Water quality and ecology

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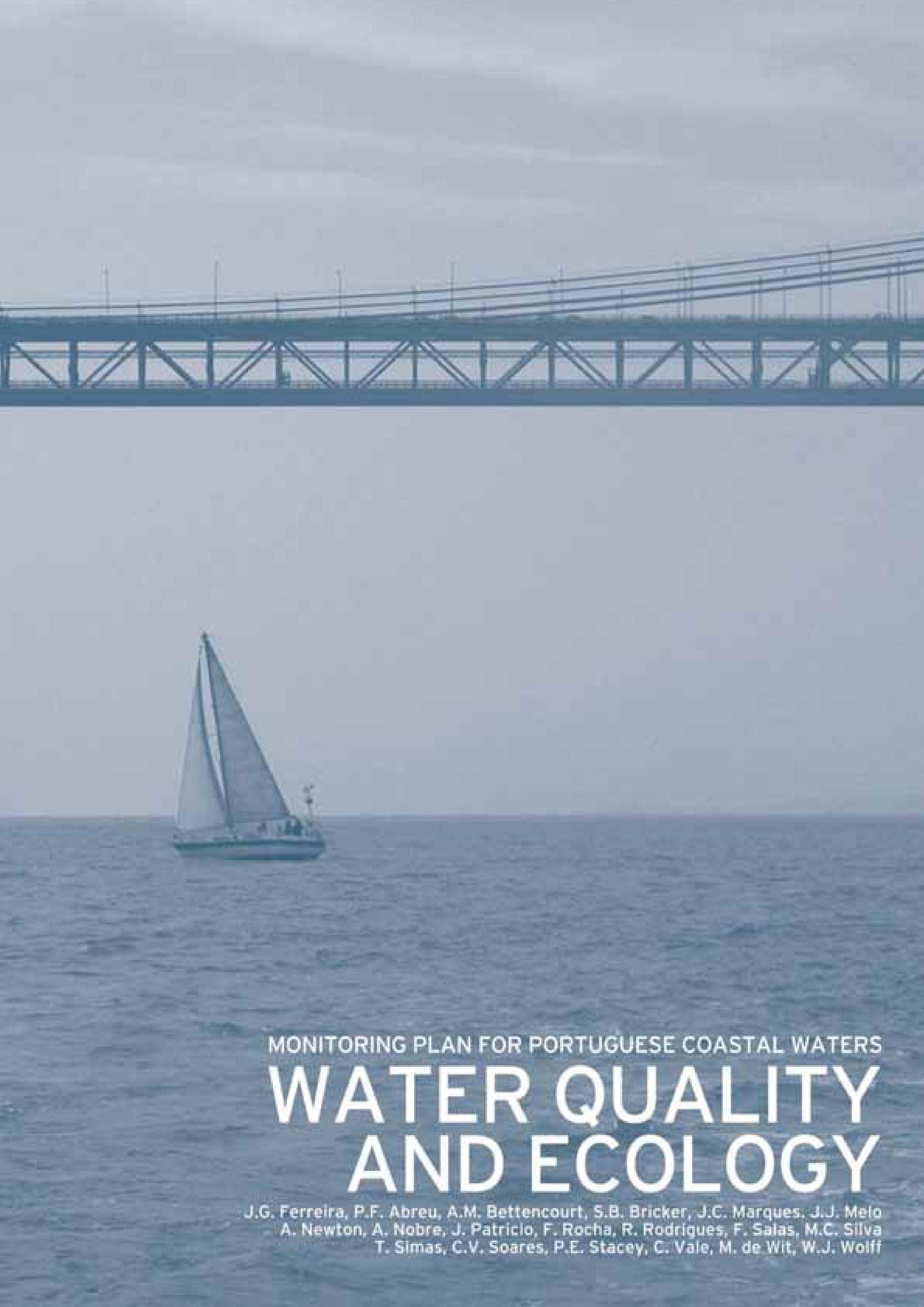

MONITORING PLAN FOR PORTUGUESE COASTAL WATERS

WATER QUALITY AND ECOLOGY

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FOREWORD

The Water Framework Directive represents a paradigm shift for water management in the European Union and addresses a broad range of issues and systems. MONAE is the second of two books providing guidelines for the application of the Directive in Transitional and Coastal Waters. It follows the publication of TICOR, which concerns typology and reference conditions in coastal zones.

The project "Monitoring Plan for Water Quality and Ecology of Portuguese Transitional and Coastal Waters", or MONAE, was financed by the Portuguese Water Institute, INAG, and carried out by an interdisciplinary team drawn from marine science and management experts in the E.U., U.S. and South Africa.

The execution of a project focused on monitoring appeared at the outset to be a potentially arid proposition, but it rapidly became clear that there were many topics to consider, and plenty of room for imaginative discussion. The MONAE book is a product of this work, supported by scientific journal papers, and complemented by resources available at http://www.monae.org

The Water Framework Directive has triggered a much-needed dialog between scientists and managers, and forced the marine science community in the E.U. to think along new lines. Management of transitional waters (estuaries) and coastal waters to meet the requirements of the Directive poses major challenges: there is a need for scientifically validated tools that are appropriate for quality assessment, optimised for simplicity and cost; we must understand what can be managed and what cannot, distinguish between natural variability and trends, and separate human from natural change.

This book aims to provide the reader with a blueprint for the development of a successful and economically viable monitoring plan, based on soundly formulated hypotheses and containing appropriate verification instruments. Data were drawn from many sources, including the databases built during the TICOR project. Our thanks go to all who provided data and information, and to the colleagues who reviewed successive drafts.

Huge technological evolution is to be expected in sensors, together with more radical changes in the approaches to monitoring ecological quality in marine systems: we have thus avoided being over-prescriptive, except to recommend that the best methods be used, drawing examples from current practice. Furthermore, at the time of writing there is no ecological paradigm that can inform coastal management, which at present relies substantially on empirical relationships. Despite these limitations, we hope that MONAE will be useful to the marine science and management community.

MONAE TEAM

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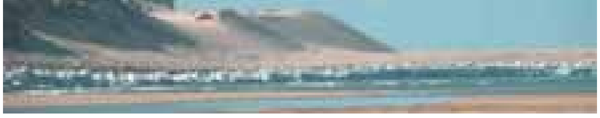
EXECUTIVE SUMMARY

The E.U. Water Framework Directive (WFD – Directive 2000/60/EC) outlines the requirements for monitoring of surface waters in the European Union, within the general framework of river basin management plans. Three distinct types of monitoring are stipulated, in order to meet the overall goal of assessing the quality status of European waters. The focus of this book is only on transitional (estuarine) and coastal waters, for which the following monitoring types and objectives are defined in the WFD.

Monitoring type	Objectives
Surveillance monitoring	• Supplement and validate the assessment of the likelihood that transitional or coastal waters are failing to meet the environmental quality objectives • Efficient and effective design of future monitoring programmes • Assessment of long-term changes in natural conditions in order to distinguish between non-natural and natural alterations in the ecosystem • Assessment of long-term changes resulting from widespread anthropogenic activity
Operational monitoring	• Establish the status of those bodies identified as being at risk of failing to meet their environmental objectives • Assess any changes in the status of such bodies resulting from the programmes of measures
Investigative monitoring	• Where the reason for any exceedences of environmental objectives is unknown • Where surveillance monitoring indicates that the objectives set under Article 4 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 • To ascertain the magnitude and impacts of accidental pollution



The Monitoring Plan for Water Quality and Ecology for Portuguese Transitional and Coastal Waters (MONAE) was a project developed with the broad aim of setting guidelines for the development of WFD-compliant monitoring plans in Portuguese Transitional and Coastal Waters.

General objectives of MONAE

- Provide an integrated approach to monitor all Portuguese Transitional and Coastal Waters
- Have the potential to address management issues, i.e. to be hypothesis-driven
- Establish the guidelines for monitoring the water quality and ecology of Portuguese Transitional and Coastal Waters throughout the next decades
- Integrate the monitoring requirements of the WFD for Transitional and Coastal Waters
- Define and apply a methodology for the definition of water bodies in Portuguese coastal and transitional types
- Possess internal flexibility, in order to accommodate new methodologies that may be developed and/or applied over its life-cycle
- Use a hierarchical approach, allowing cost-optimisation with respect to information requirements

MONAE builds on previous work on typology and reference conditions published in TICOR (http://www.ecowin.org/ticor/) and in a number of supporting scientific papers.

The MONAE book begins with a brief general introduction and description of the problem, followed by a further seven chapters.

Problem definition and objectives

WFD context, problem definition and general objectives

Methodology

Details on the MONAE process

Tools

Summary of tools used in MONAE, and end-product methodologies

Data overview

Review of historical data; Producers, metadata, WFD compliance and international comparison

Spatial domain

Spatial scope and typology; Methodology for water body definition and its application

Monitoring plans

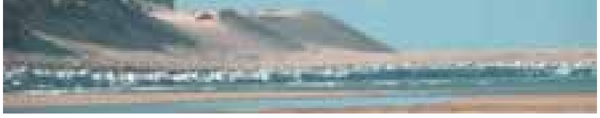
General considerations for all types of monitoring; Detailed guidelines for surveillance, operational and investigative monitoring

Economic analysis

Estimated costs of monitoring; Normalisation to Euro zone Purchasing Power Parity; Benefits

Public participation

Tools; Input regarding policy; Environmental education; Collaborative monitoring



Each chapter was written so as to be readable on its own, by including the key concepts, methodologies and results relevant to the theme. The tools chapter provides an overview of the techniques used for different parts of the work, together with those that may be applied for obtaining end-products, such as the definition of water bodies. We have chosen not to make any specific recommendations of software or other products, due to the progress anticipated in technology over the next decades. Where appropriate, we have indicated what tools were used to obtain the results presented herein.

A summary of the key outputs and findings of MONAE is presented below.

DATA OVERVIEW

Data collection in Portuguese Transitional and Coastal Waters (Figure 1) has been carried out regularly in several thematic areas, including hydromorphology, marine geology, water quality, phytoplankton, shellfish and specific pollutants.

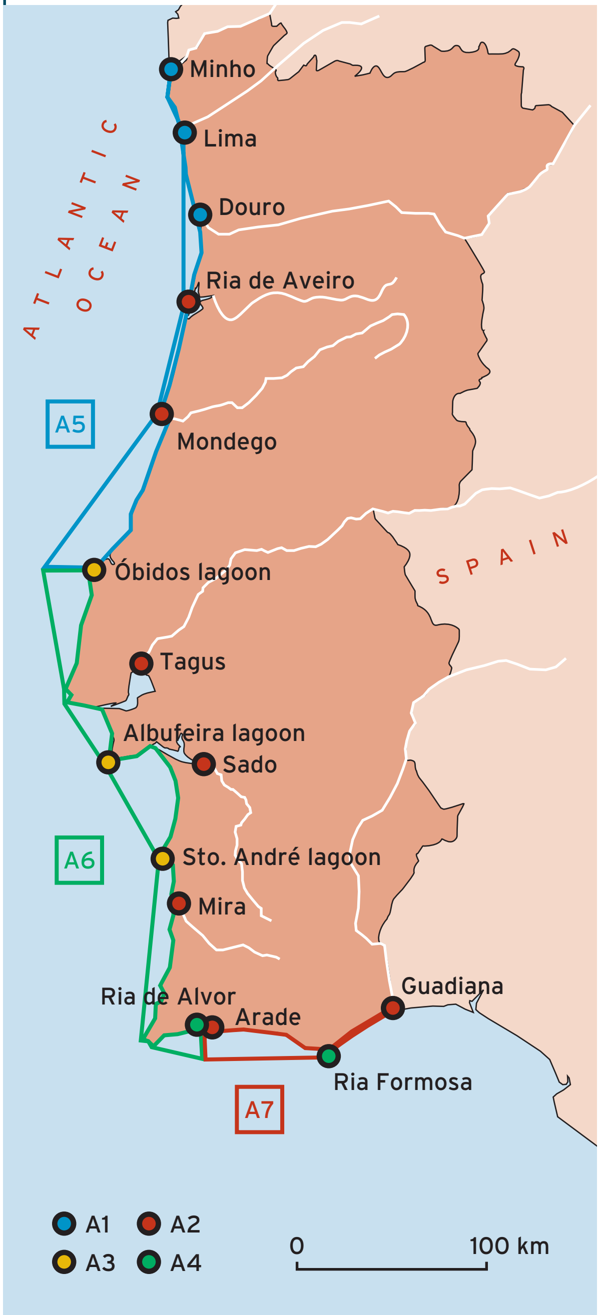
Most of the data collected by institutions in Portugal are stored in internal databases. The availability of historical data is thus compromised by data fragmentation, which stems from the lack of coordination of monitoring activities both at a system (e.g. estuary or lagoon) and at national level.

Figure 2 summarises the currently available historical datasets as well as other less accessible data.

There is a large quantity of data for Portuguese Transitional and Coastal Waters. However the datasets are concentrated both in time and space, which means that in most cases they are not representative of a comprehensive system survey, due to the nature of the sampling design.

In several systems the number of sampling stations, although high, covers only part of the

Figure 1. **Map of the Portuguese typology for Transitional and Coastal Waters (transitional and restricted coastal types A1-A4 indicated in colour).**



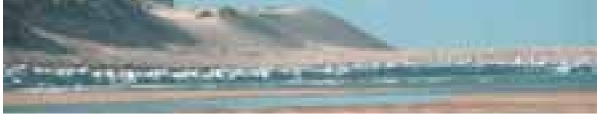


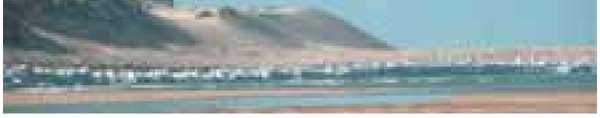
Figure 2. **Available historical datasets for Portuguese Transitional and Coastal Waters.**

					Number of records						
							Parameters				
	Type	Systems	Area (km^2)	Sampling period	Stations	Samples	Physico-chemical	Biological	Other	Total	Results
Transitional waters	A1	Minho	23	1982 - 2002	17	322	25	7	2	34	3 538
		Lima	5	1984 - 2002	31	603	31	37	1	69	8 096
		Douro	6	1987 - 2002	39	292	34	7	1	42	5 006
	A2	Ria de Aveiro	60	1972 - 2002	84	1 441	45	40	6	91	13 499
		Mondego	9	1985 - 2002	48	726	17	261[1]	12	290	18 317
		Tagus	330	1971 - 2002	146	8 702	50	86	15	151	81 003
		Sado	160	1963 - 2002	299	3 801	39	5	16	60	24 164
		Mira	3	1983 - 2002	119	6 469	19	155[1]	4	178	30 704
		Guadiana	18	1977 - 2002	114	24 412	39	7	4	50	60 826
Coastal waters	A3	Óbidos	6	1962 - 2004	60	560	5	-	12	6	U
		St. André	2	1984 - 1986	17	1 239	11	3	0	14	9 760
	A4	Ria Formosa	49	1984 - 2002	70	97 021	78	74	13	165	139 932
	A5	From Minho estuary until Cabo Carvoeiro	3 200	1923 - 2003	987	1 730	3	U	U	3	U
	A6	From Cabo Carvoeiro until Ponta da Piedade	4 200	1923 - 2004	1 748	2 856	3	U	U	3	U
	A7	From Ponta da Piedade until Vila Real de Sto António	1 000	1923 - 2001	648	948	3	U	U	3	U

U - Unavailable information; [1] - Includes species list.

system. This issue must be addressed when designing future monitoring plans, since there is a need to choose representative sampling stations in accordance with the water bodies defined for an effective implementation of the WFD.

