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Benthic indicators: Analysis of the threshold values of ecological quality classifications for transitional waters

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Abstract

The effect of the modifications of the threshold values generally adopted for the five EcoQ (Ecological Quality) classes recognized by the European Water Framework Directive (WFD) for the most used benthic indicators and diversity indicators (AMBI, BENTIX, BOPA, BQI, H′, ITI and M-AMBI) were studied to test whether it is possible to obtain the same or similar ecological classifications for transitional waters using these different indicators, and determine whether the current classifications can be improved. The analysis included: (i) the use of indicator equations, (ii) the use of reference indicators, and (iii) the use of indicator distribution laws. These investigations demonstrated that it was impossible to obtain an exact intercalibration of the ecological classifications with the selected indicators. However, some propositions to improve the actual classification were suggested.

Keywords: Benthic index; Ecological indicators; Thresholds; Intercalibration; WFD

1. Introduction

The implementation of the European Water Framework Directive (WFD) has led to an important debate within the European scientific community. This debate has recently led to the publication of a whole issue of *Marine Pollution Bulletin* (Devlin et al., 2007). This journal has previously published several papers on the development of benthic indicators and their use for determining the Ecological Quality of water bodies (see any of the papers by Borja, Dauvin, Rosenberg, and Simboura, for example). Though structural indicators do now exist, two problems related to the use of these indicators have not yet been resolved: (1) reference conditions have not yet been established for each water body, essentially due to a lack of historical data and reference states; and (2) in spite of the intercalibration exercises carried out for the coastal waters of the European Union (JRC-EEWAI, 2007), thresholds values for the indices chosen by the Member States of the European Union do not permit a correct and harmonious classification whatever the index used, especially in transitional waters. The two problems are closed and the second is particularly complicated, raising many questions that cannot be easily answered. Must these threshold values be fixed? Must they vary according to the environmental gradient such as the salinity or according to the peculiarity of different European Seas (e.g., Atlantic and Mediterranean)? Can each EU Member State really choose a different benthic indicator? How can a single value be used to communicate the information obtained from various indicators? The answers to the many questions require serious reflection about the threshold values separating the five EcoQ.

The most used benthic indicators are explained in detail in issue 55 of *Marine Pollution Bulletin* (Devlin et al., 2007), and thus this paper does not re-explain their computational steps. Instead, we propose an overview of the EcoQ threshold values used today in the WFD (Table 1). Our objective is to see whether or not it is possible to modify these thresholds values in order to obtain the same or similar ecological classifications for a water body with these

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Table 1
Threshold values separating the five ecological status for the selected benthic indicators (see text for definitions), according to Muxika et al. (2007) for the M-AMBI, Borja et al. (2000) for the AMBI, Simboura and Zenetos (2002) for the BENTIX, Dauvin and Ruellet (2007) for the BOPA, Vincent et al. (2002) for H′, Rosenberg et al. (2004) for the BQI (adapted for our dataset as suggested in this reference), Dauvin et al. (2007) for the average score and Mearns and Word (1982) for the ITI

ecological status	M-AMBI	AMBI	BENTIX	BOPA	H'	BQI	Average Score	ITI	ecological status
	+∞	0,0	6,0	0.00000	+∞	12.0	1,0	100	
high									normal
	0.85	1.2	4.5	0.04576	4	9.6	1,5		
good									
	0.55	3.3	3.5	0.13966	3	7.2	2,5	60	
moderate									perturbed
	0.39	4.3	2.5	0.19382	2	4.8	3,5		
poor								30	
	0.20	5.5	2,0	0.26761	1	2.4	4,5		degraded
bad									
	0.00	7.0	0,0	0.30103	0	0.0	5,0	0	

Arrows indicate the direction of the variation.

different indicators, with an eye towards improving the current classifications. The thresholds used in this note are those first proposed by the authors of the indicators, except for the H′ indicator, for which we used the thresholds suggested by Vincent et al. (2002), and the BQI, whose original thresholds were adapted to our dataset as proposed by Rosenberg et al. (2004).

