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The European Water Framework Directive and the DPSIR, a methodological approach to assess the risk of failing to achieve good ecological status

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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 water resources management in Europe, based mainly upon ecological elements; its final objective is achieving at least 'good ecological quality status' for all water bodies by 2015. The approach to identify these water bodies includes, amongst others, the sub-division of a water body into smaller water bodies, according to pressures and resulting impacts. The analyses of pressures and impacts must consider how pressures would be likely to develop, prior to 2015, in ways that would place water bodies at risk of failing to achieve ecological good status, if appropriate programmes of measures were not designed and implemented. This contribution focuses on the use of the DPSIR (Driver, Pressure, State, Impact, Response) approach, in assessing the pressures and risk of failing the abovementioned objective, using the Basque (northern Spain) estuarine and coastal waters as a case study, using the following steps: (i) determination of the water bodies to be analysed; (ii) identification and description of the driving forces producing pressures over the region; (iii) identification of all existing pressures within the water bodies; (iv) identification, from them, of the most relevant pressures; (v) determination, from the relevant pressures, of those which are significant; (vi) assessing the impacts on water bodies (in terms of ecological and chemical impacts); and (vii) assessing the risk of failing the WFD objectives.

Keywords: Water Framework Directive; DPSIR approach; pressure; environmental impact; risk assessment; Basque Country

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 ecological quality status' for all water bodies by 2015. The status will be based upon the biological (phytoplankton, macroalgae, benthos and fishes), hydromorphological and physico-chemical quality elements, with the biological elements being especially important.

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In order to assist the WFD implementation, a 'Common Implementation Strategy' (CIS) was agreed in May 2001. The CIS incorporated 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 http://forum.europa.eu.int/Public/irc/env/wfd/home (see Vincent et al., 2002; Murray et al., 2002).

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".

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 waters and heavily modified water bodies); (iii) the sub-division of surface water categories into types, then assigning the surface waters to one of those types; and (iv) the sub-division 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).

Recently, some methodological approaches to implementing parts of such a complex Directive have been developed in Europe (Henocque and Andral, 2003; Borja et al., 2004a,b,c; Casazza et al., 2004). However, taking into account the very considerable amount of work to be carried out, some complementary research should be undertaken in order to accomplish the abovementioned WFD objectives, as highlighted by Borja (in press).

Within the context of this strategy, a working group was set up, focused upon the identification of pressures and assessment of impacts, within the characterisation of water bodies, according to Article 5 of the Directive. The main objective of this working group, launched in October 2001 and named IMPRESS, was the development of a non-legally binding and practical Guidance Document on this topic within the WFD. Their conclusions were published as WFD CIS Guidance Document No. 3 (IMPRESS, 2002).

The analysis of pressures and impacts must consider how pressures would be likely to develop, prior to 2015, in ways that would place water bodies at risk of failing to achieve ecological good status if appropriate programmes of measures were not designed and implemented (IMPRESS, 2002). This will require consideration of the effects of existing legislation and forecasts of how the key economic factors that influence water uses will evolve over time; likewise, how these changes may affect the pressures on the water environment. Therefore, it is not clear how to assess, in practice, the risks of failing to achieve this objective. Clarification may be provided in a daughter Directive, to be established under Article 17. This Directive is expected also to establish criteria for the identification of significant and sustained upward trends [Article 4.1(b)(iii)]. Until these criteria have been established, Member States will need to decide what constitutes a significant and sustained upward trend, according to their own criteria. The review of the pressures and impacts is required, in the design of monitoring programmes which must be operational by 2006 (Article 8), and also to help develop programmes of measures, which must be established by 2009, to be made operational by 2012 (Article 11).

In this way, IMPRESS (2002) established the DPSIR (Driver, Pressure, State, Impact, Response) approach (OECD, 1993; Elliott, 2002; European Commission, 2002) as a possible analytical framework for determining pressures and impacts under the WFD. The DPSIR Framework provides an overall mechanism for analysing environmental problems, with regards to sustainable development. Hence, 'Driving Forces' are considered normally to be the economic and social policies of governments, and economic and social goals of those involved in industry. 'Pressures' are the ways that these drivers are actually expressed, and the specific ways that ecosystems and their components are perturbed, i.e. for the ecosystem effects of fishing, the central pressure would be fishing effort. These pressures degrade the 'State' of the environment, which then 'Impacts' upon human health and ecosystems, causing society to 'Respond' with various policy measures, such as regulations, information and taxes; these can be directed at any other part of the system.

Likewise, ideally, a pressures and impacts assessment will be a four-step process:

- describing the 'driving forces', especially land use, urban development, industry, agriculture and other activities which lead to pressures, without regard to their actual impacts;
- identifying pressures with possible impacts on the water body and on water uses, by considering the magnitude of the pressures and the susceptibility of the water body;
- assessing the impacts resulting from the pressures; and
- evaluating the risk of failing the WFD objectives.

Although this methodological approach offers only general guidelines, in assessing such impacts and risks (IMPRESS, 2002), some applications of the DPSIR approach to marine waters have been undertaken recently (Elliott, 2002; Ledoux and Turner, 2002; Casazza et al., 2002; Bowen and Riley, 2003; Bricker et al., 2003; Cave et al., 2003; Newton et al., 2003; Islam and Tanaka, 2004; Scheren et al., 2004; Xu et al., 2004); however, these studies have not focused on the WFD objectives. Hence, the objective of this contribution is to analyse the pressures and impacts at a regional level (taking the Basque Country, in the northern Spain, as a case study), developing further methodologies, to be able to assess the risks of failing the WFD objective of achieving at least good ecological status, by 2015. In this contribution, responses to the impacts have not been considered, although they are included in Borja et al. (2004e).