The data overview carried out shows that most datasets cannot be considered WFD compliant due to the lack of data availability for several of the biological quality elements (particularly aquatic flora, benthic invertebrate fauna and fish fauna) in most of the systems; the Ria de Aveiro, Tagus and Sado have the most complete datasets concerning biological quality elements. Apart from the spatial limitations referred above, particularly those observed in mesotidal stratified estuaries (type A1), the data for most of the hydromorphological and physico-chemical supporting elements are accessible for most systems. The fragmentation of monitoring outputs must be addressed for WFD compliant monitoring of Portuguese Transitional and Coastal Waters.



SPATIAL DOMAIN

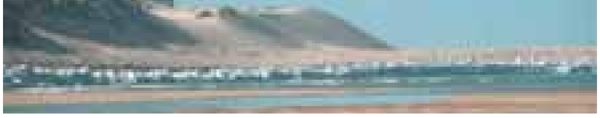
An approach for the division of Transitional and Coastal Waters in Portugal into water bodies for management and monitoring purposes was developed in MONAE.

Two distinct methodologies were used: for the definition of *Open Coastal Water Bodies* literature results were used, and for *Transitional and Restricted Coastal Water Bodies*, a bottom-up data analysis approach was carried out.

There are common points to both methodologies, since in both cases natural factors such as salinity or morphology are combined with the human dimension, using the significant pressures and/or key elements of state. The application of these methodologies has resulted in the definition of 60 transitional and coastal water bodies for Portugal, which are detailed in Figure 3. It is envisaged that

Figure 3. Summary of water bodies defined for Transitional and Coastal Waters in Portugal. The Leça estuary was excluded, since it is classified as an artificial structure.

Types	Water category	Systems	Nº of water bodies
A1 Mesotidal stratified estuary	Transitional	Minho estuary	5
		Lima estuary	3
		Douro estuary	3
		Leça estuary	-
A2 Mesotidal well-mixed estuary	Transitional	Ria de Aveiro	5
		Mondego estuary	3
		Tagus estuary	4
		Sado estuary	6
		Mira estuary	3
		Arade estuary	1
		Guadiana estuary	3
A3 Mesotidal semi-enclosed lagoon	Coastal	Óbidos lagoon	2
		Albufeira lagoon	1
		St. André lagoon	1
A4 Mesotidal shallow lagoon	Coastal	Ria Formosa	5
		Ria de Alvor	1
A5 Mesotidal exposed Atlantic coast	Coastal	Open coast	6
A6 Mesotidal moderately exposed Atlantic coast	Coastal	Open coast	4
A7 Mesotidal sheltered Atlantic coast	Coastal	Open coast	4
Total			**60**



future revisions of this list may allow the final number of water bodies defined for transitional and coastal systems in Portugal to be no greater than 50.

MONITORING PLANS

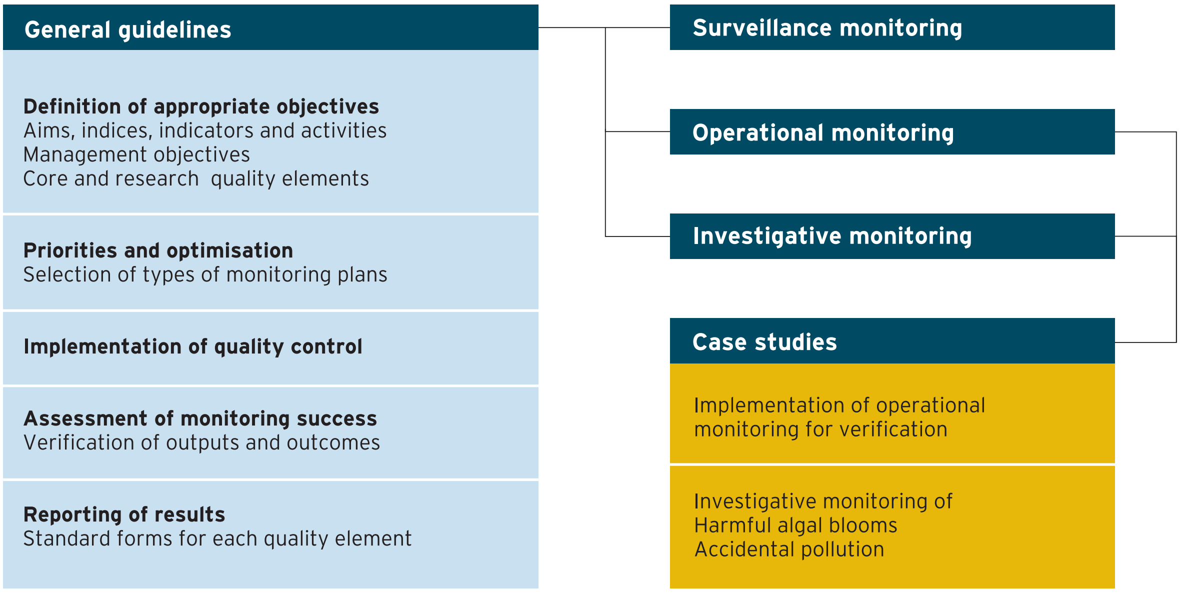
The general approach to the definition of guidelines for monitoring plans is shown in Figure 4.

Key points are highlighted below for the three types of monitoring.

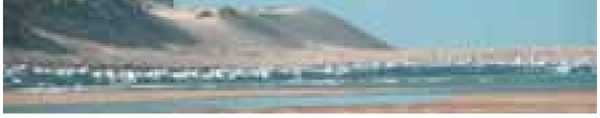
Surveillance monitoring

Appropriate frequencies for sampling biological quality elements and supporting quality elements are proposed for open coastal waters, inshore coastal waters and transitional waters. Guidelines are also provided for vertical resolution of water column sampling. The definition of water bodies shown in Figure 3 will result in a tentative network of 60-120 stations for all of Portugal, considering 1-2 stations per water body as an indicator of spatial resolution. Modifications to the number of water bodies will result in potential changes to the station network, both in number and distribution.

Figure 4. General guidance scheme for development of monitoring plans.



MONAE recommends that the following WFD "paradox" - *Member States must be sure that all*



Water Bodies have Good Ecological Status but only a subset may be sampled – should be addressed by sampling at least one station per water body for surveillance monitoring.

Operational monitoring

Two key objectives are indicated in the WFD for operational monitoring.

Operational monitoring

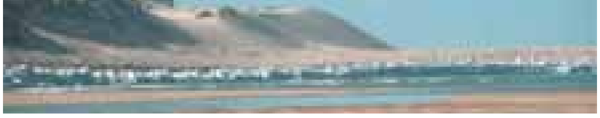
- Establish the status of those bodies identified as being at risk of failing to meet their environmental objectives
- Assess any changes in the status of such bodies resulting from the programmes of measures

The first objective (*screening*) of operational monitoring is concerned with further investigation into a water body which is at risk of non-compliance with environmental objectives, i.e. which appears from surveillance monitoring data to be at moderate, poor or bad status for one or more quality elements. This is interpreted in MONAE to be applicable mainly for water bodies diagnosed as being at moderate status, where more detailed studies will help establish the status of the water body.

The second objective (*verification*) is to verify *post-facto* if management measures are working, i.e. from a Pressure-State-Response perspective, if a reduction in pressure due to management response has resulted in the expected change in state.

In the first case (screening), the design of a monitoring programme must therefore take into account (a) the measurement of state, where the design considerations are those indicated for surveillance monitoring as regards particular quality elements; (b) the determination of pressure to establish whether there is a match between pressure and state; (c) source apportionment if required, in order to inform appropriate management measures.

In the second case (verification), the design of a monitoring programme for verification of compliance presupposes that there is a clear



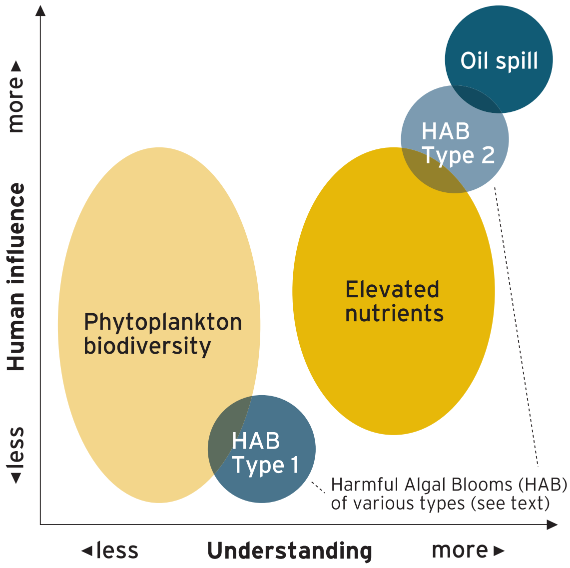
hypothesis that relates the anthropogenic pressure to the ecological status.

Investigative monitoring

This type of monitoring is research-oriented, and aims (i) to clarify unknown or poorly understood pressure-state relationships in order to inform an appropriate response; or (ii) to investigate accidental pollution events such as oil spills, and provide a blueprint for management measures, including mitigation and actions for future prevention.

Investigative monitoring of the marine environment is by nature interdisciplinary – the problems addressed are diverse, and constrained by different levels of understanding. Issues range e.g. from the interpretation of the effects of an accidental oil spill, where most processes are well understood, to the understanding of changes in biodiversity, affecting e.g. phytoplankton or benthic species composition, which are rather poorly understood (Figure 5).

Figure 5. Examples of environmental problems in marine systems, scaled by human influence and process understanding.



MONAE is set in the context of a WFD medium-term time horizon of about 20 years, and recognizes that (a) methodologies are constantly under development; and (b) future paradigm shifts will potentially make some of these methods obsolete. It therefore recommends that investigative monitoring should always draw on the best available techniques, combining the state of the art in field determinations, laboratory experiments and simulation models in order to provide the answers to the investigative monitoring questions posed by managers and scientists. Case studies on the research of naturally occurring harmful algal blooms and accidental oil spills are used as examples of the current state of the art in investigative monitoring.

ECONOMIC ANALYSIS

The general definitions of different cost concepts are reviewed, and an estimate of existing monitoring costs from systems in different countries is then used to estimate a unit cost for monitoring, based on a *station-sample pair*.

Station-sample pair

A sample taken at a station on one occasion, which may include only one depth or multiple depths. The entity is defined as a sampling visit to a particular geographic location.

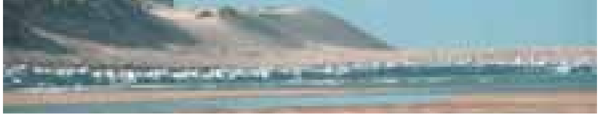


Figure 6. Annual cost of monitoring for the application of the WFD in transitional and coastal systems in Portugal in 2004 PPP€.

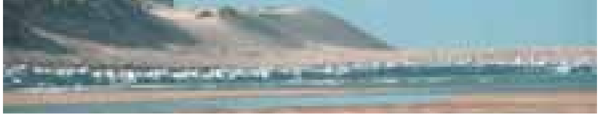
	Transitional and inshore coastal waters	Open coastal waters	Total cost (2004 PPP€)
Surveillance monitoring	1,736,000	250,000	1,986,000
Operational monitoring	391,000	19,000	410,000
Investigative monitoring	191,000	64,000	255,000
Total cost (2004 PPP€)	**2,318,000**	**333,000**	**2,651,000**

The information used to compile unit costs was drawn from work carried out in Portugal, the United States and China, within the framework of monitoring activities and research projects. The data were then normalised to Purchasing Power Parity (PPP€). This approach allowed a comparison among different countries, both in terms of overall costs and the relative proportions of cost components. These data were then used to extrapolate costs for all three types of monitoring under the WFD, and are summarised in Figure 6.

As regards surveillance monitoring, about 88% of this cost is associated to the inshore monitoring work (transitional and inshore coastal waters), the remaining 12% being that of monitoring open coastal waters. This difference is partly due to the far greater number of transitional and inshore water bodies and associated sampling stations and also to the significantly higher monitoring frequency.

The unit costs of operational monitoring are based on the estimates for surveillance monitoring. Using a precautionary approach, it is assumed that 30% of water bodies in transitional and inshore coastal waters, and 10% of water bodies in open coastal waters would require operational monitoring. Unit monitoring costs are additionally reduced because operational monitoring typically addresses a subset of biological quality elements and supporting quality elements.

Investigative monitoring is, by its very nature, difficult to value. This is compounded by the fact that it will include many emerging and new issues, for which there is no precedent and whose costs are unpredictable. The review presented on historical data identifies investigative monitoring principally as an



activity of academic institutions and research institutes. The research budget funding to scientific projects in marine sciences and technology is thus a potential indicator of the scope and cost of investigative monitoring, and has been used to estimate the values presented in Figure 6.

An analysis of the potential benefits of the successful implementation of WFD monitoring plans is also carried out, considering that these are a subset of the total benefits of WFD system management. Both use and non-use values are considered, and it is recommended that the detailed monitoring plans, which will be drawn up explicitly, consider these valuation issues on a case by case basis.

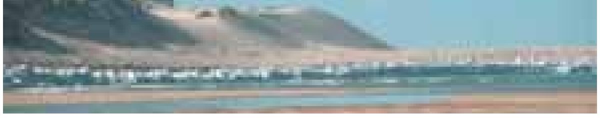
PUBLIC PARTICIPATION

Public participation is an integral part of the application of the WFD. An overview of concepts and scope is carried out, followed by an analysis of specific issues associated to public participation in Portugal.