Three approaches were analyzed: the use of indicator equations, the use of reference indicators, and the use of indicator distribution laws.

2. Material and methods

2.1. Benthic indicators

The indicators that have been successfully used to assess the ecological quality of macrobenthic communities can be divided into four categories:

- *Indicators strictly based on ecological groups*. This category includes the AMBI (AZTI Marine Biotic Index) developed by Borja et al. (2000), which analyzes the proportions of five ecological groups according to a gradient of organic matter enrichment; the BENTIX developed by Simboura and Zenetos (2002), which simplifies the assessment of taxa to two ecological groups; and the BOPA (Benthic Opportunistic Polychaetes Amphipods index) developed by Dauvin and Ruellet (2007) to respect the principle of taxonomic sufficiency by using only two well-known zoological groups as indicator species, consequently limiting the misclassification of taxa caused by too many ecological groups.
- *Indicators strictly based on trophic groups*. The primary indicator in this group is the ITI (Infaunal Trophic Index; Mearns and Word, 1982), which holds that the ecological quality of the community increases with the dominance of suspension feeders and decreases with the dominance of subsurface deposit feeders.
- *Indicators strictly based on diversity*. Two types of indicators are in this category: those based on the theory of information as H′ (the Shannon–Weaver Index with $\log_2$) proposed by Shannon (1948) and those which consider that species found in an area with low diversity are indicators of bad ecological quality, as the BQI (Benthic Quality Index) proposed by Rosenberg et al. (2004).
- *Indicators synthesizing several other indicators*. The principal indicator in this group is the M-AMBI (Multivariate AMBI) developed by Muxika et al. (2007), which subjects the values from the AMBI and the H′ indicators, as well as species richness values, to factor analysis and discriminant analysis. Other authors have recommended a scoring system combining the various indicators, attributing a score between 1 and 5 to the five EcoQs obtained with each index and then dividing the sum of these scores by the maximum score possible, thus yielding a relative score (as in Coates et al., 2007) or dividing the sum by the total number of scores, thus yielding a average score (as in Dauvin et al., 2007).

2.2. Data analysis

The data selected for use in this study are from the transitional water body T3 in the Seine estuary (Normandy, France), an area for which benthic data are numerous

(Dauvin, 2007). This area extends approximately 45 km in length and is exposed to a salinity gradient (ranging from the polyhaline zone near to the mouth to the oligohaline zone near the eastern limits), and has a significant amount of maritime traffic due to boats going to and from the Rouen and Le Havre harbours, which together constitute the third European harbour in terms of tonnage. All the data were extracted from the MABES (Macrobenthos of the Bay and Estuary of the Seine) database, which is available from the data administrator of GIP Seine-Aval (nbacq@seine-aval.fr). This database compiles many standardized abundances of macrobenthic species from 1986 to 2005, with 279 samples in T3, and includes the trophic groups of the majority of the species encountered. Indicators values calculated from all these samples are used, giving us an average image of the state of the estuary. T3 hosts two different benthic communities: a poorly diversified *Macoma balthica* muddy community and a more diversified *Abra alba* muddy-fine sand community (Dauvin and Desroy, 2005). A faunal impoverishment gradient runs along the salinity gradient (the maximal species richness values for the polyhaline, mesohaline and oligohaline zones are, respectively, 54, 21 and 6 taxa), and the Rouen Harbour navigation channel is itself impoverished (rarely more than 3 species in each sample). In T3, the average total abundance is 1028 ind. m^{-2} (2–72,484 ind. m^{-2}), and the average diversity is 2.02 bits. As proposed in the AMBI software v.4 (© AZTI), the reference conditions required for M-AMBI were set using the highest H′ value (4.22 bits), the highest species richness value (54 species), and the lowest AMBI value (0.15) specific to T3 for "high EcoQ" conditions, while null values for H′ and species richness and an AMBI = 6 were used for "bad EcoQ" conditions.

