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Paradox of estuarine quality: Benthic indicators and indices, consensus or debate for the future

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Abstract

The European Water Framework Directive will have instituted the concept of Ecological Quality Status (EQS) as a way to assess the biological quality of water masses. The EQS will be based mainly upon the composition of the different biological compartments in the ecosystem specially the benthos as compared to certain reference sites. Such management tools are already well established for freshwater (i.e. biotic indices), but not for coastal and estuarine (i.e. transitional) waters. In the framework of the Seine-Aval programme a workshop on benthic indicators was organized at Wimereux (France) in June 2005. The aim of this workshop and this paper is (1) to present the experiences of the Seine Aval researchers, and the French scientific approaches to benthic indicators, with those international experiences and approaches that have been published or are under development; and (2) to examine the existing benthic tools and their possible use in the characterization of the state of estuarine ecosystems. The debate during the workshop and the numerous recently published on the WFD are discussed in term of the implementation of the WFD in transitional water bodies using benthic indicators and indices. Some proposals for the future underline the needs to re-examine and adapt the different index thresholds, to take into account physical disturbances, to inventory the existing conditions vs reference conditions and to be as pragmatic as possible in using the WFD in transitional waters.

Keywords: European Water Framework Directive (WFD); Benthic index; Benthic indicators; Estuaries; Seine estuary; Transitional water bodies

1. Introduction

The implementation of the European Water Framework Directive (WFD) (see Henocque and Andral, 2003; Borja, 2005) has provoked a large debate on the use of benthic bio-indicators and indices to determine the quality of the estuarine (transitional) and coastal waters in Europe and along its coast, in terms of the WFD's Ecological Quality Status (EcoQ) (see Borja et al., 2000, 2003, 2004a,b; Borja and Heinrich, 2005; Borja and Muxika, 2005; Marin-Guirao et al., 2004; Salas et al., 2004; Simboura and Zenetos, 2002; Simboura, 2004; Muxika et al., 2005; Simboura et al., 2005). Most of the more recently developed indices, such as AMBI and BENTIX (Borja et al., 2000; Simboura and Zenetos, 2002; Muxika et al., 2005), were based on dividing soft benthic species into previously defined ecological groups (see Pearson and Rosenberg, 1978; Grall and Glémarec, 1997) and then determining the respective proportion of the different groups in the benthic communities (via sampling). All of the recent indices provide information about the relative abundances of the sensitive species faced with increasing organic matter in the sediment and those of the species that are resistant or indifferent to such increases, or even favored by such conditions (e.g., the opportunistic species that proliferate when the sediment is rich in organic matter). But the main problem is that all the indices, which aim to determine anthropogenic stress, relate to abundances of stress tolerant species, which may also be tolerant of natural stressors such as in

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estuaries. Similarly, many indices, as described here, relate to anthropogenically organic-rich systems whereas estuaries are naturally organic rich systems. So, M. Elliott (personal communication) propose to use the term 'paradox of estuarine quality' for such ecosystem.

However, most of the benthic indices and the diverse indicator species were used in coastal environments, and their use in transitional waters, particularly in zones with variable salinity levels (0.5–30), must be monitored carefully. In fact, in estuarine waters, especially in the oligohaline zone (salinity 0.5–5), the number of species is reduced; reflecting the number of species that were able to adapt to low and variable salinity levels and thus survived. This low species richness value is often paired with high abundance levels and the dominance of one or several species (Dauvin and Desroy, 2005). Given this specificity, it would seem prudent to develop specific methods for transitional waters before implementing the Water Framework Directive (WFD) in estuaries (Quintino et al., 2006). This paper proposes such a method, based on the research conducted by the Seine-Aval program.

2. The Seine-Aval program

The Seine estuary is the largest megatidal estuary in the English Channel and, as such, is economically important for France, with 25% of France's population as well as 40% of its industry and agriculture concentrated in and around it. Several multidisciplinary research programs have been carried out in the Bay of Seine over the last two decades, notably the 'Baie de Seine' program and the 'Baie de Seine' site of the French National Coastal Environment Program (PNEC). In the 1990s, the Seine-Aval scientific research program started, with the dual objective of assessing the ecological situation of the estuary and learning more about how the estuary functions. Since its inception, this program has significantly increased the knowledge available about the Seine estuary (Lafite and Romana, 2001). The program employs an integrated scientific approach, which first takes the various compartments of the system into account, and then, after consultation with users and decision-makers, organizes the implementation of various operational tools. By following the same approach, it is hoped that, by 2006, the European Water Framework Directive will have established the concept of Ecological Quality Status (EcoQ) as a way to assess the biological quality of water bodies. The EcoQ will be assessed mainly by comparing the composition of the different biological compartments in the ecosystem (e.g., phytoplankton, macrophytes, benthos and fish, the latter only in transitional waters) to certain reference sites (Borja, 2005). Such management tools are already well established for fresh water (i.e. biotic indices, see for example the recent paper by Gabriels et al., 2005), but not for coastal and estuarine (i.e. transitional) waters.