Goals of public participation in coastal management

- Transparency: Relevant information should be made accessible to the public, and all non-classified information should be public recorded by default
- Hearing of interested parties: This is the core of public participation, stakeholders should be heard, their views duly considered, and addressed
- Citizenship and environmental education: Effective public participation does not grow out of thin air, it must be learned, preferably through experience and action
- Data mining: Public participation may yield a large amount of useful data

Two modes of collaborative monitoring merit a comment. The first is the co-operation between



environmental Non-Governmental Organisations and schools. The second is the use of low-cost sensors, which dramatically improves the ability of a volunteer to gather scientifically valid data. Both have the potential to generate a huge amount of relevant, cost-effective information. Public intervention may also be important for emergency alert purposes, such as oil spills or dead dolphins, although in this case there must be a competent authority with permanent real-time response capacity.

Finally, the specificity of public participation in coastal management is examined in detail, and a methodology is proposed for the design and implementation of an information system designed to deal with the two-way information flow between the management community and the public at large.

PROBLEM DEFINITION AND OBJECTIVES

THE WATER FRAMEWORK DIRECTIVE

General aspects

The approval by the European Union of Directive 2000/60/EC, commonly known as the Water Framework Directive (WFD), established a comprehensive set of objectives for water quality in European waters.

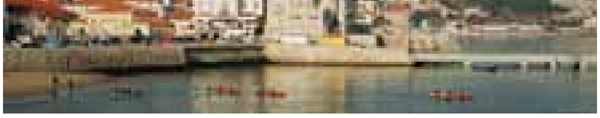
This directive establishes a framework for community action in water policy and management concerns, and applies to all waters, including groundwater, inland surface water, and coastal and transitional waters.

Main objectives of the WFD

- Prevent further deterioration of water resources, protecting and enhancing ecosystem status
- Promote sustainable water use based on long-term protection of water resources
- Enhance protection and improvement of the aquatic environment using specific measures in order to obtain a progressive reduction of discharges, emissions and losses of priority substances, as well as the cessation or phasing out of discharges and emissions of priority hazardous substances
- Ensure the progressive reduction and prevent further pollution of groundwater
- Contribute to mitigate the effects of floods and droughts

Purpose of the WFD objectives

- Assure the provision of water of good quality and quantity for human consumption as well as for the needs of other socio-economic activities, in a sustainable manner
- Protect territorial and marine waters, especially through elimination of sea water pollution
- Achieve the objectives of relevant international agreements, including those which aim to prevent and eliminate pollution of the marine environment



All this can be summarised in a key objective of WFD: To achieve a good water status for all community waters by the year 2015.

Transitional and coastal waters, typology and reference conditions

The WFD defines transitional waters as "bodies of surface water in the vicinity of river mouths which are partly saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows" and coastal waters as "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."

The Typology and Reference Conditions for Portuguese Transitional and Coastal Waters (TICOR) project provided a definition of typology in Portuguese Transitional and Coastal Waters (TCW), and reviewed the most promising methodologies for the establishment of type-specific reference conditions.

DEVELOPMENT OF A MONITORING PLAN

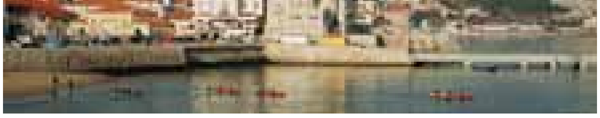
Justification

The implementation of the WFD raises many challenges, which are widely shared by Member States. These include the complexity of the text and the range of possible solutions to scientific, technical and practical questions, the extremely demanding timetable, incomplete technical and scientific basis with some fundamental issues in Annex II and V, which need further elaboration in order to make the transition from principles and general definitions to practical implementation successful, and a strict limitation of human and financial resources.

Monitoring programmes will determine the compliance of E.U. Member States with the reference conditions defined for each water type. Three types of monitoring programmes are defined in the WFD, each addressing different

Typology, reference conditions and ecological status

- Transitional and coastal waters are divided into different types, based on hydromorphological and physical attributes
- For each of these types there is a requirement to define type-specific reference conditions for the biological quality elements and the supporting quality elements listed in the WFD
- These form the basis for classification of ecological status of water bodies



Monitoring type	Objectives
Surveillance monitoring	• Supplement and validate the assessment of the likelihood that transitional or coastal waters are failing to meet the environmental quality objectives • Efficient and effective design of future monitoring programmes • Assessment of long-term changes in natural conditions in order to distinguish between non-natural and natural alterations in the ecosystem • Assessment of long-term changes resulting from widespread anthropogenic activity
Operational monitoring	• Establish the status of those bodies identified as being at risk of failing to meet their environmental objectives • Assess any changes in the status of such bodies resulting from the programmes of measures
Investigative monitoring	• Where the reason for any exceedences of environmental objectives is unknown • Where surveillance monitoring indicates that the objectives set under Article 4 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 • To ascertain the magnitude and impacts of accidental pollution

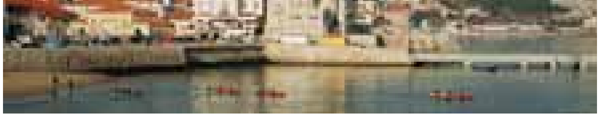
questions, and consequently varying in scope in both time and space, and in the range of quality elements which need to be monitored.

OBJECTIVES

In order to develop a comprehensive monitoring plan for Portuguese TCW the Monitoring Plan for Water Quality and Ecology for Portuguese Transitional and Coastal Waters (MONAE) project was carried out. MONAE brought together an interdisciplinary team, for a period of one year, with the following objectives. (See box below)

In order to achieve these aims, the project team reviewed a range of monitoring approaches used

- Provide an integrated approach to monitor all Portuguese Transitional and Coastal Waters
- Have the potential to address management issues, i.e. to be hypothesis-driven
- Establish the guidelines for monitoring the water quality and ecology of Portuguese Transitional and Coastal Waters throughout the next decades
- Integrate the monitoring requirements of the WFD for Transitional and Coastal Waters
- Define and apply a methodology for the definition of water bodies in Portuguese coastal and transitional types
- Possess internal flexibility, in order to accommodate new methodologies that may be developed and/or applied over its life-cycle
- Use a hierarchical approach, allowing cost-optimisation with respect to information requirements



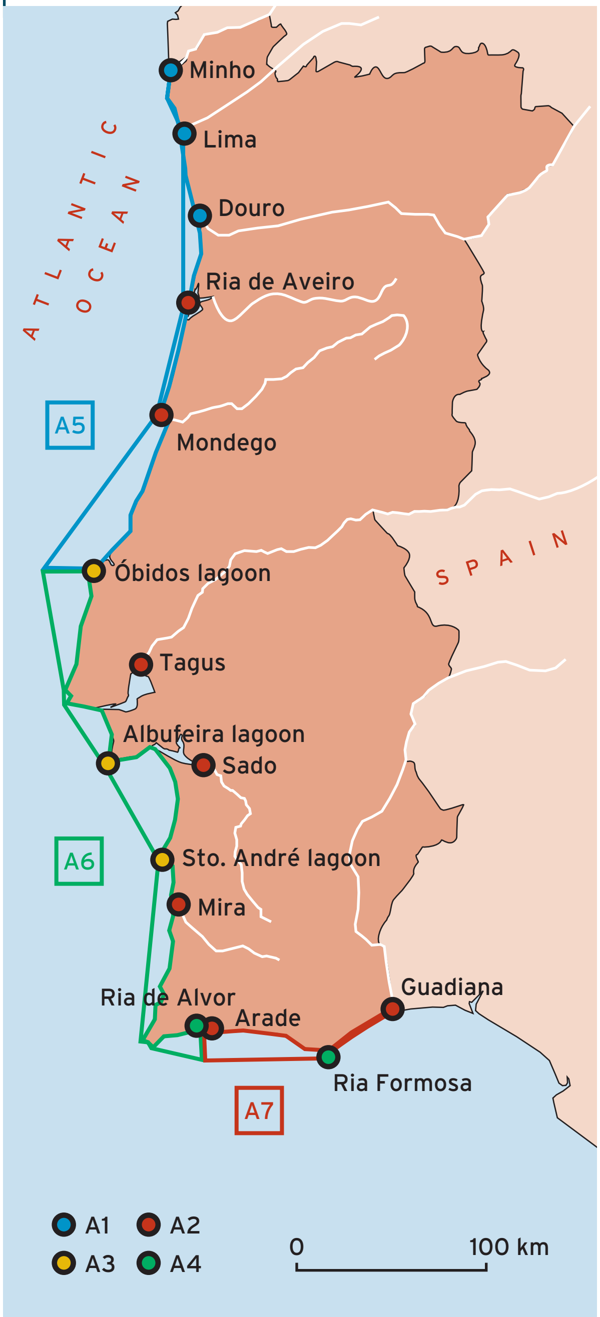
in the E.U., U.S. and elsewhere, and developed a comprehensive guidance document which may be broadly divided into five parts:

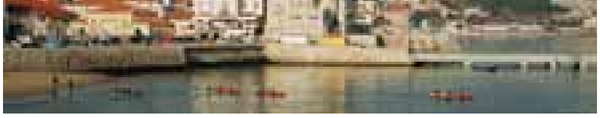
1. State of the art of monitoring in Portuguese TCW, with a general overview of existing information, gap analysis, WFD compliance, and comparison with historical data in other countries;
2. Spatial scope of the monitoring work which must be undertaken in order to address the requirements of the WFD, and proposed division of transitional and coastal water bodies;
3. Detailed monitoring plans for the three types of monitoring activity. This does not identify specific station locations or sampling events at the system scale, but provides a robust guidance for the implementation of monitoring plans, as regards design, questions to be addressed, and expected outputs and outcomes;
4. Economic analysis of the various types of monitoring activity, including financial aspects, non-compliance issues and benefits;
5. Public participation in monitoring activities as specified in Article 46 of the WFD: "To ensure the participation of the general public including users of water in the establishment and updating of river basin management plans, it is necessary to provide proper information of planned measures and to report on progress with their implementation with a view to the involvement of the general public before final decisions on the necessary measures are adopted".

SPATIAL AND TEMPORAL SCOPE

Figure 7 shows the transitional and coastal water systems for which monitoring plans must be implemented.

Figure 7. **Map of the Portuguese typology for Transitional and Coastal Waters (transitional and restricted coastal types A1-A4 indicated in colour).**





A summary of the physical and watershed characteristics of the main transitional waters and inshore coastal systems considered in MONAE is shown in Figure 8.

The different stages of application of the WFD are shown in Figure 9, from the approval of the Directive in 2000 until the revision of the programme of measures in 2015.

Article 8 states that comprehensive monitoring plans must be operational by the end of 2006. The concepts and methodologies presented in this book are intended to inform the elaboration of the detailed management plans.

GENERAL APPROACH

Three different themes are key to the MONAE approach, and are shown below.

MONAE themes

- Which questions should a specific monitoring plan address? An alternative statement is: Which hypotheses should a plan test?
- Which is the most cost-effective approach to answering these questions? An alternative statement is: Which Biological Quality Element(s) or Supporting Quality Element(s) and approach (field sampling, experimental, modelling) is best suited to understand the problem?
- What are the yardsticks of success in a monitoring plan? These are of two types: (i) Implementation, i.e. are programme goals being met - examples: Is the sampling covering systems according to the plan? Is the sampling strategy being correctly followed? Are the designated parameters being measured? Does the quality control match plan specifications? (ii) Effectiveness, i.e. does the plan adequately identify whether the management measures are leading to environmental success - examples: does the plan successfully identify whether shellfish/finfish areas are increasing/decreasing? Can it assess how frequency/spatial scope of typical chlorophyll maxima are changing?

In order to pursue these aims, any monitoring plan should enable managers to identify the following:

1. Is there a problem?
2. If so, how severe is it?
3. What is the cause of the problem (including a separation into anthropogenic pressures and natural causes)?

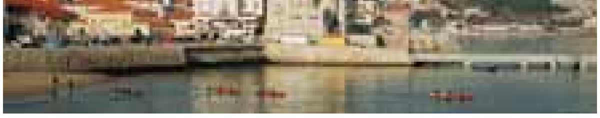


Figure 8. Summary characteristics of the main transitional systems considered in MONAE.

TICOR Systems	TICOR System Type[1]	Watershed Area (X10^3 km)	System Area[2] (km^2)	System Volume[2] (10^6 m^3)	Mean depth (m)	Tidal Range (m)	Residence Time (days)	Watershed Population (X10^3)	Dominant Land Uses	N Load (10^3 t y^{-1}) (OHI)	Eutro Status	HAB Occurrence[3]
Minho estuary	A1	Portugal: 0.8 Total: 17.1	23	67	4 - 11	2	1.5	1 000	Agriculture, forest and other vegetation	10.7	?	Observed/ P (nuisance)
Lima estuary	A1	Portugal: 1.2 Total: 2.5	5	19	2	2	1	80	Agriculture, forest and other vegetation	1.1	?	Observed/ NP
Douro estuary	A1	Portugal: 18.6 Total: 97.6	6	65	8	1.2 - 2.7	Winter: 1 Summer: 9	4 123	Agriculture, forest and other vegetation	40	?	Observed/ NP
Ria de Aveiro	A2	3.4	60	84	1 - 10	2	4	700	Agriculture, forest and other vegetation	1.4	M	Observed/ P (toxics from offshore)
Mondego estuary	A2	6.7	9	21	High tide North Channel: 5-10 South Channel: 2-4	3	North Channel: 2 South Channel: 9	66	Agriculture, forest and other vegetation	North Channel: 0.09 South Channel: 0.051	ML	Not Observed
Tagus estuary	A2	Portugal: 24.7 Total: 80	330	2 200	Upper: 2 Middle: 7 Lower: 46	2.6	19	9 030	Agriculture, forest and other vegetation	30	ML	Not Observed
Sado estuary	A2	7.7	170	770	Upper: 5 Middle: 10	2.7	21	270	Agriculture, forest and other vegetation	2.34	L	Observed/ NP
Mira estuary	A2	1.6	3	17	6	2.4	-	26	Agriculture	0.16	L	Not Observed
Ria Formosa	A4	0.8	49	92	2	2	Spring: 0.5 Neap: 2	Residents: 124 Summer: 211	Agriculture, forest and other vegetation	1.06	ML	Not Observed
Guadiana estuary	A2	Portugal: 11.6 Total: 66.8	18	96	7	1.3 - 3.5	12	1 900	Agriculture, forest and other vegetation	10	M	Observed/ P (nuisance)

[1] - A1 = Mesotidal Stratified estuary, A2 = Mesotidal well-mixed estuary with irregular river discharge, A4 = Mesotidal shallow lagoon; [2] - Values at mean sea level; [3] - NP = no problem, these spp can be observed but sometimes are not blooming or in concentrations that cause problems, P = problem.

