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The European water framework directive: A challenge for nearshore, coastal and continental shelf research

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Abstract

The European Water Framework Directive (WFD) establishes a framework for the protection of groundwater, inland surface waters, estuarine waters, and coastal waters. The WFD constitutes a new view of the water resources management in Europe because, for the first time, water management is: (i) based mainly upon biological and ecological elements, with ecosystems being at the centre of the management decisions; (ii) applied to European water bodies, as a whole; and (iii) based upon the whole river basin, including also the adjacent coastal area. Although the marine water bodies affected by the WFD relate to only 19.8% of the whole of the European continental shelf, its application constitutes a challenge and an opportunity in nearshore, coastal and continental shelf research.

This contribution highlights some of the main tasks and the research to be undertaken in the coming years, proposing investigations into: typologies; physico-chemical processes; indicator species; reference conditions; integration of the quality assessment; methodologies in determining ecological status, etc.

Keywords: Water framework directive; Policy research; Ecosystem-based approach; Reference conditions; Nearshore; Coastal; Continental shelf

1. Introduction

The European Water Framework Directive (WFD; 2000/60/EC) establishes a framework for the protection of groundwater, inland surface waters, estuarine (= transitional) waters, and coastal waters. This legislation has several well-defined objectives: (i) to prevent further deterioration, to protect and to enhance the status of water resources; (ii) to promote sustainable water use; (iii) to enhance protection and improvement of the aquatic environment, through specific measures for the progressive reduction of discharges; (iv) to ensure the progressive reduction of pollution of groundwater and prevent its further pollution; and (v) to contribute to mitigating the effects of floods and droughts. Overall, its final objective is achieving at least 'good water status' for all waters, by 2015. The WFD requires Member States to assess

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the Ecological Quality Status (EcoQ) of water bodies. The EcoQ will be based upon the status of the biological, hydromorphological and physico-chemical quality elements, with the biological elements being especially important. In coastal and transitional waters, the biological elements to be considered are phytoplankton, macroalgae, benthos and fishes (the latter only in transitional waters).

In order to assist the WFD implementation, a "Common Implementation Strategy" (CIS) was agreed in May 2001. The CIS incorporates four key activities, which include: (i) the development of guidance on technical issues; and (ii) the application, testing and validation of the guidance provided. Several working groups were created to deal with these issues. The COAST working group dealt specifically with transitional and coastal waters, with their guidance document being published in November 2002 (Vincent et al., 2002; for other working groups and guidelines, see http://forum.europa.eu.int/Public/irc/env/wfd/home; Murray et al., 2002).

The word 'integration' can be considered as the central concept of the WFD. It is a key concept in the water protection and management, addressing different aspects: (i) integration of environmental objectives; (ii) integration of water resources, at river basin scale (including, for the first time in Europe, the coastal waters); (iii) integration of the various water uses, functions and values; (iv) integration of different skills, analyses and disciplines (including different experts, such as biologists, chemists, geologists, engineers, physicists, etc.) in water management; (v) integration of the previous water legislation (dispersed throughout several Directives) into a common and coherent framework; (vi) integration of an ample range of measures, including economical and financial instruments; (vii) integration of stakeholders and society, in decision-making; (viii) integration of the different decision-making levels, affecting the water status and water resources; and lastly, but not least; (ix) the integration of water management among the Member States.

The WFD constitutes a new view of the water resources management in Europe because, for the first time, water management is: (i) based mainly upon biological and ecological elements (previously, it was based upon physico-chemical elements), with there being the ecosystems at the centre of the management decisions; (ii) applied to all European water bodies; and (iii) based upon the whole river basin, including the adjacent coastal area.

The WFD requires surface waters within the River Basin District to be divided into 'water bodies', representing the classification and management unit of the Directive. The WFD defines a 'water body' as 'a discrete and significant element of surface water such as a lake, a river, a transitional water or a stretch of coastal water'. A range of factors determines the identification of such water bodies (see below). Some of these factors will be determined by the requirements of the Directive; others by practical water management considerations. In the case of coastal waters, stretches of open coast are often continuous (unless divided by transitional waters); here, subdivisions may follow significant changes in the substratum, topographies or their aspect (as outlined by Vincent et al., 2002).

The suggested hierarchical approach to the identification of surface water bodies includes: (i) the definition of the River Basin District; (ii) the division of surface waters into one of six surface water categories (i.e. rivers, lakes, transitional waters, coastal waters, artificial and heavily modified water bodies); (iii) the sub-division of surface water categories into types, then assigning the surface waters to one type; and (iv) the subdivision of a water body of one type into smaller water bodies, according to pressures and resulting impacts (for details, see Vincent et al., 2002; Borja et al., 2004a; Heiskanen et al., 2004).

The purpose of the typology is to enable type-specific reference conditions to be established. Such conditions become then the basis for the classification schemes, with consequences for all subsequent operational aspects of the implementation of the WFD (including intercalibration of the different methodologies, in assessing the quality of each of the biological elements, monitoring, assessment and reporting). It is necessary to identify the location and boundaries of water bodies within each surface water category; further, to carry out its characterisation according to type, using a system of typology as defined in the WFD. The coastal types can be defined using either System A (which includes the ecoregion, salinity and mean depth, as determination factors), or System B (which includes latitude, longitude, tidal range and salinity (obligatory factors); together with current velocity, wave exposure, mean water temperature, mixing characteristics, turbidity, retention time (in the case of enclosed bays), mean substratum composition, and water temperature range (optional factors)).