Since 1995, the Seine-Aval program has worked intensively to acquire knowledge about how the Seine estuary functions. Growing awareness of the persistent degradation of the environmental quality in the Seine estuary finally convinced the political decision-making bodies that a global management plan was needed for this area. In this context, it is now essential that the diverse information available concerning the status, functioning and/or assessment of the underlying causes of the present situation of the Seine estuary be shared amongst the interested parties. The guiding principles for the restoration of the Seine were determined by the Estuary Council: (i) the decompartmentalization of the Seine estuary, thus allowing the free circulation of water and populations; (ii) the improvement of the physico-chemical and microbiological quality of estuarine waters; (iii) the management of estuarine habitats and populations; (iv) the monitoring and collection of data about the estuary; and (v) the organization of communication efforts regarding the estuary and the reglementary framework established by the WFD. In response to these guidelines, Seine-Aval has been working to make report card (gathering support of synthetic information, coming from variables informing about the performances of a system) and operational indicators available. These original approach associating several scientific teams involved in the interdisciplinary Seine-Aval program and the structure of the program (GIPSA) dedicated to the research application has been carried out to guide the Estuarine Council for a rehabilitation of its initial functions: maintenance of the functional links among the various ecosystems found in an estuary, knowledge and management of the natural habitats and biological populations, monitoring and improvement of the physical–chemical and microbiological water quality. The aim is to answer needs for management by providing, to decision makers, key indicators measuring the system and announcing changes, compared to the selected objectives. Such an approach is of particular importance in the framework of the Water Framework Directive as it leads to the elaboration of an assemblage of relevant indicators, used as operational tools.

One of the focuses of the Seine-Aval program is the development of pertinent indicators that are specific to the estuarine environment (see http://seine-aval.crihan.fr/). These indicators are intended to highlight the status of the estuary (e.g., descriptive indicators, environmental quality indicators, and performance indicators), and should permit the evaluation of the results of the various environmental actions and/or policies undertaken to preserve the Seine estuary. Such approaches had been developed for the UK estuaries (Rogers and Greenaway, 2005; Aubry and Elliott, 2006). These last authors proposed a series of potential indicators, which were categorized in three broad groups: coastline morphological change, resource use change and environmental quality and its perception. Still, rather than simply furnish a finished product, Seine-Aval hopes to offer guidelines that will allow researchers, data collectors, and estuarine managers and stakeholders to structure their work in such a way as to facilitate the transmission of knowledge, encouraging the acquisition of a common language and culture, thus making their work and results more valuable.

3. The water bodies in the Seine estuary in terms of the WFD

The Seine estuary is one of the main estuaries on the European northwest continental shelf. It has a tidal range of 8.5 m at the mouth during spring tide, and a tidal penetration of 170 km, reaching the Poses dam, which is the upper limit of tidal propagation (Lafite and Romana, 2001). Three main zones have been studied by Seine-Aval (Fig. 1): (i) the freshwater (fluvial) part of the estuary, extending from the Poses dam down to Caudebec, which is the upstream salinity limit; (ii) the mouth of the estuary, extending from Caudebec to Honfleur, in which a continuous salinity gradient is influenced primarily by the tides and the river currents; and (iii) the saltwater (marine) estuary, extending from Honfleur down to the euhaline zone (Garnier et al., 2001). However, one of the partner organizations of GIP Seine Aval, the Seine-Normandy Water Agency (SNWA), has established different divisions of the estuary in terms of the WFD. The SNWA has identified three transitional water bodies considering that morphological differences, and pressures and resulting impact are adequate to distinguish more than one single geographical water body in the Seine estuary: (i) water body T1 comprises the upper part of the fluvial zone, extending from Poses to just downstream of Rouen harbor at La Bouille; (ii) water body T2 extends from La Bouille to the salinity front located upstream of the Tancarville bridge; and (iii) water body T3 corresponds to the saltwater estuary that extends from the salinity front upstream of the Tancarville bridge to the mouth of the estuary (0°03′E, Héve Cape in the North, and Deauville/Trouville in the south). The salinity level in T3 ranges from 0.5 upstream to 30 downstream, the latter being in the eastern part of the bay of Seine. The SNWA requested that the Seine-Aval scientists begin by studying the use of benthic indicators for assessing the Ecological Quality Status (EcoQ) of these three bodies of water. Presently, these waters are considered to be Heavily Modified Water Bodies (HMWB) due to the canalization and dredging (see http://www.eau-seine-normandie.fr), which allow them to attain the status of 'Good Ecological Potential'.

4. The level of knowledge about the benthic fauna in the Seine estuary

In order to comply with the SNWA's request, it was first necessary to determine the level of existing knowledge. Several studies concerning the distribution of the macrobenthic populations in the Seine estuary were found to be available. However, most of these studies concentrate on the downstream section of the estuary (water body T3, defined above), and none of them examine the use of benthic organisms as indicators of the estuary's ecological status.