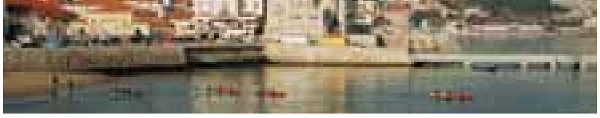


Figure 9. WFD agenda.

		Years															
WFD agenda	**Source**	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
WFD approval		⬛															
Draft register of intercalibration sites	Ann.V				🟥												
Final register of intercalibration sites	Ann.V					🟥											
Final typology in GIS maps	COAST					🟥											
Reference conditions for the intercalibration exercise	COAST					🟥											
Characterisation of River Basin Districts water bodies	Art. 5					🟥											
Review pressures and impacts	COAST					🟥											
Identify sites at risk of not achieving 'good status''[1]	COAST					🟥											
Undertake economic analysis of water use	COAST					🟥											
Intercalibration exercise (application of the monitoring system)	Ann.V							🟧									
Comprehensive monitoring programmes operational	Art. 8							🟧									
First draft of the classification of water bodies (in RBMP draft)	COAST									🟧							
Publish the River Basin Management Plans (RBMP) to include:	Art. 13										🟨						
- Designation of Artificial and Heavily Modified Bodies of Water	Art. 4										🟨						
- Final classification of the ecological status of water bodies	Coast										🟨						
Program of measures to achieve WFD objectives	Art. 11										🟨						
Implement water pricing policies	Art. 9											🟨					
Achieve non-eutrophic status in marine environment	OSPAR/COAST											🟨					
To make measures of the programme operational	Art. 11													🟩			
The combined approach for point and diffuse sources	Art. 10													🟩			
Update of reference conditions	COAST														🟦		
Update characterisation of the River Basin Districts	Art. 5														🟦		
Achieve Good surface water status	Art. 4																🟦
Revision of the programme of measures	Art. 11																🟦

[1] - These items may need to be addressed in the monitoring programme: Member States may not always reach good water status for all water bodies of a river basin district by 2015, for reasons of technical feasibility, disproportionate costs or natural conditions. Under circumstances that will be specifically explained in the RBMPs, the WFD offers the opportunity for two further six-year cycles of planning and implementation of measures.

4. What is the trend?

5. What (if any) measures should be taken?

6. On what scale will such measures have an effect?

These questions may be translated into a WFD-compliant monitoring scheme by grouping them into elements of pressure, state and response, and interpreting the problem in terms of a deviation in system state from High or Good Status for a particular set of biological and supporting quality elements. Figure 10 illustrates how this may be achieved, and includes appropriate management responses to impairments of state due to both anthropogenic and natural pressures.

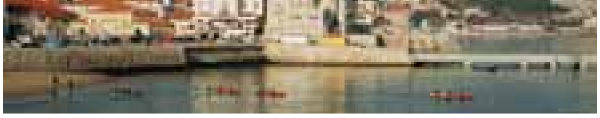
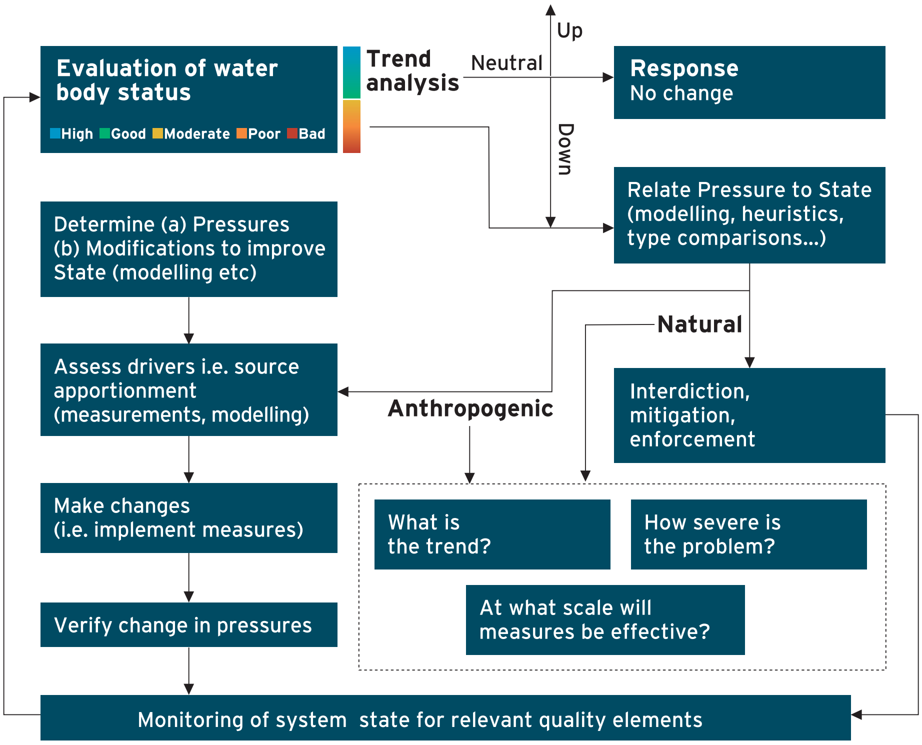


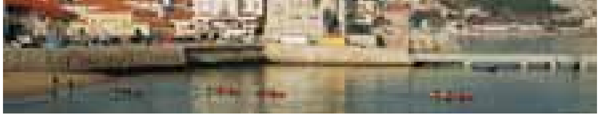
Figure 10. Questions that a monitoring plan should address.



MONITORING HYPOTHESES

A well designed monitoring programme should endeavour to test one or more hypotheses, even if the baseline objective is verification of the compliance status of a set of water bodies to the requirements of the WFD. A statement of the hypotheses to be tested, and the methodologies to be used to perform the tests must be a part of any monitoring plan.

In the case of surveillance and operational monitoring, the hypotheses may address broad questions, such as those listed below in the left pane. General hypotheses such as these may be refined to address specific issues, depending on the systems under consideration. The right pane gives examples of this type of specification.



• H0: Changes in environmental status and health are unrelated to human pressures	• Red tide events in Portuguese coastal waters are unrelated to human use • Changes in estuarine turbidity are unrelated to increased organic production • Given the nature of the Portuguese Atlantic coast, the only state changes in the coastal waters due to basin pressures are in xenobiotics in offshore sediments
• H0: Changes in (abiotic) Supporting Quality Elements are not reflected in Biological Quality Elements	• State changes in dissolved nutrients do not have a discernible effect on eutrophication symptoms such as chlorophyll *a* concentration • State changes of xenobiotics in offshore waters do not presently have a discernible effect on marine biota

Investigative monitoring programmes are by definition aimed at hypothesis testing, in order to further understanding of key processes. These must therefore be built on the basis of meaningful research questions and take the form of scientific research projects.

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METHODOLOGY

This chapter provides a brief overview of the different initiatives and stages followed during the MONAE project life cycle.

MONAE TEAM AND EXPERTISE

This work was carried out by fifteen team members and four consultants, covering a wide range of areas in marine science (Figure 11). A consultant from Northern Europe helped to provide a more balanced approach to the work from an E.U.-wide perspective, and two from the United States allowed us to put this work into a wider context, by taking into account the approaches being followed in the European

Figure 11. Expertise, experience and professional areas of the MONAE team.

Professional areas	Expertise	Experience
Fundamental research	Impact assessment	Cruises
Applied research	Marine monitoring	Field work
Water basin management	Fish ecology	Taxonomy
Fisheries management	Water quality	Mesocosms
Regulation and licensing	Ecological modelling	Experiments
Impact statements	Coastal eutrophication	Database management
Consultancy	Xenobiotics	Mathematical modelling
	Benthic ecology	Geographic information systems
	Hydrology	
	Basin management	
	Fisheries management	
	Regulatory and licensing	

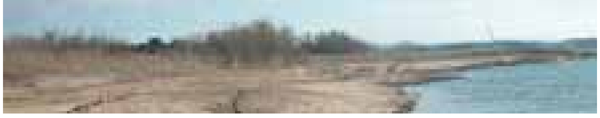
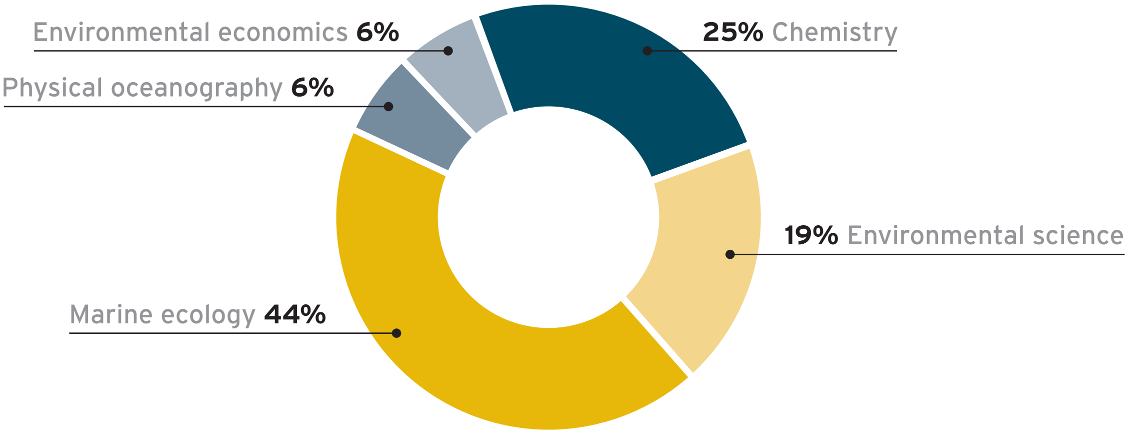


Figure 12. Distribution of the MONAE team subject areas.



Union and in the United States; a consultant from Portugal contributed to take into account the national perspective and objectives.

The nineteen-member project team was divided into five broad subject areas (Figure 12).

STRUCTURE AND TIMING

The MONAE workplan was divided into three work packages, the first of which dealt with system definitions and data collection, the second with classification and monitoring, and the third with MONAE plan definition and project coordination. The project started in February 2004 and had a duration of one year.

MONAE considered all Portuguese transitional and restricted coastal waters subject to the WFD, and all the continental open coastal area as detailed in the *Spatial and temporal scope* of the *Problem Definition and Objectives* chapter. Although the coastal areas of the Azores and Madeira were explicitly excluded, there are numerous guidelines herein which are applicable to those regions. Furthermore, many of the concepts developed in this book are relevant for freshwater monitoring plans.

Work packages, deliverables and products

The list of tasks to be carried out for each work package is shown in Figure 13, although the sequence of task completion varied to ensure a logical progression and to address challenges specific to the tasks.

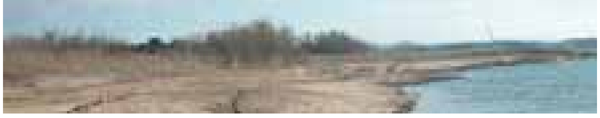


Figure 13. MONAE work packages and tasks.

Workpackage	Tasks
WP1 Data acquisition and definition of system limits	1.1 Assignment of coastal waters to river basin districts 1.2 GIS implementation 1.3 Incorporation of data into a GIS 1.4 Web implementation of databases and compatibility with SNIRH
WP2 Classification and monitoring	2.1 Ranking of coastal systems 2.2 Definition of transitional and coastal water bodies 2.3 Surveillance Monitoring 2.4 Operational Monitoring 2.5 Investigative Monitoring
WP3 Definition of MONAE and coordination of activities	3.1 Cost analysis 3.2 Priorities for monitoring 3.3 Public participation 3.4 Production of the MONAE book, journal, papers and website 3.5 Coordination of activities

Hence, the first tasks (WP2, Task 2.2) were to complete the definition of the systems based on the TICOR project to establish the geographic scope of the project and to complete the historical database for the coastal zone (WP1, all tasks) to provide organized information in relational databases and geographical information systems (GIS) that would support completion of other tasks.

This completed the overall inventory drawn up in TICOR, incorporating the full range of coastal and transitional systems in Portugal to which the WFD is applicable, which was an essential precondition for a comprehensive national water quality and ecology monitoring plan.

MONAE was organised around monthly meetings of the project team, which were roughly split along the three work packages, the first of which dealt with system definitions and data collection, and the second with water body definitions and types of monitoring, and the last with the development of the written plan itself.

There were multiple challenges in accomplishing a programme of this nature in a period of one year, including data issues, integration and transnational questions.

The deliverables identified for the three work packages are shown in Figure 14. These deliverables were consolidated into four types of

Challenges

- Data availability and adequacy. Data collection for a wide diversity of systems highlighted the imbalance between different topics and systems
- Use of a methodology matching the WFD rationale, for ecological status. The classical approach is focused on ecosystems rather than types
- Information flow and coherence between thematic areas
- Uncertainty regarding aspects of WFD guidance currently in progress

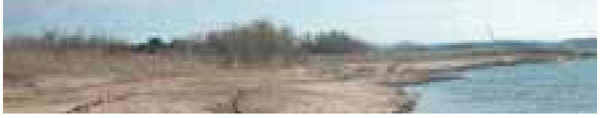


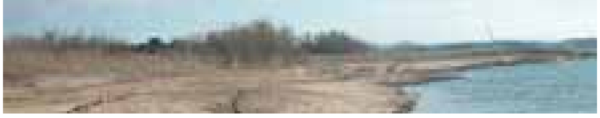
Figure 14. **Deliverables for each MONAE work package.**

Workpackage	Deliverables
WP1 Data acquisition and definition of system limits	Criteria for system delimitation and scientific justification GIS of the coastal system defining and delimiting the various zones Databases for the main transitional and coastal systems GIS of the coastal zone showing sampling stations and data for the relevant WFD and MONAE parameters Data in "SNIRH" format for uploading by INAG Identification of missing parameters, data and information for integration into WP3
WP2 Classification and monitoring	Ranking of systems according to pressure, state and impact, as well as other factors such as a socio-economic relevance Definition of water bodies for transitional and coastal systems Surveillance monitoring programmes Operational monitoring programmes where and when appropriate Investigative monitoring programmes where and when appropriate
WP3 Definition of MONAE and coordination of activities	Definition of products and costs of monitoring options Terms of reference for public participation Final MONAE document Monthly meetings and mini-workshop Final workshop

products, designed to maximise the utility of the work carried out for the decision-makers and water managers who must implement the WFD at a national level.