2. Methodological approach

The oceanography and general marine quality of the Basque Country have been studied extensively (Borja and Collins, 2004). Moreover, under the WFD, some methodological approaches have been published recently (Borja et al., 2000, 2004a,b,c; Borja and Heinrich, 2005; Borja, in press). Hence, the use of the Basque estuarine and coastal waters, in applying the DPSIR approach, could be helpful to other regions and Member States, in assessing the risk in failing the WFD objectives.

The above-mentioned IMPRESS four-step process has been refined into the seven steps below.

2.1. Determination of the water bodies to be analysed

The transitional and coastal water bodies in the Basque Country were determined following the criteria below (for additional details, see Borja et al., 2004a,e). For transitional waters, the external limits were established by the geomorphological locations limiting the estuarine waters, whilst the lateral and internal limits were established using the highest spring tidal limit (4.5 m, following González et al., 2004). The WFD does not define the minimal size limit of the water bodies, except for lakes, in which the size criteria is 0.5 km^2. Hence, the same size was used here, together with the ecological functionality of the estuary (which depends upon energy availability and capacity to maintain most of the natural processes in the estuary, at different scales and compartments of the system).

Coastal waters means surface waters 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. The inner limit of the coastal waters extends up to the outer limit of the transitional waters, and, along the remainder of the coast, by a 4.5 m tidal height (Fig. 1).

2.2. Identification and description of the driving forces

In order to predict how socio-economic forces might affect the water quality, it is necessary to describe the present drivers influencing the pressures in the study area. Hence, following the same approach used in other countries (Bowen and Riley, 2003; Cave et al., 2003; Newton et al., 2003) the most important driving forces have been identified, following the criteria of the above-mentioned IMPRESS group (for additional details, see IMPRESS, 2002; Borja et al., 2004e). These are population, industry, ports, fisheries and agriculture.

2.3. Identification of all existing pressures

As outlined in the WFD, Member States shall collect and maintain information on the type and magnitude of the significant anthropogenic pressures, to which the surface water bodies are liable to be subjected; in particular the estimation and identification of a number of factors, as follows: (i) point source pollution, by substances listed in Annex VIII of the WFD, from urban, industrial, agricultural and other installations and activities, based upon information under Directives 91/271/EEC; 96/61/EC; 76/464/EEC; 75/440/EC, 76/160/EEC, 78/659/EEC, 79/923/EE; (ii) diffuse source pollution, by substances listed in Annex VIII, from urban, industrial, agricultural and other installations and activities; based upon information under Directives 91/676/EEC; 91/414/EEC; 98/8/EC; (iii) water abstraction for urban, industrial, agricultural and other uses; (iv) water flow regulation, on overall flow characteristics and water balances; (v) morphological alterations to water bodies; (vi) other anthropogenic impacts on the status of surface waters; and (vii) land use patterns, including the identification of the main urban, industrial and agricultural areas, fisheries and forests.

Hence, the existing number of pressures were identified following the checklist in Table 1, based upon IMPRESS (2002) and our own experience, and divided into four groups: (i) pollution, including urban, industrial, agricultural and aquaculture discharges; (ii) alteration of the hydrological regime, including water abstraction, flow regulation and restoration activities; (iii) changes in the morphology, including land reclamation and infrastructures; and (iv) biology and its uses, including all kind of resource exploitation, changes in biodiversity and recreation.

Using this list and aerial photographs (0.25 × 0.25 m pixel resolution), the banks of all the water bodies were scanned, on foot and by boat, photographing all the pressures detected, taking notes of their characteristics. All this information was integrated into a GIS, for later spatial analysis, following the requirements of the WFD guidance on GIS (Vogt, 2002).

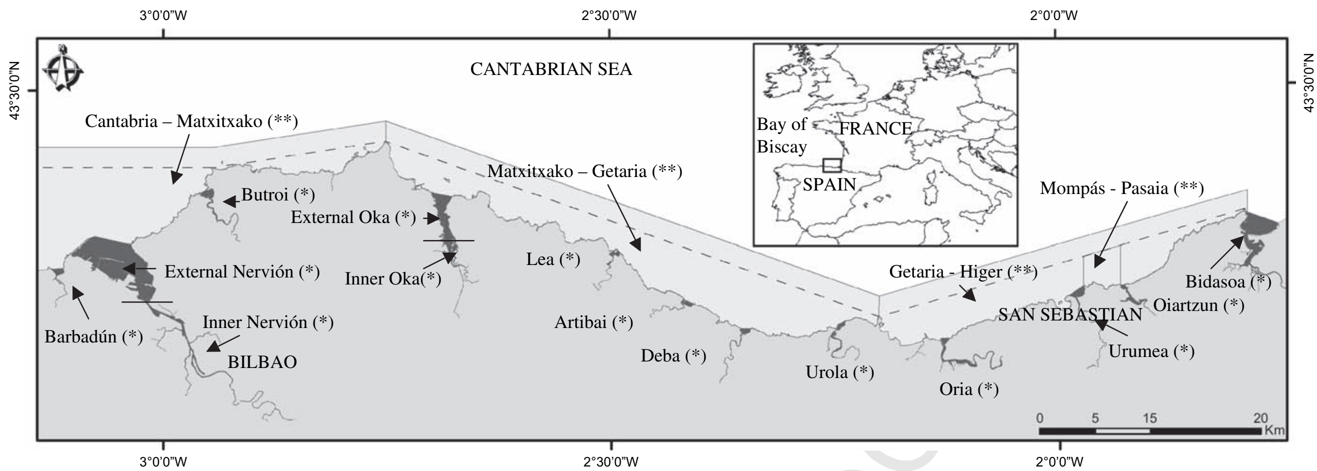

Fig. 1. Location of each of estuarine (*, black colour) and coastal (**, grey colour) water bodies, within the Basque Country. Note: dotted line shows the Basque coastal baseline. Inner and external parts of the Nervión and Oka estuaries are separated by a straight line.

