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Marine Pollution Bulletin xxx (2004) xxx–xxx
MARINE POLLUTION BULLETIN
www.elsevier.com/locate/marpolbul

Viewpoint

The water framework directive: water alone, or in association with sediment and biota, in determining quality standards?

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Keywords: Sediments; Water pollutants; Standards; EU

The European water framework directive (WFD; Directive 2000/60/EC) develops the concept of ecological quality status (EcoQ) for the assessment of the quality of water masses. The EcoQ is based upon the status of biological, hydromorphological and physico-chemical quality elements, with biological elements being especially important; and supported by the others. The physico-chemical elements include general variables (such as dissolved oxygen, nutrients, etc.) and specific pollutants. The former correspond to variables measured directly in the water. However, there is no indication about which matrices are to be sampled, or for which specific pollutants.

In order to comprehensively assess the ecological status of aquatic systems, all the significant matrices and elements should be addressed, especially those that would most likely affect the biota of the system and those providing relevant information on impacts to them.

Sediments are considered to be important in assessment of anthropogenic impacts to coastal and estuarine environments (Ridgway and Shimmield, 2002; Chapman and Wang, 2001). Similarly, biomonitors have been widely used for assessing the contamination of marine ecosystems (Cantillo, 1998; O'Connor, 1998), providing significant information on specific pollutants over relevant resolution time periods.

It is highly significant that 'water' is referred to on 373 occasions throughout the WFD, but other matrices, such as sediment or biota (biomonitors), are mentioned explicitly only 7 and 4 times, respectively. On at least three occasions the latter two terms are used in connection with the derivation of environmental quality standards (EQSs), as was outlined by Crane (2003). Hence, Article 2 ('Definitions') defines an EQS as the concentration of a particular pollutant or group of pollutants in water, sediment or biota that should not be exceeded in order to protect human health and the environment. Article 16 ('Strategies against pollution of water') states that the commission shall submit proposals for quality standards applicable to the concentrations of the priority substances in surface water, sediments or biota. Finally, in Annex V, the procedure for setting the EQSs by Member States is described, including concepts related to toxicology of substances and their bioaccumulation in the biological components.

When designing the surveillance monitoring (Annex V), the WFD does not provide clear guidance on the selection of matrices to be studied for the physico-chemical elements. However, taking into account that the monitoring network shall be designed so as to provide a coherent and comprehensive overview of ecological and chemical status, within each transitional (estuarine) and coastal water masses, sediment and biomonitor elements should be included in such a network; some recently approaches explicitly (Crane et al., 2003; Borja et al., 2004a) or implicitly (Henocque and Andral, 2003) mention such requirements. In fact, the longest monitoring programmes of the marine environment around the world consider sediment and biomonitors as important matrices for the integral assessment of ecological status (Macauley et al., 1999; Gibson et al., 2000; Claisse et al., 2002; and Kiddon et al., 2003).

There are two different levels of chemical indicators within the WFD: (i) physico-chemical conditions influencing the biological quality (related mostly to eutrophic processes, see Bricker et al. (2003) and Nielsen et al. (2003)); and (ii) the classification of the chemical status.

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0025-326X/$ - see front matter © 2004 Published by Elsevier Ltd.
doi:10.1016/j.marpolbul.2004.04.008

The relationship between the levels has been described in Borja et al. (2004a, Fig. 2).

The problem arises when an integration of the three matrices (water, sediment and biomonitors) is proposed, in order to determine the chemical quality of the system being examined. Variables which could be studied include, amongst others: basic variables in waters (such as transparency, dissolved oxygen, nutrients, etc.); and toxic metals and organic compounds in waters, sediments and biomonitors. In order to evaluate results of each group of variables to diagnose the marine quality status, the results can be referenced to and compared with: (i) some directly or indirectly related legislation (ICES, 2003); (ii) regional background levels (as is the case for heavy metals, in sediments: Ridgway and Shimmield, 2002; Crane, 2003; and Belzunce et al., 2004b) and proposed quality objectives in waters (Belzunce et al., 2004a), or biomonitors (Borja et al., 2004b); (iii) the levels obtained from other coastal areas, which can be used as comparison; and (iv) databases on toxic effect thresholds of some contaminants and ecotoxicological approaches (Long et al., 1995; Chapman et al., 1996; Gibson et al., 2000; and Crane, 2003).

An example of the determination of the extent of contamination in the five levels of the WFD, is provided by metals in sediments. A practical tool is the index of geoaccumulation (I_{geo}) proposed by Müller (1979), which measures the concentration of the metal 'n', within the sediment or size fraction, compared with its background concentration. The index can be divided into five classes: unpolluted ($I_{geo} < 1$); low polluted ($1 < I_{geo} < 3$); moderately polluted ($3 < I_{geo} < 4$); highly polluted ($4 < I_{geo} < 5$); and very highly polluted ($5 < I_{geo}$). This method has been used extensively (Ridgway and Shimmield, 2002), even in some studies related to the WFD (Belzunce et al., 2004; Franco et al., 2004). This approach, or other procedures, can be applied in determining the extent of contamination in the remainder of the variables and matrices.

