Pergamon

Marine Pollution Bulletin Vol. 40, No. 12, pp. 1100–1114, 2000

Printed in Great Britain
0025-326X/00 $ - see front matter

PII: S0025-326X(00)00061-8

A Marine Biotic Index to Establish the Ecological Quality of Soft-Bottom Benthos Within European Estuarine and Coastal Environments

A. BORJA*, J. FRANCO and V. PÉREZ
Department of Oceanography and Marine Environment, Technological Institute for Fisheries and Food (AZTI), Av. Satrústegui 8, 20008 San Sebastián, Spain

In this paper, a marine Biotic Index (BI) for soft-bottom benthos of European estuarine and coastal environments is proposed. This is derived from the proportions of individual abundance in five ecological groups, which are related to the degree of sensitivity/tolerance to an environmental stress gradient. The main difference with previously published indices is the use of a simple formula that produces a continuous Biotic Coefficient (BC) – which makes it more suitable for statistical analysis, in opposition with previous discreet biotic indices – not affected by subjectivity. Relationships between this coefficient and a complementary BI with several environmental variables are discussed. Finally, a validation of the proposed index is made with data from systems affected by recent human disturbances, showing that different anthropogenic changes in the environment can be detected through the use of this BI. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: biotic index; ecological quality; diversity; benthos; soft-bottom; European coastal environments.

Introduction

Marine environmental quality control is undertaken usually by means of monitoring different parameters in water, sediment and sentinel organisms (i.e. Mussel Watch), as in the USA (O'Connor, 1992), France (RNO, 1998) or Great Britain (Franklin and Jones, 1994). This control is centred on physico-chemical and ecotoxicological variables and, less usually, on biological variables. Dauer (1993) stated that biological criteria are considered important components of water quality because: (i) they are direct measures of the condition of the biota, (ii) they may uncover problems undetected or underestimated by other methods; and (iii) such criteria provide measurements of the progress of restoration efforts.

New European rules (see Directive Proposal 1999/C 343/01, Official Journal of the European Communities 30/11/1999) emphasize the importance of biological indicators, in order to establish the ecological quality of European coasts and estuaries. Benthic invertebrates are used frequently as bio-indicators of marine monitoring, because various studies have demonstrated that macrobenthos responds relatively rapidly to anthropic and natural stress (Pearson and Rosenberg, 1978; Dauer, 1993).

River ecology has an established long tradition in applying macrobenthos as bio-indicators; likewise some biotic indices have been proposed (Woodiwiss, 1964; Cairns *et al.*, 1968; Chandler, 1970; ISO-BMWP, 1979, etc.). On the other hand, some attempts to provide useful 'tools' to measure ecological quality in the marine environment have been developed in Europe and North America (Hily, 1984; Majeed, 1987; Dauer, 1993; Grall and Glémarec, 1997; Weisberg *et al.*, 1997).

All the aforementioned studies utilize soft-bottom communities to construct the indices, because macrobenthic animals are relatively sedentary (and cannot avoid deteriorating water/sediment quality conditions), have relatively long life-spans (thus, indicate and integrate water/sediment quality conditions, with time), consist of different species that exhibit different tolerances to stress and have an important role in cycling nutrients and materials between the underlying sediments and the overlying water column (Hily, 1984; Dauer, 1993).

In this contribution, a marine Biotic Index (BI) is designed to establish the ecological quality of European coasts. This explores the response of soft-bottom communities to natural and man-induced changes in water quality, integrating long-term environmental conditions.

---

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

Methods

Sampling

The Department of Land Action, Housing and Environment of the Basque Government has established a network of monitoring stations along the Basque coast-line (North of Spain). This provides water, sediment and biological quality information from 30 sampling stations (Fig. 1). The benthic sampling has been carried out every February, from 1995 to 1998 using the research vessel '*Ortze*'.

At each of these stations, three replicates of benthos were collected with a Van Veen grab (1215 cm^2). The samples were filtered immediately, using a sieve of mesh size of 1 mm and fixed in a solution of 4% formalin (Holme and McIntyre, 1971).

Sediment data

At each station, a sediment sample was obtained to determine redox potential, organic matter content and contaminant levels (heavy metals and organic compounds). The redox potential was measured, on board, by means of an Orion 977800 platinum electrode which was connected to a Crison 501 pH-meter-milivoltimeter.

A 200 g sediment sample was dried at 80°C for 24 h, then it was washed with freshwater on a mesh of 63 μm. The dried residue was sieved on a column of eight sieves (size 31 μm to 4 mm). The percentages of gravel, sand and mud were calculated as: >2 mm fraction, 63 μm – 2 mm and <63 μm, respectively (Holme and McIntyre, 1971).

The organic matter content was calculated by the loss on ignition method: drying at 105°C, 24 h; then combusting at 520°C, 6 h (Kristensen and Anderson, 1993).

Metal concentrations (As, Cd, Cu, Cr, Hg, Ni, Pb and Zn) were analysed on the <63 μm fraction. Extraction was made first with nitric acid, during 15 h, at ambient temperature; and second, with nitric and hydrochloric acids (1:3 in volume), using a microwave oven (130 W, 4 min; 0 W, 1.5 min; 250 W, 5 min; 0 W, 2 min; 400 W, 4 min). Detection was made by atomic absorption, using flame, graphite furnace and cold vapour techniques. The analytical procedure was checked with reference material (BCR marine sediment-harbour PACS-1); differences with this material were lower than 10%.

For PCB (eight congeners), DDT and HCH determination a portion of the original sample was desiccated with anhydrous sodium sulphate and extraction was made with iso-octane, after conditioning and clean-up of the extract the analysis was made with an HP-5890 gas chromatograph. On the other hand, for PAH (10 compounds) determination, the extraction was made with ether, and the analysis was made by means of HPLC.

Water quality data

The mean bottom oxygen concentration was measured with a CTD Sea-Bird 25, or with a portable YSI-55 oxymeter. Salinity was measured with the same CTD, or with a Kahlsico SR10 induction salinometer.

Biological data

The identification was undertaken in the laboratory by means of a binocular microscope (4–40×). After computing the mean abundance of each taxon, at each sampling station, the macrobenthic community structure was described calculating the following descriptors (Washington, 1984): richness (number of identified taxa); abundance (N: ind m^{-2}); numerical diversity (Shannon Wiener H'_n: bits ind^{-1}); biomass (Dry Weight, B: g m^{-2}); and biomass diversity (Shannon Wiener H'_b: bits g^{-1}).

BI model

The model here developed is based on that first used by Glémarec and Hily (1981) and then by Hily (1984), which utilizes soft-bottom benthos to construct a BI.

Soft-bottom macrobenthic communities respond to environmental stress (i.e. the introduction of organic matter in the system) by means of different adaptive strategies. Gray (1979) summarizes these strategies into three ecological groups: *r* (*r*-selected: species with short life-span, fast growth, early sexual maturation and larvae throughout the year); *k* (*k*-selected: species with relatively long life, slow growth and high biomass); and *T* (stress tolerant: species not affected by alterations).

Salen-Picard (1983) has proposed four progressive steps relating to stressed environments: (i) initial state (in an unpolluted situation, there is a rich biocenosis in individuals and species, with exclusive species and high diversity); (ii) slight unbalance (regression of exclusive species, proliferation of tolerant species, the appearance of pioneering species, decrease of diversity); (iii) pronounced unbalance (population dominated by pollution indicators, very low diversity); and (iv) azoic substrata.

Following these four steps, Hily (1984) and Glémarec (1986) have stated that the soft-bottom macrofauna could be ordered in five groups, according to their sensitivity to an increasing stress gradient (i.e. increasing organic matter enrichment). Their concept is similar to that developed for the Infaunal Index for Southern California, described by Mearns and Word (1982) and Ferraro *et al.* (1991). These groups have been summarized by Grall and Glémarec (1997), as outlined below.

Group I. Species very sensitive to organic enrichment and present under unpolluted conditions (initial state). They include the specialist carnivores and some deposit-feeding tubicolous polychaetes.

Group II. Species indifferent to enrichment, always present in low densities with non-significant variations with time (from initial state, to slight unbalance). These include suspension feeders, less selective carnivores and scavengers.

Group III. Species tolerant to excess organic matter enrichment. These species may occur under normal conditions, but their populations are stimulated by

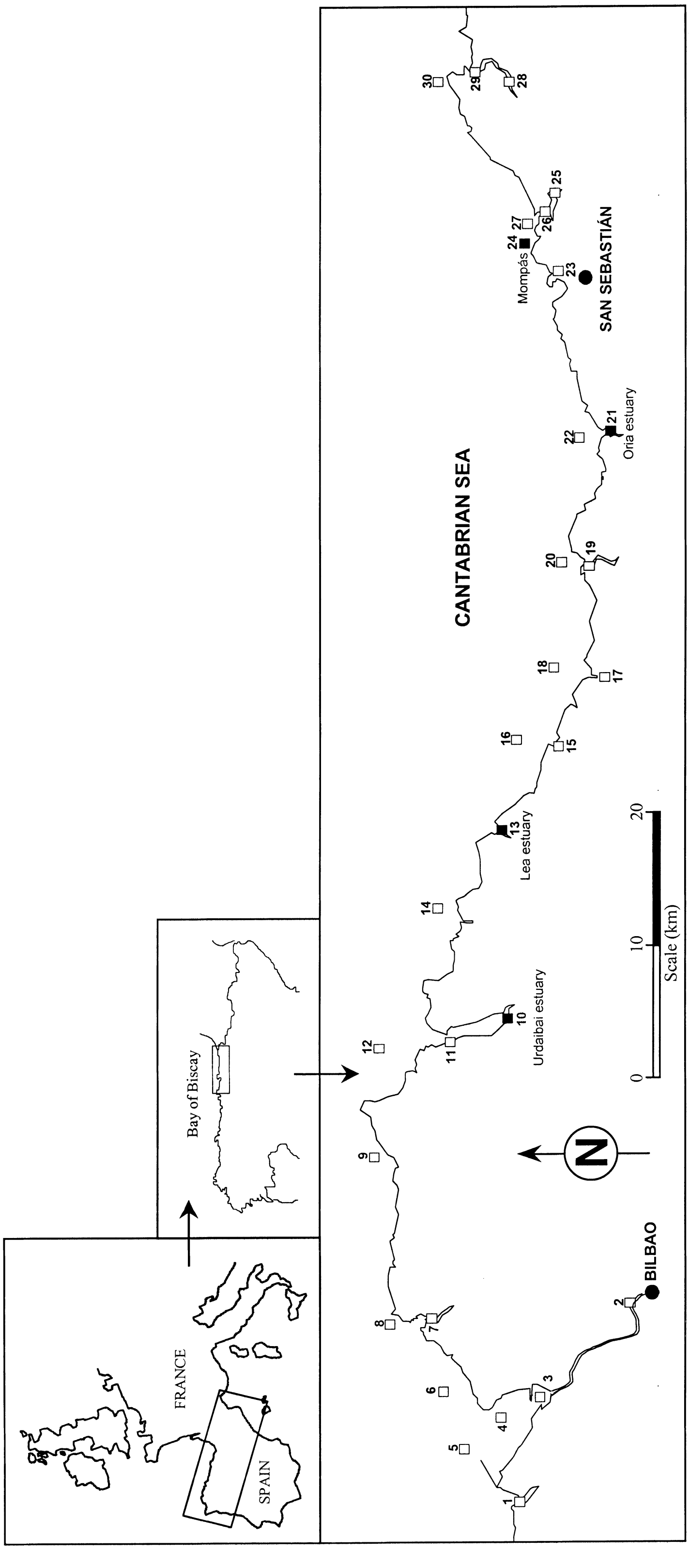

Fig. 1 Position of the 30 stations monitored along the Basque coastline (North of Spain), from 1995 to 1998. The stations used to validate the model are shown in black.

organic richment (slight unbalance situations). They are surface deposit-feeding species, as tubicolous spionids.