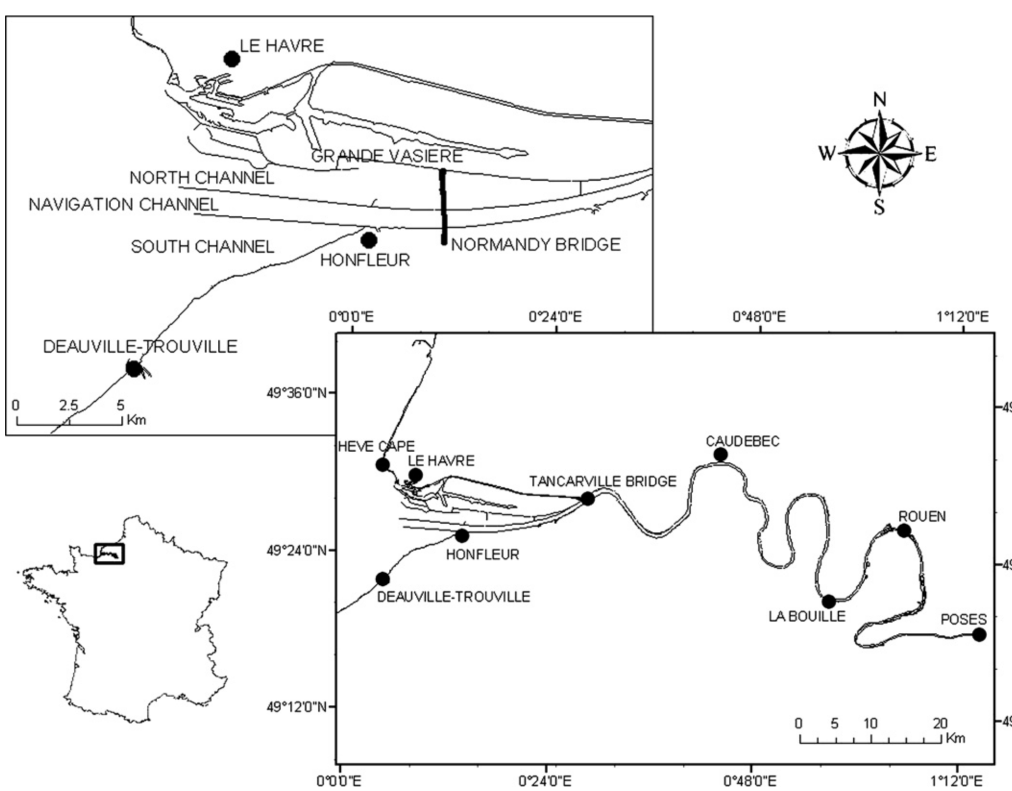

Fig. 1. The Seine estuary.

4.1. Data for water bodies T1 and T2 (poses to Tancarville bridge)

Data about benthic fauna in the fluvial part of the Seine estuary (water bodies T1 and T2) are rare, and most of this data was obtained during Costil's 1997 monitoring program (Costil, 1998). Examination of the available data about the distribution and ecology of the benthic invertebrates in this sector showed that the species present are common, with most of them also found in other large European rivers. The abundance values are relatively low, especially in the navigation channel, with higher values in the intertidal areas (Costil, 1998). The benthic fauna is typical of rivers with large flood plains, essentially composed of species that require little, even very little, in terms of environmental quality (i.e. the chemical quality of the water and the amount of dissolved oxygen). In fact, certain groups, such as the Tubificidae oligochaetes and some chironomids or leeches, are known to tolerate extremely degraded, polluted environments. Continued development, particularly the canalization of the Seine, has certainly contributed to the impoverishment of the fauna. The physical disturbances (e.g., a tidal dynamic characterized by a very strong current and river traffic creating waves that break against the banks) have probably also had an influence on the fauna in the rivularia intertidal zone, which explains the observed upstream–downstream gradient in taxonomic richness. These disturbances also have a marked impact on the macrozoobenthos in the channel, as seen in the nearly azoic character of the sector upstream of Caudebec (Costil, 1998).

4.2. Data for water body T3 (Tancarville bridge to the mouth of the estuary)

More data (both qualitative and quantitative) are available about the benthic fauna in the T3 water body at the mouth of the estuary than for the two others (T1 and T2) (For a synthesis of the available information, see Dauvin, 2002 and Dauvin and Desroy, 2005.) Two main benthic communities are found on the intertidal flats. The first, a *Nephtys cirrosa* fine sand community dominated by amphipods (e.g., *Urothoe brevicornis* and *Bathyporeia* spp.), is present in the marine part of the estuary. The second, a *Malcoma balthica* community, occupies the mudflats of both the North (Grande vasière) and South Channels and the border of the Navigation Channel. Two sub-communities, whose differences are related to the bathymetric level of the tidal flats and their location in the estuary, have been identified. In the downstream part of T3, the *M. balthica* community is more diversified (≅30 species), with moderate abundance values (2400 ind. m^{-2}). In the upstream part of T3, the community is less diversified (<10 species), with mean abundances reaching 10,000 ind. m^{-2} and dominance of the oligochaetes *Tubifex* spp. and the polychaete *Manayunkia aestuarina*. However, in the Navigation Channel, the macrobenthic fauna of the mudflats is particularly poor.