If System A is adopted, the surface water bodies are differentiated initially in terms of the relevant ecoregions, in accordance with the geographical areas identified in Fig. 1. The water bodies within each ecoregion are differentiated in terms of surface water body types, according to the above-mentioned descriptors. If System B is adopted, the Member States must achieve at least the same degree of differentiation as would be achieved using System A. Accordingly, the surface water bodies within the river basin district will be differentiated into types using: (i) values for the obligatory descriptors; and (ii) such optional descriptors, or combinations of them, as are required to ensure that type-specific biological reference conditions can be reliably derived.

On the basis of the 'obligatory factors', it is possible to divide the maritime area into three basic eco-regions: (i) the Atlantic/North Sea Eco-region Complex, comprising the North Atlantic Ocean, North Sea, Norwegian Sea and the Barents Sea Eco-regions; (ii) the Baltic Sea Eco-region; and (iii) the Mediterranean Sea Eco-region, which includes also the Black Sea (see Vincent et al., 2002; Casazza et al., 2003; Borja et al., 2004a; Heiskanen et al., 2004, for additional details on 'optional factors', in determining typologies).

Recently, some methodological approaches in implementing such a complex Directive have been undertaken in Europe (Henocque and Andral, 2003; Borja et al., 2004a; Casazza et al., 2004). However, taking into account the very considerable amount of work to be carried out (as shown in this Introduction) some research should be undertaken in order to accomplish with the WFD objectives (mainly, to achieve the 'Good Ecological Status'), by 2015. This observation is especially relevant in the case of coastal waters, because little attention has been paid to this particular area in relation to the WFD. Hence, the number of scientific papers published since 1999 in peer-review journals, referring specifically to marine aspects (these include transitional waters) of the WFD, represents only some 10% of the total published contributions (Fig. 2). Moreover, an important number of papers have been presented in non-peer-review journals, conferences, reports and the grey literature. The proportion could be the same, but access to this literature is sometimes very difficult.

Hence, the aim of this contribution is to encourage, by identifying some of the aspects of the WFD requiring scientific research, the investigation of the European coastal waters in relation to the WFD. Some of the problems and controversies, currently present amongst the scientific community, will be discussed.

2. The extension of the coastal waters, under the WFD

The WFD defines coastal water as 'the surface water on the landward side of a line, every point of which is at a distance of one nautical mile on the seaward side from the nearest point of the baseline from which the breadth of territorial waters is measured, extending where appropriate up to the outer limit of transitional waters'. As stated by Andersen et al. (2004), open marine waters are not included. However, the WFD is likely to influence management of all marine ecosystems, because all land-based inputs of pollutants pass through the coastal zone to the open waters.

Hence, the coastal area is the portion of the ocean where physical, chemical and biological processes are affected directly by land, mainly through the rivers (see Milliman, 2001). Usually, this area extends over the continental shelf (with a water depth of 200 m, or less). The European coastal zone (including the Baltic Sea, the Mediterranean Sea, and the European Atlantic Sea) extends over $2.05 \times 10^6\,km^2$, representing 8.4% of