Consistent with these deliverables, the final products of MONAE are:

1. A digital set of raw data for all the MONAE ecosystems. This dataset supported the work carried out during the project and forms the basis for the historical dataset which will be improved upon by the different WFD monitoring initiatives which must now be implemented. This takes the form of a number of relational databases, published on the web;
2. A geographical information system for the typology and water bodies of Portuguese Coastal and Transitional waters;
3. A set of scientific papers published in peer-reviewed international journals, with the objective of scientifically validating the methodologies explored or developed in MONAE;
4. A book describing the objectives, approach and main outcomes of the project, i.e. the Monitoring Plan for Water Quality and Ecology, aimed at a broad technical readership.

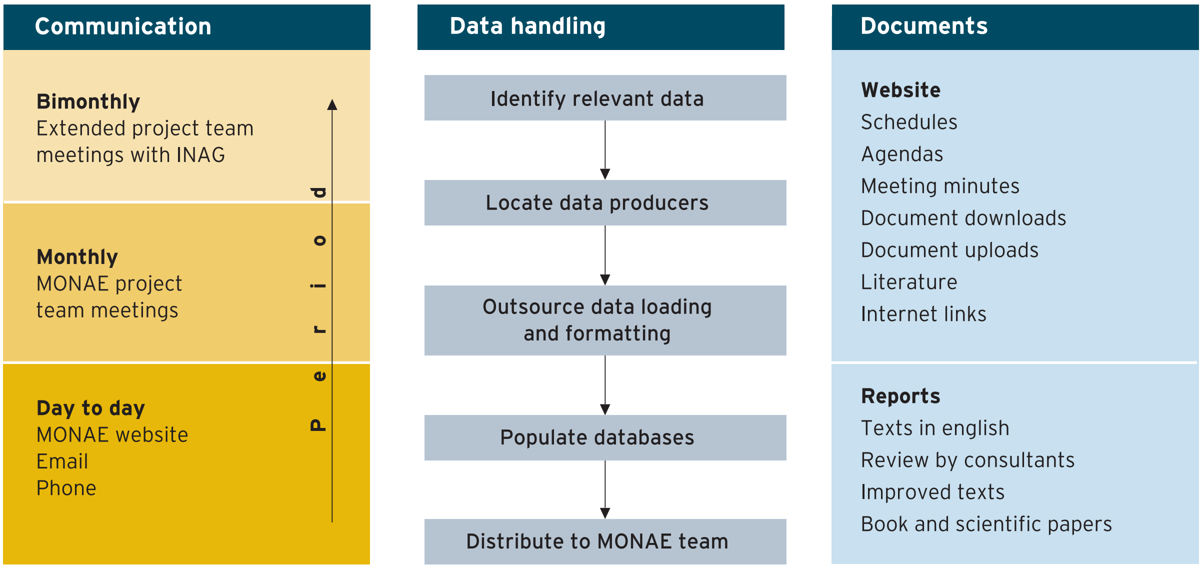


PROJECT MANAGEMENT

The approach taken for project management is shown in Figure 15. Management was divided into three key areas: 1) team communication, 2) data handling and dissemination and 3) document production and delivery.

The website developed for use over the project life-cycle acted as a hub for disseminating information. Every project meeting included a series of talks given by participants, based on work carried out in the interim periods: the slides and other materials from each of these were made available on the website, along with many published articles relevant to the project. The information which was produced during this process formed the backbone of the work presented herein.

Figure 15. Management approach for MONAE.



Throughout the duration of the project, a series of watershed events and milestones were defined at the workshops and were used to reach consensus decisions on a range of concepts, methodologies and practical application issues.

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TOOLS

This chapter presents an overview of the tools used and defined in the comprehensive guidance document produced during the MONAE project and presented in subsequent chapters.

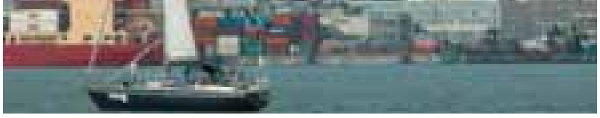
Supporting tools

- Geographic information system
- Water quality database
- Statistics
- Useful models for monitoring

End product methodologies

- Delimitation of water bodies
- Monitoring plan guidelines and case studies
- Framework for a cost-effective response to the requirements of the WFD
- Public participation

It includes a description of the tools that supported the work developed in MONAE, for example for the analysis of available data or for the definition of water bodies, and it also includes tools, such as statistics and different types of models, to be used in the design of site-specific monitoring plans or in the analysis of monitoring results. Additionally, as a product of this project there are several guidance methodologies to be used by managers and scientists in the implementation of monitoring plans for each system, or at a national level in the prioritization of monitoring activities and sites.



SUPPORTING TOOLS

Geographic Information Systems

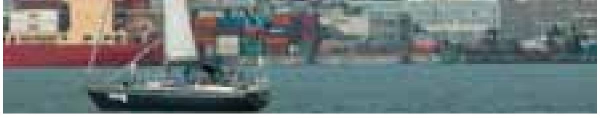
The major improvement to existing geographic information systems (GIS) data and mapping layers was to georeference the raster bathymetries and the vector files of system limits. The georeferencing was made consistent whenever possible with the hydrographic charts from the Portuguese Hydrographic Institute. The objective was to achieve the best fit of the digital bathymetries within the limits of the hydrographic charts without performing transformations to the digital bathymetries.

Key actions

- Improvements to the geographical data collected and produced during the TICOR project
- Use of GIS spatial analysis functions to define transitional water bodies

Most of the transitional systems are only partially covered by bathymetries because their upper limit is defined by salinity criteria – these limits often extend beyond the area covered by the bathymetry. The GIS data were improved by extending the existing shapefile limits to the limits defined in TICOR. Topographic 1:25 000 charts from the Portuguese Army Geographic Institute were used to define the upper limits of transitional systems whenever they were not available in the hydrographic charts.

Definition of water bodies		GIS operations
Natural dimension	Morphology	**Vector editing** Divide the system into sections according to the methodology defined in the Spatial domain chapter
	Salinity	**Interpolation** Interpolate median salinity values calculated with measured data to the entire system **Raster reclassification** Divide the surface into three ASSETS salinity classes
Human dimension	Pressure	**Vector measurements** Calculate areas for land cover categories per sub-basin. Calculate the length of the sub-basin border with the system **Vector editing** Divide the system into sections according to sub-basins. Associate a potential land-based nutrient load with each section
	State	**Interpolation** Interpolate chlorophyll *a* percentile 90 and dissolved oxygen percentile 10 values calculated with measured data to the whole system **Raster reclassification** Divide the surface in accordance with the ASSETS thresholds



The definition of transitional system water bodies was supported by GIS spatial analysis functions.

Databases

The Barcawin2000™ software was used to assimilate new data into existing relational databases. In the *Data overview* chapter the main features of the existing databases are summarised for each system. This type of relational water quality database provides an efficient way to explore the data, since information from very different sources is stored in a standard format, and a set of optimised functions permits efficient searching and listing. Complex searches are possible, e.g. using conditional sample dates, campaign names or tidal situations.

Data integrity is verified on input by means of a series of validation routines, e.g. range checking and flagging of unusual values, and referential integrity assures the consistency of information contained in the various data tables.

Statistics

The statistical models have two functionalities:

- Support for the design of the specific monitoring programmes
- Guidance for the analysis of the monitoring results

The following uses are highlighted for the application of statistics to the results of the monitoring programmes:

Guidance for monitoring results with statistics

Data processing and assessment for:

- Evaluation of random variability and variability induced by anthropogenic activity
- Identification of natural and "controllable" trends which depend on pressures due to anthropogenic drivers
- Determination of cause and effect relationships that support the execution and legal implementation of management actions

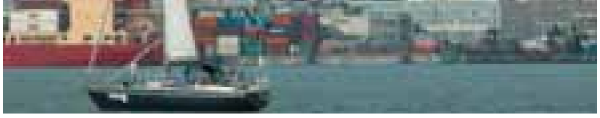
Another area that may need the support of statistical models or techniques is hypothesis testing, especially:

a) To address a "paradox" of the WFD - *Member States must be sure that all Water Bodies have Good Ecological Status but only a subset may be sampled*

b) To identify hotspots or problem areas

Statistical support for monitoring programme design

- **Definition of spatial units (e.g. water bodies):** Analyse the significance of the similarities or differences according to the criteria used for the delimitation of water bodies
- **Definition of temporal strata:**
  a. Sampling events (e.g. in relation to seasons, freshwater inflows, tidal situation/type, etc.)
  b. Frequency of sampling – time intervals between sampling events at each sampling station



Hypothesis testing to address a WFD paradox

If Water Body X is at Good Ecological Status with certain pressures, Water Body Y is also at Good Ecological Status if it has:

- Similar susceptibility
- Equivalent pressure indicators
- Loads in similar relative positions (e.g. with reference to the salinity distribution)

Hypothesis testing to identify hotspots

- Are the differences in relevant variables significant to define the domain/extension of the problem areas?

In this context statistics will be used to verify the significance of observed parameter differences within and outside of the "problem area" or "hot spot"

Useful models for monitoring

There is a two-way link between monitoring and modelling. Monitoring provides the data to be assimilated by models for setup, calibration and validation. On the other hand, modelling provides insight into systems and processes that improve the monitoring approach, including definition of parameters, optimised temporal and spatial sampling coverage through interpolation and extrapolation, and scenario testing and prediction. Figure 16 presents a synthesis of useful models for monitoring, together with their respective roles. As a

Model functions in monitoring

- Help define the monitoring scheme (including temporal and spatial sampling distribution, parameters)
- Complement field data (integrate field surveys and remote sensing)
- Fill data gaps (by interpolating/extrapolating/predicting)
- Data analysis (define state, process, pressure, trends, etc.)
- Data synthesis and conversion to information (inform managers)
- Classify the ecological status (present monitoring results)

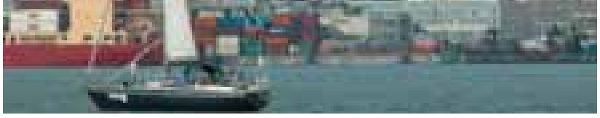


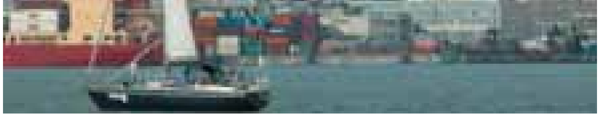
Figure 16. **Useful models for monitoring.**

Type of model	Examples	Role in monitoring
Spatial models	GIS surfaces	Spatial distribution of sampling stations Fill data gaps
Remote sensing of water quality and habitats	Algorithms for detection/ quantification of substances Supervised classification models (e.g. seagrass mapping)	Show problem areas (useful for station distribution) Complement field data surveys Fill data gaps
Complex dynamic models	Hydrodynamics/water quality/ecology	Define measurement frequency Improve monitoring approach Sensitivity analysis
Mass balance/budget models	Mass balance/distribution of substances in different ecosystem Components	Data synthesis Fill data gaps
Screening models	ASSETS/OSPAR-COMPP	Synthesis and conversion to information Evaluation of monitoring success
WFD ecological classification tools	To be defined by ECOSTAT WG 2.A	Presentation of monitoring results (ecological status)

consequence of the functions of models in monitoring these can help to define effective and efficient field programmes, which minimise cost whilst maximising information.

Additionally, there are regulatory (e.g. WFD classification tools) and scientific requirements in the monitoring activities that need modelling support (e.g. spatial interpolation of sampling station data).

To ensure that there is a link between monitoring and modelling, the general process for conducting a model development/ application must be tuned to the monitoring activities.



General considerations for model development/application

Modelling needs and requirements analysis

- Assess the needs of the project (regulatory or scientific need for using a model)
- Define the model purpose, objectives and outputs
- Define the quality objectives to be associated with the model outputs

Model development (conceptualisation and/or implementation)

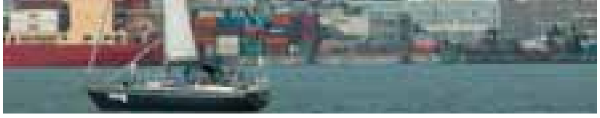
- Model design (either based on existing models or using a new conceptual model)
- Model coding
- Model testing

Model application

- Identify the most current and appropriate data, parameter values, expert opinion and assumptions that are consistent with model requirements. Perform the model calibration
- Evaluate if data/parameters/models for the application meet desired performance criteria
- Model validation
- Summarise results and document

Using these general considerations for model development and application, the key links between monitoring and modelling were highlighted:

- The modelling needs and requirements analysis should be tightly coupled with the identification of the monitoring requirements for a specific site
- The evaluation and validation component of the model application will demonstrate if the monitoring is providing adequate data for modelling
- An evaluation of the results of the model application should be done in order to determine how useful the model results are to monitoring



SPATIAL DOMAIN

The key spatial entities of MONAE are (from top to bottom) *water categories* (only TCW), *types* and *water bodies*. The schematization of these entities is detailed in the *Spatial domain* chapter.

The typology work carried out in the TICOR project resulted in the classification of the Portuguese TCW system into a total of seven types. Each type contains one or more systems, which in turn contain one or more water bodies; the latter is the basic management unit to be defined by E.U. Member States in accordance with the WFD classification requirements.

Criteria for definition of water bodies

Natural characteristics		Human dimension	
Morphology	Salinity	Pressure	System state

The methodology used to define water bodies is based on the WFD guidance documents and on the concept of homogeneous zones. Its application to Portuguese TCW systems is detailed in the *Spatial domain* chapter of this book.

MONITORING PLANS

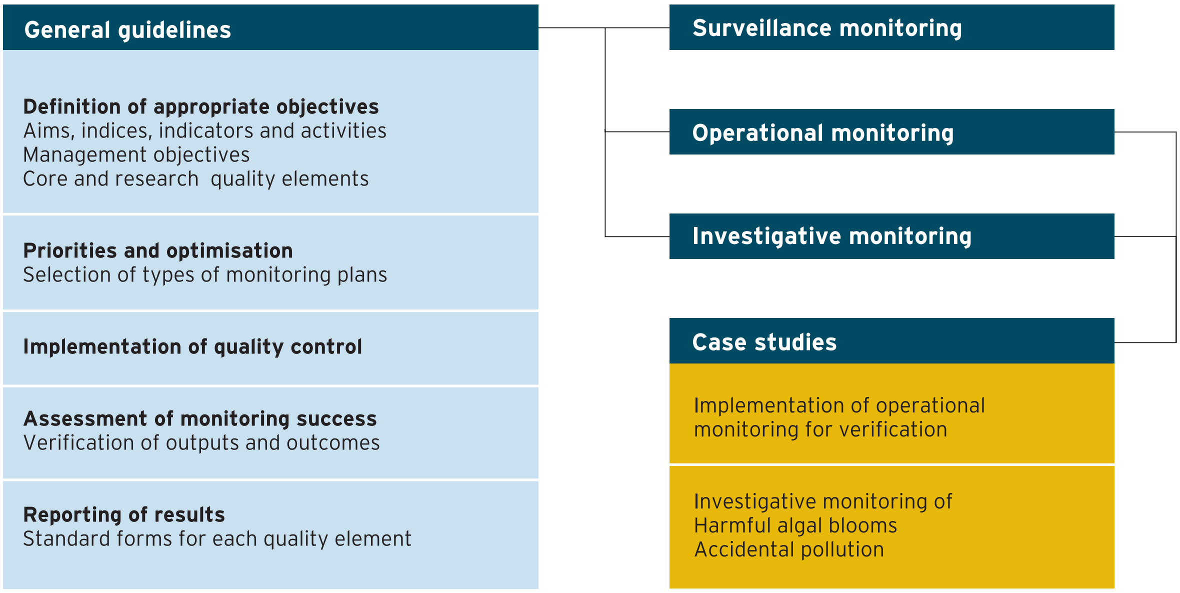
The *Monitoring plans* chapter is the core section of this book.