2.4. Identification of the most relevant pressures

After studying all the information compiled in the GIS, nine relevant pressures (or groups of pressures) were identified as outlined below.

(i) Pressure from nutrients (Table 2), related to pollution, has been assessed by studying the mixing characteristics, which provides the dilution potential of a water body, together with the flushing time. Nutrient load data were obtained from the samplings of this contribution and nutrient loads from Borja et al. (2003, 2004d,e) and Valencia et al. (2004), using a nutrient balance similar to that used in Scheren et al. (2004). This approach has been used to provide a measure of the sensitivity of the water body to nutrient inputs. Subsequently, by comparing the total nutrient loads, with the sensitivity, a pressure level has been derived. The nutrients modify the ecosystems and

Table 1
Estuarine and marine pressure checklist considered as part of the WFD pressures and impact assessment in the Basque Country

Pressures
Pollution
Urban discharges
Storm water and overflow
Untreated outfall
Treated outfall
Untreated submarine outfall
Treated submarine outfall
Diffuse source
Industrial discharges
Gas/petrol
Chemicals
Pulp, paper
Textiles
Food processing
Brewing/distilling
Power generation
Wood/timber treatment
Construction
Iron/steel
Industrial mixed discharges
Lixiviates
Agriculture/farm discharges
Point source
Diffuse source
Aquaculture discharges
Mining discharges
Gas and oil
Sand extraction
Storage (slag, rubbish) lixiviation
Maritime transport discharges
Contaminated land
Polluted sediments
Clinker disposal
Military sites
Shipyards and boat repair
Oil pump
Alteration of hydrological regime
Water abstraction
Hydroenergy
Aquaculture
Thalassotherapy
Flow regulation
Sea walls
Jetties
Barrier
Dams
Restoration and engineering activities
Changes in morphology
Land reclamation (urban)
Land reclamation (industrial)
Land reclamation (harbours)
Shore reinforcement/dyke
Marinas
Fishing harbours
Commercial harbours
Permanent anchorage
Occasional anchorage
Dredging activities
Dumping of dredged sediments
Signposting
Engineering works
Infrastructures
Bridges
Tide mills
Submarine ways
Tunnel
Promenade
Biology and uses
Resource exploitation
Fishing/angling
Shellfishing
Algae exploitation
Changes in biodiversity
Introduced species
Introduced diseases
Recreation
Beaches
Saltwater pools

Table 2
Determination of the pressure level produced by nutrient discharge (using nitrogen as a vector), on marine and estuarine waters. Modified and adapted from Bricker et al. (1999) and Roger Proudfoot (Environment Agency, UK, personal communication). S, sensitivity; P, pressure

Mixing characteristics	Dilution potential	Flushing time		
		High (hours)	Moderate (days)	Low (weeks)
Well mixed	High	Low S	Low S	Moderate S
Partly mixed	Moderate	Low S	Moderate S	High S
Permanently stratified	Low	Moderate S	High S	High S

Nitrogen load		Sensitivity		
		Low	Moderate	High
Low	<100 kg N d^{-1} km^{-2}	Without P	Without P	Low P
Moderate	100–200 kg N d^{-1} km^{-2}	Low P	Low P	Moderate P
High	200–300 kg N d^{-1} km^{-2}	Low P	Moderate P	Moderate P
Very High	>300 kg N d^{-1} km^{-2}	Moderate P	High P	High P

cause eutrophication, as the most important impact. Of course, not all nutrient inputs cause always eutrophication, but this approach is a way to determine the potential effect of high nutrient inputs into a water body.

(ii) Water pollution was determined (Table 3) as the percentage of water samples, studied from 1994 to 2003 (Borja et al., 2003, 2004d), not complying with the quality objectives, for some priority (= hazardous) substances compiled in several European Directives and Spanish legislation, as mentioned previously. These Directives were used in the absence, presently, of hazardous substances lists and quality objectives in the WFD.

(iii) The surface of a water body containing polluted sediments was used also to determine sediment pollution pressure (Table 3). Data were obtained from Borja et al. (2003, 2004d) and Belzunce et al. (2004b), for the period 1994–2003. As potential impacts, hazardous substances can produce toxicity, pollution of the ecosystems, etc.

(iv) Abstraction of water can modify natural flows, representing hydrological reference conditions (IMPRESS, 2002). Hence, following expert judgement, water abstraction was selected as the main pressure related to the hydrological regime in the region (Table 3). The level of pressure was determined depending upon the total volume abstracted, and the total volume of the water body. In terms of potential impacts, water abstraction produces saline intrusion, changes in flow regime and residence time, etc.

(v) Morphological changes were assessed by using several of the most relevant pressures (Table 3) on the region, based upon the list in Table 1 and after studying data from the GIS. Hence, dredged sediments (and disposal) are an important source of morphological pressure on the region; however, its potential importance is different, if the dredged area is located within or outside a port. The most important impact is related with smothering of the sea bed, alteration of invertebrate assemblages, loss of habitats and the introduction of pollutants, to the ecosystem.

(vi) On the other hand, shoreline reinforcement also causes morphological changes, and has been detected as an important source of anthropogenic change in the Basque Country (modifying flow regime, residence time, loss of habitats, etc.). Here, the level of pressure is different for estuaries and coastal water bodies (Table 3).