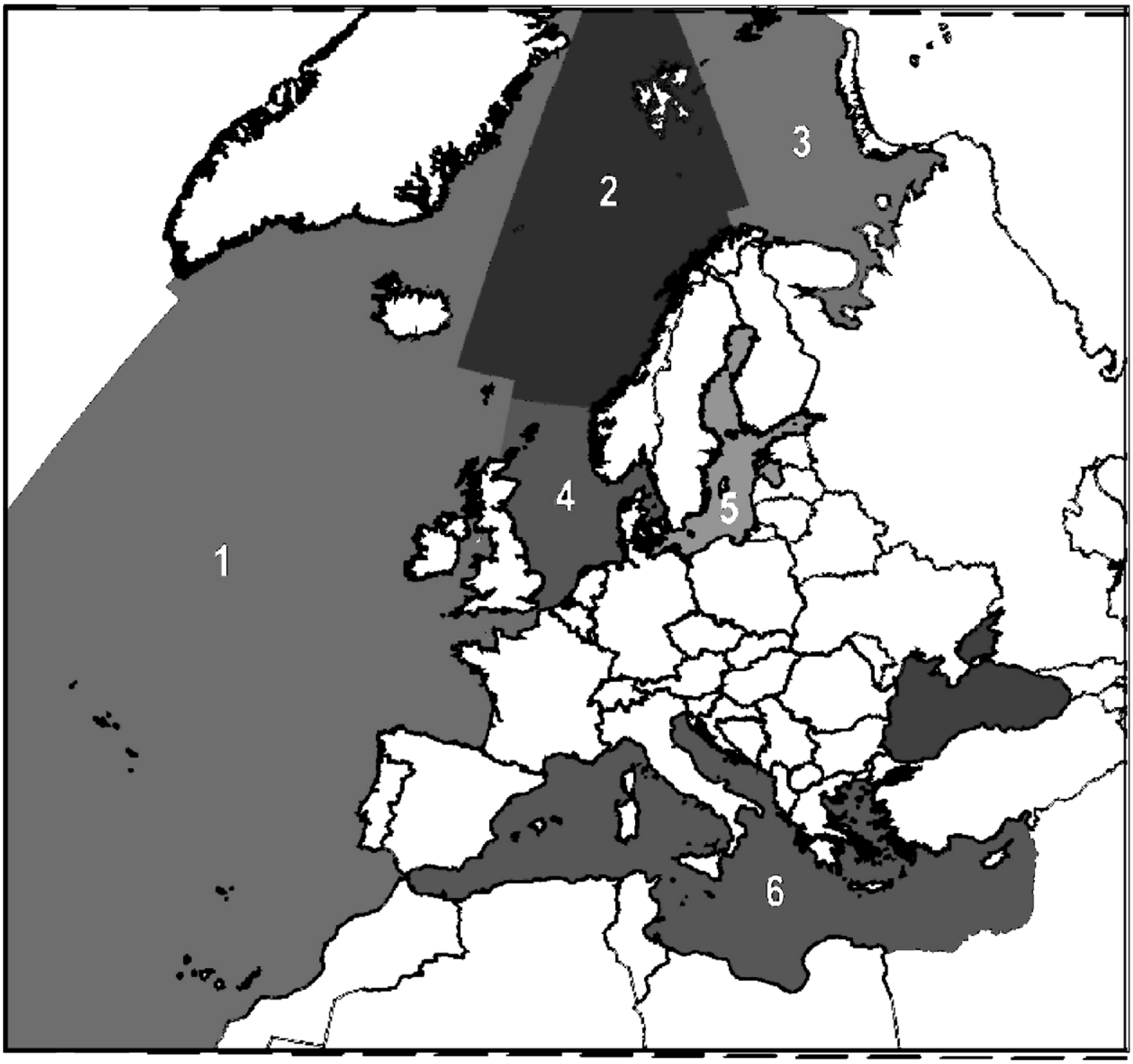

Fig. 1. Different eco-regions defined within the WFD. Key: 1—Atlantic Ocean; 2—Norwegian Sea; 3—Barents Sea; 4—North Sea; 5—Baltic Sea; and 6—Mediterranean Sea.

the world coastal zone surface area (Gazeau et al., 2004).

Taking into account the above-mentioned definition, the coastal waters included in the WFD represent only a small proportion (19.8%, with a surface of 405,703 km^2) of this area (Table 1). Most of the coastal waters belong to Norway (24.6% of the total), which is not a EU Member State, but collaborates in the implementation of the WFD. This country is followed by United Kingdom, Greece, Sweden, and Finland. Another approach could include the whole of the continental shelf area within the WFD, including the territorial waters, i.e. the first 12 miles (mentioned only in relation to chemical status), etc. However, the coastal area included is, by far, the most

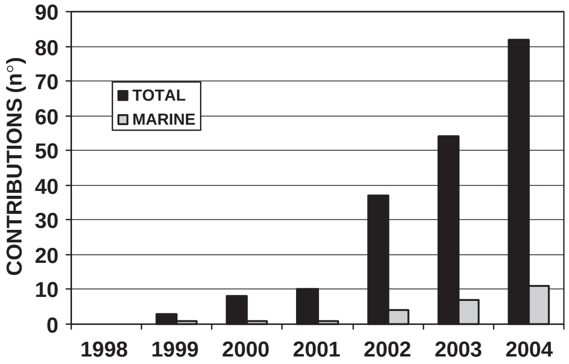

Fig. 2. Number of total and marine scientific contributions published in peer-reviewed journals, over the period 1998–2004, on the Water Framework Directive. Source: ISI Web of Knowledge^{SM}.

important in relation to the study of land–ocean interactions and processes. Such nearshore/coastal areas represent only 6.3% of the continental shelf, on a global basis, but 42% of the value of annual ecosystem services (Constanza et al., 1997). Taking into account the importance of this area, the European Commission launched European Land–Ocean Interaction Studies (ELOISE) as a contribution to Land–Ocean Interaction in the Coastal Zone (LOICZ), as a programme element of the International Geosphere Biosphere Program (IGBP)(Murray et al., 2001). This programme can assist in providing information and expertise in implementing the WFD (Vermaat et al., 2005).

Against this background, an interesting regional contribution has been undertaken by Neal et al.

Table 1
Coastal water areas, sensu the WFD, within each of the European countries, compared with the total European coastal area