Group IV. Second-order opportunistic species (slight to pronounced unbalanced situations). Mainly small sized polychaetes: subsurface deposit-feeders, such as cirratulids.

Group V. First-order opportunistic species (pronounced unbalanced situations). These are deposit-feeders, which proliferate in reduced sediments.

The distribution of these ecological groups, according to their sensitivity to pollution stress, provides a BI with eight levels, from 0 to 7 (Hily, 1984; Hily *et al*., 1986; Majeed, 1987).

In the aforementioned monitoring network of sampling stations, together with other studies developed by AZTI along the Basque coastline within the last five years (Borja *et al*., 1995, 1999a,b), more than 900 taxa have been identified. These species are representative of the most important soft-bottom communities present at European estuarine and coastal systems. The taxa have been classified (list in Appendix A) according to the above ecological groups, following Majeed (1987), Dauer (1993), Weisberg *et al.* (1997), Grall and Glémarec (1997) and Roberts *et al.* (1998). Only about 12% of the taxa have not been possible to be assigned to an ecological group.

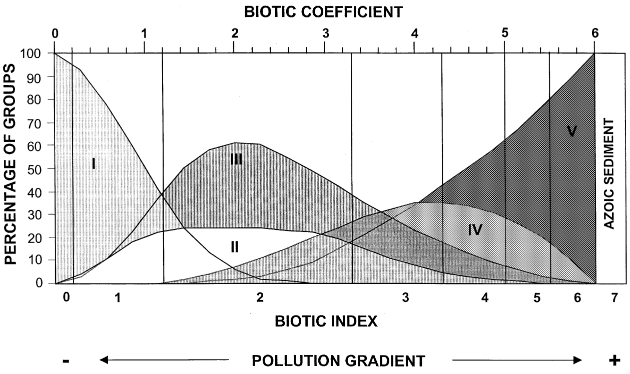

Fig. 2 Theoretical model, modified from Hily (1984), Hily *et al*. (1986) and Majeed (1987), which provides the ordination of soft-bottom macrofauna species into five ecological groups (Group I: species very sensitive; Group II: species indifferent; Group III: species tolerant; Group IV: second-order opportunistic species; Group V: first-order opportunistic species), according to their sensitivity to an increasing pollution gradient. The relative proportion of abundance of each group in a sample provides a discreet BI with eight levels (0–7) and an equivalent continuous BC (values between 0 and 6).

Based upon Hily's model (Hily, 1984; Hily *et al*., 1986; Majeed, 1987), Fig. 2 shows the theoretical distribution of relative abundance of each ecological group, along a pollution gradient.

A possible limitation in the utilisation of the model of Hily is that each BI has a discreet value and its calculation is not systematized. In order to improve the index, a single formula is proposed here. This is based upon the percentages of abundance of each ecological group, within each sample, to obtain a continuous index (the Biotic Coefficient (BC)), where

$$\begin{aligned}\text{Biotic Coefficient} &= \{(0 \times \%\,\text{GI}) + (1.5 \times \%\,\text{GII}) \\ &\quad + (3 \times \%\,\text{GIII}) + (4.5 \times \%\,\text{GIV}) \\ &\quad + (6 \times \%\,\text{GV})\}/100.\end{aligned}$$

The above-mentioned ecological groups (GI, GII, GIII, GIV and GV) are summarized in Table 1. Species not assigned to a group were not taken into account. These species represent only a mean abundance of 1.4%, for the total number of samples.

In this way, use of the BC can derive a series of continuous values, from 0 to 6, being 7 when the sediment is azoic. Nonetheless, the BC can be compared to the Grall and Glémarec (1997) BI, as adapted in this paper (Table 1). The result obtained is a 'pollution classification' of a site which is a function of the BC. Consequently, this represents the benthic community 'health', represented by the entire numbers of the BI.

Results

The mean and standard error values of grain size and physical characteristic associated with each of the sampling stations (17 estuarine and 13 littoral) are listed in Table 2. The water depth range is very large at each of the stations (under Mean High Water Neap to 24 m in the estuaries and 30–35 m associated with the littoral samples). Mean salinity, at bottom water, ranges from 16.2 to 35.3 in estuaries, but is restricted within the coastal areas (35.3–35.5).

The range in the percentage of oxygen saturation is very high within the estuaries (43–119%), but ranges in the littoral stations from 92% to 97%. The organic

TABLE 1

Summary of the BC and BI (modified from Grall and Glémarec, 1997).

Site pollution classification	Biotic Coefficient	Biotic index	Dominating ecological group	Benthic community health
Unpolluted	$0.0 < \text{BC} \leq 0.2$	0	I	Normal
Unpolluted	$0.2 < \text{BC} \leq 1.2$	1		Impoverished
Slightly polluted	$1.2 < \text{BC} \leq 3.3$	2	III	Unbalanced
Meanly polluted	$3.3 < \text{BC} \leq 4.3$	3		Transitional to pollution
Meanly polluted	$4.5 < \text{BC} \leq 5.0$	4	IV–V	Polluted
Heavily polluted	$5.0 < \text{BC} \leq 5.5$	5		Transitional to heavy pollution
Heavily polluted	$5.5 < \text{BC} \leq 6.0$	6	V	Heavy polluted
Extremely polluted	Azoic	7	Azoic	Azoic

TABLE 2

Physico-chemical characterisation of sampling stations, showing mean and standard error (SE) values of some sedimentological and water parameters.[a]

Station number	Station type	Depth (m)	Salinity	Dissolved oxygen (ml l^{-1})	% Oxygen saturation	% Sand	% Mud	% Organic matter	Redox potential (mV)
		Mean	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
1	E	I	23.5 ± 2.3	6.1 ± 0.2	101 ± 3.8	95.1 ± 3.8	4.6 ± 4.0	5.2 ± 0.2	296 ± 41.7
2	E	3	16.2 ± 2.0	3.1 ± 0.5	43 ± 6.0	38.5 ± 6.3	47.7 ± 6.2	8.7 ± 1.0	−101 ± 38.2
3	E	14	35.1 ± 0.1	5.0 ± 0.1	87 ± 1.7	19.6 ± 2.1	80.1 ± 2.1	13.0 ± 0.3	−53 ± 37.7
4	E	24	35.3 ± 0.1	5.4 ± 0.1	94 ± 1.3	80.7 ± 4.6	18.3 ± 4.8	6.0 ± 0.4	153 ± 45.2
5	L	34	35.3 ± 0.1	5.6 ± 0.1	96 ± 1.7	96.3 ± 0.8	3.3 ± 0.9	3.9 ± 0.3	248 ± 45.5
6	L	32	35.3 ± 0.1	5.5 ± 0.1	95 ± 1.7	94.8 ± 3.2	0.4 ± 0.2	6.8 ± 1.7	405 ± 18.2
7	E	I	29.5 ± 1.6	6.1 ± 0.2	105 ± 3.3	85.3 ± 2.4	0.5 ± 0.2	2.3 ± 0.1	388 ± 18.7
8	L	34	35.4 ± 0.0	5.5 ± 0.1	95 ± 1.5	81.5 ± 6.7	0.7 ± 0.5	3.8 ± 0.8	389 ± 7.2
9	L	33	35.4 ± 0.0	5.5 ± 0.1	96 ± 2.0	98.4 ± 0.2	1.1 ± 0.2	3.4 ± 0.4	322 ± 26.9
10	E	I	25.7 ± 2.5	6.1 ± 0.2	102 ± 3.3	27.4 ± 2.9	64.8 ± 4.2	7.7 ± 0.4	25 ± 20.2
11	E	I	34.8 ± 0.1	6.6 ± 0.2	119 ± 3.3	97.6 ± 1.3	0.3 ± 0.3	3.4 ± 0.5	410 ± 45.0
12	L	31	35.5 ± 0.0	5.6 ± 0.1	97 ± 1.8	95.6 ± 0.8	3.6 ± 0.8	3.6 ± 0.7	268 ± 43.8
13	E	I	26.3 ± 3.0	6.5 ± 0.2	111 ± 3.1	82.4 ± 4.8	12.5 ± 3.9	4.6 ± 0.7	167 ± 50.4
14	L	34	35.5 ± 0.0	5.6 ± 0.1	96 ± 2.0	93.8 ± 2.3	5.4 ± 2.3	3.7 ± 0.3	299 ± 34.5
15	E	I	28.9 ± 1.6	5.0 ± 0.3	87 ± 3.9	38.6 ± 3.1	16.7 ± 2.6	6.1 ± 0.5	0 ± 32.3
16	L	34	35.4 ± 0.1	5.3 ± 0.3	94 ± 3.4	94.3 ± 3.5	0.1 ± 0.1	3.7 ± 0.6	336 ± 11.5
17	E	I	17.5 ± 2.7	5.9 ± 0.2	89 ± 3.7	55.8 ± 5.8	40.3 ± 6.8	6.7 ± 0.6	63 ± 48.9
18	L	32	35.4 ± 0.1	5.4 ± 0.1	94 ± 1.8	95.1 ± 1.0	3.3 ± 1.0	4.2 ± 0.1	264 ± 37.2
19	E	I	23.3 ± 2.2	5.8 ± 0.2	96 ± 2.9	40.1 ± 5.2	51.3 ± 5.6	9.0 ± 0.7	24 ± 21.3
20	L	32	35.4 ± 0.0	5.3 ± 0.1	93 ± 2.0	84.8 ± 6.5	8.7 ± 6.7	5.5 ± 1.2	286 ± 39.0
21	E	I	21.1 ± 2.2	6.0 ± 0.2	97 ± 3.0	85.3 ± 5.0	7.4 ± 4.8	4.0 ± 0.6	313 ± 38.0
22	L	32	35.4 ± 0.1	5.4 ± 0.1	95 ± 2.0	86.2 ± 2.9	11.0 ± 2.7	3.8 ± 0.2	83 ± 18.1
23	E	I	21.1 ± 3.1	5.7 ± 0.3	92 ± 5.2	84.2 ± 5.8	5.4 ± 4.1	4.2 ± 1.3	210 ± 49.3
24	L	34	35.4 ± 0.0	5.5 ± 0.1	95 ± 2.3	81.6 ± 4.2	17.3 ± 4.3	5.0 ± 0.6	−84 ± 45.4
25	E	9	34.0 ± 0.2	3.2 ± 0.3	55 ± 4.9	36.7 ± 7.6	59.9 ± 8.8	28.2 ± 2.8	−185 ± 8.0
26	E	8	33.3 ± 0.4	5.0 ± 0.2	88 ± 3.7	46.8 ± 6.7	36.0 ± 7.6	9.4 ± 1.0	−71 ± 21.9
27	L	32	35.4 ± 0.0	5.3 ± 0.1	92 ± 2.2	89.1 ± 4.7	3.4 ± 2.2	3.4 ± 0.5	240 ± 53.0
28	E	I	19.3 ± 2.3	5.2 ± 0.3	83 ± 4.4	80.8 ± 5.0	13.7 ± 5.2	5.0 ± 1.0	102 ± 35.1
29	E	I	26.2 ± 1.6	5.6 ± 0.2	91 ± 4.6	91.9 ± 2.2	0.7 ± 0.3	2.7 ± 0.1	285 ± 32.0
30	L	33	35.3 ± 0.1	5.5 ± 0.1	97 ± 2.1	89.0 ± 5.7	6.4 ± 5.5	5.8 ± 1.8	232 ± 61.4

[a] E: estuarine site; L: littoral site; I: intertidal site.

matter content in the sediments is higher in the estuaries (2.3–28.2%) than in littoral zone (3.4–6.8%). This corresponds to a higher range of the mud content within the sediments (0.3–80.1% and 0.1–17.3%, respectively). The redox potential ranges from −185 to 410 mV within the estuaries, and from −84 to 405 mV within the littoral samples.