2.3. Approaches

The first approach is theoretical and tries to find correspondence between the equations of the different indicators to obtain correspondence between different indices scales because it is necessary to have a theoretical correspondence so that it is possible in practice. The second uses a reference indicator, i.e., an indicator supposed to give correct ecological classification, to calibrate other indicators and so to produce the same average ecological assessment for a water body with all these indices. The last uses the mathematical properties of the indicators values, i.e., their distribution laws, to get the same proportion of each EcoQ for a water body with different indicators and to improve the actual classification.

3. Results and discussion

3.1. Report on the ecological status of the Seine estuary

The ecological status of the transitional water body T3 of the Seine estuary, according to each of the selected indices, is shown in Fig. 1. Clearly, the different indices did not produce the same ecological classifications for the zone. AMBI and BOPA are more optimistic than BQI or H′: the percent of samples classed as "high" or "good" are approximately 90% for the first two and only 10% for the last two. Given these results, two hypothesis are possible: either some, or all, indices are inappropriate; or the EcoQ threshold values (i.e., the values signifying the boundaries between the EcoQ classes) of the indices must be modified so that they produce the same or at least similar results for a given area.

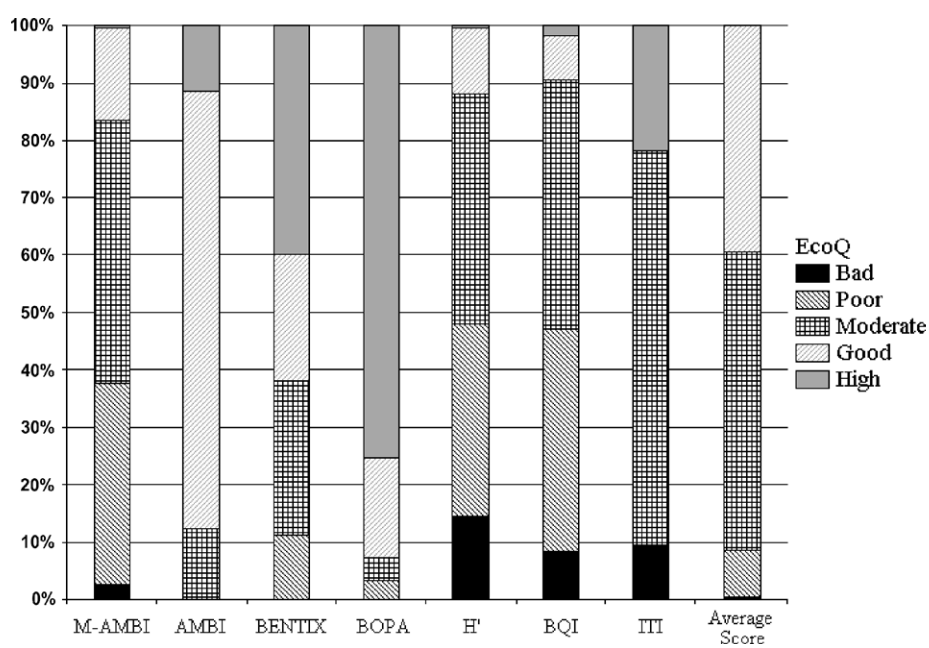

Fig. 1. Percentages of samples ($n_{max} = 279$) from the transitional water body T3 in the Seine estuary for each Ecological Quality (EcoQ) status according to the selected benthic indices (see text for definitions).

All the selected indices, except ITI, reveal a gradient between the Bay of Seine and the Seine estuary (Dauvin et al., 2007). But, is it a perturbation gradient? Indeed, a salinity gradient exists between theses two sites and could affect the indicator values. Zettler et al. (2007) have demonstrated that salinity can have an impact only on the indicator values based on diversity (e.g., BQI and H′ in this study), and consequently not on those based on ecological or trophic groups. Thus, the AMBI and BOPA values reveal that the gradient is, in fact, a perturbation gradient. Consequently, all the indices tested appear to be appropriate.

The first possible hypothesis being proved incorrect, the second must hold true. The threshold values should be modified so that the various indices chosen by EU Member States will produce the same ecological quality assessment for a given zone.