Country	Coastal length (km)	Surface areas (km^2)	Source
Belgium	76.2	191	Estimated by the author
Bulgaria	456.8	1142	Estimated by the author
Cyprus	671.3	1678	Estimated by the author
Denmark	5316.2	15,949	Estimated by the author
Estonia	2956.0	7390	Estimated by the author
Finland	1300.0	34,000	Perus et al. (2004)
France	7329.8	20,670	Melina Lamouroux (Agence de l'Eau Adour-Garonne)
Germany	3623.7	9652	Hartmut Heinrich (BSH)
Greece	15,146.7	45,440	Estimated by the author
Ireland	6437.1	14,251	Peter Cunningham (EPA, Dublin)
Italy	9225.8	13,012	Cecilia Silvestri (APAT, Roma)
Latvia	565.5	1414	Estimated by the author
Lithuania	257.7	644	Estimated by the author
Malta	197.8	495	Estimated by the author
Netherlands	1913.8	5741	Estimated by the author
Norway	53,198.6	100,000	Frode Olsgard (NIVA)
Poland	1032.3	2581	Estimated by the author
Portugal	2830.1	8400	Fuensanta Salas (IMAR, Coimbra University)
Romania	695.5	1739	Estimated by the author
Slovenia	41.2	103	Estimated by the author
Spain	7268.1	21,821	Ana Lloret (CEDEX)
Sweden	26,383.8	35,830	Mats Blomqist (Hafok AB)
United Kingdom	19,716.6	63,561	Graham Phillips (NMR) & Peter Holmes (EA)
Total under the WFD	166,640.6	405,703	
Total European coastal areas		2,050,000	Gazeau et al. (2004)

Notes: Coastal length data are based on the World Vector Shoreline, United States Defense Mapping Agency, 1989 (http://earthtrends.wri.org/text/coastal-marine/variable-61.html). The surface areas estimated by the author were calculated on the basis of multiplying straight coastal-lines by 2.5 and, by 3, those with large indentations and islands.

(2003), in presenting an overview of the hydrochemical and physical functioning of UK river basins, estuaries and coastal waters, through to the open sea; this is related to British environmental research, over the last 10 or more years. Such an approach represents an attempt to determine land–ocean interactions within the WFD, at a regional scale. Similarly, Cave et al. (2003) have presented an overview of the Humber catchment at a local scale, which aimed to achieve integrated catchment and coastal zone management by analysing, within the framework of the WFD, the response of the coastal area to changes in fluxes of nutrients and contaminants from the catchments. Both of these studies highlight the close relationships between the river catchments and coastal zones, following some of the concepts of the WFD.

In summary, the WFD only provides comprehensive coverage of a small (and arbitrarily defined) part of the European marine waters. This unfortunate geographical compromise has led the Commission and its member states to call for a new framework for Europe's seas: the European Marine Strategy (EMS). The framework for the EMS was first presented to the Council of Ministers, by the Danish Presidence, in late 2002, and there are now calls for a new Directive for European Seas (http://europa.eu.int/eur-lex/en/com/pdf/2002/com2002_0539en01.pdf). Hence, some of the research undertaken in the implementation of the WFD should fit into it.

On the other hand, the future incorporation of Romania and Bulgaria to the EU, will bring the Black Sea into the boundaries of European legislation. This incorporation, together to the extension of the marine waters under the EMS will have major implications in the marine research and the implementation of the European Directives, including the WFD.

3. Some interpretations and problems in implementing the WFD

The WFD is the most important piece of European water legislation for many years and, as such, will change the way in which water is monitored and regulated (Crane, 2003); nonetheless, ambiguity in some of the concepts and methodologies produces different interpretations. Hence, the main objective of the above-mentioned CIS is to provide support to the implementation of the WFD, by developing: (i) a coherent and common understanding; and (ii) guidance on the key elements of the Directive. The main principles in this common strategy include: the sharing of information and experiences; and the development of common methodologies and approaches. Experts from all European countries, together with stakeholders from the water community, are involved. This approach is related to the necessity for a broad consensus amongst the different Member States, in the meaning of the different concepts included in the WFD; these include, for example, the use of common methodologies in the ecological status assessment and in the intercalibration process.

As an example of the meaning of the concepts, some debate has been initiated in relation to the controversy of including different matrices in the assessment of the physico-chemical status and quality guidelines. Hence, Crane (2003) claims the use not only of waters (as outlined in the WFD), but also sediments in determining such a status. Borja et al. (2004c) agree with this critique, proposing methodologies to include this element, together with data obtained from water and biomonitors, in such an assessment. However, other scientists disagree with this point of view (see this debate in Borja and Heinrich, 2005). Further, a discussion to be undertaken is the possibility of including zooplankton as a new biological element. In this way, the role of the Continuous Plankton Recorder information, in supporting the WFD, has been suggested by Brander et al. (2003), although most of data provided by this methodology refer to the area outside WFD boundaries.

A second example of the controversy arises from the interpretation of one of the key elements within the WFD, which is the principle of 'one out-all out', in determining the ecological status. According to the WFD 'the ecological status shall be represented by the lower of the values for the biological and physico-chemical monitoring results for the relevant quality element'. An important question which arises relates to the level of application of the aforementioned principle. For instance, does it mean that if one of the biological elements (phytoplankton, benthos, macroalgae or fishes) or one of the variables in the physico-chemical elements (e.g. cadmium concentration in water) is out of the guideline levels, the entire water body should be classified in the same way? Some authors (see Borja et al., 2004a) have disagreed with this rule, outlining the need of discussion within the international working groups in implementing the WFD. Some reasons for discussing this is because, due to different sampling frequencies, there is high spatial and temporal variability of some of the biological elements. Likewise, because of the role of some of the elements as good indicators, i.e. benthos and fishes, any form of weighting in the data should be investigated. This is in order to avoid a misclassification of a water body based upon only a limited representative element or upon an under-represented variable.