From 30 stations, some 114 samples of benthos have been obtained over a 4 year period. These samples correspond to different environments (estuarine, littoral, intertidal, subtidal) and physico-chemical characteristics (reduced and oxidized sediments, hypoxia and oversaturation in the bottom waters, poor organic matter proportion and enrichment, etc.).

After the application of the BC, considering its correspondence with the BI (Table 1), the results were: 2 samples with a $\mathrm{BI} = 0$; 23 samples of $\mathrm{BI} = 1$; 48 samples of $\mathrm{BI} = 2$; 15 samples of $\mathrm{BI} = 3$; 7 samples of $\mathrm{BI} = 4$; 6 samples of $\mathrm{BI} = 5$; 6 samples of $\mathrm{BI} = 6$; and 7 samples of $\mathrm{BI} = 7$.

Fig. 3 shows the results obtained by comparing different biological parameters, on samples having the same biotic indices. The $\mathrm{BI} = 7$ is equivalent to an azoic site, so all the biological parameters are equal to 0 in these particular samples.

The mean abundance increases from 36.7 ind m^{-2} ($\mathrm{BI} = 0$) to 2 559 ind m^{-2} ($\mathrm{BI} = 6$), with the exception of $\mathrm{BI} = 5$, with a value of 456 ind m^{-2} (Fig. 3(a)). Within the lowest of the Biotic Indices (0, 1 and 2), the standard error of the mean is very small; it is progressively larger in the highest.

Statistical analyses were made considering the BC because, as this coefficient can derive continuous values, it is more suitable for this purpose than the BI. Taking into account all the samples analysed, the non-parametric Spearman rank correlation between the abundance and the BC is not statistically significant ($p > 0.05$).

On the other hand, biomass (Fig. 3(b)) increases from 0.1 g m^{-2} ($\mathrm{BI} = 0$) to 14.3 g m^{-2} ($\mathrm{BI} = 4$). However for Biotic Indices 5 and 6, dominated by small opportunistic species, the biomass is lower than 4 g m^{-2}. There is no a statistically significant correlation between biomass and BC (Spearman rank correlation).

Fig. 3(c) shows the mean richness of the samples. Except in the case of $\mathrm{BI} = 0$, with a mean richness of 2, in the other biotic indices the richness decreases progressively from 26 to 27 species ($\mathrm{BI} = 1$ and 2) to 0 species ($\mathrm{BI} = 7$). Richness and BC are highly correlated ($p < 0.001$, Spearman rank correlation).

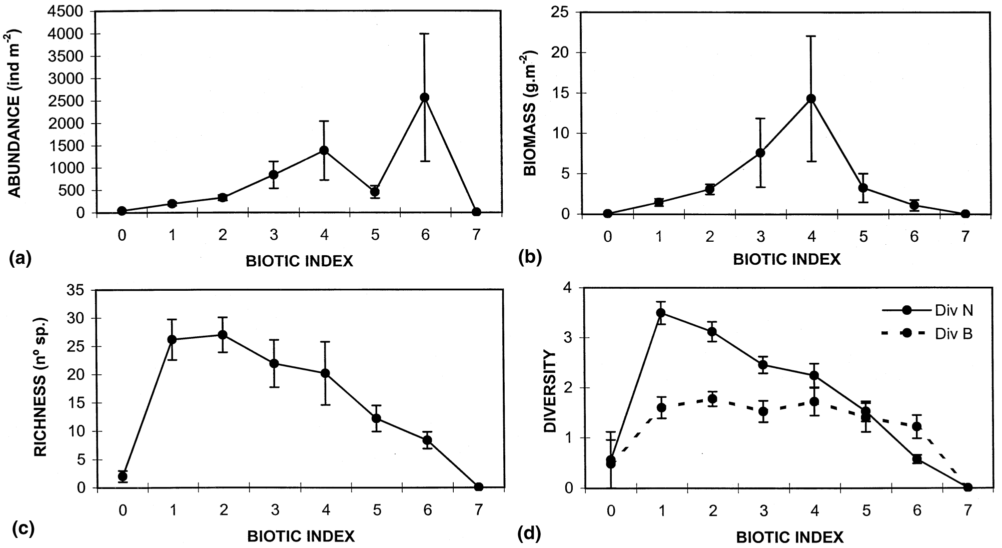

Fig. 3 Mean and standard error values of different biological parameters obtained on samples having the same biotic indices. (a) abundance; (b) biomass; (c) richness; and (d) diversity (derived from number of individuals *N* and biomass *B*).

Numerical diversity (Fig. 3(d)) shows a similar pattern to that of richness. There is a progressive decrease in the mean values, from 3.5 bits ind^{-1} (BI = 1) to 0 bits ind^{-1} (BI = 7), with the exception of BI = 0 which is associated with a low value (0.6 bits ind^{-1}). Biomass diversity has values of about 1.6 bits g^{-1}, between BI = 1 to 4; then, it decreases to 0 (BI = 7). Both variables are correlated with BC ($p < 0.001$ and $p < 0.05$ for numerical and biomass diversities, respectively), using Spearman rank correlation.

The relationships between some of the sedimentological and water quality parameters and biotic indices are shown in Fig. 4. BI = 0 is associated with the highest mean redox potential (Fig. 4(a): 360 mV). This parameter becomes progressively lower, with BI = 7 having a mean potential which is very reduced (–125 mV). Samples with low biotic indices (0 and 1) are associated with less than 2% of mud (Fig. 4(b)) and the values increase to 63% (BI = 7). Some anomalies were detected in BI = 5 and 6, which present 10–20% of mud. The organic matter content has a similar pattern of distribution to that of granulometry (Fig. 4(c)). Data on the mean bottom dissolved oxygen content are presented in Fig. 4(d). The highest value corresponds to BI = 0

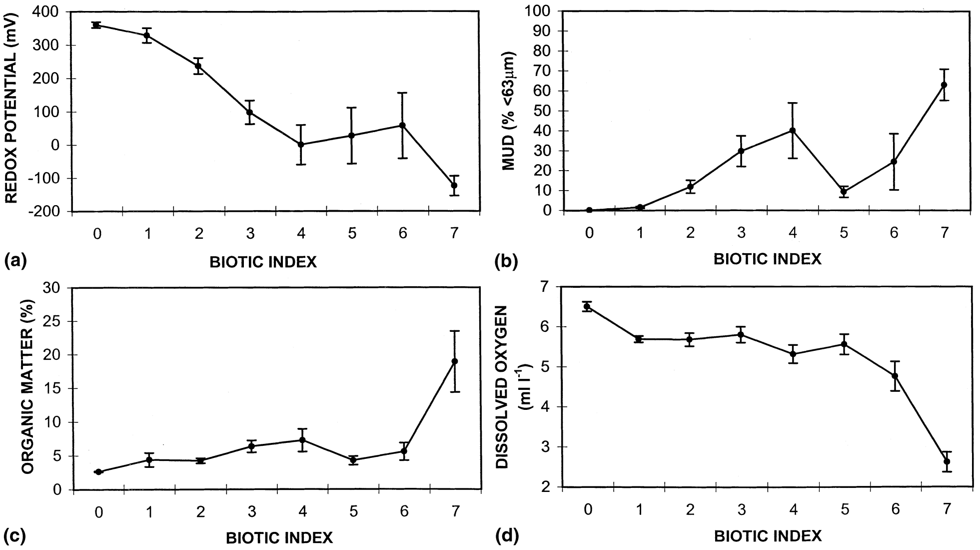

Fig. 4 Mean and standard error values of different sedimentological and water quality parameters obtained on samples having the same biotic indices. (a) redox potential; (b) percentage of mud; (c) organic matter content; and (d) bottom dissolved oxygen content.

(6.5 ml l^{-1}), decreasing to 2.6 ml l^{-1} at BI = 7. The Spearman rank correlations between these variables and BC are highly significant ($p < 0.001$).

The mean concentrations relating to some of the heavy metals in the sediments associated to each BI are shown in Fig. 5. Arsenic and mercury contents do not reveal any clear pattern of distribution with the BI. Other metals present increasing concentrations from BI = 0 to BI = 7, with the exception of some specific peaks (BI = 3, for chromium and nickel; and BI = 6, for lead and copper) and troughs (BI = 4 and 5, for cadmium, nickel and zinc). Except arsenic and mercury all the metals are positively correlated with BC ($p < 0.01$, Spearman rank correlations).

On the other hand, the organic compounds (Fig. 6) do not show a similar pattern to that of the metals. Only PCB increase in their concentrations from BI = 0 to BI = 7; however the differences are very small. PAH is at their smallest concentrations in BI = 5 and 6. The only significant correlation is found between BC and PCB ($p < 0.05$, Spearman rank correlation).

Comparing the percentage of samples of each BI that goes beyond the ER-L (or Effects Range-Low, representing concentrations below which adverse effects to fauna are expected to occur rarely (Long *et al.*, 1995)), the data presented in Fig. 7 shows that BI = 0 does not include samples that surpass these limits for metals and organic compounds. Normally, the other biotic indices

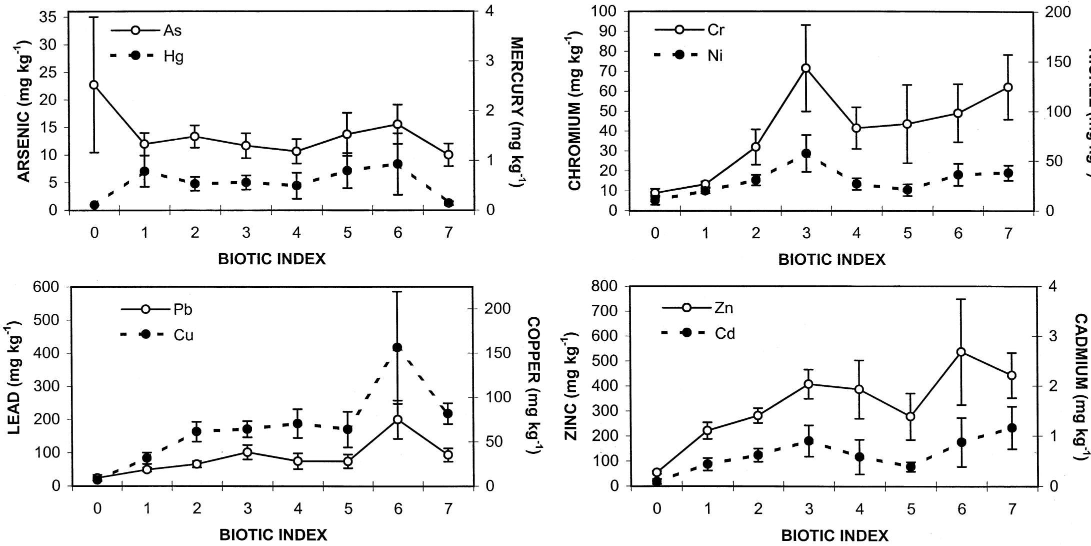

Fig. 5 Mean and standard error values of eight heavy metal contents in sediments obtained on samples having the same biotic indices.