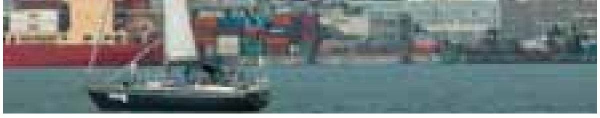
The first section deals with common guidelines to all three types of monitoring plans, and is followed by sections addressing each type in turn (Figure 17).

ECONOMIC ANALYSIS

The *Economic analysis* chapter presents a framework for a cost-effective response to the requirements of the WFD application as regards monitoring. It includes basic definitions of

Figure 17. **General guidance scheme for development of monitoring plans.**





monitoring cost, and develops a methodology for determining monitoring unit costs based on the unit costs of a station-sample pair. An approach was defined for cost comparison analysis among countries by normalising the data to Purchasing Power Parity for the Euro zone (PPP€). This allows a normalised comparison of the overall costs in each country as well as of the relative proportions of cost components, and additionally takes into account inflation. Data from Portugal and other countries were applied for cost estimates for transitional and coastal systems.

An estimate of the annual cost (in 2004 PPP€) of WFD monitoring of Portuguese transitional and coastal systems is made using this methodology, and the general logistical constraints of WFD monitoring are also discussed.

PUBLIC PARTICIPATION

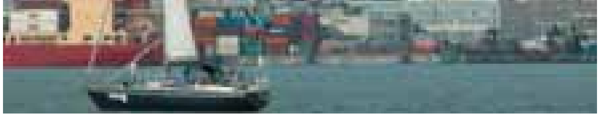
Public participation tools can support coastal water management in the following areas:

1. Transparency of relevant authorities. This may include calling the attention and informing the public on relevant issues (in this case, regarding coastal water quality and management);
2. Gathering interested parties' opinions regarding water management policy;
3. Promoting environmental education of target public, thus generating an increase of public pressure in favour of better coastal water management;
4. Data mining from public initiative, i.e. collaborative monitoring.

Goals (1) and (2) are the ones most directly related to the requirements of the WFD,

Public participation information system tool - key features

- More complex than common databases - must handle a wider variety of information
- Comprehends:
  - Transducer/validator module to manage data input
  - Core system with a multimedia database and data management modules
  - Data treatment module with off-line archive, action dispatcher and report generator
  - The system supports multiple sources and users of data; most of them are also social actors, or relevant "publics"



although goal (3) is perhaps the most important in the long run. Goal (4) has the dual implication of promoting, on the one hand, environmental awareness and public response, and on the other hand of being a source of low-cost, low-tech, high coverage (hence quite cost-effective) data.

A conceptual model of a public participation system was designed and is described in detail in the *Public participation* chapter.

KEY REFERENCES

EPA, United States Environmental Protection Agency. 2002. Guidance for Quality Assurance Project Plans for Modeling. EPA QA/G-5M. Office of Environmental Information, Washington DC. 121p.

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DATA OVERVIEW

The acquisition of data through field observations, sample collection and laboratory measurements is widely used for monitoring purposes. The monitoring effort requires periodic sampling at time intervals that allow a critical evaluation of quality status. In Portugal this type of monitoring is particularly linked to public institutions, which have historically executed monitoring programmes to comply with national and E.U. legislation.

Most of the data collected by academic institutions such as universities does not have the scope required to be considered as monitoring, but provides an adequate background to monitoring programmes. In some cases this type of information is valuable for the definition of WFD reference conditions. Historical data should also be used for the selection of the water bodies as well as for choosing future monitoring stations.

The aim of this chapter is to provide an overview of the monitoring activities that generated historical data for Transitional and Coastal Waters in Portugal and to compare them with those of other countries. The following analysis of the historical dataset is carried out:

- An overview of the existing data and where they are available;
- Examination of whether the existing information is WFD compliant;
- Gap analysis based on the existing data;
- Comparison with historical data available in other countries.

MONITORING IN PORTUGAL AND COMPARISON WITH OTHER COUNTRIES

Institutional context

The monitoring of Portuguese Transitional and Coastal Waters involves a number of different institutions. INAG is the Environmental Ministry agency responsible for the implementation of the WFD in Portugal. The Fisheries Institute (IPIMAR), and Hydrographic Institute (IH) are the main government laboratories which carry

out sampling programmes. Additionally, a number of universities and research centres carry out monitoring work under contract, and execute research projects that inform coastal management.

Monitoring activities

To address national and international legislation or emerging environmental issues, there are ongoing regular sampling programmes (see box below) and more specific programmes that study particular systems and/or environmental issues.

Monitoring products

The datasets obtained by the various agencies and academic institutions are stored locally, and as a rule, synthesis and interpretations are published in national reports and scientific journals. In the last few years some of these datasets have been collated and loaded into web-accessible databases (e.g. http://snirh.inag.pt/ and http://www.barcaweb.com/). Data reports are dispersed throughout the institutions that produced them and initiatives are currently underway to consolidate these into a literature metadatabase. Most of these datasets are not comprehensive surveys and correspond to limited data relating to spot samples at a few stations.

Coordination of the monitoring effort

There is no reporting standard for monitoring outputs, neither is there a consolidated metadata or data repository of monitoring

Regular monitoring activities

Hydromorphology – Regular hydromorphological surveys that include production of maritime charts and tide tables; 12 continuous recording tide gauges; wave climate buoys; coastal weather stations that register meteorological data; regular sampling campaigns to determine salinity, temperature and currents along the coast and sediment mapping.

Marine geology – Sediment sampling surveys in coastal and transitional waters, including the cartography of coastal sediments.

Water quality – Includes seasonal determination of nutrients, photosynthetic pigments, physical parameters, heavy metals and synthetic pollutants in the main estuaries and lagoons.

Phytoplankton – Determination of the phytoplankton community structure along the coast. Determination of phytoplankton concentration in the main transitional and sheltered coastal waters.

Shellfish – Bivalve sampling in coastal areas and lagoons includes abundances and physiological studies. Weekly or fortnightly sampling, depending on the time of the year, carried out for examination of biotoxins along the coast between the Minho and Guadiana estuaries.

Specific pollutants – Include heavy metals, as well as organics such as PCBs, dioxins, and PAHs. Sampling stations have been defined in transitional waters (Minho, Cávado, Ave, Douro, Ria de Aveiro, Mondego, Tagus, Sado, Mira, and Guadiana) and in inshore coastal waters (Ria Formosa, Lagoa de Óbidos). Stations are sampled twice a year and analyses of grain size, total organic carbon, heavy metals, PAHs and organochlorines are carried out. Stations in coastal waters have also been monitored.

activities at a national, regional or system (e.g. estuary or lagoon) basis. Most of the data collected by institutions in Portugal are stored in internal databases, which are not easily available to other institutions or to the general public. However, some of this information can be found in the form of reports located in the libraries of such institutions. The availability of historical data is thus compromised by data fragmentation, which stems from the lack of coordination of monitoring activities both at a system and at a national level.

Monitoring in other E.U. countries and in the U.S.

In the U.K., monitoring of coastal and transitional waters is carried out by different institutions, departments, authorities or boards. All data are consolidated by the Department of the Environment through the National Monitoring Programme, with the production of a coordinated dataset at a national scale.

The U.S. has also adopted a consolidated strategy where the Environmental Protection Agency (EPA) defines the general elements to be contained in the State Monitoring Program. Each state is required to submit its reports and data sets to EPA for incorporation into a national database.

For transboundary systems (e.g. the Minho and Guadiana estuaries) the Wadden Sea Cooperation provides an example of monitoring coordination carried out by the Danish, German and Dutch governments.

OVERVIEW OF HISTORICAL DATA SETS

Figure 18 summarises the currently available historical datasets for Portuguese systems, as well as other less accessible data.

Most of the available historical datasets were collected over the last 20 years, although in some well studied systems, such as the Tagus and Sado, the time series cover the last 30 and 40 years, respectively. The variability in the sampling period, sampling frequency and number of sampling stations is due to the sporadic nature of the studies carried out, which are spatially and temporally conditioned by their objectives and funding. The number of sampling stations in most of the Portuguese systems seems to be spatially adequate for surveillance monitoring purposes. This conclusion comes

Figure 18. **Available historical datasets for Portuguese Transitional and Coastal Waters.**

					Number of records						
							Parameters				
	Type	Systems	Area (km²)	Sampling period	Stations	Samples	Physico-chemical	Biological	Other	Total	Results
Transitional waters	**A1**	Minho	23	1982 - 2002	17	322	25	7	2	34	3 538
		Lima	5	1984 - 2002	31	603	31	37	1	69	8 096
		Douro	6	1987 - 2002	39	292	34	7	1	42	5 006
	A2	Ria de Aveiro	60	1972 - 2002	84	1 441	45	40	6	91	13 499
		Mondego	9	1985 - 2002	48	726	17	261[1]	12	290	18 317
		Tagus	330	1971 - 2002	146	8 702	50	86	15	151	81 003
		Sado	160	1963 - 2002	299	3 801	39	5	16	60	24 164
		Mira	3	1983 - 2002	119	6 469	19	155[1]	4	178	30 704
		Guadiana	18	1977 - 2002	114	24 412	39	7	4	50	60 826
Coastal waters	**A3**	Óbidos	6	1962 - 2004	60	560	5	-	12	6	U
		St. André	2	1984 - 1986	17	1 239	11	3	0	14	9 760
	A4	Ria Formosa	49	1984 - 2002	70	97 021	78	74	13	165	139 932
	A5	From Minho estuary until Cabo Carvoeiro	3 200	1923 - 2003	987	1 730	3	U	U	3	U
	A6	From Cabo Carvoeiro until Ponta da Piedade	4 200	1923 - 2004	1 748	2 856	3	U	U	3	U
	A7	From Ponta da Piedade until Vila Real de Sto António	1 000	1923 - 2001	648	948	3	U	U	3	U

U - Unavailable information; [1] - Includes species list.

from the comparison with other historical datasets worldwide, through the ratio *Nº stations/system area* (Figure 19). Most of the values for Portuguese systems equal or exceed 1 while in other countries this ratio is generally lower than 0.1. It would however be expected that this ratio will not scale linearly, i.e. very large systems will by nature have a lower station density due to cost and logistic constraints.

However, the mean number of station-sample pairs per year (Figure 20) shows that for the

Figure 19. **Number of stations per unit area in Portuguese transitional and coastal systems. Comparison with data from systems in other countries.**

	Systems		Number of stations	Area (km^2)	Stations per km^2	Sources
Portuguese types and systems	**A1**	Minho	17	23	0.7	Historical datasets collected from several Portuguese institutions
		Lima	31	5	6.2	
		Douro	39	6	6.5	
	A2	Ria de Aveiro	84	60	1.4	
		Mondego	48	9	5.3	
		Tagus	146	330	0.4	
		Sado	299	160	1.9	
		Mira	119	3	40	
		Guadiana	114	18	6.3	
	A3	Óbidos	60	6	10	
		St. André	17	2	8.5	
	A4	Ria Formosa	70	49	1.4	
United States	**Barnegat Bay**		121	194	0.6	Historical data in USGS NWISWeb
	San Francisco Bay		40	1 240	0.03	
	Chesapeake Bay		41	11 170	0.004	Chesapeake Bay Program
	Long Island Sound		18	3 400	0.005	EPA monitoring program
	Fleet lagoon		6	5	1.2	EA monitoring
United Kingdom	**Northern Ireland**	Lough Foyle	42	189	0.2	Historical data from several institutions
		Lough Larne	7	8	0.9	
		Belfast Lough	63	168	0.4	
		Strangford Lough	22	148	0.2	
		Carlingford Lough	113	49	2.3	

most part of the systems each station is sampled less than once a year. This means that although there are a reasonable number of sampling stations per system, the corresponding data are rather scarce due to the low sampling frequency (considering the number of years of sampling), which is due to the sporadic nature of the studies carried out and to the lack of a common base of sampling stations across measurement programmes. There may be some skew in this analysis because data shown for other countries do not always include the full set of data collection programmes,

Figure 20. **Station-sample pairs per year for Portuguese systems.**

Types / Systems		Number of stations	Number of samples	Samples per station	Sampling period (years)	Station-sample pairs per year[1]
A1	Minho	17	322	19	20	<1
	Lima	31	603	19	18	<1
	Douro	39	292	7	15	<1
A2	Ria de Aveiro	84	1 441	17	30	<1
	Mondego	48	726	15	17	<1
	Tagus	146	8 702	60	31	2
	Sado	299	3 801	13	39	<1
	Mira	119	6 469	54	19	3
	Guadiana	114	24 412	214	25	9
A3	Óbidos	60	560	9	42	<1
	St. André	17	1 239	73	2	37
A4	Ria Formosa	70	97 021	1 386	18	77
A5	From Minho estuary until Cabo Carvoeiro	987	1 730	2	80	<1
A6	From Cabo Carvoeiro until Ponta da Piedade	1 748	2 856	2	81	<1
A7	From Ponta da Piedade until Vila Real de Sto António	648	948	1	78	<1