In order to assess the quality status along the Basque coast, Franco et al. (2004) used the water, sediment and biomonitor data from a monitoring network (see Borja et al., 2003, 2004a) to calculate an integrative index of

Table 1
Example of the calculation of the integrative index of quality (IIQ) for two locations, based upon different variables and matrices (modified from Franco et al., 2004)

Matrix	Variables	Location 1		Location 2	
		Classification	Score	Classification	Score
Case a: without weighting					
Water	Basic variables	Moderate	3	Good	4
	Heavy metals	Poor	2	Good	4
	Organic compounds	Good	4	Bad	1
Sediment	Heavy metals	Moderate	3	Bad	1
	Organic compounds	High	5	Poor	2
Biomonitors	Heavy metals	Poor	2	Bad	1
	Organic compounds	High	5	Bad	1
Total scores for water only			9		9
Classification over 15 scores for water only			Moderate		Moderate
Total scores (IIQ)			24		14
Classification over 35 scores:			Moderate		Poor
Case b: weighting sediment and biomonitors					
Water	Basic variables	Moderate	3	Good	4
	Heavy metals	Poor	2	Good	4
	Organic compounds	Good	4	Bad	1
Sediment	Heavy metals	Moderate	$3\times3 = 9$	Bad	$1\times3 = 3$
	Organic compounds	High	$5\times3 = 15$	Poor	$2\times3 = 6$
Biomonitors	Heavy metals	Poor	$2\times2 = 4$	Bad	$1\times2 = 2$
	Organic compounds	High	$5\times2 = 10$	Bad	$1\times2 = 2$
Total scores (IIQ)			47		22
Classification over 65 scores:			Good		Bad

Case 'a' was derived without weighting the scores, in Case 'b', sediment was weighted × 3 and biomonitors × 2. Basic variables can include: Secchi disc, nutrients, dissolved oxygen, etc.; heavy metals (the authors include 10); organic compounds, which can include PCB, DDT, PAH, HCH, HCB, etc. Classification key: Case 'a': high—31–35 scores; good—25–30; moderate—19–24; poor—13–18; bad—7–12; Case 'b': high—57–65 scores; good—46–56; moderate—35–45; poor—24–34; and bad—13–23.

quality (IIQ), based upon the methodology of Borja et al. (2001, 2002). In this contribution we propose to adapt it to the WFD, classifying each group of variables in terms of five possible levels of quality: 'high'; 'good'; 'moderate'; 'poor'; and 'bad'. A score value (5, 4, 3, 2, 1, respectively) is given to each of these levels, establishing an IIQ for an area. In Table 1 example, using only water within the classification, both locations should be classified as 'moderate' quality (there are 9 scores over the most favourable possible situation of 15 scores: if all the 3 variable groups attained a 'high' classification (5 scores as 'high' × 3 variables = 15 scores)). Likewise, including sediment and biomonitors, Location 1 in the Case 'a' approach presents an IIQ value of 24 scores, meaning that the location can be classified as 'moderate' quality (24 over 35 scores, for 7 variable groups); and Location 2 can be classified as 'poor' (14 scores over 35) (Table 1).

Taking into account that sediment and biomonitors can provide integrative records of pollution (Ridgway and Shimmield, 2002), compared to the high variability found in waters, the method proposed in this contribution permits the possibility of weighting the scores. On the basis of this approach, the sampling frequency and the time-scale of variability of each of the matrices, it is seen that sediment is probably the most relevant matrix in relating specific pollutants to biological status, followed by biomonitors and waters. Therefore, Table 1 presents the changes which occur when weighting sediments × 3, biomonitors × 2 and waters × 1. Hence, Location 1, with better quality in sediments and biomonitors, improves in terms of its final classification. Likewise, Location 2, with a worse quality associated with these elements, worsens in terms of its final classification.

This simple method permits the classification of quality, by means of either five levels (i.e. physico-chemical conditions influencing the biological quality) or two levels of quality (i.e. in the classification of the chemical status: 'good' or 'failing in achieving good'), following the WFD (see Borja et al., 2004a). In the latter case, the scores from the weighted example could be grouped, with 13–45 scores 'failing' and 46–65 'good'.

This approach follows the recommendations of Borja et al. (2004a), in implementing the WFD. The information is included in a pragmatic and realistic way, avoiding any complicated methodologies which could make it impossible to implement a monitoring network (or use data from long-term monitoring networks), in terms of efficiency and cost. Moreover, this approach facilitates the final determination of the ecological status, without considering the WFD principle 'one out, all out', which could lead to a failing of the WFD which might happen if only a single variable of one of the matrices does not arrive at a 'good status' (see Borja et al., 2004a).

Hence, responding to the question posed in the title, not only water should be incorporated into determining quality standards of the WFD. Sediment and biomonitors must also be included. Such a procedure would improve the final ecological quality determination, using pragmatic and scientifically understandable approaches.

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