Table 3
Determination of the overall pressure level produced by the most relevant pressures in the Basque Country, on marine and estuarine waters. Adapted from Borja et al. (2004e). E, estuarine water bodies; C, coastal water bodies

Pressure level	Pollution			Hydrological regime				Morphological changes					Biology
	Water pollution (%)	Sediment pollution (%)		Water abstraction (10^4 m^3 d^{-1})		Dredged Sediments (10^4 m^3 y^{-1})		Shoreline reinforcement (%)		Intertidal losses (%)	Berths (*n*)		Alien species (*n*)
		E	C	E $<5\times10^6$ m^3	E $>5\times10^6$ m^3	Ports	Other	E	C		Ports	Other	
Without	<5	<10	<5	<1	<5	<1	<0.1	<10	<5	<5	<100	<50	0
Low	6–15	11–25	6–10	2–5	6–10	1–10	0.1–1	11–30	6–10	6–25	101–200	51–100	1
Moderate	16–30	26–50	11–25	6–10	10–100	11–20	2–10	31–60	11–30	26–50	201–500	101–200	2
High	>30	>50	>25	>10	>100	>20	>10	>60	>30	>50	>500	>200	3

(vii) In the same way, intertidal losses, in response to land reclamation, are another important source of pressure (Table 3); these were determined mainly from the original data of Rivas and Cendrero (1992), supplemented by more recent GIS data.

(viii) As another index of morphological changes, the number of berths within each water body has been used (Table 3); this can be also a source of pollution (i.e. TBT inputs), but here is taken as a source of habitat alteration (i.e. as an indicator of changes in the bottom bed morphology).

(ix) Taking into account that most of the fishes are caught out of the water bodies, the only relevant biological pressure, used in this contribution, was the introduction of benthic alien species (Table 3), as listed below:

- Algae: *Sargassum muticum*;
- Polychaeta: *Marenzelleria viridis*, *Ficopomatus enigmaticus*, *Boccardia proboscidea*, *Boccardia semibranchiata* and *Desdemona ornata*;
- Crustacea: *Elminius modestus*, *Balanus amphitrite*, *Brachynotus sexdentatus* and *Hexapleomera robusta*;
- Mollusca: *Cyclope neritea*.

Some species, introduced between the end of the 19th century and the middle of the 20th century (such as *Crassostrea gigas* or *Asparagopsis armata*) have not been considered as alien, because they are naturalized (Occhipinti-Ambrogi and Galil, 2004).

The impact produced by this pressure is related to substitution of populations, destruction of habitats, food competition and the loss of genetic pools. In general, the presence of alien species makes it difficult to achieve ‘‘a taxonomic composition that corresponds totally or nearly totally to undisturbed conditions’’ (Annex V, of the WFD). In this way, no indication exists in the WFD about the ecological effect of the alien species and, probably in some cases, a high number of alien species does not equate to high risk. Hence, the determination of pressure from this factor can be arbitrary; however, some indicative level of risk is needed.

2.5. Identification of significant pressures

When the WFD states that ‘‘significant pressures must be identified’’, this can be taken to mean any pressure that, on its own or in combination with other pressures, may lead to a failure to achieve the specified objective (IMPRESS, 2002). Such an interpretation introduces a scale-dependence. It is also worth noting that the actual criterion used to assess significant pressures is that they imply that the water body is at risk of failing to meet objectives.

Although the WFD establishes that significant pressures should be considered in the risk assessment, neither the WFD nor IMPRESS (2002) determine the meaning of ‘significant’. Hence, in this contribution, four levels (Table 4) have been considered, as outlined below.

(i) High pressure (significant), when there is a high probability of producing either an ecological or chemical environmental impact.
(ii) Moderate pressure (significant), when there is some probability of producing either an ecological or chemical environmental impact.
(iii) Low pressure (not significant), when there is a high probability of not producing an ecological or chemical environmental impact.
(iv) Without pressure (not significant).

In order to assess the overall pressure on each of the water bodies, a relative rating (6, 4, 2 and 0, respectively) has been allocated to each of the abovementioned four levels. Subsequently, a mean pressure was calculated, for each of the water bodies, with the overall pressure being assessed as: (i) without pressure (values from 0 to 1); (ii) low pressure (1 to 3); (iii) moderate pressure (3 to 5); and (iv) high pressure (>5).

2.6. Assessing the impacts on water bodies

The environmental impact assessment was determined following the methodologies developed by Borja et al. (2000, 2004a,b,c) and Solaun et al. (2003), the

Table 4
Assessing the risk of failing the WFD objectives, based upon the significant pressure level and impacts determined within each water body. Modified and adapted from IMPRESS (2002). Note: ‘High’, ‘Good’, etc., are the Ecological Quality Status levels within the WFD; ‘Not apparent’, ‘Probable’ and ‘Verified’ are the impact level equivalence, under the pressure-impact approach

Pressure		Impact (ecological and chemical status)					
		High	Good	Moderate	Poor	Bad	Without data
		Not apparent		Probable	Verified		
High Moderate	Significant	Low risk		Moderate risk	High risk		Moderate risk
Low Without	Not Significant	Without risk		Moderate risk	High risk		Low risk

results were obtained from the assessment of recent years, in the Basque Country (Borja et al., 2003, 2004d). For additional details, see Borja et al. (2004e). This assessment includes all the elements of the WFD, as outlined in the Introduction to this contribution.

2.7. Assessing the risk of failing the WFD objectives

By comparing overall pressure and environmental impacts detected, on each water body, following the method shown in Table 4, it is possible to assess the risk of failing the WFD objectives of achieving at least the good ecological status, by 2015.

3. Results

3.1. Determination of water bodies

Twelve transitional water bodies were identified throughout the Basque Country (Fig. 1). Some geomorphological and hydrological data, used in the subsequent pressure and risk assessment, are shown in Table 5.