Two main subtidal communities have been identified in the marine part of T3 at the mouth of the Seine: a diversified and abundant *Abra alba–Pectinaria koreni* muddy sand community occupies the external part of the estuary and the entrance to the North and South Channels, and a poorly diversified *M. balthica* community with low abundance values inhabits inner subtidal bottoms in the North, South and Navigation Channels.

5. The Wimereux workshop

To respond to the SNWA's request, a workshop on benthic indicators was organized at the Wimereux Marine Station for the 6th and 7th of June 2005. The aim of the workshop was (1) to compare the French scientific approaches to benthic indicators, as witnessed by the practices of Seine-Aval researchers, with the approaches and practices used, published and/or under development internationally; and (2) to inventory the existing tools and their potential for use in characterizing the ecological status of transitional water bodies. Forty researchers and doctoral students participated in both days' programs.

In order to insure the international nature of the workshop, four non-French colleagues who have been working on the topic of benthic indicators were invited to participate in the workshop: Angel Borja (AZTI Laboratory, San Sebastian, Spain), Daniel M. Dauer (Department of Biological Sciences, Old Dominion University, Norfolk, USA), Mike Elliott (Institute of Estuarine and Coastal Studies, Hull University, Hull, UK), and Rutger Rosenberg (Department of Marine Ecology, Göteborg University, Kristineberg Marine Research Station, Sweden).

- Borja discussed the use of AMBI (Borja et al., 2000, 2003, 2004a,b; Borja and Heinrich, 2005) for assessing 'Ecological Status' under the European Water Framework Directive (WFD). In order to minimize the problems due to misclassification, Borja recommended using AMBI as part of a multimetric approach in which AMBI is one of a set of measurements and indices, such as diversity or richness, for example. AMBI has been verified successfully in relation to a very large set of environmental impact sources, including drill cutting discharges, submarine outfalls, harbor and dyke construction, heavy metal inputs, eutrophic processes, engineering works, diffuse pollutant inputs, recovery in polluted systems under the impact of sewerage schemes, dredging processes, mud disposal, sand extraction, oil spills, and fish farming. It has been applied throughout the Atlantic, Baltic, Mediterranean, North, and Norwegian Seas in Europe, but also in geographical areas in Hong Kong, Uruguay and Brazil.
- Dauer reviewed the accomplishments of the benthic monitoring program in the Chesapeake Bay (USA), focusing on the development of the benthic index of bio-

tic integrity (B-IBI) (Weisberg et al., 1997) to characterize the status of the benthos and to establish relationships between the condition of benthic communities and the water quality, sediment quality and watershed stressors on a bay-wide spatial scale (Dauer et al., 2000; Llanso et al., 2002a,b; Dauer and Llanso, 2003). The accomplishments in the Chesapeake Bay program were presented in the context of the steps needed to develop and validate a benthic index for assessing environmental health, introducing four types of benthic indices that have been developed and applied to coastal and estuarine waters in the USA: (1) the Index of Biotic Integrity, (2) the Linear Discriminant Analysis Index, (3) the Multivariate Ordination—PCA Index, and (4) the Species Tolerance/Sensitivity Index. Dauer also underlined one of the major limitations of macrobenthic community monitoring data: its inability to identify the cause of degraded conditions in benthic communities.

- Elliott spoke about the range of techniques used for defining the quality of estuarine and coastal benthos, highlighting the role of the univariate and multivariate techniques developed for assessing marine and estuarine benthos by the Marine Benthic Invertebrate Task Team (MBITT, Environment Agency, Peterborough), which was established in the UK and Ireland to implement the benthic part of the Water Framework Directive. He explained the process used to derive and test the multimetric approach, which includes several univariate indices. He shows on three study areas on the west coast of Portugal (e.g., coastal shelf off Aveiro, Tagus estuary and Sado estuary) that comparing the use of several indicators gave different quality status levels (Quintino et al., 2006). His presentation introduced the Ecosystem Approach as a management mechanism applied by national and international marine management agencies in agreements in the UK, emphasizing the importance of benthic studies and the knowledge of sediment-invertebrate interaction in the successful implementation of this approach (Elliott, 1994, 1996, 2002, 2003; Elliott and McLusky, 2002; Hiscock et al., 2003). McLusky and Elliott (2004) summarize the approaches and give useful references.
- Rosenberg presented his benthic quality index (BQI) method for classifying marine benthic quality in accordance with the European Water Framework Directive (Rosenberg et al., 2004). To establish this BQI, values indicating organisms' tolerance to environmental disturbances were determined objectively for the benthic species along the west coast of Sweden, based on 4676 samples from 257 stations. This species tolerance value was combined with the values for abundance and diversity to calculate a benthic quality index (BQI) for assessing the environmental status at a particular station. The aptitude of the BQI was evaluated in terms of known spatial and temporal disturbance gradients. Rosenberg's BQI method was compared with the AMBI on a set of data from the Gulf of Lions (Labrune et al., 2006). The BQI was able to efficiently distinguish impacted from un-impacted sites, whereas the AMBI was not. The surprising differences in the EcoQ assessments of AMBI and BQI were mostly due to the fact that the dominant species of polychaete *Ditrupa arietina* featured a low $ES50_{0.05}$, calculated as explain by Rosenberg et al. (2004), but was classified by AMBI as a GI species (disturbance-sensitive).