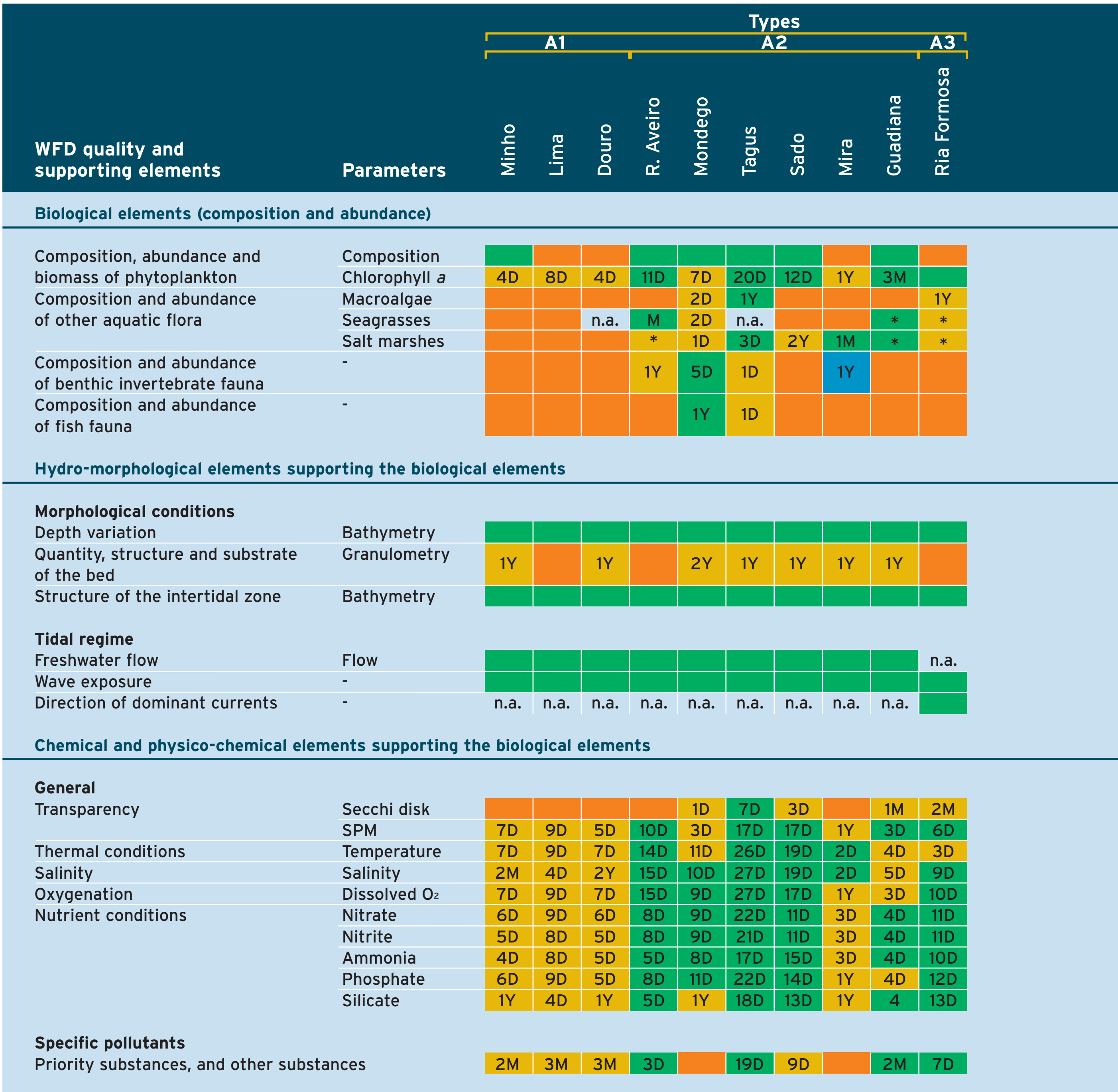
[1] - Samples per station/sampling period.

particularly research projects – the dispersion of sampling stations and lack of effort to establish a common base (where applicable) is an unfortunate reality in many countries.

The sampling frequency and the spatial coverage of the available historical datasets in Portuguese Transitional and Coastal Waters have been reviewed for the WFD quality elements (Figure 21).

All systems present some data limitation in what concerns biological quality elements (BQE), particularly aquatic flora and benthic invertebrate fauna. Type A1 has the least studied systems, with data covering only part of the system. The most complete historical datasets are those for the Ria de Aveiro, Tagus and Sado estuaries and for the Ria Formosa coastal system.

Figure 21. Overview of the Portuguese historical data considering the WFD quality elements in Transitional and Coastal Waters.



		Types									
		A1			A2						A3
WFD quality and supporting elements	**Parameters**	Minho	Lima	Douro	R. Aveiro	Mondego	Tagus	Sado	Mira	Guadiana	Ria Formosa
Biological elements (composition and abundance)											
Composition, abundance and biomass of phytoplankton	Composition	🟩	🟧	🟧	🟩	🟩	🟩	🟩	🟧	🟩	🟧
	Chlorophyll *a*	🟨 4D	🟨 8D	🟨 4D	🟩 11D	🟨 7D	🟩 20D	🟩 12D	🟨 1Y	🟩 3M	🟩
Composition and abundance of other aquatic flora	Macroalgae	🟧	🟧	🟧	🟧	🟨 2D	🟩 1Y	🟧	🟧	🟧	🟨 1Y
	Seagrasses	🟧	🟧	n.a.	🟩 M	🟨 2D	n.a.	🟧	🟧	🟩 *	🟨 *
	Salt marshes	🟧	🟧	🟧	🟨 *	🟨 1D	🟩 3D	🟨 2Y	🟩 1M	🟩 *	🟨 *
Composition and abundance of benthic invertebrate fauna	-	🟧	🟧	🟧	🟨 1Y	🟩 5D	🟨 1D	🟧	🟦 1Y	🟧	🟧
Composition and abundance of fish fauna	-	🟧	🟧	🟧	🟧	🟩 1Y	🟨 1D	🟧	🟧	🟧	🟧
Hydro-morphological elements supporting the biological elements											
Morphological conditions											
Depth variation	Bathymetry	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Quantity, structure and substrate of the bed	Granulometry	🟨 1Y	🟧	🟨 1Y	🟧	🟨 2Y	🟨 1Y	🟨 1Y	🟨 1Y	🟨 1Y	🟧
Structure of the intertidal zone	Bathymetry	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Tidal regime											
Freshwater flow	Flow	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	n.a.
Wave exposure	-	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Direction of dominant currents	-	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	🟩
Chemical and physico-chemical elements supporting the biological elements											
General											
Transparency	Secchi disk	🟧	🟧	🟧	🟧	🟨 1D	🟩 7D	🟨 3D	🟧	🟨 1M	🟨 2M
	SPM	🟨 7D	🟨 9D	🟨 5D	🟩 10D	🟨 3D	🟩 17D	🟩 17D	🟨 1Y	🟩 3D	🟩 6D
Thermal conditions	Temperature	🟨 7D	🟨 9D	🟨 7D	🟩 14D	🟨 11D	🟩 26D	🟩 19D	🟩 2D	🟨 4D	🟨 3D
Salinity	Salinity	🟨 2M	🟨 4D	🟨 2Y	🟩 15D	🟩 10D	🟩 27D	🟩 19D	🟩 2D	🟨 5D	🟩 9D
Oxygenation	Dissolved O_2	🟨 7D	🟨 9D	🟨 7D	🟩 15D	🟩 9D	🟩 27D	🟩 17D	🟨 1Y	🟨 3D	🟩 10D
Nutrient conditions	Nitrate	🟨 6D	🟨 9D	🟨 6D	🟩 8D	🟩 9D	🟩 22D	🟩 11D	🟨 3D	🟩 4D	🟩 11D
	Nitrite	🟨 5D	🟨 8D	🟨 5D	🟩 8D	🟩 9D	🟩 21D	🟩 11D	🟨 3D	🟩 4D	🟩 11D
	Ammonia	🟨 4D	🟨 8D	🟨 5D	🟩 5D	🟩 8D	🟩 17D	🟩 15D	🟨 3D	🟩 4D	🟩 10D
	Phosphate	🟨 6D	🟨 9D	🟨 5D	🟩 8D	🟩 11D	🟩 22D	🟩 14D	🟨 1Y	🟨 4D	🟩 12D
	Silicate	🟨 1Y	🟨 4D	🟨 1Y	🟩 5D	🟨 1Y	🟩 18D	🟩 13D	🟨 1Y	🟩 4	🟩 13D
Specific pollutants											
Priority substances, and other substances		🟨 2M	🟨 3M	🟨 3M	🟩 3D	🟧	🟩 19D	🟨 9D	🟧	🟩 2M	🟩 7D

n.a. - "not applicable"; * - means only species composition is available.

Sampling frequency

D - Several days in the same month, most of the year
M - Once a month during part of the year
Y - No more than twice per year
The sampling period in years is indicated before letters

Spatial coverage in the system

🟧 No data
🟨 Part
🟩 All

CONCLUSIONS

There is a large quantity of data for Portuguese Transitional and Coastal Waters. However the datasets are concentrated both in time and space, which means that in most cases they are not representative of a comprehensive system survey. This is due to the specific nature of the sampling design, designed to address research objectives rather than monitoring objectives.

In several systems the number of sampling stations, although high, covers only part of the system. This issue must be addressed when designing future monitoring plans, since there is a need to choose representative sampling stations in accordance with the water bodies defined for an effective implementation of the WFD.

Overall, this analysis suggests that much of the data acquisition has occurred as part of initiatives that would be tentatively classified under the WFD as operational and investigative monitoring. Surveillance monitoring seems to have been undertaken only in particular systems; this is identified as a serious gap in current knowledge.

The present data overview shows that most of the datasets cannot be considered WFD compliant due to the lack of data availability for several of the biological quality elements (particularly aquatic flora, benthic invertebrate fauna and fish fauna) in most of the systems – the Ria de Aveiro, Tagus and Sado have the most complete datasets concerning biological quality elements. Apart from the spatial limitations referred above, particularly those observed in type A1, the data for most of the hydromorphological and physico-chemical supporting elements are accessible for most systems.

The fragmentation of the monitoring outputs must be addressed for WFD compliant monitoring of Portuguese Transitional and Coastal Waters. Guidelines on the structure of each monitoring type are given in the introductory section of the *Monitoring plans* chapter.

KEY REFERENCES

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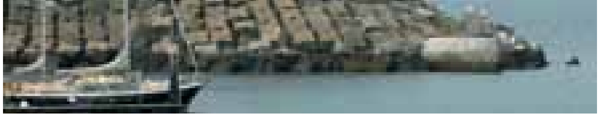
SPATIAL DOMAIN

The objectives of this chapter are to review the WFD typology for Portuguese TCW, and to develop and test a methodology for the definition of water bodies. A consistent and manageable set of transitional and coastal water bodies is a key component in the development of appropriate monitoring plans.

- Review the typology for Portuguese Transitional and Coastal Waters
- Outline the rationale for identification of water bodies
- Apply the methodologies developed for the definition of water bodies in Portuguese TCW
- Present the results obtained for water body definition in two well studied systems
- Define water bodies in all transitional and coastal Portuguese systems larger than 1 km^2 (minimum area recommended in the WFD Guidance on the Common Understanding of Terms) using this methodology



TYPOLOGY REVIEW

The typology for Portuguese Transitional and Coastal Waters was defined in the TICOR Project (Figure 22 and Figure 23).

IDENTIFICATION OF WATER BODIES

The WFD Guidance on Monitoring states that "water bodies are the units that will be used for reporting and assessing compliance". Article 2.10 of the WFD defines a body of surface water as "a discrete and significant element of surface water such as (...) a transitional water or a stretch of coastal water". The water body is, according to the Guidance on Monitoring, "a sub-unit in the river basin (district) to which the environmental objectives of the Directive must apply" and should not extend over different

Figure 22. **Typology for Portuguese Transitional and Coastal Waters.**

Type	Descriptor	Obligatory factors		Optional factors	Systems
Transitional waters					
A1	Mesotidal stratified estuaries	Latitude: Longitude: Tidal range[1]: Salinity:	41º 50' N to 41º 08' N 08º 41' W to 08º 53' W 3.5 m (Mesotidal) Polyhaline (24 psu)	Mixing conditions: Stratified	Minho estuary Lima estuary Douro estuary Leça estuary
A2	Mesotidal well-mixed estuaries with irregular river discharge	Latitude: Longitude: Tidal range: Salinity:	40º 37' N to 37º 09' N 08º 43' W to 07º 23' W 3.3-3.8 m (Mesotidal) Polyhaline (20 psu)	Mixing conditions: Well-mixed	Ria de Aveiro Mondego estuary Tagus estuary Sado estuary Mira estuary Arade estuary Guadiana estuary
Coastal waters					
A3	Mesotidal semi-enclosed lagoon	Latitude: Longitude: Tidal range: Salinity:	9º 26' N to 38º 05' N 09º 13' W to 08º 47' W 2 m (Mesotidal)[2] Mesohaline[3]	Shape: Semi-enclosed Depth: < 2m	Óbidos lagoon Albufeira lagoon St. André lagoon
A4	Mesotidal shallow lagoon	Latitude: Longitude: Tidal range: Salinity:	36º 58' N to 37º 08' N 07º 51' W to 08º 37' W 3.4 m (Mesotidal) Euhaline (35 psu)	Shape: shallow Depth: 2m	Ria de Alvor Ria Formosa
A5	Mesotidal exposed Atlantic coast	Latitude: Longitude: Tidal range: Salinity:	41º 50' N to 39º 21' N 08º 41' W to 09º 24' W 3.3-3.5 m (Mesotidal) Euhaline (35 psu)	Wave exposure: exposed	From Minho estuary until Cabo Carvoeiro
A6	Mesotidal moderately exposed Atlantic coast	Latitude: Longitude: Tidal range: Salinity:	39º 21' N to 37º 04' N 09º 24' W to 08º40' W 3.4-3.5 m (Mesotidal) Euhaline (35 psu)	Wave exposure: moderately exposed	From Cabo Carvoeiro until Ponta da Piedade
A7	Mesotidal sheltered coast	Latitude: Longitude: Tidal range: Salinity:	37º 04' N to 37º 11' N 08º 40' W to 07º 24' W 3.4 m (Mesotidal) Euhaline (35 psu)	Wave exposure: sheltered	From Ponta da Piedade until Vila Real de Sto. António

[1] - Mean spring tidal range; [2] - During periods of free connection to the ocean; [3] - Strongly influenced by occasional freshwater inputs and by cycles of temporary communication with the ocean.