The total Atlantic catchment area of the Basque Country covers 5300 km^2, providing annually 150 $m^3\ s^{-1}$ of freshwater to the coastal water bodies. The total estuarine volume is $490.4 \times 10^6\ m^3$, at high water. The largest estuary is the Nervión, with 82% of the total volume, 34% of the catchment area and 24% of the freshwater flow. Most of the estuaries present $>50\%$ of intertidal areas, in relation to the total area, excepting those with dredging activities, due to the presence of a harbour, e.g. Nervión and Oiartzun (Table 5). The Oka and Oria estuaries show high tide renovation rates (mean tidal prism/total estuary volume = >1); others, such as Nervión, Urumea, Bidasoa and Oiartzun, have very low tide renovation rates (Table 5). In terms of residence time (the time for a particle reaching the estuary from the river, to arrive to the coastal waters), the highest values are from Nervión (224 days), Oka (63 days) and Oiartzun (35 days). On the other hand, most of the Basque estuaries have very low residence times (Table 5).

Finally, three coastal water bodies were identified, related to the coast orientation (for additional details, see Borja et al., 2004e) (Fig. 1).

3.2. Identification and description of the driving forces

The population trend in the Basque Country, since 1970, shows a slowing down in growth, with a total population of 2.1 million inhabitants in 2001 (EUSTAT, 2001). However, there are several major urban centres within the Basque Country. The Nervión river drains Bilbao's conurbation (a total of 17 villages), having more than 1 million inhabitants and providing the highest inhabitant density in the region (3623.5 hab km^{-2}) (Table 6). The other important conurbations are located around the Urumea river (near 3000 hab km^{-2}, in San Sebastian area) and the Oiartzun river (2151.3 hab km^{-2}). The area near the French border (the Bidasoa river) also has important population densities (around 1000 hab km^{-2}). The lowest population pressures are on the estuaries of Oka and Oria.

The Basque Country is a highly industrialised region, with most of the companies concentrated along the estuaries of Nervión (65,337, including industry and energy, construction, commerce, transport and services), Oiartzun (24,164) and Bidasoa (7013). Other important industry concentrations (ranging from 1000 to 2200) are on Artibai, Oria and Urumea estuaries, and the three

Table 5
Mean geomorphological and hydrological characteristics of the Basque estuarine water bodies. Modified from Valencia et al. (2004). Drainage areas extracted from Eraso et al. (2001)

Water body	Catchment area (km^2)	River flow ($m^3\ s^{-1}$)	Estuary length (km)	Estuary depth (m)	Estuary volume[a] ($10^6\ m^3$)	Subtidal volume[b] ($10^6\ m^3$)	Total flooded area[c] (km^2)	Intertidal area (%)	Tidal prism	Flushing time (h)	Residence time (days)
Barbadún	128.9	2.9	4.4	5	1.59	0.56	0.753	69	0.42	5	0.01
Nervión	1798.8	36.0	22.0	30	402.10	348.65	29.24	28	56.8	78	223.75
Butrón	172.2	4.7	8.0	10	2.20	0.79	1.599	78	1.37	10	0.04
Oka	183.2	3.6	12.5	10	12.87	5.73	10.277	86	12.88	149	62.62
Lea	99.3	1.8	2.0	5	1.03	0.38	0.500	65	0.89	3	0.04
Artibai	104.3	2.5	3.5	10	2.18	1.35	0.455	34	0.23	7	0.001
Deba	530.3	14	5.5	5	2.90	1.61	0.740	54	0.67	2	0.04
Urola	342.2	8.0	5.7	10	2.53	1.15	0.835	53	1.84	16	0.17
Oria	881.9	26.0	11.1	10	3.13	1.10	2.360	84	3.37	8	0.25
Urumea	272.4	17.0	7.7	10	6.79	4.35	1.397	36	1.38	13	0.33
Oiartzun	85.6	4.8	5.5	20	7.29	5.21	1.001	19	2.29	42	35.46
Bidasoa	700.0	29.0	11.1	10	45.80	31.06	6.827	18	6.10	33	1.46

[a] Mean estuary volume, for 2.5 m tidal height.
[b] Subtidal volume, for 0 m tidal height.
[c] Total flooded area, for 4.5 m tidal height.

coastal water bodies (Table 6). However, some of these areas (such as the Nervión and Oiartzun estuaries) are in a post-industrial phase, with the disappearance of the mining industry, the decline of large polluting iron and steel plants (see Belzunce et al., 2004a,b; Cearreta et al., 2004), and an increase in petrochemical and power industries.

There are 28 ports within the Basque water bodies: 3 commercial harbours, 6 marinas and 19 combining fishing activities and marinas. The main port developments are concentrated in the Nervión and Oiartzun estuaries, with two important commercial ports, Bilbao and Pasaia, respectively.

The port of Bilbao (http://www.bilbaoport.es) has an important economic impact on the Basque GNP, with an income of 419 million euros annually. In 2003, up to 3485 ship movements per year were handled by the port (5% down on 2002); however, 7,833,816 t were exported (12% more than in 2002) and 20,551,161 t were imported (10% more than in 2002). On the other hand, the main activity of Pasaia is the handling of scrap (33%) and the exportation of steel-manufactured products (20%) and vehicles (up to 3 million, from 1980 to 2003). Otherwise, the main fishing ports are located in the coastal water bodies (such as Bermeo and Getaria) and some estuarine water bodies (such as Bidasoa, Artibai and Lea).

The main fishing activities are centred on the coastal water bodies and, especially, the adjacent continental shelf and open sea. The most important commercial species caught annually are mackerel, anchovy and tuna, representing more than 90% of the captures. Shellfishing is not very important, centred only within three estuarine waters (Table 6), with clam being the main target species.

The total number of agricultural and livestock raising farms is 11,370, totalling 3330 km^2 (Table 6). The land use in the area is mainly forest (38%), grazing land (28%), unproductive (17%), and arable and horticultural lands (5%).