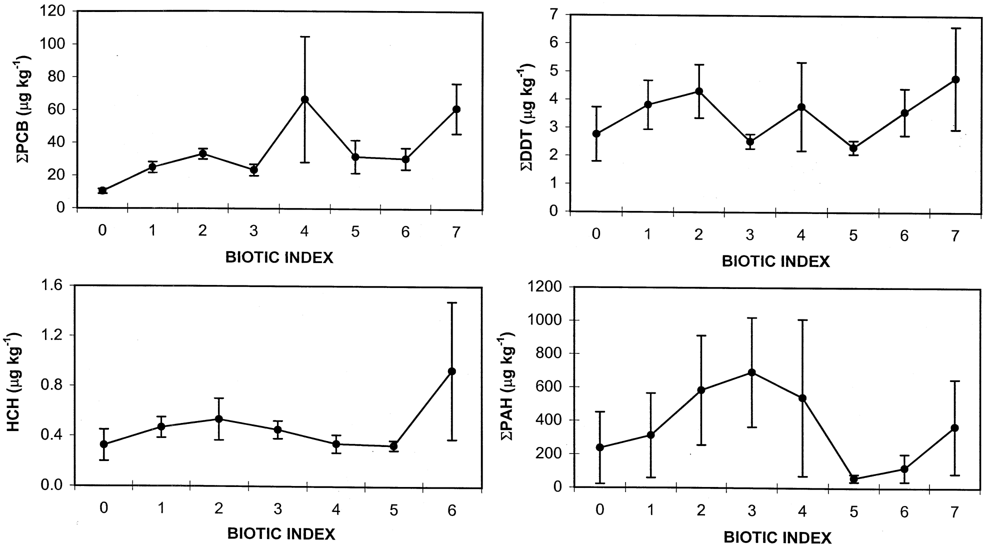

Fig. 6 Mean and standard error values of four organic compound contents in sediments obtained on samples having the same biotic indices.

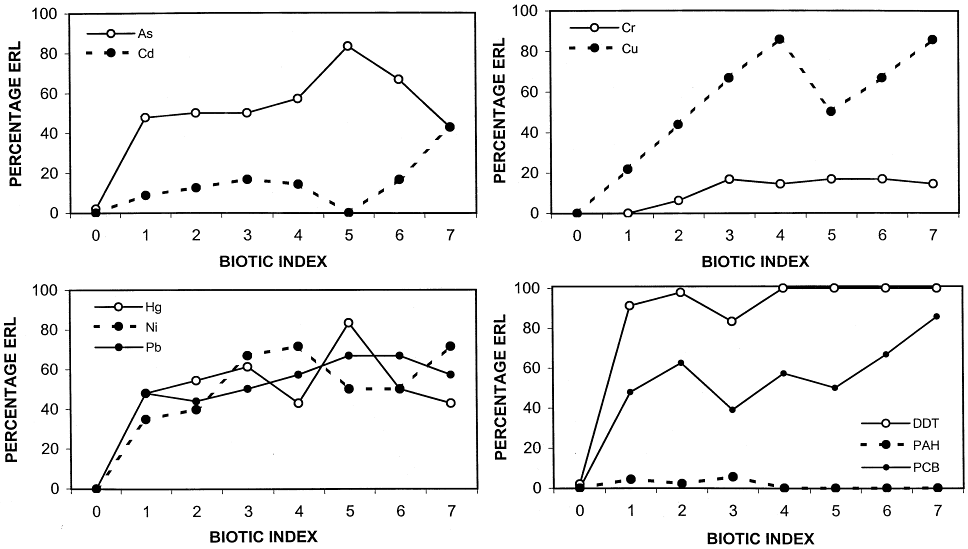

Fig. 7 Percentage of samples of each biotic index that goes beyond the ER-L (or Effects Range-Low, representing concentrations below which adverse effects are expected to occur rarely), for seven heavy metals and three organic compounds.

increase progressively in the percentage of samples surpassing these limits (see data presented for arsenic, mercury, nickel, lead, copper, chromium, PCB and DDT).

Discussion

Many of the biotic indices developed in the literature (Clements *et al.*, 1992; Mouthon, 1993; Stark, 1993; Grall and Glémarec, 1997; Roberts *et al.*, 1998, etc.) have been based on the paradigm of Pearson and Rosenberg (1978), as stated by Weisberg *et al.* (1997) in developing their own index. The paradigm states that benthic communities respond to improvements in habitat quality in three progressive steps: the abundance increases; species diversity increases; and dominant species change from pollution-tolerant to pollution-sensitive species.

This generally accepted paradigm has been adapted from Grall and Glémarec (1997) in this contribution, in order to obtain an European BI. This should be able to distinguish easily estuaries and coastal reference sites from polluted sites, with different levels of anthropogenic or natural degradation.

The index derived provides a semi-quantitative measurement of the degree of impact on soft-bottom macrofauna, which is reflected by changes in the qualitative and quantitative community composition.

As the BI has been established on the basis of analysis of samples obtained from a monitoring network, with a prevalence of polluted sites, there are only two unpolluted samples (BI = 0) which correspond to a 'normal' community (*sensu* Grall and Glémarec, 1997). The diversity results do not correspond to those expected from the aforementioned paradigm, because the richness is very low. Conversely, samples with BI = 1 (also unpolluted in the present proposal, corresponding to an impoverished community) or higher, BI = 2–6 (corresponding to slightly to heavily polluted sites) have well-defined values of biological parameters; this is as might be expected from the results of Pearson and Rosenberg (1978).

Some biotic indices, or Coefficients of Pollution (i.e. Bogdanos and Satsmadjis, 1985) do not appear to be suitable for application in some cases. This is due to the lack of sensitivity of these indices to intermediate pollution levels (MAFF, 1993), corresponding with slightly polluted areas. Hily (1984) and Grall and Glémarec (1997) have described similar difficulties.

The above limitation appears to be due to a general under-estimation of the faunal abundance in comparison with unpolluted areas. This is because faunal abundance will increase under slight to moderate pollution, but numbers of species can either stay constant or show only a slight increase. In the present proposal, this problem appears to be eliminated because the approach has a high sensitivity at these levels, with well-defined values in the biological parameters.

Organic enrichment and muddy bottoms, associated with subsequent low redox potential and hypoxia, are related with opportunistic species (Majeed, 1987) in 'heavily polluted' levels, according to the BI (BI = 5–7). Diaz and Rosenberg (1995) have suggested that benthic infaunal mortality could be initiated when the oxygen concentration falls below 2 ml l^{-1}. Ritter and Montagna (1999) have recently proposed that 3 mg l^{-1} (= 2.14 ml l^{-1}) defines the breakpoint between normoxic and hypoxic benthic communities. The mean oxygen concentration obtained for BI = 7 indicates that life could be very limited in those sites. However, within BI = 6, there are some situations of very low oxygen concentration which explain the presence of species which are resistant to severe or moderate hypoxia. These species are classified within ecological Groups IV and V.

Samples with BI = 6 and 7 are associated with sites that experience periodic hypoxia, consisting of repeated brief periods (days or weeks, in the case of BI = 6) or seasonal hypoxia (months, in the case of BI = 7), that generate mass mortality or complete elimination of the macrofauna. Some of the samples with BI = 7 are located within the Bilbao estuary, for which Sáiz-Salinas (1997) and González-Oreja and Sáiz-Salinas (1998) have demonstrated that the oxygen limitation represents the key factor in the estuarine defaunation of sampling stations within the estuary.

Physico-chemical results related to the BI (see Fig. 4) have some unexpected results at the level of BI = 5 and 6. The trend of increasing percentages of mud and organic matter, together with decreasing redox potential, break-down at these particular levels. BI = 5 and 6 correspond to high percentages of ecological Group V (with a mean of 77.5% of species in BI = 5, together with 92.7% in BI = 6). These species are mainly deposit-feeders. As such, they could modify the proportion of organic matter in the sediments on which they feed and, subsequently, modify the grain size composition of the sediments. The optimal grain size may be different for the settling larvae, juveniles and adults of a variety of deposit-feeders (Snelgrove and Butman, 1994), changing their physico-chemical properties. For example, Hall (1994) has stated that faecal pellets of benthic invertebrates modify the grain size of the surficial sediments.

In spite of the fact that hypoxia seems to control the presence of the groupings with BI = 7 and that organic matter content is very important in ascribing samples to the BI, ecotoxicological effects appear to play only a secondary role in the analyses; however it may have had an effect in the longer time, as cited by Sáiz-Salinas (1997) for the Bilbao Estuary.

In order to validate the derived BI, for more general application, four stations from the 30 stations sampled have been selected for more detailed analysis. The evolution of the percentage of ecological grouping, the BI and the BC, derived for between 1995 and 1998, at these stations is shown in Fig. 8.

Within the Urdaibai estuary (Figs. 1 and 8(a)) the results obtained from a single station, in the inner part of the estuary, shows a dominance of ecological Group III. This is characteristic of estuarine communities located at sites with organic matter inputs. The derived BI shows that, in 1995 and 1996, the site is slightly polluted (BI = 2) due mainly to the aforementioned organic matter enrichment. In 1997 and 1998, the BI increases progressively (BI = 3 and 4); as such classifying this station as 'meanly polluted'. Such a trend is caused by the increasing dominance of ecological Group V, which indicates the presence of opportunistic species. On the other hand, the BC increases gradually with time, which indicates a rising contamination in this site during the last years.

The increase in the BI could be the result of dredging activities undertaken along this particular estuary, within the last few years. At the same time, there are changes in the sediment composition, the abundance of suspended matter, etc. These provide the basis for an increase in the opportunistic species at this particular location.