In addition to the presentations of the four guest speakers, 13 other papers were presented during the four sessions: seven on the topic of benthic indicators and indices, two on multi-criteria approaches to estuarine ecosystems, two on the role of benthic indicators in the Water Framework Directive, and two on complementary approaches, such as biomarkers. The entire seminar program, summaries of the different papers, and the actual Powerpoint presentations are available on the Seine-Aval FTP server (ftp://ftp-sa.crihan.fr).

This workshop permitted a comparison of the state-of-the-art practices in France, Europe and the United States. Given the diversity of bio-indicators and indices that have been proposed for use in estuarine and coastal waters (e.g., Diaz et al., 2003), the workshop also provided an overview of the advantages and disadvantages of the different approaches.

6. Discussion and proposals for the future

6.1. Some considerations about benthic indicators and indices

Benthic invertebrates are frequently used as bio-indicators in marine monitoring, and benthic indices are commonly used to assess the biological quality of the environment (Elliott, 1994; McLusky and Elliott, 2004). Various studies have demonstrated that the macrobenthos responds relatively rapidly to both anthropogenic and natural stress (see Pearson and Rosenberg, 1978; Dauer et al., 2000; Bustos-Baez and Frid, 2003. Because macrobenthic organisms seem to provide reliable indicators of biotic integrity, the benthic index has proved one of the most useful measurements of estuarine conditions, both in the United States (see Dauer et al., 2000; Llanso et al., 2002a,b; Dauer and Llanso, 2003) and in Europe (see Borja et al., 2000, 2003, 2004a,b; Borja, 2005; Borja and Heinrich, 2005; Borja and Muxika, 2005; Marin-Guirao et al., 2004; Salas et al., 2004; Simboura and Zenetos, 2002; Simboura, 2004; Simboura et al., 2005; Muxika et al., 2005; Dauvin et al., in press; this volume). However, several authors have reviewed the use of benthic indices (see for example Diaz et al., 2003; Occhipinti-Ambrogi and Forni, 2004; SGSOBS, 2004; Caeiro et al., 2005), and some of them acknowledge that a benthic index is unlikely to be universally applicable, since organisms are not equally sensitive to all types of anthropogenic disturbance and thus are likely to respond differently to different types of perturbation.

The advantages of using macrobenthic organisms to assess ecological quality are multiple: (i) these organisms are relatively sedentary, meaning that they cannot avoid deteriorating water/sediment quality conditions; (ii) they have relatively long life-spans; (iii) they comprise diverse species that exhibit different tolerances to stress; and (iv) they play an important role in cycling nutrients and materials between the underlying sediments and the overlying water column, and (v) they are the fundamental role providing links to the higher trophic levels (birds and fishes) (see McLusky and Elliott, 2004). Still, Rakocinski and Zapfe (2005) have recently underlined several disadvantages of the existing benthic indices: (i) they represent a static expression of an ecological condition, (ii) they are not explicitly linked to changes in ecological function, (iii) they may not be specific with respect to different kinds of stressors, (iv) they are subject to underlying taxonomic changes across estuarine gradients, (v) their use can be labor intensive, and (vi) they are not applied consistently across biogeographic provinces.

The concept of SMART indicators (simple, measurable, achievable, realistic, and time limited) was discussed intensively during the Wimereux workshop in order to provide the most objective response possible to decision-making bodies like the Seine-Normandy Water Agency. Clearly, benthologists consider that the macrofauna is a charismatic fauna group whose importance as a bioindicator can no longer be doubted. The general advantages and disadvantages of the benthic indicators and indices, which have always been taken into account at scientific meetings and forums (see SGSOBS, 2004; Escavarage et al., 2004; Magni et al., 2004), were again examined carefully during the June workshop. The discussion also focused on the various indicator types: structural vs. functional; spatial vs. temporal; taxonomic vs. non-taxonomic; bottom–up causes vs. top–down responses (e.g., rapid responses, reliable/specific responses, general applicability responses).

Without a doubt, numerous indices have been developed. Diaz et al. (2003) has gone so far as to reproach the scientific community for a "tautological development of new indices" that are ultimately futile, given the wealth of correctly functioning indices that already exist. The WFD itself bears a part of the responsibility for this phenomenon. Many of the new indices—for example, AMBI, BENTIX and BQI—were developed specifically with the WFD in mind and yet all are based on the Pearson and Rosenberg model for organic enrichment and Leppakoski's work in the 1960s and 1970s (see reference in Pearson and Rosenberg, 1978). I myself have participated in the development of a benthic index based on the opportunistic polychaete/amphipod ratio (Gomez Gesteira and Dauvin, 2000) for monitoring the impact of a pollution incident, such as an oil spill, on soft-bottom macrobenthic communities; and my colleagues and I have recently adapted it to allow estuarine and coastal communities to be divided into the five classes suggested by the WFD (Dauvin and Ruellet, in press, this volume). The resulting index is called BOPA, which considers the total number of individuals collected in the samples, the frequency of opportunistic polychaetes, and the frequency of amphipods (except the genus *Jassa*).