3.3. Identification of existing pressures

The highest number of pressures (499) was detected in the Nervión estuary (Table 6), the most industrialised water body; this was followed by the Bidasoa estuary (270) and the Deba estuary (198). The lowest numbers (<80) were recorded in areas of low population density and the presence of low industrialised water bodies, such as Barbadún, Butrón, Lea, and the coastal area of Cantabria-Matxitxako. When the pressures were calculated as a number per square kilometre, the lowest values were observed in the coastal water bodies.

3.4. Identification of relevant pressures

Although the number of water treatment plants is increasing in the Basque Country, in recent years (Franco et al., 2004), nutrients are still one of the most important pressures on the water bodies, as shown in Table 7. Hence, except for the Oka and coastal water bodies, all of the water bodies have values >900 kg N d^{-1} km^{-2}.

Some estuarine water bodies, such as those of the Nervión, Deba, Oria, Urumea, and Oiartzun, show >25% of the samples exceeding the quality objectives (Table 7) for priority substances in water, for the period 1994–2003 (Borja et al., 2004d). However, a decreasing pollution trend in waters has been detected by Belzunce et al. (2004a) and Borja et al. (2004d). The same

Table 6
Main driving forces acting in the Basque Country, for each water body, together with pressures determined in this contribution. Data on the driving forces have been abstracted from EUSTAT (2001). Data of pressures are presented in terms of total number, number per square kilometre and number per linear kilometre, obtained from the GIS. NA, not available

Water body	Driving forces					Pressures		
	Population (n km^{-2})	Industry (n)	Ports (n)	Fisheries (t y^{-1})	Agriculture (n)	(Total no.)	(n km^{-2})	(n km^{-1})
Barbadún	320.7	407	0	–	396	52	70.5	11.8
Nervión	3623.5	65337	5	–	2264	499	23.1	22.7
Butrón	207.5	728	1	1	890	78	47.0	9.8
Oka	85.3	421	1	4	1000	137	13.4	11.0
Lea	175.2	577	1	–	444	45	88.2	22.5
Artibai	305.8	1054	1	–	435	83	194.2	23.7
Deba	111.4	931	1	–	507	198	272.4	36.0
Urola	211.7	844	1	–	349	144	146.2	25.3
Oria	89.8	1082	1	–	562	149	68.2	13.4
Urumea	2957.7	1329	0	–	328	145	108.6	18.8
Oiartzun	2151.3	24164	1	–	606	144	147.1	26.2
Bidasoa	1020.5	7013	5	1	707	270	37.7	24.3
Cantabria-Matxitxako	238.5	2042	2	NA	1527	53	0.3	0.9
Matxitxako-Getaria	185.4	1684	4	7205.5	1130	125	0.5	2.2
Getaria-Higer	949.4	2162	4	2836.1	225	102	0.7	1.6

Table 7
Data determined from the GIS for the most relevant pressures, within each of the Basque water bodies

Water body	Nutrients (kg N d^{-1} km^{-2})	Water pollution (%)	Sediment pollution (%)	Water abstraction (10^4 m^3 d^{-1})	Dredged sediments (10^4 m^3 y^{-1})		Shoreline reinforcement (%)		Intertidal losses (%)	Berths (*n*)		Alien species (*n*)
					Ports	Other	Ports	Other		Ports	Other	
Barbadún	2005	10	0.0	–	–	0	0.0	46.4	81	–	3	0
Nervión	904	27	82.8	236	32.0	–	90.7	2.1	30	1555[a]	–	>3
Butrón	1342	13	0.0	–	10.8	1	7.1	22.3	37	319	88	0
Oka	210	12	0.0	–	0	3	1.9	51.4	30	150	206	1
Lea	2016	4	0.0	0.1	0	0	11.3	58.4	15	150	28	0
Artibai	2788	8	34.1	0.1	10.1	0.4	19.1	32.2	40	202	–	0
Deba	9445	33	60.8	–	–	0.2	3.8	56.9	45	70	58	1
Urola	5427	23	52.9	0.1	3.5	2.5	10.0	36.4	57	578	60	0
Oria	5331	29	17.6	–	–	4.5	12.3	40.7	59	96	72	0
Urumea	3075	28	46.1	–	–	0	0.0	43.8	88	–	5	0
Oiartzun	1629	39	70.0	87.9	20.1	–	66.8	24.6	55	200[a]	–	>3
Bidasoa	1233	19	5.5	0.1	1.1	0	13.2	62.4	60	1682	722	2
Cantabria-Matxitxako	163	10	2.1	–	0.3	0	7.4	5.5	<1	30	4	1
Matxitxako-Getaria	74	9	0.0	4.8	1.2	0	9.2	10.0	<1	315[a]	–	1
Getaria-Higer	171	9	3.3	4.6	1.1	0.9	8.7	22.2	<1	755	242	1

[a] Commercial ports (only the number of berths are shown, but not the ship movements). Intertidal losses from Rivas and Cendrero (1992).

estuaries are the most polluted, in terms of surface polluted sediments, with values >50% (Table 7). The trend in decreasing sediment pollution has been detected by Belzunce et al. (2004b).

Water abstraction has increased dramatically in recent years, mainly in the Nervión estuary (Table 7); this is due to the power industry development; however, also in coastal waters, due to land-based turbot aquaculture.

Over the past years, extensive dredging to ensure navigability has been undertaken in the Basque ports and estuaries (Uriarte et al., 2004). The Basque ports which have been dredged extensively are those of Bilbao (Nervión estuary) and Pasaia (Oiartzun estuary). Over the last 23 years, some 5×10^6 m^3 of material has been removed from 15 locations; of this, some 59% relates to the harbour at Bilbao, 20% at Pasaia, and 21% at the remaining locations (Uriarte et al., 2004). The mean volume of materials dredged, in the past 3 years, is shown in Table 7.