In February 1995, the station in the Oria estuary (Figs. 1 and 8(b)), was located some 500 m landward of the mouth. Group I was dominant and the BI (2) provides a classification of the site as 'slightly polluted'. In 1995 and 1996, some channelling works were under-

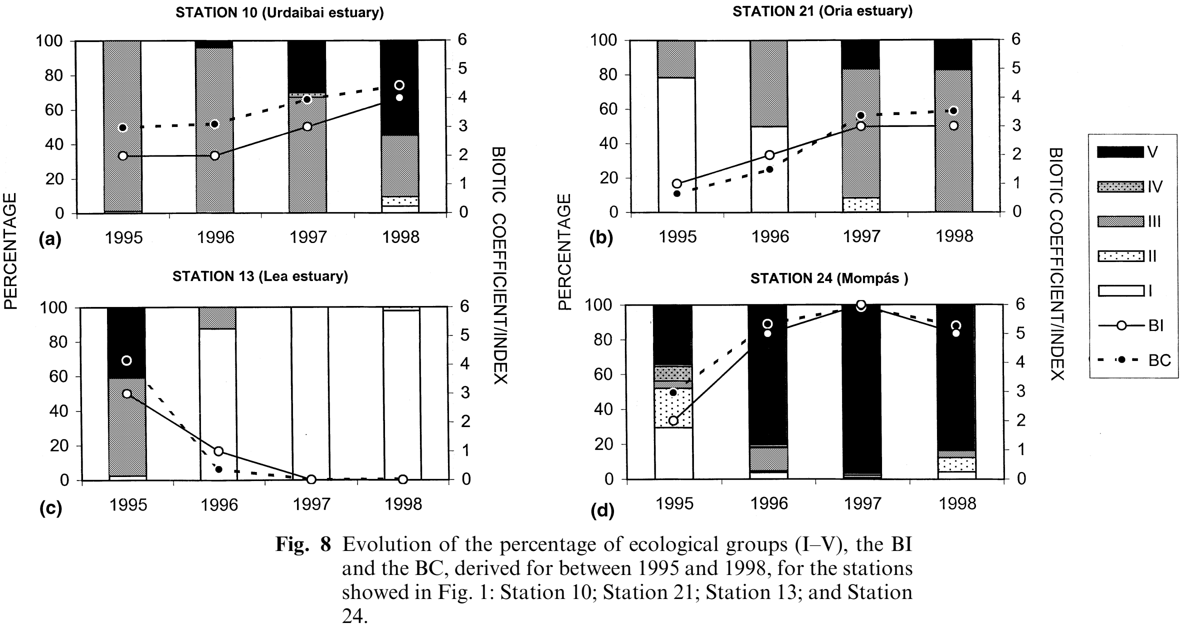

Fig. 8 Evolution of the percentage of ecological groups (I–V), the BI and the BC, derived for between 1995 and 1998, for the stations showed in Fig. 1: Station 10; Station 21; Station 13; and Station 24.

taken in this estuary, extending the mouth of the estuary some 500 m offshore. This development has led to an increase in the distance from the mouth of the estuary to the sampling station, with a subsequent change in the physico-chemical conditions (Borja *et al.*, 1999a). This change resulted in an increase in the mud and organic matter content, together with a decrease in dissolved oxygen. This change in the physical setting provides an explanation for the increase in the dominance of ecological Groups III and V (more characteristic at the inner part of the estuary), modifying the BI to 'meanly polluted' (3). The BC increased during this period, from 1.4 to 3.5.

The Lea is a small estuary within the Basque Country (Figs. 1 and 8(c)) which, in the past 4 years, has been subjected to a sewerage plan, eliminating urban and industrial effluent discharges into the estuarine waters. The estuary was dominated by the opportunistic Group V in 1995, with a BI of 3 (meanly polluted). Following the introduction of the sewerage scheme, the ecological Group I, composed of species that are sensitive to pollution, increased in its dominance. This represented, in 1997 and 1998, nearly 100% of the community. Throughout these two last years, the BI is 0. The BC decreases from 4.2 in 1995 to 0.4 in 1996 and near 0 in 1997 and 1998. So, in the last two years this station can be classified as an unpolluted site.

Finally, within the coastal area of Mompás, near San Sebastián (Figs. 1 and 8(d)), there is an important change in the ecological group composition between 1995 and 1996. At the beginning of this period, there is a co-dominance of Groups V, I and II. However, there is a clear dominance of Group V from 1996 to 1998. At the same time, the BI changes from 2 (slightly polluted) to 5–6 (heavily polluted). The BC, which was 3.0 in 1995, increased to values between 5.3 and 5.9 during the last three years. This particular coastal area has received large amounts of domestic and industrial waste from the San Sebastián area since the 1970s. Further, in 1995 and 1996, some sewerage works were constructed and an important volume of urban and industrial polluted waters, derived from nearby areas such as Pasajes or Tximistarri, were diverted to Mompás. The waste includes contaminants (heavy metals and organic compounds) and a high amount of organic matter originating from the paper manufacturers (Franco *et al.*, 1999).

Conclusions

The BC, proposed here as a BI to establish the ecological quality of the soft-bottom benthos within the European coastal environments, takes into account the faunal composition. As such, it ascribes each species to an ecological grouping, according to their sensitivity to an increasing stress gradient.

The different composition, in terms of the abundance of the various ecological groups in these samples provides a continuous BC (with values between 0 and 6). This is referenced to a BI, representing quality of bottom conditions in a discreet range from 0 (unpolluted) to 7 (extremely polluted). This composition is governed by the physico-chemical factors within the sediments and the overlying water column in terms of: organic matter content; percentage of mud within the sediments; dissolved oxygen content within the bottom waters; and the concentration of pollutants.

Biological parameters (such abundance, richness, biomass or diversity) provide a useful (and more broadly applicable) description of each level of the BI. It is considered (as described by Dauer, 1993) that biological criteria may complement toxicity and chemical assessment methods, to serve as independent evaluations of the ecological quality of marine and estuarine ecosystems.

Validation of the model developed shows that different anthropogenically changes in the environment can be detected through the use of the BI, including alterations to the natural system such as dredging, engineering works, sewerage plans and the dumping of polluted waters. On the other hand, the BC provides a more accurate view of the evolution of the ecological status of a particular location. Further, the fact that this particular coefficient can derive continuous values makes it more suitable for application to statistical analysis than the BI (i.e. temporal trend analysis).

The BI proposed here is relatively simple and can, meaningfully, be applied when attempting to determine the ecological status of European coastlines. Although this index has been developed in the Bay of Biscay, the methodology can be applied for other European coastal areas, only conditioned by the assignation of the species to the ecological groups described here. In fact, many of the species compiled in the Appendix A are present in North Sea and Mediterranean. So, the index may be improved with the contributions of newly assigned species from these seas and further examples of its more general application and validation.

Finally, this index facilitates the understanding of complex benthic data, summarizing a considerable amount of ecological information into a single representative value.

This study was supported by different contracts undertaken between the Department of Land Action, Housing and Environment of the Basque Government and AZTI. One of the authors (V. Pérez) was supported by a grant from the Department of Agriculture and Fishing of the Basque Government. We thank the staff of the Department of Oceanography of AZTI for their assistance during the field sampling and laboratory analyses and the INSUB Group that was charged of the taxonomical analysis. We wish to thank also Professor Michael Collins (School of Ocean and Earth Science, University of Southampton, UK) and an anonymous referee for kindly advising us on some details of this paper.

Appendix A

See Table 3.

TABLE 3

List of species and taxa (in alphabetical order) that have been found in all the stations along the whole studied period (the assigned ecological groups (see text) are also shown).[a]

Species	Group	Species	Group	Species	Group	Species	Group	Species	Group
Abarenicola claparedi	I	*Angulus tenuis*	I	*Bela powisiana*	I	*Chone infundibuliformis*	II	*Diastylis rugosa*	I
Abarenicola sp.	I	*Anomia ephippium*	I	*Bela* sp.	I	*Chone* sp.	II	*Diastylis* sp.	I
Abissoninoe hibernica	II	*Anoplodactylus petiolatus*	N.A	*Bittium reticulatum*	I	*Chthamalus stellatus*	I	*Diastylis tumida*	I
Abra alba	III	*Anoplodactylus pygmaeus*	N.A	*Boccardia chilensis*	I	*Circe minima*	I	*Diodora apertura*	I
Abra nitida	III	*Antenella* sp.	I	*Boccardia polybranchia*	I	*Circulus striatus*	I	*Diogenes pugilator*	II
Abra prismatica	III	*Anthozoa* sp.	I	*Boccardia* sp.	I	*Cirratulus chrysoderma*	IV	*Diopatra neapolitana*	I
Abra sp.	III	*Anthura gracilis*	I	*Bodotria arenosa*	II	*Cirratulus cirratus*	IV	*Diplocirrus glaucus*	I
Abra tenuis	III	*Aonides oxycephala*	III	*Bodotria scorpioides*	II	*Cirriformia tentaculata*	IV	*Dispio uncinata*	III
Acanthocardia aculeata	I	*Aora gracilis*	I	*Brada villosa*	N.A	*Cirripedo* sp.	I	*Divaricella divaricata*	I
Acanthocardia echinata	I	*Aora typica*	I	*Branchiomma vesiculosum*	I	*Clausinella fasciata*	I	*Donax trunculus*	I
Acanthocardia paucicostata	I	*Aphelochatea multibranchiis*	N.A	*Branchiostoma lanceolata*	I	Clavidae	I	*Doris* sp.	I
Acanthocardia sp.	I	*Apherusa cirrus*	I	*Brania oculata*	II	*Clymene* cf. *praetermisa*	I	*Dosinia exoleta*	I
Acanthocardia tuberculata	I	*Apherusa ovalipes*	I	*Brania pusilla*	II	*Clymene lumbricoides*	I	*Dosinia juv. indet.*	I
Acanthochitona critinus	I	*Aphonupis grubei*	I	*Bugula* sp.	I	*Clymene modesta*	I	*Dosinia lupinus*	I
Acanthochitona fascicularis	I	*Aphrodite aculeata*	N.A	*Callianassa* sp.	III	*Clymene oerstedii*	I	*Dosinia* sp.	I
Achelia hispida	I	*Apicularia guerini*	I	*Callianassa subterranea*	III	*Clytia* sp.	I	*Drilonereis filum*	II
Achelia simplex	I	*Apistobranchus tullbergi*	I	*Callianassa truncata*	III	*Cnidaria* sp.	I	*Ebalia* sp.	N.A
Aclis gulsonae	N.A	*Aponuphis bilineata*	II	*Calliostoma papillosum*	I	*Cochlodesma praetenue*	N.A	*Ebalia tuberosa*	N.A
Acronida brachiata	I	*Aporrhais pespelecani*	I	*Calliostoma zizyphinum*	I	*Copepoda indet.*	N.A	*Echinocardium cordatum*	I
Acteon sp.	I	*Aporrhais* sp.	I	*Calyptraea sinensis*	I	*Copépodo* sp.	N.A	*Echinocyamus pusillus*	I
Actinia equina	I	*Apseudes latreillei*	III	*Campylaspis glabra*	N.A	*Corbula gibba*	III	*Echinoidea* sp.	I
Aglaophamus rubella	N.A	*Arcturella* sp.	N.A	*Capitella capitata*	V	*Corophium acherusicum*	III	*Echiuroidea* sp.	I
Aglaophamus sp.	N.A	*Arenicola marina*	N.A	*Capitella* sp.	V	*Corophium acutum*	III	*Echiurus echiurus*	I
Aiptasia mutabilis	N.A	*Aricia latreilli*	I	*Capitellides giardi*	V	*Corophium arenarium*	III	*Edwardsia* sp.	II
Alcyonacea indet	N.A	*Aricidea catherinae*	I	*Capitomastus minimus*	IV	*Corophium insidiosum*	III	*Ehlersia ferrugina*	N.A
Alkmaria romijni	III	*Aricidea cerruti*	I	*Caprella fretensis*	N.A	*Corophium multisetosum*	III	*Ensis* sp.	I
Alpheus glaber	N.A	*Aricidea* cf. *assimilis*	I	*Caprella linearis*	N.A	*Corophium* sp.	III	*Eocuma dimorpha*	II
Alvania crassa	I	*Aricidea fragilis*	I	*Caprella penantis*	N.A	*Corophium volutator*	III	*Eocuma dollfusi*	II
Alvania semistriata	I	*Aricidea jeffreysii*	I	*Carcinus maenas*	III	*Coryne pusilla*	I	*Epilepton clarkiae*	I
Alvania sp.	I	*Aricidea minuta*	I	*Caryophyllia smithi*	I	*Corystes cassivelaunus*	I	*Epithonium clathrus*	I
Amatea trilobata	I	*Aricidea* sp.	I	*Caulleriella alata*	III	*Cossura longocirrata*	N.A	*Epitonium turtoni*	I
Amathia pruvot	I	*Armandia cirrosa*	I	*Caulleriella bioculata*	III	*Cossura pygodactylata*	N.A	*Ericthonius brasilensis*	N.A
Ampelisca brevicornis	I	*Armandia* spp	I	*Caulleriella* sp.	III	*Cossura* sp.	N.A	*Eteone longa*	II
Ampelisca cf. *spooneri*	I	*Aspidosiphon muelleri*	I	*Caulleriella zetlandica*	III	*Crangon allmani*	I	*Eteone picta*	II
Ampelisca heterodactyla	I	*Astacilla longicornis*	I	*Cavernularia pusilla*	I	*Crangon crangon*	I	*Euclymede praetermissa*	I
Ampelisca juv. indet.	I	*Astarte* sp.	I	*Ceradocus semiserratus*	I	*Crassostrea angulata*	III	*Euclymene affinis*	I
Ampelisca sarsi	I	*Astarte sulcata*	I	*Cerastoderma edule*	III	*Crepidula fornicata*	III	*Euclymene oerstedii*	I
Ampelisca sp.	I	*Astarte triangularis*	I	*Cerastoderma lamarcki*	III	*Cucumaria elongata*	I	*Euclymene* sp.	I
Ampelisca spinifer	I	*Asterina gibosa*	I	*Ceratostoma erinaceum*	I	*Cucumaria* sp.	I	*Euclymenidae indet.*	I
Ampelisca spinimana	I	*Astropecten irregularis*	I	*Cerebratulus marginatus*	III	*Cultellus pellucidus*	I	*Eudorella truncatula*	N.A
Ampelisca tenuicornis	I	*Astropecten irregularis typicus*	I	*Cerebratulus* sp.	III	*Cumopsis fagei*	II	*Eulalia bilineata*	II
Ampelisca toulemonti	I	*Athanas nitescens*	I	*Cereus pedunculatus*	I	*Cumopsis* sp.	II	*Eulalia mustela*	II
Ampharete finmarchica	I	*Athecata* sp.	I	*Ceriantario* sp.	I	*Cyathura carinata*	III	*Eulalia sanguinea*	II
Ampharete grubei	I	*Atylus falcatus*	I	*Cerianthus lloydii*	I	*Cyclope neritea*	I	*Eulalia* sp.	II
Ampharete juv. indet.	I	*Atylus guttatus*	I	*Cerianthus membranaceus*	I	*Cylichna cylindracea*	I	*Eulalia tripunctata*	II
Ampharete lindstroemi	I	*Atylus* sp.	I	*Cerianthus* sp.	I	*Cylichna* sp.	I	*Eulalia viridis*	II
Ampharete sp.	I	*Atylus swammerdami*	I	*Cestopagurus timidus*	I	*Cylichnina subcylindrica*	I	*Eulimella acicuta*	I
Amphicteis gunneri	III	*Atylus vedlomensis*	I	*Chaetopterus variopedatus*	I	*Cymodoce truncata*	I	*Eulimella* sp.	I
Amphipholis squamata	I	*Audouinia tentaculata*	IV	*Chaetozone B* spp	IV	*Cythara attenuata*	I	*Eumida bahusiensis*	II
Amphitrite johnstoni	I	*Autolytus longeferiens*	N.A	*Chaetozone* cf. *gibber*	IV	*Cythara costata*	I	*Eumida sanguinea*	II
Amphiura brachiata	I	*Autolytus* sp.	N.A	*Chaetozone gibber*	IV	*Dardanus arrosor*	N.A	*Eumida* sp.	II