There is a paradox/cycle in benthic studies in that when an index or technique gets used a lot it makes more people want to use it even more, e.g., the Shannon–Weiner index or the PRIMER package—this does not necessarily mean that it is the best or even the most appropriate technique but it just stops workers having to think about different ways (M. Elliott, personal communication).

As Borja has pointed out, using soft-bottom benthic communities has certain advantages: they are disturbance indicators with a real effect on the biota at the species-community level, and they are global pollution/disturbance indicators with easily worked elements. However, there are disadvantages: among them, the need for taxonomic experts (these are an endangered species!—the WFD will require more but there are not enough being produced: M. Elliott, personal communication), whose services are expensive and whose work is time-consuming, which limits the speed at which results can be obtained. The pros and cons of Taxonomic Sufficiency, or the need for identification at high taxonomic levels, have been discussed generally in other publications (see Dauvin et al., 2003; Terlizzi et al., 2003), and the problems of species identification for research consultancies conducting environmental impact assessments has been examined in a recent article (Dauvin, 2005). For this reason, it is surprising to note that recently developed analyses and methods in marine ecology require a species identification that is as precise as possible. Even the recently created AMBI, BENTIX and BQI, designed to evaluate the different coastal and estuarine water bodies in accordance with the WFD, require taxonomic identification to the species level. The BOPA index, on the other hand, adheres to the principle of Taxonomic Sufficiency, requiring identification only to the level of zoological groups such as opportunistic polychaetes and amphipods, amongst which only the *Jassa* group require particular attention.

6.2. Use of benthic indicators and indices in transitional water bodies

6.2.1. Indices based on species

The various indices must still be validated for the specific conditions of transitional estuarine waters in an environment naturally organically high where stress-tolerant species are typical. This complex environment, which is characterized by low benthic diversity, is inhabited by species that have adapted to transitional conditions: marine species that have adapted to desalinated waters and freshwater species that have adapted to salty or brackish waters. These adapted species are present in high abundance in the intertidal mudflats, while the subtidal bottoms are poorer both in number of species and in number of individuals (Dauvin and Desroy, 2005). Given such natural impoverishment, certain indices (e.g., AMBI, BQI) can no longer be used or calculated, since their use or calculation thresholds have already been reached. Consequently, AMBI does not seem to be an appropriate tool for assessing disturbance levels in an estuarine system like the Westerschelde, for example (Escavarage et al., 2004). Because of this the UK MBITT multimetric has rescaled its indices for use in estuaries (see Aubry and Elliott, 2006).

In addition, there is another more or less subjective, and sometimes arbitrary, aspect of the classification of species into different categories (see Labrune et al., 2006 for the case of the polychaete *Ditrupa*). Although Borja has defended the idea of assigning species to the same ecological group uniquely according to the species' biogeographical latitudinal range, it can be argued that species react differently depending on inter-species interaction and environmental conditions. If this is true, assigning a species to different ecological groups according to the region would fast become a challenge in which subjectivity—related to the experience and expertise of the scientist—plays an even greater role.

It can also be argued that using indicators developed for coastal waters in the estuarine environment gives a distorted impression of the ecological status emphasize that they are likely to indicate an estuary is degraded when in fact it is a just a normal, low diversity, high abundance community, i.e. a natural estuary. This distortion is due both to the reactivity of the system (e.g., rapid modifications to the substratum) and to the low species diversity in such variable salinity zones, which are not necessarily inherently degraded. Furthermore, these interface environments are subject to cumulative pressures. Anthropogenic stresses—such as aggregate extraction, chemical contamination from metal and organic pollution, dredging, erosion due the wake of navigating vessels, industrial activity, and sewage discharge—combined with extreme natural conditions—such as variations in salinity levels, strong currents in the channels, and the presence of a Maximal Turbidity Zone and an anoxic zone, as well as zones in which fine sedimentary matter has been deposited—make it extremely difficult to determine the exact causes of the environmental status observed.

6.2.2. Other indices

Certain researchers—for example, Escavarage et al. (2004) for the Westerschelde estuary and Caeiro et al. (2005) for the Sado estuary—have developed indices based on benthic biotopes for classifying habitats. These indices rely on physical and chemical variables that are strongly related to community patterns. However, to use such a biotope index, the gradient and arrangement of benthic communities must be defined in advance. Such an *a priori* approach requires definite knowledge of the reference conditions for the different estuarine habitats in order to determine whether the communities are degraded, or not. Therefore there is the danger of a circular argument in that regions are defined and then techniques are used to define regions (which by nature have to be the same as the first ones defined) (M. Elliott, personal communication).

