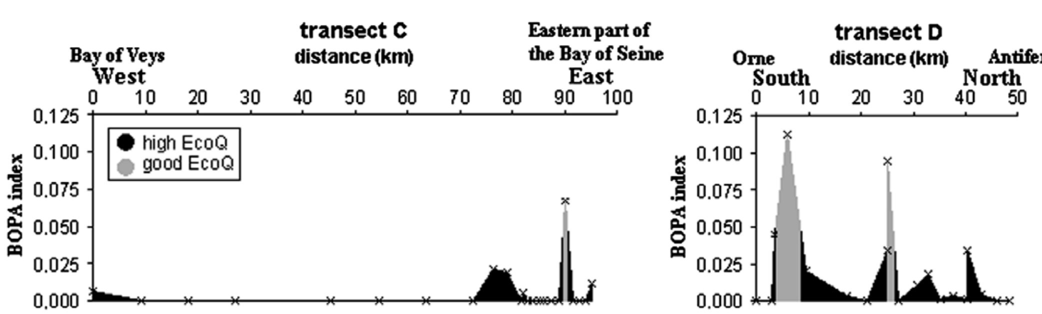

Fig. 5. Spatial distribution of the BOPA index along a west/east transect in the Bay of Seine in the Eastern part of the English Channel (C in Fig. 1) and along a north/south transect at the mouth of the Seine estuary (D in Fig. 1).

rated into the BOPA index is a necessary condition to a generalized use of a benthic index. According to Diaz et al. (2003), 81% of indices using taxonomic identification require a determination at the species level. The concept of taxonomic sufficiency must be applied if benthic indices are to be used at low cost by people who are not experts in taxonomy.

4.2. Advantages

Applying "taxonomic sufficiency" in the BOPA index decreases the cost of implementation by allowing identification to be done with only a minimum knowledge of macrobenthic species, and will, it is hoped, minimize the number of identification errors (see Dauvin, 2005). It decreases the time needed to complete the analysis, thus facilitating the reactivity required by the managers and politicians in monitoring man-made perturbations. Nine and 12 taxa respectively were sufficient for calculating the BOPA index for the samples from the Bay of Seine and from the Bay of Morlaix: for the Bay of Seine, there were seven taxa for opportunistic polychaetes (compared to 10 without the principle of "taxonomic sufficiency"), one taxon for amphipods (instead of 22), and one for the other organisms (instead of 182); for the Bay of Morlaix, there were nine taxa for opportunistic polychaetes (instead of 16), one for all amphipods except the *Jassa* (instead of 95), one for the *Jassa* (1 species), and one for the other organisms (instead of 385). The *Jassa* were added to the "other organisms" to obtain the value for f_X.

Such taxonomic reduction represents a vast simplification. Except for the *Jassa*, amphipods are unanimously recognized as being sensitive to organic enrichment, and the list of opportunistic polychaetes is rarely contested, wheareas the ecological groups of the others species vary depending on the region (NEA GIG Benthic Invertebrate Group, 2004; Simboura, 2004). Moreover, because the AZTI list is regulary updated (Borja and Muxika, 2005), it is difficult to compare results over time. On the other hand, comparing the results of various studies is easy with the BOPA index because, unlike the AMBI and BENTIX, its use of frequencies makes it independent of the surface unit chosen for expressing abundances.

The application of the BOPA index to the data from the four studies described earlier demonstrated the BOPA index's sensitivity to increases in organic matter in sediment (e.g., the BOPA index increases near rivers, as shown for the Rivière de Morlaix site) as well as to oil pollution. This index can vary very quickly (increasing or decreasing), and thus it is appropriate for surveying the temporal changes of benthic systems at high frequencies.

4.3. Disadvantages

The BOPA index calculation takes into account only three categories of organisms—opportunistic polychaetes, amphipods (except *Jassa*), and other species—but only the first two categories intervene directly in calculation. Though opportunistic polychaetes represent the majority of the opportunistic macrobenthic species (more of 70%) in the list proposed by the AMBI team (www.azti.es), oligochaeta is also an important opportunistic taxon that is not taken into account in the BOPA index; it was excluded because oligochaetes are very rare in coastal marine and polyhaline systems. Similarly, sensitive species are much more numerous than other ecological groups (ca. 40% of the taxa listed by the AMBI team), but only amphipods are considered in BOPA index. The consequence of the decision to focus on opportunistic polychaetes and amphipods is that, given a poor ecosystem in which these two categories of organisms are rare or absent, it could be difficult, if not impossible, to interpret the results. An adaptation for mesohaline, oligohaline and freshwater estuarine zone will be necessary in the future by including oligochaetes and by modifying the thresholds of the five classes of the WFD.

4.4. Operational limits of the BOPA index

Borja and Muxika (2005) have specified that AMBI cannot be used "when the percentage of unassigned taxa is >50%", and consider that the results would not be very reliable if that number was >20% or if there were less than three individuals or three taxa. No operational limits were specified for BENTIX (Simboura and Zenetos, 2002; Simboura, 2004). As a general rule, we think that an operational limit must be set for any index using total abundance values in the calculation. Based on our own experiments, we propose an empirical threshold of 20 individuals as a safety margin to insure that results are interpretable.

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