On the other hand, as a third example of the controversy, in several workshops and working groups, some scientists consider the approach of the WFD in assessing the ecological status a step backwards, complaining about the excessive ‘over simplification’ of this legislation, i.e. in determining typologies of the water bodies, in applying methodologies for the assessment of the ecological status, etc. Probably this problem arises from the considerable gap (at least, in some European countries) between the scientific community interests and those of the persons involved in the WFD implementation. Both groups see each other as a ‘different World’, without any clear links. In my opinion this is an error and, studying the economical effort to be undertaken over the next few years (see some examples, in Table 2) within the WFD, it is clear that the availability of scientific-based methodologies will prove economical. This can be done only by means of increasing both marine research and scientist–implementer collaboration, as proposed in this contribution. In this way, some authors (see Leonard, 2002) provide examples of how biological research can provide cost-effective solutions to analytical problems and an opportunity to predict the way in which some human activities may have an impact on the marine environment.

Table 2
Some WFD implementation costs established for the whole United Kingdom and for the Basque Country (Spain)

Location/concept	Costs (millions)
United Kingdom[a]	
Complying with the WFD	£3200–11,200
Administration	£5–6
Planning process	£37–54
Monitoring and assessment	£144
Reaching good status	£3000–11,000
Point source reductions (industry)	£400–1500
Point source reductions (water services)	£1000–5000
Diffuse pollution reduction	£1000–3500
Remediation costs	£100–700
Alleviation of low flows	£25–250
Basque country (Spain)[b]	
Monitoring and assessment (2004–2005)	€2.4
Wupper catchment (Germany)[c]	
Implementing the WFD (per year)	€5–11

[a]Kallis and Butler (2001).
[b]Borja et al. (2004a).
[c]Kolisch et al. (2002).

4. The timetable of the WFD

In some working groups, one of the recurrent questions is: are we at an appropriate time to propose new subjects of research within the WFD? Against this background, some of the planning requirements of the WFD have very short deadlines (see Table 3; Murray et al., 2002). By the end of 2004 (or mid-2005, due to some delays) most of the main tasks, prior to the monitoring programme, should be finalised, i.e. pressures and impacts characterisation (which has been finalised in April 2005), proposal of intercalibration sites, etc. However, the WFD is a ‘dynamic Directive’ which allows further incorporation of new methodologies, changes in the previous definitions and classification of sites, etc., because any increase in knowledge should feed-back into any further assessments. The first ecological status assessment should be undertaken by 2006, but this exercise

Table 3
Timetable of the river basin planning requirements, under the European WFD

Year	River basin planning requirements
2003	Transpose Directive by each Member State Identify river basin districts and the competent authorities
2004	Characterisation of pressures and impacts and risk assessment Economic analysis of water use Register of protected areas Final intercalibration sites register
2005	Intercalibration exercises
2006	Monitoring programmes Work programme for first River Basin Management Plans
2007	Interim overview of the significant water management issues
2008	Publish draft River Basin Management Plans for consultation
2009	Finalise and publish first River Basin Management Plans
2012	Measures fully operational Work programme for second River Basin Management Plans
2013	Review characterisation and risk assessment Review economic analysis of water use Interim overview of the significant water management issues
2014	Publish second draft River Basin Plans for consultation
2015	Achieve environmental objectives ('Good Ecological Status') in first Basin Plans Finalise and publish second River Basin Plans

should be carried out every 3 years. Hence, any new development and methodology, including integrated approaches, could be introduced at any point throughout the process, until its culmination, in 2015.

5. What has been achieved and what should be researched?

The WFD requires advances in research efforts to achieve these aims: improved participation methods, together with an understanding of their use, need to be developed; science and modelling need to be undertaken in a more holistic, integrated way; methods for evaluating economic and social impacts of policies need to be developed and implemented; and, scenario-based approaches need to be developed, to permit the testing of potential policies and management changes, to test their potential impacts on environmental quality (Letcher and Giupponi, 2005).

The opportunities to progress in this particular field of the WFD implementation have been outlined by several authors. Townend (2002) highlights the future needs in three essential blocks: monitoring, system models and education. In the case of monitoring, the key requirements are centred around the assessment of the present state of the system (requiring the identification of sets of indicators, to be used in such assessment) and rates of change (including both short- and long-term changes). The need for researching system models arises from the inherent non-linearity of the processes and the complexity of their interactions. In this way, 'fuzzy' techniques play an increasing role in determining systems functioning (Silvert, 1997).

On the other hand, Neal et al. (2003) identify seven areas of research for British waters (which can be extended to an important part of Europe): (i) system sensitivity to change, in relation to the ecological status (including climate change, sea level change, thresholds, etc.); (ii) sediment budgets/dynamics (investigating contaminants fate, erosion, deposition, re-mobilisation, etc.); (iii) tidal river reaches; (iv) ecology and bioavailability (processes affecting plankton growth, indicator species, critical pathways for pollutants through the food web, the assessment of impacts in terms of ecotoxicology, etc.); (v) water quality (sources and sinks of pollutants, role of microparticulate materials in the transfer of pollutants, etc.); (vi) water quality issues, in relation to biological response and human health; and (vii) environmental modelling.