The Bergen Declaration (http://odin.dep.no/archive/mdvedlegg/01/11/Engel069.pdf) underlines the need for an integrated ecosystem approach to the management of human activities affecting the North Sea (Carlberg, 2005) (see also Aubry and Elliott, 2006 for integrative indicators for estuaries). The declaration identified ten ecological components (EcoQ elements) that should be monitored; among them are four elements related to benthic communities: (i) changes/deaths in the zoobenthos due to eutrophication, (ii) imposex in dogwhelks (*Nucella lapillus*) and two other elements: (iii) density of sensitive (i.e. fragile) species, and (iv) density of opportunistic species. The two first elements are priorities, but the second element, imposex, cannot be used in transitional water bodies since *Nucella lapillus* is not present in transitional waters. The three others serve as the basis for classifying soft benthic species into ecological groups (see Pearson and Rosenberg, 1978; Grall and Glémarec, 1997; Borja et al., 2000). In the same vein, Occhipinti-Ambrogi et al. (2004) recommended a fuzzy approach to developing biotic indices of ecological quality. They argue that such an approach is appropriate for three reasons. First, since species need not be classified into precise ecological groups, one species with intermediate behavior could be both sensitive and tolerant at a certain level, which a fuzzy approach would take into account. Second, fuzziness would allow different expert judgments to be combined, and third, it would allow an index to be built without (arbitrary) weight coefficients and mathematical functions.

Macrobenthic processes usually reflect the variability of ecosystem functions, regardless of anthropogenic and natural elements, and may in fact be more valuable than indicators species and biotic indices in the estuaries (Rakocinski and Zapfe, 2005). Rybarczyk and Elkaim (2003) analyzed the Seine estuary's trophic network and demonstrated both that it lacked a dominant resource and that its state of development was different from a mature ecosystem, depending on external connections. De Jonge et al. (2006) also argue for a process or functional-based approach compared to the structural approach which seems to be the main aspect in the WFD.

6.2.3. Reference conditions

Reference conditions are the physico-chemical (or biological) conditions of the system, reflecting the best physico-chemical (or ecological) status possible and the least anthropogenic impact (Borja, 2005). Transitional waters, however, are characterized by highly variable physico-chemical and hydro-morphologic conditions, typically resulting in a mosaic of different habitats (Escavarage et al., 2004). Due to the high variability of environmental parameters in the estuaries (e.g., salinity, dissolved oxygen, temperature), the species living in such environments adapt to the variability and become tolerant of changes, including the presence of organic and metal contaminants. Certain estuaries, like the Seine estuary, have particularly high levels of pollution, yet continue to support abundant benthic populations; the biomass remains high, and the estuary maintains its productivity (Dauvin, in press). For the Westerschelde, Escavarage et al. (2004) proposed that the maximal ecological potential (MEP) could be represented by the estuary's status in 1900. But, for most of the case, it is difficult to have a reference condition for so long ago as the only way to get back to it is to remove people. For the Seine, given the 'Port 2000' project involving the construction of new port facilities in Le Havre, the status of the estuary in 1970 was chosen as the reference point at which the estuary functioned at its highest quality. For both the Westerschelde and the Seine, using ecotope surface area (e.g., tidal flats) as an indicator of habitat diversity and production promises to be effective and feasible (Escavarage et al., 2004). But this is still a structure approach—the important point is not having the area there but making sure it functions properly.

6.2.4. Long-term monitoring

There seems to be a general consensus that a good indicator should have superior predictive abilities (i.e. able to highlight stress where stress should be occurring), be applicable over broad regions and in diverse environmental conditions, and stand up to legal examination (Magni et al., 2004). For transitional water bodies, a strategy of long-term monitoring approaches like those used in the Gironde estuary must also be defined (David et al., 2005). It is this type of long-term survey that is currently lacking for the Seine estuary.

6.3. Need for a multi-criteria approach for the WFD

The 5-category water quality classification system (High, Good, Moderate, Poor and Bad) is not contested, even though it is felt that a preliminary classification into two broad categories—good and bad (as for the chemical quality)—would have facilitated the work done in transitional waters. But, the only important boundary is between Moderate and Good—if an area is Moderate then money has to be spent to make it Good but if an area is Good then there is not need to make it High. Quintino et al. (2006) commented this point after analyzing several datasets. However, the problem of the sometimes arbitrary thresholds between the categories remains—the divisions between categories are created arbitrary e.g., the WFD says 5 classes so the continuum of change is divided, sometimes equally, into five parts—there is often (it appears) no ecological justification for making the divisions at certain parts nor for the fact that the 'good' band is just as large as the 'poor' band.

Scientists and developers alike realize that using one single index, to classify the different bodies of water, is not possible. They acknowledge that several indices and/or indicators must be used in a multi-criteria method similar to the one used in the Chesapeake Bay (USA) (see Dauer et al., 2000; Llanso et al., 2002a,b; Dauer and Llanso, 2003; Borja et al., 2006). Thus, there is agreement that a strategy is needed that can take the different criteria, indices and indicators into account, but which strategy would be best? Averaging the criteria after coding? Weighting (see Aubry and Elliott, 2006 for the discussion of weighting indicators), the different criteria, by assigning higher values to certain criteria than to others? Or, as required by the WFD, using the most penalizing criterion to assign a category? In the UK the system will default to the worst category, e.g., if four of the biological elements indicate good but the 5th indicates moderate then the area will default to being called 'moderate' (Aubry and Elliott, 2006).