Amphiura chiajei	I
Amphiura filiformis	I
Amphiura juv. indet.	I
Amphiura sp.	I
Anaitides lineata	II
Anaitides maculata	II
Anaitides mucosa	II
Anaitides sp.	II
Anapagurus hyndmani	I
Anapagurus laevis	I
Anapagurus sp.	I
Anguilla anguilla	II
Exogone sp.	II
Fabricia sabella	N.A
Fabulina fabula	I
Filograna implexa	N.A
Galathea intermedia	I
Galathea sp.	I
Galathea squamifera	I
Galathowenia oculata	I
Galeomna turtoni	I
Gammarella fucicola	III
Gammaridea	I
Gammaropsis palmata	I
Gammaropsis shophiae	I
Gammaropsis sp.	I
Gammarus insensibilis	I
Gammarus sp.	I
Gari costulata	I
Gari depressa	I
Gari fervensis	I
Gari tellinella	I
Gariidae indet.	I
Gattyana cirrosa	N.A
Gibbula magus	I
Glycera alba	II
Glycera capitata	II
Glycera convoluta	II
Glycera lapidum	II
Glycera rouxii	II
Glycera sp.	II
Glycera tesselata	II
Glycera tridactyla	II
Glycera unicornis	II
Glycinde nordmani	II
Glycinde nordmanni	II
Gnathia oxyurea	I
Gobius niger	III
Goniada maculata	II
Goniada sp.	II
Goodallia triangularis	I
Gouldia minima	I
Gregariella barbatella	I
Guernea coalita	N.A
Gymnammodytes semisquamatus	N.A
Gyptis capensis	II
Axionice maculata	N.A
Bachycuma brevicornis	N.A
Balcis alba	I
Barleeia rubra	II
Bathyporeia elegans	I
Bathyporeia nana	I
Bathyporeia pelagica	I
Bathyporeia pilosa	I
Bathyporeia sarsi	I
Bathyporeia sp.	I
Bathyporeia tenuipes	I
Bela nebula	I
Hesionura elongata	II
Heterocirrus bioculatus	IV
Heterocirrus spp	IV
Heteromastus filiformis	III
Hexacorallia sp.	I
Hiatella artica	I
Hinia incrassata	II
Hinia juv. indet.	II
Hinia pygmaea	II
Hinia reticulata	II
Hippolyte varians	I
Hippomedon denticulatus	I
Hyala vitrea	I
Hyale nilssoni	I
Hyalinoecia bilineata	N.A
Hyalinoecia fauveli	N.A
Hyalinoecia sp.	N.A
Hydrobia ulvae	III
Hydroides norvegica	N.A
Idotea linearis	N.A
Idunella picta	N.A
Inachus dorsettensis	I
Inachus sp. larva	I
Iphimedia obesa	I
Iphinoë serrata	I
Iphinoe sp.	I
Jaera albifrons	I
Jaera sp.	I
Janira maculosa	N.A
Jasmineira elegans	N.A
Jupiteria minuta	N.A
Kefersteinia cirrata	N.A
Kellia suborbicularis	I
Labidoplax cf. *thomsoni*	I
Labidoplax digitata	I
Labidoplax spp	I
Lacydonia miranda	N.A
Lagisca extenuata	II
Lanice cirrata	III
Lanice cirrata	III
Lanice conchilega	II
Lanice conchilega	II
Lanice spp	II
Laonice sp.	N.A
Chaetozone setosa	IV
Chaetozone sp.	IV
Chamelea gallina	I
Chamelea gallina striatula	I
Chamelea striatula	I
Chauvetia brunnea	I
Cheirocratus sundevallii	I
Cheriocratus sp.	I
Chironomida	IV
Chlamys varia	I
Chone collaris	II
Chone filicaudata	II
Leucothoe spinicarpa	I
Levinsenia gracilis	N.A
Lilleborjia pallida	I
Liocarcinus arcuatus	I
Liocarcinus arcuatus	I
Liocarcinus depurator	I
Liocarcinus holsatus	I
Liocarcinus marmoreus	I
Liocarcinus pusillus	I
Liocarcinus sp.	I
Liocarcinus vernalis	I
Liocarcinus zariquieyi	I
Listriella picta	I
Loripes lucinalis	I
Lucinoma borealis	I
Lucinoma borealis	I
Lumbrinerides sp.	II
Lumbrineriopsis paradoxa	II
Lumbrineris cf. *gracilis*	II
Lumbrineris emandibulata	II
Lumbrineris emandibulata mabiti	II
Lumbrineris gracilis	II
Lumbrineris impatiens	II
Lumbrineris latreilli	II
Lumbrineris latreilli	II
Lumbrineris sp.	II
Lunatia alderi	II
Lutraria angustior	I
Lutraria lutraria	I
Lutraria lutraria	I
Lutraria sp.	I
Lyonsia norvegicum	I
Lysianassa ceratina	I
Lysianassa insperata	I
Lysidice ninetta	II
Lysippe labiata	N.A
Macoma baltica	I
Macropodia rostrata	I
Mactra corallina	I
Mactra stultorum	I
Mactracea indet.	I
Maera grossimana	I
Maera othonis	I
Maera sp.	I
Demonax sp.	N.A
Demospongia sp.	I
Dentalium novemcostatum	I
Dentalium sp.	I
Desdemona cf. *ornata*	II
Desdemona ornata	II
Devonia perrieri	I
Diastylis bradyi	I
Diastylis cf. *tumida*	I
Diastylis cornuta	I
Diastylis laevis	I
Diastylis lucifera	I
Marphysa fallax	II
Marphysa sanginea	II
Marphysa sp.	II
Marphysa sp. *(belli?)*	II
Martastherias glacialis	I
Mediomastus fragilis	III
Megaluropus agilis	I
Megamphopus cornutus	I
Melinna cristata	III
Melinna palmata	III
Melinna sp.	III
Melita gladiosa	I
Melita palmata	III
Merceriella enigmatica	II
Metaphoxus fultoni	I
Metaphoxus pectinatus	I
Metazoea de porcellanidae	N.A
Microdeutopus anomalus	I
Microdeutopus damnoniensis	I
Microdeutopus sp.	I
Microdeutopus stationis	I
Microdeutopus versiculatus	I
Microphthalmus sczelkowii	N.A
Microspio sp.	N.A
Micrura sp.	N.A
Modiolula phaseolina	I
Modiolus barbatus	I
Modiolus gallicus	I
Modiolus modiolus	I
Monoculodes carinatus	I
Monopylephorus irroratus	V
Montacuta ferruginosa	II
Musculus discors	I
Mya arenaria	II
Myrtea spinifera	I
Mysella bidentata	I
Mysia undata	I
Mysidacea	II
Mystides elongata	II
Mystides limbata	II
Mytilaster minimun	I
Mytilus edulis	III
Nassarius incrassatus	II
Nassarius reticulatus	II
Eunice harassii	II
Eunice sp.	II
Eunice vittata	II
Euphrosyne foliosa	I
Eurydice affinis	I
Eurydice pulchra	I
Eurydice sp.	I
Eurydice spinigera	I
Eurynome aspera	I
Eurynome spinosa	I
Eurysyllis tuberculata	II
Exogone naidina	II
Nephtys cirrosa	II
Nephtys hombergi	II
Nephtys hystricis	II
Nephtys incisa	II
Nephtys juv. spp	II
Nephtys kersivalensis	II
Nephtys paradoxa	II
Nephtys sp.	II
Nephtys sp. *juv.*	II
Nephtys spp	II
Nereimyra punctata	III
Nereiphylla rubiginosa	N.A
Nereis caudata	IV
Nereis cf. *lamellosa*	III
Nereis diversicolor	III
Nereis longissima	III
Nereis sp.	III
Nothria geofiliformis	II
Nothria lepta	II
Nothria sp.	II
Notirus irus	I
Notocirrus sp.	N.A
Notomastus latericeus	III
Notomastus lineatus	III
Notomastus sp.	III
Nucula nitida	I
Nucula nitidosa	I
Nucula nucleus	I
Nucula sp.	I
Nucula sulcata	I
Nucula turgida	I
Ocenebra erinacea	II
Odostomia sp.	II
Oligochaeta	V
Onuphidae juvenil	II
Onuphis cf. *geophiliformis*	II
Onuphis conchylega	II
Onuphis eremita	II
Ophelia bicornis	I
Ophelina acuminata	N.A
Ophiocentrus brachiatus	I
Ophiocomina nigra	I
Ophiodromus flexuosus	II
Ophiopsila aranea	I