The percentage of shoreline reinforcement is very high, both within the ports (mainly in Nervión and Oiartzun) and outside them (Table 7). Hence, some of the water bodies, such as the Oka, Lea, Deba and Bidasoa, have had >50% of their perimeters reinforced. Likewise, there are differences in terms of defence 'hardness', i.e. Deba presents vertical concrete dykes or sea walls, with small intertidal areas, but Oka, Lea or Bidasoa have extensive intertidal areas, with soft land barriers.

All the Basque estuaries have lost major intertidal areas since Post-Flandrian times (Table 7), due to anthropogenic land reclamation and natural infilling (Rivas and Cendrero, 1992). The largest losses correspond to Urumea, Barbadún and Bidasoa (Table 7).

The most important ports (located within the Nervión and Oiartzun estuaries) have a high number of berths (Table 7). However, in recent years some tourist areas (such as Bidasoa, Urola and the coast between Getaria and Higer cape) have experienced a dramatic increase in the number of boats (represented by the construction of several marinas), both within the ports and outside, providing 'free' moorings (Table 7).

Finally, the highest numbers of introduced species correspond to water bodies with a high number of berths, or intense ship movements, i.e. Nervión, Oiartzun and Bidasoa (Table 7); this indicates the potential influence of maritime transport and communications, in the dispersion of these alien species.

3.5. Identification of significant pressures

The thresholds proposed in Tables 2 and 3 were applied to the values presented in Table 7, obtaining the classification for each of the nine relevant pressures (Table 8). Following the criteria of the WFD (see Section 1 for details on the hierarchical approach to the identification of surface water bodies), the sub-division of a water body into smaller water bodies should be undertaken when pressures and resulting impacts are important (for details see Vincent et al., 2002). Hence, due to the high pressure on the inner parts of the Nervión and Oka estuaries, these water bodies have been divided into two smaller water bodies (Table 8). Similarly, the coastal water body of Getaria-Higer has been divided, due to

Table 8
Assessment of the pressure level, in terms of relevant pressures and water body; overall pressure, impact assessment and risk assessment, by water body. W, without; L, low; M, moderate; H, high; NS, not significant; S, significant

Water body	Nutrients	Water pollution	Sediment pollution	Water abstraction	Dredged sediments	Shoreline reinforcement	Intertidal losses	Berths	Alien species	Global pressure	Impact assessment	Risk assessment
Barbadún	M	L	W	W	W	M	H	W	W	L–NS	Probable	M
Inner Nervión	H	H	H	M	H	H	H	M	H	H–S	Verified	H
External Nervión	M	M	M	H	H	H	M	H	H	H–S	Probable	M
Butrón	M	L	W	W	M	L	M	M	W	L–NS	Not apparent	W
Inner Oka	M	L	L	W	M	M	M	W	L	L–NS	Verified	H
External Oka	M	W	W	W	M	H	L	M	L	L–NS	Probable	M
Lea	M	W	W	W	W	H	L	L	W	L–NS	Probable	M
Artibai	M	L	M	W	L	M	M	M	W	L–NS	Verified	H
Deba	M	H	H	W	L	H	M	L	L	M–S	Verified	H
Urola	M	M	H	W	L	M	H	H	W	M–S	Probable	M
Oria	M	M	L	W	M	M	H	L	W	L–NS	Not apparent	W
Urumea	M	M	M	W	W	M	H	W	W	L–NS	Verified	H
Oiartzun	H	H	H	M	H	H	H	H	H	H–S	Verified	H
Bidasoa	H	M	W	W	L	H	H	H	M	M–S	Probable	M
Cantabria-Matxitxako	L	L	W	W	W	L	W	W	L	W–NS	Not apparent	W
Matxitxako-Getaria	W	L	W	W	L	M	W	H	L	L–NS	Not apparent	W
Getaria-Higer	L	L	W	W	L	H	W	H	L	L–NS	Not apparent	W
Mompás-Pasaia	H	H	L	W	W	L	W	W	L	L–NS	Probable	M

the presence of a large submarine outfall in the Mompás-Pasaia area (Table 8).

Applying the rating shown in Section 2.5, the results obtained were (Table 8): Oiartzun and inner and external Nervión, with high (significant) pressure (scores 5.78, 5.55 and 5.1, respectively); Bidasoa, Urola and Deba, with moderate (significant) pressure (scores 3.78, 3.56, 3.56, respectively); Oria (2.89), Artibai (2.67), inner and external Oka (both with 2.44), Urumea (2.44), Butrón (2.22), Getaria-Higer (2.22), Mompás-Getaria (2), Barbadún (1.78), Matxitxako-Getaria (1.78) and Lea (1.55), with low (not significant) pressure; and, finally, Cantabria-Matxitxako without pressure (0.89).

3.6. Environmental impact assessment on water bodies

Environmental impacts (Table 8) have been verified in the inner part of the Nervión (for chemical and all biological elements), in the inner part of the Oka (for macroalgae and benthos), in Artibai (for chemical and all biological elements), Deba (for chemical and all biological elements), Urumea (for benthos and macroalgae) and Oiartzun (for chemical and all biological elements). The impact is probable in the Barbadún, the external parts of the Nervión and Oka, the Lea, Urola, Bidasoa and the Mompás-Pasaia coastal area. Finally, the impact is not apparent in the remainder of the coastal areas and in the Oria and Butrón transitional water bodies.

3.7. Risk assessment of failing WFD objectives

The risk of not achieving good ecological status in the Basque water bodies is as outlined below (Table 8). The highest risk is in the inner Nervión, the inner Oka, Artibai, Deba, Urumea and Oiartzun. There exists moderate risk in Barbadún, external Nervión, external Oka, Lea, Urola, Bidasoa, and the Mompás-Pasaia coastal water body. The remainder of the water bodies are not at risk.