Hence, in the coming years much research funding will go to projects to support the implementation of the WFD. This research will need to be interdisciplinary, or at least multidisciplinary, as nearly all elements of the WFD have technical, ecological, economic, legal and administrative aspects (Mostert, 2003). In fact, all of the above-mentioned potential investigations could be grouped under the different elements, terminologies and works to be undertaken under the WFD, taking into account that all the research will need to be very pragmatic (Mostert, 2003; Borja et al., 2004a; Heiskanen et al., 2004).

5.1. Eco-regions

The WFD divides the European seas into six different eco-regions (see Fig. 1): Atlantic Ocean, Norwegian Sea, Barents Sea, North Sea, Baltic Sea, and Mediterranean Sea (including Black Sea). One of the problems with this classification is the inclusion of archipelagos, such the Canaries or Azores, into the Atlantic eco-region; this extends from 25° to 75°N (Mauritania to north Iceland). Taking into account the high ecological differences within this area, a Macaronesian eco-region should be included. Probably the same problem could be found in the case of the Mediterranean, where the eastern and western basins and the Black Sea are very different, in terms of ecosystem functioning. In this particular issue, scientific knowledge could provide a broad basis for the next steps within the WFD.

5.2. Typologies

When scientists are confronted with the classification of typologies, normally their first reaction is the definition of a very high number of them (resulting from the combination of the different geomorphological and hydrodynamic characteristics included in the definition, such as salinity, tidal range, depth, current velocity, wave exposure, water mixing, residence time, substrata characteristics, etc.). This approach produces an unmanageable situation in subsequent steps of the WFD, which include the establishment of the reference conditions and management plans for each of the water bodies and typologies. Hence, Borja et al. (2004a) recommend the definition of no more than 15–20 typologies, within the Atlantic eco-region (at this moment there are 8, only for coastal waters).

One of the most common criticisms to this approach arises from the over-simplicity of this model, from a scientific point of view; thus, claims have been made for the use of some classifications (such as EUNIS), in this determination. Although this classification is being used, some integration is needed, because of the patchiness of habitats within the different typologies and water bodies. This could be further determined in the light of the Habitats and Birds Directive, not discussed in this contribution but also having important monitoring requirements.

5.3. Methodologies and reference conditions for the physico-chemical elements

The reference conditions must represent the physico-chemical (or biological) conditions of the system, in the best physico-chemical (or ecological) status possible and with the lowest anthropogenic impact possible, to which to assign the 'high' status (Casazza et al., 2004).

Andersen et al. (2004) have proposed the use of the paleoecological reconstruction of fluctuations in total nitrogen, in the determination of undisturbed physico-chemical conditions suitable for its use as reference conditions. These authors demonstrate that this method produces results with a reasonable degree of accuracy, when determining the quality status. On the other hand, Nielsen et al. (2003) propose the use of historical data and modelling in assessing reference conditions, by applying them to some Danish marine waters.

In the case of Italy, the legislation establishes the use of a trophic index 'TRIX' (Vollenweider et al., 1998), derived from the most used physico-chemical parameters in coastal water analysis, for the classification of the quality status (Casazza et al., 2002).

The use of multivariate analysis in determining physico-chemical reference conditions and quality status, when no reference sites exist, has been discussed in Borja et al. (2004a) and Bald et al. (in press). These methodologies appear as a simple, objective and promising tool (Bald et al., in press).

On the other hand, one of the major research issues in the future will be related to the non-regulated water contaminants (Daughton, 2004), such as pharmaceuticals and personal care products, endocrine disrupting compounds, brominated flame retardants, etc., called 'new' or 'emerging' pollutants. In fact, as for March 2004, the American Chemical Society had indexed nearly 23 million organic and inorganic substances; only 230,000 were inventoried, or regulated, by government bodies world-wide (Daughton, 2004). This limitation arises because the list of hazardous substances (priority substances) provided by the WFD is very short, being referred to previous European Directives.

Hence, some of the most important tasks to be undertaken in the next few years are: research on reference conditions for each of the typologies; the development of accurate methodologies, in assessing the quality status; methodologies in integrating results from different matrices; and the incorporation of new hazardous substances into the priority substances list (investigating their effects on the biological elements).

5.4. Methodologies and reference conditions for biological elements

In many instances, problems detected using ecological quality criteria are not linked directly to known chemical contamination pressures, e.g. surface waters of a 'good chemical status' may have a 'poor ecological status'. Such a difference may be due to other anthropogenic influences than organic enrichment or biological processes (e.g. bioaccumulation of pollutants or biostimulation by nutrients), such as: (i) the presence of unknown or unmonitored substances; (ii) the combined effects of various substances; (iii) interactions with physical factors or habitat deterioration; or (iv) the highly dynamic nature of aquatic, especially marine and estuarine, synergestic systems. In this respect, research is deemed necessary to investigate the causes of deterioration of the ecological status of surface waters, linking them to chemical or other significant pressures. Such research would support the analyses described under Annexes II and V of the Directive.