3.2. Use of equation indicators

Two types of use of indicator equations can be distinguished: (i) equations based on two different notions (e.g., AMBI based on ecological groups and ITI based on trophic groups), which consequently can produce complementary information, and (ii) equations based on the same notion (e.g., AMBI and BENTIX, both based on ecological groups), which consequently should be able to provide the same result for the ecological status of a benthic community.

3.2.1. Ecological groups vs. trophic groups

To obtain the same ecological classification using an indicator based on ecological groups (e.g., AMBI) and an indicator based on trophic groups (e.g., ITI), it is necessary, but not sufficient, that there be a correspondence between the two types of groups.

Classifying all taxa of the MABES database according to ecological groups on one hand, and trophic groups on the other one, different results are obtained (Table 2). All this reflects in the absence of correspondence between the classifications of the ecological states resulting from the two kinds of indices. For example, a sample containing only surface deposit feeders and mixed species necessarily corresponds to a single ITI value of 33.3, but can, depending on the specific composition of the sample, correspond to a range of AMBI values from 0 to 7 (i.e., all the possible values). Thus, ITI provides complementary information to the information obtained with AMBI or BENTIX. However, this information may be contradictory: the presence of species sensitive to organic matter enrichment does not necessarily imply that the trophic balance is good.

Given this lack of correspondence, to compare the ecological status of two sampling sites, it appears that indices based on the same notions must be used for each sample. This could mean using AMBI for both, or ITI for both, or even AMBI and ITI together for both. However, can indicators based on the same notion but computed differently be used to compare the ecological status of two sampling sites?

Table 2
Number of taxa belonging to each ecological group (1: species sensible to organic enrichment; 2: species indifferent to organic enrichment; 3: species tolerant of organic enrichment; 4: second order opportunistic species; 5: first order opportunistic species) and each trophic group (SF: suspension feeders; C&O: Carnivorous and omnivorous species; SDF&M: surface deposit feeders and mixed feeders; SSDF: sub-surface deposit feeders) in the MABES database (>800 samples)

Number of taxa	Number of taxa trophic group				
	SF	C&O	SDFM	SSDF	
Ecological group					
1	50	50	56	30	186
2	13	99	23	5	140
3	9	18	26	7	60
4	1	2	15	2	20
5	0	0	2	3	5
	73	169	122	47	411

3.2.2. BENTIX vs. AMBI

Simulating all the possible cases of benthic community composition, in terms of ecological groups using steps of 10%, produced the dataset for the BENTIX vs. AMBI couple, shown in Fig. 2. Except for the particular case in which BENTIX = 0 (azoic conditions), which cannot correspond to an AMBI value, BENTIX and AMBI appear to be highly correlated ($r = 0.86$, $n = 949$). Nonetheless, given the principle "only one EcoQ for one indicator value", it seems to be impossible to obtain the same ecological classification using these two indicators. For example, a BENTIX value of 2 corresponds to a "poor" EcoQ, which corresponds to a range of AMBI values from 3 to 6. Consequently, all the BENTIX values corresponding to an AMBI value of 3 should be judged "poor" EcoQ. Among these values, the BENTIX value of 4.4 also corresponds to the AMBI value of 1.2, which can also correspond to a BENTIX value of 6. Finally, by applying a straightforward principle, all the BENTIX values between 2 and 6 (i.e., all the values on the continuous scale) will be in the same EcoQ class if AMBI and BENTIX are to produce the same EcoQ class for a sample.

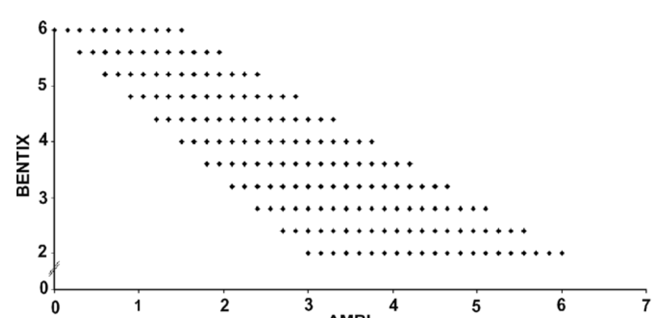

Fig. 2. Simulations of the BENTIX (Simboura and Zenetos, 2002) and AMBI (Borja et al., 2000) values by steps of 10% for each ecological group defined in the AZTI list.