4. Discussion

The values of the main driving forces acting in the Basque Country, together with the number of pressures determined for each water body (from Table 6) were used to perform a factor analysis (FA). This analysis (Fig. 2) shows the disposition of the water bodies, in relation to the two first extracted factors of the new multidimensional space, defined by the FA. Nearly 89% of the total system variability is explained by these factors. The first factor explains more than 56% of the total system variability, being considered the principal factor. The density population and industry number acquire high loadings (0.98 and 0.71, respectively) in the positive direction of this factor. The second factor explains 22% of the total variability, with agriculture as the main driving factor (load = 0.97). Finally, the third factor

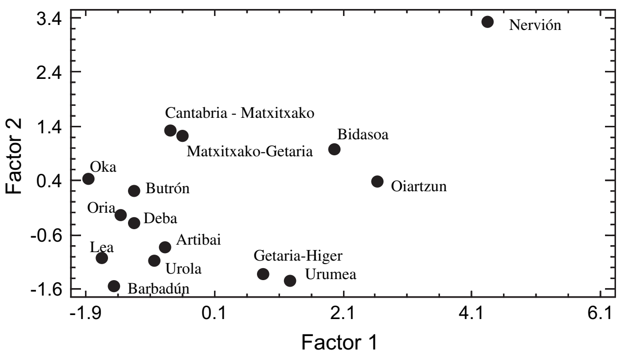

Fig. 2. Distribution of the Basque water bodies, within the new multi-dimensional space defined by the factor analysis (rotated, using the Varimax rotation method, in order to facilitate the interpretation of the analysis results). Normal distribution of the data was achieved using log $(1 + X)$ transformation, standardised by subtracting the mean and dividing it by the standard deviation.

explains only 10.4% of the variability, being related with ports as driving factor (load = 0.94).

These results show that the main driving factors explaining the variability of pressures upon Basque water bodies are the population density and industry concentration. Population is the key factor determining pollution loads in other regions (Scheren et al., 2004). These two drivers produce the most relevant pressures (Table 9), in terms of water and sediment pollution, shoreline reinforcement and intertidal losses, which can be considered as the pressures impacting most within the Basque Country (see Borja et al., 2004e). Hence, the most important pressures and impacts, both in qualitative and quantitative terms, were recorded in Nervión, Bidasoa and Oiartzun, with high population density, combined with industry and port development (Fig. 2, Table 6). On the other hand, the less impacted water bodies were the Barbadún and Lea (Fig. 2, Table 6); these are less industrialised, but have some implications in terms of agricultural pressures.

Table 9
Level of influence of the main drivers upon the relevant pressures detected within the Basque Country. Key: *** High; ** moderate; * low

Relevant pressures	Drivers				
	Population	Industry	Ports	Fisheries	Agriculture
Nutrients	***	**	*	*	***
Water pollution	**	***	**	*	**
Sediment pollution	**	***	**	*	*
Water abstraction		***		*	
Dredged sediments		*	***		
Channelling	***	***	***		**
Intertidal losses	***	***	***		***
Anchoring			***	***	
Alien species			**	**	

Likewise, different pressures do not impact upon the different water bodies, at the same spatial and temporal scales, as outlined by IMPRESS (2002). In this work, the scaling issues have been reduced, by monitoring pressures at a high level (identifying all of the potential pressures), then selecting the most relevant ones; finally, by assessing the most significant ones. This approach assures a good spatial cover, in the analysis. On the other hand, the use of data evolution from long-term monitoring (see Borja et al., 2003, 2004d; Borja and Collins, 2004) assures an adequate temporal scale. Both cases reduce the uncertainty of the analyses, obtaining an improved understanding of the present situation of risk in Basque water bodies, regarding achievement of the WFD objectives.

Most of the coastal areas of the world have been reported to be 'damaged', due to pollution and other pressures; these significantly affect marine resources and ecosystems. Unfortunately, marine pressures and impacts are characterised by interconnectedness, complicated interactions, uncertainty, conflicts and constraints, making it difficult to control this problem (Islam and Tanaka, 2004). Therefore, advances in the knowledge of these interactions and tools, in assessing the risks caused by these pressures, are needed; this is not only in the framework of the WFD, but also in the general assessment of the marine sustainability, as outlined by Ledoux and Turner (2002).

The use of the DPSIR analysis in the Basque Country, together with the methodologies in identifying relevant pressures and impacts, has been demonstrated as a useful approach in assessing the risk of failing the WFD objectives. In this way, this contribution can serve as a case study for marine management over a wider area, within the ecological footprint of several stressors, and also for many different catchments and coastlines, as required by Elliott (2002), and applied recently to the Humber (Cave et al., 2003) and Elbe (Nunneri and Hofmann, 2005) catchments.

This approach is similar to that used by Xu et al. (2004), in Hong Kong, in which they follow five major steps of analysis: (i) review of human activities; (ii) identification of human-induced stresses; (iii) analysis of ecosystem responses to the stresses; (iv) development of ecosystem health indicators; and (v) assessment of ecosystem health. Furthermore, the general approach used here can complement those used in integrated coastal zone management processes, such as the case of the Catalan coast (Sardá et al., 2005).

In this contribution, the use of the DPSIR is proposed, as a well-known methodology, and together with some new methodological approaches, in assessing the significance of the relevant pressures identified in the

Basque Country (as a case study). The boundaries established here, for the different levels of pressure, could probably be adapted to other regions. In general, this method benefits from good data sets, with data gaps being filled in by field studies. This approach includes both the collation and quality assurance of existing data, together with the collection of new data. However, the overall approach has been demonstrated as being useful, when there exist enough data, both at spatial and temporal scales. Such a requirement is necessary in order to reduce uncertainties in assessing the risk of failing the achievement of good ecological status, within the WFD objectives, by 2015.

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