Several studies provide information that could facilitate this choice. Rogers and Greenaway (2005) have reviewed the set of marine ecosystem indicators currently in use, or under development, in the UK to support the major national and international biodiversity and ecosystem policies. In addition, Magni et al. (2004) have recommended the use of weight-of-evidence approaches that bring together information from multiple indicators, including multiple biological endpoints as well as additional data on chemical, bio-geo-chemical, toxicological, physical, and hydrographic conditions.

Within the context of the WFD strategy, the working group IMPRESS proposed the DPSIR approach (see Elliott, 2002):

- **D**riving forces—human activities and the economic sectors responsible for the pressures on the environment;
- **P**ressures—particular environmental stressors, including direct pressures such as emissions;
- **S**tate changes—changes in the environmental variables (geo/physical/chemical/biological) that describe the characteristics and conditions of the coastal zone;
- **I**mpact—the human value of the changes in the ecosystem and resources, including health issues;
- **R**esponse—evaluation of the different policy options that could provide a response to the environmental problems.

Borja et al. (2006) examine the use of the DPSIR approach on a case study of Basque estuarine and coastal waters (northern Spain). It appears that this approach could be adapted to other regions, possibly for use in the Bay of Seine and the Seine estuary.

6.4. Proposals for the future

Based on the various meetings and conferences that have taken place and papers that have been published on the subject since the advent of the WFD, particularly those mentioned in the introduction of this note, there appears to be a certain consensus on the following points:

- The need to re-examine and adapt the different index thresholds for the estuarine environment with the goal of moving towards standardized methods based on discussions between scientific experts and managers of estuarine environments. Those who would prefer that their index be used throughout the European Union do not share this position.

- The need to take physical disturbances into account (e.g., dynamic forcing of the systems) and to favor multi-criteria approaches, including the indices that are based on the structure and production of the communities, in the development of a report card. This probability/weight of evidence-based-approach is extremely important as should be emphasized—no single index will give all indications of quality therefore the researchers have to work on the basis that if a whole suite of indicators show an area to be good, even if one shows it to be poor, this should say that it is good—the scientific information is not good enough to say otherwise.
- The need to take typologies, physico-chemical processes, indicator species, reference conditions, integration of quality assessments, and the various methodologies for determining ecological status (Borja, 2005) into account in order to attain the 'Good Ecological Status' by 2015, as required by WFD objectives (Maximum Ecological Potential or Good Ecological Potential for Heavily Modified Water Bodies). This process far exceeds the single benthos approach, whose proposals are often applicable only to the soft-bottom substrata; in fact, developing new tools for hard-bottom substrata will be another important challenge for benthologists (Borja, 2005).
- The need to inventory the existing conditions at every estuarine site and to monitor a few indicators over time at a limited number of sites in order to evidence the evolution of estuarine systems from degradation to stability to degradation.
- The need to be, as Mike Elliott suggested during the workshop, as pragmatic as possible in using the WFD methods, making them environmentally sustainable, economically viable, technologically feasible, socially desirable/tolerable, legally permissible, administratively achievable and politically expedient (Elliott et al., 2006).

Another point must be added specifically for the Seine: the need to compare Seine-Aval practices with those employed in other great estuaries, particularly those on the Atlantic coast of France. This last point will be addressed in 2006 as required by the WFD, as part of a research project on benthic indicators in transitional waters financed by the French Ministry of the Environment and of Sustainable Development. This project, which will be coordinated by X. de Montaudouin (University of Bordeaux1), has a dual objective:

- to highlight the limits of the existing indices for sheltered soft-sediment ecosystems (the Bays of Arcachon and Marennes-Oléron, and the Gironde and Seine estuaries); and
- to adapt or calibrate these indices for such carbon enriched ecosystems and for highly variable salinity systems with the broader goal of providing a reliable tool for diagnosing environmental health, for use under the Water Framework Directive.

The benthic indicator story is by no means finished. A special session of the ASLO meeting, "Global Challenges Facing Oceanography and Limnology", had been held in June 2006 in Victoria, British Columbia, Canada. The title of the special session was "Assessing the environmental quality status of estuarine and coastal systems: comparing methodologies and indices", with Angel Borja and Daniel M. Dauer as chairs. This session had be summarized as follows: "When developing protocols for evaluating biological integrity, benthic macroinvertebrate communities are the most consistently emphasized biotic component of aquatic ecosystems. A plethora of methodologies are presently available, with hundreds of indices, metrics and evaluation tools. An ecologically parsimonious approach dictates that investigators should place greater emphasis on evaluating the suitability of indices that already exist prior to developing new ones. Hence, the objective of this session is to compare the various methodologies that already exist for the different systems around the world, trying to improve our knowledge of the suitability of such approaches when evaluating benthic communities". And the debate continues...

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