Thus, according to the above analysis, even two indicators based on the same notion not produce systematically the same assessment of a sample's ecological status. It would be a major problem if the ecological assessment of a water body was based on a single sample. But it is not the case. Consequently, although the indices cannot systematically produce an identical ecological classification for a sample, the mean (of the ecological classification) calculated at the level of the water body can be identical with two indicators. It is necessary that it is true for the maximum of the water bodies. This is the method adopted at a global scale for intercalibration exercises (Borja et al., 2007; JRC-EEWAI, 2007) which will remain necessary as long as the EU Members States are able to choose their own indicator and not to adopt a single indicator chosen for the entire EU. The objective thus becomes determining the indicator thresholds that agree most.

3.3. Use of a reference indicator

All the indices used are appropriateness to the evaluation of the ecological quality even if classifications resulting of their use are not identical as mentioned previously and the question is not to know which is the best. But to determine the indicator thresholds that most agree, it is best to choose a reference indicator that is deemed to provide the correct ecological classification. This reference indicator, which can be a synthesis indicator (as the M-AMBI) or the average score, provides the proportions that should be in the samples for each EcoQ in the dataset. These proportions can then be applied to all the indices to determine the new thresholds between the EcoQ classes.

The new thresholds, obtained using the average of the AMBI, BENTIX, BOPA, H′, BQI and ITI scores as a reference value, are given in Table 3. In this example, the ecological status of the T3 zone given by all the indices used correspond to that shown in Fig. 1 for the average score. This is not really intercalibration, but rather harmonization, because only the average classification obtained with the indices corresponds, not the classifications obtained for each sample. This nuance is important because the ecological quality of a benthic community can vary quickly in transitional waters (see Blanchet et al., 2007, for the T3 zone of the Seine estuary). Consequently, in spite of this harmonization, the pattern of variation of the ecological quality assessment can vary depending on the indicator chosen. Given that harmonization is not enough, EU Members States must be convinced of the necessity of defining a single indicator, or a single suite of indicators which provide complementary information, for evaluating the ecological quality status of the benthic communities, wherever these communities are found in Europe.

3.4. Use of indicator distribution laws

Since the probability of belonging to each EcoQ category is actually different depending on the indicator used, if the Members States continue to use different indicators, it will, at the very least, be necessary to re-examine the indicator threshold values. The probability of belonging to

Table 3
Threshold values separating the five ecological status obtained for the selected benthic indicators (see text for definitions) using the average of the AMBI, BENTIX, BOPA, H′, BQI and ITI scores as a reference value

ecological status	M-AMBI	AMBI	BENTIX	BOPA	H'	BQI	Average Score	ITI
	1.00	0.00	6.00	0.00000	5.00	12.00	1.0	100.0
high								
	0.90	0.15	5.95	0.00010	4.25	11.55	1.5	97.0
good								
	0.46	2.00	4.54	0.01200	2.27	5.55	2.5	50.7
moderate								
	0.27	3.40	2.50	0.14000	0.92	2.50	3.5	29.0
poor								
	0.10	4.30	2.00	0.25000	0.30	1.20	4.5	1.0
bad								
	0.00	7.0	0.00	0.30103	0.00	0.0	5.0	0.0

Arrows indicate the direction of the variation.

each EcoQ category—and not the distribution of the intervals between the threshold values—must be chosen by the scientific community, or more probably by the managers. If the probabilities resulting of the actual intervals are satisfactory, whether they are regular as for the BQI ((maximal value – minimum value)/5) or that they are irregular as for the AMBI ($4.3 - 3.3 = 1$ unit for the moderate status and $3.3 - 1.2 = 2.1$ units for the good status; Table 1), they could continue to be used.