Hiscock et al. (2003) have outlined the conceptual approach that scientists have adopted in understanding human impacts in using marine resources and marine environment. Nonetheless, the need for improved integration, if a truly ecosystem-based approach is to be realised in the future, as some European Directives, international conventions and organisations demand, should be recognised. Hence, OSPAR, HELCOM, ICES, WSSD, Barcelona Convention, IMO, MEDPOL, etc., are looking for new or improved tools to assess anthropogenic impacts on the marine environment, which have more explicit management utility. Many countries are now addressing the question of how to improve assessment of the ecological quality of their waters, in relation to the chemical status. Therefore, the objective of the above initiatives is to evolve easily understood measures of ecological change, which have clear practical application in the achievement of management goals; namely, to define, understand, protect or restore biological integrity.

In the particular case of benthos, whilst numerous studies provide tentative evidence of changes in the benthic faunal and floral community in response to anthropogenic stressors, relatively few provide unequivocal evidence of clear-cut cause/effect relationships, other than in response to gross pollution. In addition, whilst the use of summary indicators of ecological changes as management tools are relatively well established for freshwater bodies (i.e. especially biotic indices), they are less so for coastal and transitional waters in Europe.

The theoretical basis and the necessary scientific and social consensus on the assessment of ecological quality, in marine waters, are still to be established within a European context.

On the other hand, as outlined by Borja et al. (2004a) and Casazza et al. (2004), the main problem in defining the biological reference conditions, in most of the European coastal regions, arises from the absence of areas without any anthropogenic impact. In the case of the Mediterranean eco-region, possible reference areas could be marine reserves, because they provide the best ecological conditions in the area, together with previous data; these may be used in order to compare with the remainder of the water bodies (Casazza et al., 2004).

5.4.1. Phytoplankton

Presently, only very few methods have been proposed for the assessment of phytoplankton-based ecological quality (Ifremer, in Vincent et al., 2002; Borja et al., 2004a). However, these methods are not developed specifically to fulfill the requirements of the WFD, but relate to the presence of toxic algae or phytoplankton blooms. Conversely, the use of flow cytometry, as proposed by Moreno and Laine (2004), is a good tool in assessing the trophic status; hence, it can assist in assessing the phytoplankton ecological status. Likewise, the phytoplankton indicator species, together with its role in the general coastal quality status, should be investigated.

5.4.2. Macroalgae

Phytobenthos (macroalgae and seagrasses) form the structural base, behaving as the ecosystem engineers (sensu Jones et al., 1994) of some of the most productive ecosystems of the world. They respond directly to the abiotic and biotic aquatic environment and, as such, represent sensitive bioindicators of its changes (for a short-review see Orfanidis et al., 2001). Well-documented patterns predict reduction of species diversity as human-induced disturbance/stress increases (Pearson and Rosenberg, 1978). In contrast to benthic invertebrates, few benthic macrophytic indices have been proposed for use in marine waters (Orfanidis et al., 2001, 2003; Swedish method, in Vincent et al., 2002; Panayotidis et al., 2004; Borja et al., 2004a). Other approaches, probably useful in the WFD implementation, have been proposed for the HELCOM monitoring programme (Bäck et al., 2002). However, its broad applicability and effectiveness still has to be verified, together with the investigation of the role of many macroalgae species, as sensitive or indicator species.

5.4.3. Benthos

As well as their central role in marine ecosystem functioning, the benthic invertebrates are a well-established target in evaluations of environmental quality status. Various studies have demonstrated that the macrobenthos responds relatively rapidly to anthropogenic and natural stress (Pearson and Rosenberg, 1978; Dauer, 1993). Several authors have reviewed the use of biotic indices, in assessing the benthic 'health' (see a useful summary in Diaz et al., 2004). Many authors (e.g. Washington, 1984) accept that a biotic index is unlikely to be universally applicable, as organisms are not equally sensitive to all types of anthropogenic disturbance and are likely to respond differently to different types of perturbation. As such, they may provide a way to establish a multimetric bioassessment method that, in turn, can be modified for different geographical regions. Several indices have been proposed for use in marine waters, some of them attempt to include the five-step environmental model of the WFD (Borja et al., 2000, 2003a, 2004b; Simboura and Zenetos, 2002; Rosenberg et al., 2004).

Diaz et al. (2004) state that the 'tautological development of new indices appears to be endemic, self-propagating and rarely justified', recommending that investigators place greater emphasis on evaluating the suitability of indices that already exist, prior to the development of new ones. In this way, the use of existing indices, together with multimetric approaches, could be the most promising way in accomplishing the WFD (Borja et al., 2004a). The research undertaken on indicator and sensitive species, together with their responses to different impact sources (see Hiscock et al., 2004) can lead to an improved understanding of the ecosystem functioning, with regard to the assessment of ecological status. The research of reference conditions for each of the typologies, together with the quality assurance of the monitoring data, are the most important tasks to be undertaken in the coming years. Moreover, the development of new tools for hard-bottom substrata is another important challenge for benthologists.

5.4.4. Fishes

The WFD included the study of fishes, for the assessment of the ecological status, only in transitional waters. However, this could be a fundamental weakness in current legislation, and has been a major topic of discussion in the EMS.

5.5. The integration of methodologies

The integration of all the elements and variables, into a unique assessment, has been discussed in only very few contributions (Borja et al., 2004a, c; Franco et al., 2004). More studies should be carried out in the coming years, in order to determine an accurate ecological status assessment.