TABLE 3 (CONTINUED)

Species	Group	Species	Group	Species	Group	Species	Group	Species	Group
Gyptis rosea	II	*Leanira yhleni*	N.A	*Magelona alleni*	I	*Natantia* sp.	N.A	*Ophiotrix fragilis*	I
Halcampa sp.	I	*Lembos* sp.	N.A	*Magelona filiformis*	I	*Natica alderi*	II	*Ophiura albida*	II
Haminoea navicula	II	*Lepidonotus clava*	II	*Magelona minuta*	I	*Natica catena*	II	*Ophiura ophiura*	II
Harmothoe antilopes	II	*Lepidonotus squamatus*	II	*Magelona mirabilis*	I	*Neanthes caudata*	III	*Ophiura* sp.	II
Harmothoe cf. *lunulata*	II	*Leptocheirus pectinatus*	III	*Magelona papillicornis*	I	*Neanthes irrorata*	III	*Ophiura texturata*	II
Harmothoe glabra	II	*Leptocheirus pilosus*	III	*Magelona* sp.	I	*Neanthes juv. indet.*	III	*Ophiura texturata (juv.)*	II
Harmothoe imbricata	II	*Leptochelia savignyi*	N.A	*Magelona wilsoni*	I	*Neanthes* sp.	III	*Ophryotrocha labronica*	II
Harmothoe impar	II	*Leptochiton asellus*	I	*Malacoceros ciliata*	III	*Nebalia bipes*	V	*Ophryotrocha puerilis*	II
Harmothoe lunulata	II	*Leptochiton cancellatus*	I	*Malacoceros fuliginosus*	V	*Nebalia* sp. *indet.*	V	*Ophryotrocha* sp.	II
Harmothoe sp.	II	*Leptochiton inhaerens*	I	*Malacoceros girardi*	III	*Nebalia thyphlops*	II	*Opistodonta pterochaeta*	N.A
Harmothoe sp.*(antilopes?)*	II	*Leptoneris glauca*	III	*Malacoceros* sp.	III	*Nematoda*	III	*Orbinia cuvieri*	N.A
Harmothoe spinifera	II	*Leptosynapta* cf. *gallienei*	I	*Malacoceros vulgaris*	III	*Nematonereis unicornis*	II	*Orchomene nana*	N.A
Harpinia antennaria	I	*Leptosynapta gallienei*	I	*Maldane glebifex*	I	*Nemertea*	III	*Orchomene similis*	N.A
Harpinia pectinata	I	*Leptosynapta inhaerens*	I	*Manayunkia aestuarina*	II	*Neoamphitrite affinis*	N.A	*Oriopsis armandi*	N.A
Harpinia sp.	I	*Leucothoe incisa*	I	*Mangelia attenuata*	I	*Neoamphitrite* cf. *affinis*	N.A	*Oriopsis* sp.	N.A
Haustorius arenarius	I	*Leucothoe incisa*	I	*Mangelia nebula*	I	*Neoamphitrite* sp.	N.A	*Ostrea edulis*	I
Hediste diversicolor	III	*Leucothoe lilljeborgi*	I	*Mangelia smithi*	I	*Nephtys assimilis*	II	*Ovatella myosotis*	N.A
Hermione hystrix	II	*Leucothoe richiardii*	I	*Mangelia* sp.	I	*Nephtys caeca*	II	*Owenia filiformis*	I
Hesione pantherina	II	*Leucothoe* sp.	I	*Marphysa bellii*	II	*Nephtys* cf. *paradoxa*	II	*Owenia fusiformis*	I
Pachygrapsus marmoratus	II	*Phyllodoce rosea*	II	*Protodrilus* sp.	N.A	*Sphaerosyllis hystrix*	II	*Tholarus cranchii*	I
Paguroidea indet.	I	*Phyllodoce* sp.	II	*Psamechinus miliaris*	I	*Sphaerosyllis pyrifera*	II	*Thracia phaseolina*	I
Pagurus bernhardus	I	*Phylocheras bispinosus*	I	*Psammobia costulata*	I	*Sphaerosyllis* sp.	II	*Thracia villosiuscula*	I
Pagurus prideauxi	I	*Phylocheras monacantus*	I	*Psammolyce arenosa*	II	*Sphaerosyllis taylori*	II	*Thyasira flexuosa*	III
Pagurus sp. *larva*	I	*Phylocheras trispinosus*	I	*Pseudobrania* sp.	II	*Sphenia binghami*	I	*Thyone fusus*	I
Palaemon serratus	I	*Pilargis verrucosa*	I	*Pseudocuma longicornis*	II	*Spio armata*	III	*Timoclea ovata*	I
Pandora albida	I	*Pilumnus hirtellus*	I	*Pseudocuma similis*	II	*Spio decoratus*	III	*Tonicella marmorea*	I
Pandora inaequivalvis	I	*Pinnotheres pisum*	N.A	*Pseudocuma* sp.	II	*Spio filicornis*	III	*Tricolia pullus*	I
Pandora pinna	I	*Pionosyllis serrata*	II	*Pseudopolydora antennata*	IV	*Spio martinensis*	III	*Triphora adversa*	I
Panoploea minuta	I	*Pisidia longicornis*	I	*Pseudopolydora paucibranchiata*	IV	*Spio* sp.	III	*Triphora aspera*	I
Paradoneis armata	III	*Pisidium* sp. *indet.*	I	*Pseudopolydora pulchra*	IV	*Spiochaetopterus costarum*	III	*Triphora perversa*	I
Paradoneis lyra	III	*Pisione remota*	II	*Pseudopolydora* sp.	IV	*Spiochaetopterus* sp.	III	*Trivia monacha*	I
Paragnathia formica	III	*Pista cristata*	I	*Pseudoprotella phasma*	N.A	*Spiochaetopterus typicus*	III	*Trophonopsis muricatus*	I
Paramphitrite tetrabranchia	N.A	*Plakosyllis brevipes*	II	*Pseudosyllis brevipennis*	II	*Spiophanes bombyx*	III	*Tryphosella nanoides*	I
Paraonis fulgens	N.A	*Plathelmintes*	II	*Pseudosyllis* sp.	II	*Spiophanes kroyeri*	III	*Tryphosella sarsi*	I
Paraonis gracilis	N.A	*Platynereis dumerilii*	III	*Pygospio elegans*	III	*Spirobranchus polytrema*	N.A	*Tryphosites longipes*	II
Paraonis lyra	N.A	*Pleuronectidae* sp.	II	*Quadrans serratus*	I	*Spisula elliptica*	I	*Tubificoides benedii*	V
Parapionosyllis cf. *gestans*	II	*Podoceus variegatus*	N.A	*Raphitoma purpurea*	I	*Spisula solida*	I	*Tubificoides pseudogaster*	V
Parapionosyllis gestans	II	*Poecilochaetus serpens*	I	*Raphitoma* sp.	I	*Spisula subtruncata*	I	*Tubulanus polymorphus*	II
Parapionosyllis labronica	II	*Poecilochaetus serpens*	I	*Retusa truncatula*	I	*Staurocephalus rudolphii*	IV	*Tubulanus* spp	II
Parapionosyllis minuta	II	*Polycirrus aurantiacus*	IV	*Retusa umbilicata*	I	*Stenothoe monoculoides*	II	*Turbelario* sp.	N.A
Parapionosyllis sp.	II	*Polycirrus* cf. *medusa*	IV	*Rhizorus acuminatus*	N.A	Stenothoidae	II	*Turboella parva*	I
Parathelepus sp.	I	*Polycirrus medusa*	IV	*Ringicula auriculata*	I	*Sternaspis scutata*	III	*Turbonilla acuta*	I
Pariambus typicus	III	*Polycirrus* sp.	IV	*Ringicula conformis*	I	*Sthenelais boa*	II	*Turbonilla elegantissima*	I
Pariambus typicus varinermis	III	*Polycirrus tenuisetis*	IV	*Ringicula* sp.	I	*Sthenelais* cf. *minor*	II	*Turbonilla lactea*	I

Parvicardium exiguum	I	*Polydora antennata*	IV	*Sabella pavonina*	I	*Sthenelais limicola*	II	*Turbonilla rufa*	I
Parvicardium minimum	I	*Polydora caeca*	IV	*Sabella* sp.	I	*Sthenelais minor*	II	*Turbonilla* spp	I
Parvicardium ovale	I	*Polydora ciliata*	IV	*Sabellaria alveolata*	I	*Sthenelais* sp.	II	*Turritella communis*	I
Parvicardium papillosum	I	*Polydora flava*	IV	*Sabellaria spinulosa*	I	*Streblosoma bairdi*	N.A	*Turritella triplicata*	I
Parvicardium scabrum	I	*Polydora juv.* spp	IV	*Scalibregma inflatum*	III	*Streblospio dekhuyzeni*	III	*Unciola crenatipalma*	N.A
Pectinaria auricoma	I	*Polydora ligerica*	IV	*Scaphander lignarius*	I	*Streblospio shrubsolii*	III	*Upogebia* cf. *tipica*	I
Pectinaria koreni	I	*Polydora ligni*	IV	*Schistomeringos caeca*	II	*Stremblosoma intestinalis*	N.A	*Upogebia deltaura*	I
Pectinaria sp.	I	*Polydora polybranchia*	IV	*Schistomeringos rudolphi*	IV	*Striarca lactea*	I	*Upogebia pusilla*	I
Perinereis cultrifera	III	*Polydora pulchra*	IV	*Scionella lornensis*	N.A	*Sycon ciliatum*	I	*Upogebia* sp.	I
Perioculodes longimanus	I	*Polydora* sp.	IV	*Sclerocheilus minutus*	N.A	*Sycon raphanus*	I	*Upogebia stellata*	I
Pharus legumen	I	*Polygordius apendiculatus*	I	*Scolaricia* sp.	I	*Syllis cornuta*	II	*Upogebia typica*	I
Phascolion strombi	I	*Polymnia nebulosa*	III	*Scolaricia typica*	I	*Syllis gerlachi*	II	*Urothoe brevicornis*	I
Phascolion strombus	I	*Polynoe scolopendrina*	II	*Scolelepis fuliginosa*	V	*Syllis gracilis*	II	*Urothoe elegans*	I
Phascolosoma elongatum	I	*Polyophthalmus pictus*	I	*Scolelepis* sp.	III	*Syllis prolifera*	II	*Urothoe poseidonis*	I
Phascolosoma granulatum	II	*Pomatoceros lamarckii*	N.A	*Scolelepis squamata*	III	*Syllis* sp.	II	*Urothoe pulchella*	I
Phascolosoma vulgare	I	*Pomatoceros triqueter*	N.A	*Scoloplos armiger*	I	*Syllis variegata*	II	*Vauthompsonia cristata*	N.A
Phaxas pellucidus	I	*Pontocrates altamarinus*	I	*Scrobicularia plana*	III	*Synchelidium haplocheles*	I	*Veneracea*	I
Pherusa monilifera	I	*Pontocrates arenarius*	I	*Scrupocellaria scrupea*	N.A	*Synchelidium maculatum*	I	*Venerupis aurea*	I
Pherusa plumosa	I	*Portumnus latipes*	I	*Semivermilia* sp.	N.A	*Tanais dulongii*	N.A	*Venerupis pullastra*	I
Pherusa sp.	I	*Potamilla reniformis*	N.A	*Sertulariidae*	I	*Tapes decussata*	I	*Venerupis rhomboides*	I
Philine aperta	II	*Potamilla* sp.	N.A	*Sextonia longirostris*	II	*Telepsavus costarum*	I	*Venerupis senegalensis*	I
Philine loweni	II	*Potamilla torelli*	N.A	*Sigalion* cf. *mathildae*	II	*Telina tenuis*	I	*Venus casina*	I
Philine spp	II	*Potamopyrgus jenkinsi*	II	*Sigalion mathildae*	II	*Tellimya ferruginosa*	II	*Venus fasciata*	I
Pholoe minuta	II	*Praxillea oerstedi*	N.A	*Sigalion squamatum*	II	*Tellina compressa*	I	*Venus gallina*	I
Pholoe synopthalmica	II	*Prionospio caspersi*	IV	*Siphonoecetes kroyeranus*	I	*Tellina donacina*	I	*Venus juv.* sp.	I
Phoronis psammophila	I	*Prionospio cirrifera*	IV	*Siphonoecetes* sp.	I	*Tellina fabula*	I	*Venus ovata*	I
Photis longicaudata	I	*Prionospio ehlersi*	IV	*Siphonoecetes striatus*	I	*Tellina pusilla*	I	*Venus striatula*	I
Phoxocephalus rudolphii	I	*Prionospio fallax*	IV	*Sipuncula*	I	*Tellina pygmaea*	I	*Venus verrucosa*	I
Phthisica marina	I	*Prionospio malmgreni*	IV	*Skenea* sp.	III	*Tellina* sp.	I	*Veretillum cynomorium*	I
Phyllochaetopterus sp.	N.A	*Prionospio multibranchiata*	IV	*Skenia serpuloides*	N.A	*Tellina squalida*	I	*Veretillum* sp.	I
Phyllodoce groelandica	II	*Prionospio* sp.	IV	*Socarnes erythrophthalmus*	N.A	*Tellina tenuis*	I	*Verruca stromia*	I
Phyllodoce lamelligera	II	*Prionospio steenstrupi*	IV	*Solen marginatus*	I	*Terebella lapidaria*	I	*Vituperis esribosa*	V
Phyllodoce laminosa	II	*Processa canaliculata*	I	Solenacea	I	*Terebellides stroemi*	I	*Xantho pilipes*	N.A
Phyllodoce lineata	II	*Processa modica*	I	*Sphaerodoropsis* sp.	N.A	*Terebellomorpha* sp. *indet*	II	*Xenosyllis scabra*	II
Phyllodoce longipes	II	*Processa nouveli*	I	*Sphaeroma monodi*	II	*Thalassema neptuni*	I	*Zenobiana prismatica*	II
Phyllodoce maculata	II	*Processa parva*	I	*Sphaeroma rugicaudata*	II	*Tharyx marioni*	N.A	*Zoantharia* sp.	I
Phyllodoce mucosa	III	*Processa* sp.	I	*Sphaeroma serratum*	II	*Thelepus setosus*	N.A		
Phyllodoce paretti	II	*Protodorvillea kefersteini*	II	*Sphaerosyllis bulbosa*	II	*Thia scutellata*	II		