Standardizing the indices by limiting their values to between 0 and 1 and adopting the same direction of variation for each index (0 for the worst status and 1 for the best status) would facilitate the attribution of identical probabilities for all the indices. By limiting the values, the standardized value of AMBI = 5 would be $(7 - 5)$ $7 = 0.29$, while the standardized value of ITI = 60 would be 60/100 = 0.60. The standardized values of the indices referred to in this note are shown in Fig. 3 for the T3 zone of the Seine estuary, except for the BENTIX which follows a particular law (see below).

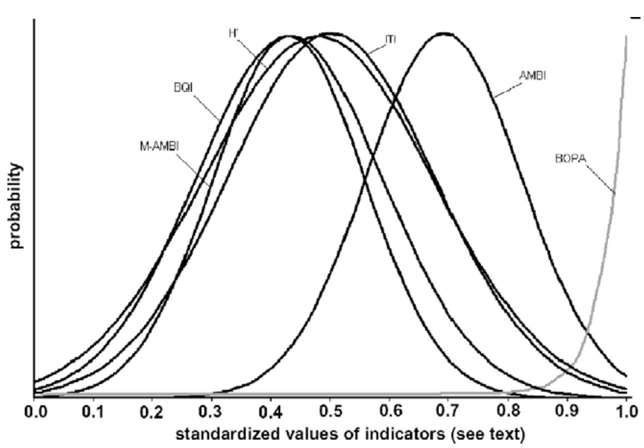

Fig. 3. Standardized values between 0 (worst status) and 1 (best status) of the selected indicators for the transitional water body T3 in the Seine estuary. Indicators following a normal law are traced in black and those following an exponential law are traced in grey.

BENTIX follows a quadratic law; BOPA follows an exponential law, while AMBI, H′, M-AMBI, BQI and ITI all follow normal laws. Using these distribution laws (type of law, mean and dispersion), it is easy to attribute the same probability to each indicator for each EcoQ. For example, if a regular probability p to belong to each EcoQ is used ($p = 1/5$ classes $= 0.2$), the new threshold values for the BQI would be 0.30, 0.39, 0.47, 0.56 and 1 in standardized values (i.e., 3.6, 4.7, 5.7, 6.8 and 12 with the actual scale). Another probability distribution could be used to, for example, to decrease the weight of the extreme statuses (as with $p = 0.10, 0.25, 0.30, 0.25, 0.10$, respectively, for the range from "bad" to "high"), but it is still necessary to choose these p-values.

In Fig. 4, the new standardized thresholds proposed for the indices based in normal law are specific to our dataset and consider that each EcoQ is represented by 20% of the samples taken in T3. Consequently, the mean value of each index corresponds to the moderate status, but when the new thresholds are applied, local variations (e.g., temporal or geographical) appear more equitably on the maps than with a scale with regular intervals. Rosenberg et al. (2004) implicitly proposed already emphasizing the extreme classes by considering the minimum and maximum values of the BQI as representative of "bad" and "high" status, but not equitably because they attributed a regular interval of BQI values between each EcoQ and that the probabilities of the BQI values are not regular. Indeed, the probability to obtain a result around the mean is greater than around an extreme value in the case of a normal law. In order to determine the new thresholds, this standardization must be carried out during intercalibration exercises using a large dataset containing an equal number of samples from each EcoQ.