In this way, a main task for the next 2 years is the intercalibration process among the different methodologies, countries, typologies, etc., with the aim to determine the quality of the different approaches; this would establish, throughout Europe, a system suitable for assessing the ecological status and comparably at different levels. In this way, statistical research into the determination of the most suitable boundaries in the ecological quality ratios, combined with a comparison of these boundaries under different elements, will be an interesting contribution to the WFD implementation.

In parallel to this task, a monitoring programme for European waters should be undertaken (by 2006). Some monitoring networks are established already in line with the WFD requirements, or are easily adaptable to them, such as: the UK network (http://www.cefas.co.uk/monitoring/page-b3.asp); the Basque network (north of Spain)(Borja et al., 2003b; Belzunce et al., 2004); the French network (Claisse et al., 2002); the Italian network (Casazza et al., 2004); the proposal for a Scottish network (Peter Holmes, personal communication), etc. The monitoring networks, as proposed within the WFD, are of three different types: (i) surveillance monitoring, to provide information for supplementing and validating the impact assessment procedure, the efficient and effective design of future monitoring programmes, the assessment of long-term changes in natural conditions, and the assessment of long-term changes resulting from widespread anthropogenic activity; (ii) operational monitoring, undertaken to establish the status of those bodies identified as being at risk of failing to meet their environmental objectives, and to assess any changes in the status of such bodies resulting from the programmes of measures; and (iii) investigative monitoring, carried out where the reason for any exceedances is unknown (i.e. where surveillance monitoring indicates that the environmental objectives for a body of water are not likely to be achieved and operational monitoring has not already been established), in order to ascertain the causes of a water body or water bodies failing to achieve the environmental objectives, or to ascertain the magnitude and impacts of accidental pollution. The intercalibration of data and ecological status assessment, between the different national monitoring programmes, will probably be difficult because of its heterogeneity (Heiskanen et al., 2004); as such, this is one of the major tasks within the WFD.

The investigative monitoring opens an interesting window to research in marine waters, because many of the processes in which pollution affects the biological elements are poorly known. As an example, some scientists (see Boesch, 2002) have highlighted the problems of nutrient over-enrichment in the coastal ecosystems, as observed during the last half of the 20th century, together with the effectiveness of science in documenting the consequences and root causes of this problem, providing the basis for its abatement. Likewise, this author claims that the efforts made have usually been based upon the relatively arbitrary goal of reducing nutrient inputs by a certain percentage, without much understanding of how and when this would affect the coastal ecosystem; this, in itself, constitutes a challenge and opportunity in coastal research.

In this context, and as mentioned previously, LOICZ and ELOISE have done very large expenditure on coastal research, which is combined to focus on the important questions of how the land–ocean interaction operates, and of how this is influenced by human activities (Vermaat et al., 2005). These authors outlined the possibilities for a sustainable use of the European coastal zones, discussing on (i) external changes, including climate change; (ii) internal changes, such as demographic changes, and future policies; and (iii) local changes resulting from activities in river basins.

The problems which have arisen along European coasts, together with the approaches undertaken, are similar to those identified in other seas. For example, in Canada, where Vandermeulen and Cobb (2004) describe a similar debate in implementing ecosystem-based management, in assessing marine environmental quality.

Some of the research to be undertaken under the WFD, for the whole of Europe, is similar to that proposed for the near future in the Basque Country (northern Spain), by Collins and Borja (2004), as outlined below:

(i) Studies of land/ocean interactions, with more refined data being obtained on the loads of the rivers transferred to the adjacent continental shelf, together with the extension and influence of river plumes upon processes on adjacent littoral areas (see Vermaat et al., 2005).
(ii) Studies on atmosphere–ocean interaction, together with its influence on ecosystems, species and heat transfer. The transport mechanisms should be determined, integrating atmosphere/ocean models, then applying them to ecosystems modelling.
(iii) Studies at the water–sediment interface, together with the influence on remobilisation of contaminants from sediments, and its impact over communities.
(iv) Studies into sources and sinks of various substances, through the development of an understanding of their transport pathways. Other processes, such as bioaccumulation, bioavailability, etc., should be studied (in some cases using biomarkers in sentinel organisms).

Finally, the comments of Donald F. Boesch in 1999 (Boesch, 1999) are fully applicable to the WFD and the coastal research challenges: 'Sustainable governance of the ocean demands a more integral and timely role for science. Although science has played a limited role in global ocean governance regimes, science has made essential contributions to governance on regional scales, particularly when there is strong scientific consensus, clear identification of problems and solutions, and convergence with cultural ideas'.

6. Conclusions

Perhaps, for the first time, the whole of Europe can develop and implement a contrasted, checked and intercalibrated methodology for the assessment of the ecological status of nearshore and coastal areas. Even though the marine areas presently under the WFD represent only a small part of the whole of the European continental shelf, the challenge for scientists is to develop suitable methodologies which could be applied to different eco-regions. This approach is in order to assess, in the most accurate way, the coastal ecological status, taking into account not only its scientific value but also the effective cost–benefit relationship. In this way, novel solutions should be proposed for the implementation of the WFD; these should be as simple, realistic and pragmatic as possible, without losing their scientific basis. Finally, some of the lacks detected through this contribution could be solved with the new European Marine Strategy, now under discussion.

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