---

[a] N.A. – not assigned.

Bogdanos, C. and Satsmadjis, J. (1985) Quantitative effect of sediment coarseness and depth on the macrobenthos of an unpolluted and closed Mediterranean Gulf. *Revue Internationale d' Oceanographie medicale* **77/78**, 74–85.

Borja, A., Valencia, V., García, L. and Arresti, A. (1995) Las comunidades bentónicas intermareales y submareales en San Sebastián-Pasajes (Guipúzcoa, N de España). *Actas IV Coloquio Internacional de Oceanografía del Golfo de Vizcaya* (Santander) 165–181.

Borja, A., Franco, J., Belzunce, M. J. and Valencia, V. (1999a) *Red de Vigilancia y Control de la calidad de las aguas litorales del País Vasco (otoño 1997–verano 1998)*. Departamento de Ordenación del Territorio, Vivienda y Medio Ambiente, Gobierno Vasco, 333 pp + appendices.

Borja, A., Belzunce, M. J., Franco J. and Castro, R. (1999b) *Seguimiento ambiental de los estuarios del Nervión, Barbadún y Butrón durante 1998*. Consorcio de Aguas Bilbao-Bizkaia, 228 pp + appendices.

Cairns, J., Douglas, W. A., Busey, F. and Chaney, M. D. (1968) The sequential comparison index – a simplified method for non-biologists to estimate relative differences in biological diversity in stream pollution studies. *Journal of Water Pollution Control. Fed* **40**, 1607–1613.

Chandler, J. R. (1970) A biological approach to water quality management. *Water Pollution Control* **69**, 415–422.

Clements, W. H., Cherry, D. S. and Van Hassel, J. H. (1992) Assessment of the impact of heavy metals on benthic communities at the Clinch River (Virginia): evaluation of an index of community sensitivity. *Canadian Journal of Fisheries and Aquatic Sciences* **49**, 1686–1894.

Dauer, D. M. (1993) Biological criteria, environmental health and estuarine macrobenthic community structure. *Marine Pollution Bulletin* **26** (5), 249–257.

Diaz, R. J. and Rosenberg, R. (1995) Marine benthic hypoxia: a review of its ecological effects and the behavioural responses of benthic macrofauna. *Oceanography and Marine Biology Annual Review* **33**, 245–303.

Ferraro, S. P., Swartz, R. C., Cole, F. A. and Schults, D. W. (1991) Temporal changes in the benthos along a pollution gradient: discriminating the effects of natural phenomena from sewage-industrial wastewater effects. *Estuarine, Coastal and Shelf Science* **33**, 383–407.

Franco, J., Borja, A., Belzunce, M. J. Valencia, V. (1999) *Campaña de medición de variables biológicas y fisico-químicas en el estuario del río Oiartzun y área costera próxima a cala Murgita*. Departamento de Obras Hidráulicas y Urbanismo de la Diputación Foral de Gipuzkoa, 197 p. + appendices.

Franklin, A. and Jones, J. (1994) Monitoring and surveillance of non-radiactive contaminants in the aquatic environment and activities regulating the disposal of wastes at sea, 1992. *Aquatic Environment Monitoring Report, MAFF* **40**, 1–83.

Glémarec, M. (1986) Ecological impact of an oil-spill: utilisation of biological indicators. IAWPRC-NERC Conference, July 1985. *IAWPRC Journal* **18**, 203–211.

Glémarec, M. and Hily, C. (1981) Perturbations apportées à la macrofaune benthique de la baie de Concarneau par les effluents urbains et portuaires. *Acta Oecologica Oecologia Applicata* **2**, 139–150.

González-Oreja, J. A. and Sáiz-Salinas, J. I. (1998) Exploring the relationships between abiotic variables and benthic community structure in a polluted estuarine system. *Water Research* **32** (12), 3799–3807.

Grall, J. and Glémarec, M. (1997) Using biotic indices to estimate macrobenthic community perturbations in the Bay of Brest. *Estuarine, Coastal and Shelf Science* **44** (suppl. A), 43–53.

Gray, J. S. (1979) Pollution-induced changes in populations. *Philosophycal Transactions of the Royal Society of London*. Series B, **286**, 545–561.

Hall, S. J. (1994) Physical disturbance and marine benthic communities: life in unconsolidated sediments. *Oceanography and Marine Biology Annual Review* **32**, 179–239.

Hily, C. (1984) *Variabilité de la macrofaune benthique dans les milieux hypertrophiques de la Rade de Brest*. Thèse de Doctorat d'Etat, Univ. Bretagne Occidentale. Vol. 1, 359 pp; Vol. 2, 337 pp.

Hily, C., Le Bris, H. and Glémarec, M. (1986) Impacts biologiques des émissaires urbains sur les écosystèmes benthiques. *Oceanis* **12**, 419–426.

Holme, N. A. and McIntyre, A.D. (1971) *Methods for the Study of Marine Benthos*, p. 387. Blackwell, Oxford.

ISO-BMWP (1979) *Assessment of the Biological Quality of Rivers by a Macroinvertebrate Score*. ISO/TC147/SC5/WG6/N5, International Standards Organisation, p. 18.

Kristensen, E. and Andersen, F. O. (1993) Determination of organic carbon in marine sediments: a comparison of two CHN-analyzer methods. *Journal of Experimental Marine Biology and Ecology* **109**, 15–23.

Long, E. R., MacDonald, D. D., Smith, S. L. and Calder, F. D. (1995) Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. *Environmental Management* **19**, 81–97.

MAFF (1993) Analysis and interpretation of benthic community data at sewage-sludge disposal sites. *Aquatic Environmental Monitoring Report, MAFF Directorate of Fisheries Research, Lowestoft*, Vol. 37, 80 pp.

Majeed, S. A. (1987) Organic matter and biotic indices on the beaches of North Brittany. *Marine Pollution Bulletin* **18** (9), 490–495.

Mearns, A. J. and Word, J. Q. (1982) Forecasting effects of sewage solids on marine benthic communities. In *Ecological Stress and the New York Bight: Science and management* ed. G. F. Mayer, pp. 495–512. Estuarine Research Federation, Columbia, South Carolina.

Mouthon, J. (1993) Un indice biologique lacustre basé sur l'examen des peuplements de mollusques. *Bulletin Française de la Pêche et la Piscicul* **331**, 397–406.

O'Connor, T. P. (1992) *Recent trends in coastal environmental quality: results from the first five years of the NOAA Mussel Watch project*. US Department of Commerce, NOAA, Rockville, 45 pp.

Pearson, T. and Rosenberg, R. (1978) Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology Annual Review* **16**, 229–311.

Ritter, C. and Montagna, P. A. (1999) Seasonal hypoxia and model of benthic response in a Texas bay. *Estuaries* **22** (1), 7–20.

Roberts, R. D., Gregory, M. R. and Fosters, B. A. (1998) Developing an efficient macrofauna monitoring index from an impact study – A dredge spoil example. *Marine Pollution Bulletin* **36** (3), 231–235.

R.N.O. (1998) *Surveillance du Milieu Marin*. Travaux du Réseau National d'Observation de la Qualité du Milieu Marin. Edition 1998. Ifremer et Ministère de l'Aménagement du Territoire et de l'Environnement, 52 pp.

Sáiz-Salinas, J. I. (1997) Evaluation of adverse biological effects induced by pollution in the Bilbao estuary. *Environmental Pollution* **96** (3), 351–359.

Salen-Picard, C. (1983) Schémas d'évolution d'une biocénose macrobenthique du substrat meuble. *Comptes Rendus de l'Academie des Sciencies de Paris* **296**, 587–590.

Snelgrove, P. V. R. and Butman, C. A. (1994) Animal-sediment relationships revisited: cause versus effect. *Oceanography and Marine Biology Annual Review* **32**, 111–177.

Stark, J. D. (1993) Performance of the macroinvertebrate community index: effects of sampling method, sample replication, water depth, current velocity and substratum on index values. *New Zealand Journal of Marine and Freshwater Research* **27**, 463–478.

Washington, H. G. (1984) Diversity, biotic and similarity indices. A review with special relevance to aquatic ecosystems. *Water Research* **18**, 653–694.

Weisberg, S. B., Ranasinghe, J. A., Dauer, D. M., Schaffner, L. C., Diaz, R. J. and Frithsen, J. B. (1997) An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. *Estuaries* **20** (1), 149–158.

Woodiwiss, F. S. (1964). The biological system of stream classification used by the Trent River Board. *Chemistry Industries*. **11**, 443–447.