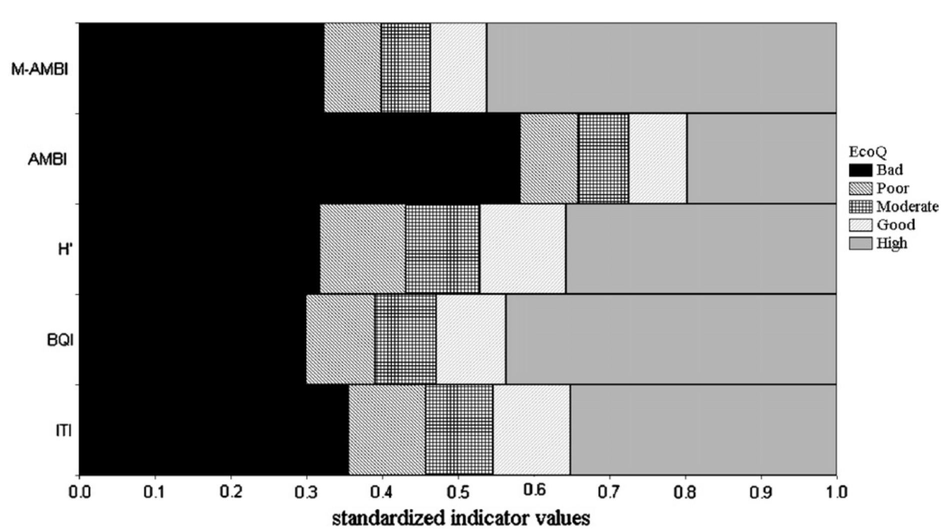

Fig. 4. Threshold values separating the five EcoQ (Ecological Quality) for the selected indicators, standardized between 0 (worst status) and 1 (best status), attributing 20% of the samples in the dataset used to each EcoQ.

4. Conclusions

The actually method of intercalibration used by the European Union is not suitable for comparing the results obtained with all the water bodies studied. In fact, the current method tries to intercalibrate indices that do not communicate the same information, which is not wise. The available indicator types—based on trophic groups, ecological groups and diversity—are complementary but not comparables (cf. ITI vs. AMBI). From each indicator category, it is preferable to choose one indicator, and only one, because even different indicators based on a same notion do not interpret the same information in the same way (cf. AMBI vs. BENTIX); thus, they can be harmonized but not intercalibrated. The EQR (Ecological Quality Ratio), designed to standardize the presentation of the results from all EU Member States, does not change this fact. The EQR is just a ratio, and if the values used in this ratio are not comparable, the resulting ratio values are not comparable either.

It is necessary to decide which indicator(s) to use: it is best to select the information synthesis provided by an indicator based on diversity, another based on trophic groups and a third based on ecological groups. Thus, it is undoubtedly necessary to use one index of each type to create a synthesis indicator, similar to the M-AMBI but not necessary using the same variables. AMBI, H' and ITI are the most used in their categories (ecological groups, diversity and trophic groups) and thus could be used. But the selection of the variables needs to be carefully considered. For example, the inclusion of H' and species richness values in the M-AMBI computation gives too much weight to diversity. The use of these two variables in a same indicator is not justified. Moreover, benthic individuals do not, for example, necessarily have to be determined to the species level. To decrease the cost of surveys but also to decrease the problems due to misidentifications and determinations that change depending on the laboratory (Schilling et al., 2006), diversity should probably be determined at a supra-specific level (perhaps genus or family) and the other indices could also specify to this level.

For the benthic indicators based on ecological groups, everyone uses the list published by the AZTI to calculate AMBI. A definitive version of this list should now be established (even if it is not perfect), and the information sources allowing the ecological groups to be assessed should be made public. Still, the previous versions of the list need to be archived in a publicly accessible place so that results can be compared according to the list used. Indeed, when the list was revised in July 2006, the new list comprised significant modifications, which resulted in moving *Pectinaria* (*Lagis*) *koreni*, for example, from group 1 to group 4. If this list is not set down definitively, the EcoQ of a sample could still change, even once the indicator thresholds are set. Creating a definitive version of the list is the only way possible to obtain an objective tool, minimizing the variability of the subjective expert judgement.

Ideally, all the Member States of the European Union should use the same indicator. If this is not enacted, it will be necessary to re-examine the threshold values between the five EcoQ so that they will have the same occurrence probability with each indicator used by the Member States. This partitioning will certainly have to be carried out using the probability distribution laws on the indicator values in big datasets containing all the ecological situations encountered in Europe (from "high" status to "bad" status) and for each type of benthic community. If the current thresholds continue to be used, muddy communities like those in the transitional water body T3 of the Seine estuary, which are naturally richer in opportunistic species than others that live in more coarse sediment (Dauvin, 2007), will continue to appear to be more perturbed than others. Thresholds values but also references conditions should be different according the communities.

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