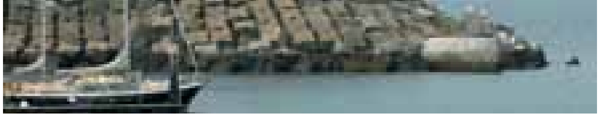
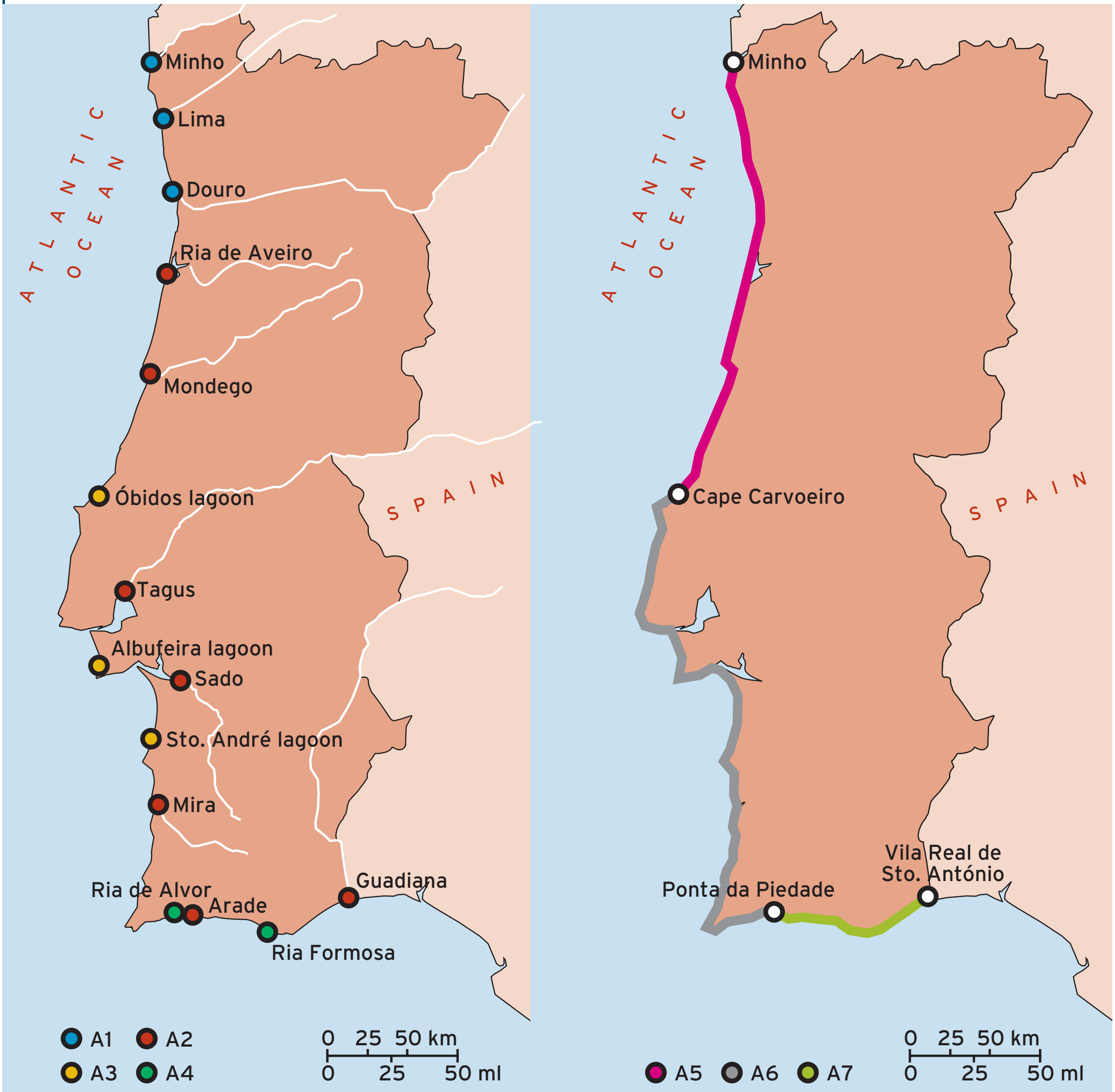


Figure 23. Map of the typology for Portuguese Transitional and Coastal Waters.



TYPOLOGY OF TRANSITIONAL WATERS AND SHELTERED COASTAL WATERS

		A1	A2	A3	A4
Area	High water	32	630	9	94
(km²)	ZO	32	586		55
	Low water	30	393		37
Volume	High water	170	4 242	18	400
(10^6 m³)	ZO	122	3 233		182
	Low water	85	2 457		89

TYPOLOGY OF OPEN COASTAL WATERS

	A5	A6	A7
Area	3 200	4 200	1 000
(km²)			
Volume	195 000	295 900	27 600
(10^6 m³)			

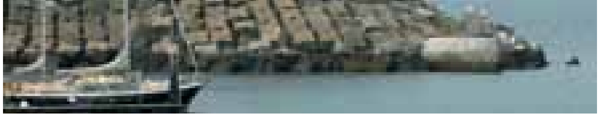
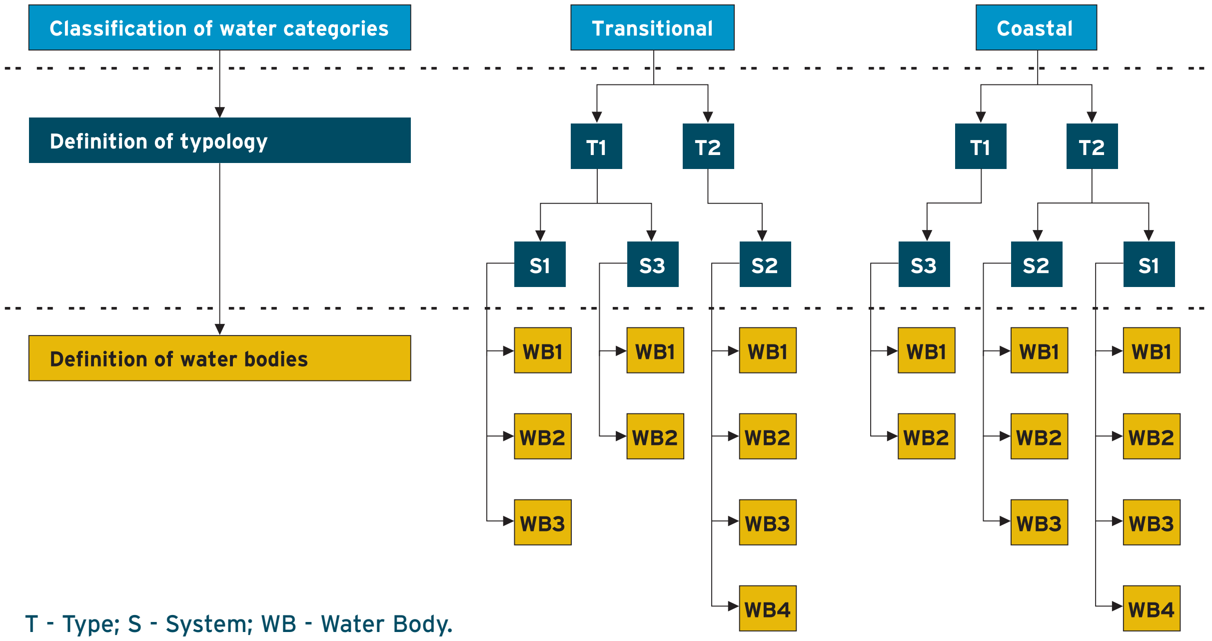


Figure 24. Summary of the key spatial elements of the WFD.

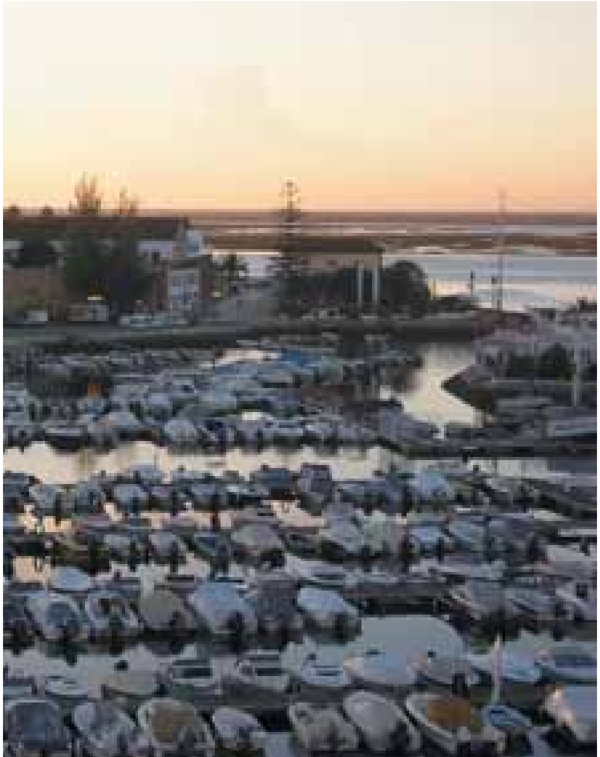


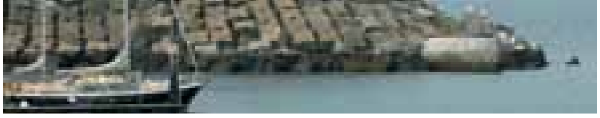
T - Type; S - System; WB - Water Body.

typologies. Figure 24 summarises the relationship between these definitions.

The main goal of identifying water bodies is "to enable the status to be accurately described and compared to environmental objectives". Therefore, "a discrete element of surface water should not contain significant elements of different status since a water body must be capable of being assigned to a single ecological status class". However, the fragmentation of surface waters into "unmanageable numbers of water bodies should be avoided". The guidance also states that "where there are numerous and significant differences in status the number of water bodies should also be numerous; where the status is similar, water bodies will tend to be larger in size and fewer in number".

Although the criteria for water body definition should be based initially on geographical and hydrological determinants, the key descriptor is the status of a particular area, which should be considered homogeneous and significantly different from adjacent areas. Therefore, the identification of the relevant anthropogenic pressures is an additional criterion to be considered for the definition of water bodies, as





stated in Annex II of the WFD. For that purpose the identification and estimation of significant point and diffuse pollution from urban, industrial and agricultural uses must be carried out.

DEFINITION OF OPEN COASTAL WATER BODIES

The methodology described herein applies to the open costal water types (A5, A6 and A7) and takes into account the requirements defined in the WFD and guidance documents discussed above.

The criteria proposed for defining Open Coastal Water Bodies aim to separate open coastal areas influenced by estuarine systems from the rest of the open coast. This is in line with numerous studies of sediments, physics, biology and contamination in the coastal zone. Two categories of Open Coastal Water Bodies may therefore be considered:

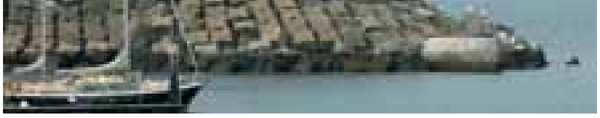
(i) Category A - Coastal water adjacent to estuaries and coastal lagoons that receive significant quantities of freshwater over the whole year, and concomitantly receive anthropogenic discharges from land;

(ii) Category B - Coastal waters from exposed to sheltered regions that show no evidence of being directly and substantially influenced by freshwater, suspended solid discharges and by anthropogenic materials.

Approach for Category A Open Coastal water bodies

The WFD requires that the biological quality elements (BQE) and the supporting quality elements (SQE) should be monitored in coastal waters up to one nautical mile measured from the inshore limit of territorial waters. In Portugal, this limit has been extended to the 30 metre depth isoline, if further offshore. The discharge of some systems influences the water quality and ecology of adjacent coastal regions beyond this limit, either on a regular basis or episodically. The procedure proposed to delimit the geographical areas in the open coastal zone that are influenced by discharges from transitional waters and associated anthropogenic substances is:

(i) Select a conservative parameter such as salinity to delimit the area directly influenced by the exchanges between estuarine systems and adjacent coastal waters. Salinity fields in these areas are greatly influenced by tidal exchange and river flow regimes. Tidal effects are dominant in macrotidal and mesotidal shallow systems. In general, the freshwater input to estuarine systems, and consequently the export to the adjacent coastal area, varies seasonally due to precipitation. Open

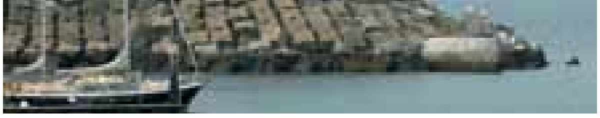


Coastal Water Bodies should be extended further offshore until they do not differ more than 0.5 psu from observations at a reference station located at an adjacent Open Coastal Water Body of Category B (0.5 psu is proposed to avoid extensive areas for Open Coastal Water Bodies strongly influenced by river plumes).

(ii) Suspended particulate matter (SPM) concentration is the second criterion, as it is greatly influenced by discharges of macrotidal and mesotidal estuaries to the coastal zone. The intensity and extent of the SPM plume vary with tidal state and type, and tend to be maximum in periods of high river flows. Strong winds and storm conditions may also increase the SPM concentrations in coastal waters due to bottom resuspension, but those values should not be considered for delimiting Open Coastal Water Bodies. For the SPM concentration, Open Coastal Water Bodies should be extended further offshore until concentrations do not differ more than one order of magnitude from the values recorded at the reference station at the adjacent category B Open Coastal Water Body. This broad interval is designed to discriminate alterations due to estuarine discharges from natural variations occurring in the SPM concentration field.

Contaminants may behave non-conservatively from transitional to coastal waters, and consequently salinity is insufficient to trace the dispersion of contaminants in the coastal zone. Since contaminants are influenced by the pathways of fine suspended particulate matter and incorporated in biogenic particles, the limits of Open Coastal Water Bodies should be defined taking into account the contaminant concentration in both the dissolved and particulate fraction. In this case concentrations should be normalised to aluminium or carbon, according to the affinity of contaminants to particle surfaces, in order to minimise differences related to the particle nature. Open Coastal Water Bodies should be extended until contaminant concentrations determined in suspended particulate matter are lower than the average values registered in adjacent Category B Open Coastal Water Bodies.

The proposed methodology for delimiting Category A Open Coastal Water Bodies is schematically presented in Figure 25. The outer limit of each Open Coastal Water Body is determined sequentially using relative differences to adjacent Category B water bodies for salinity, SPM concentration and contaminant concentration.



Time scale of observations

Shallow macrotidal and mesotidal ecosystems may exchange a large proportion of their water volume with the adjacent ocean due to tidal action. Observations carried out near the outlet channel at low spring tides thus better reflect the presence of estuarine-derived material, and generally conditions differ substantially from those near high tide.

Since exchanges vary seasonally with the river flow regime the extension of each Open Coastal Water Body also increases accordingly. The limit should be calculated for typical winter river flows and around low spring tide.

Extreme flood conditions should not be considered because they will possibly influence broader areas only on decadal timescale.

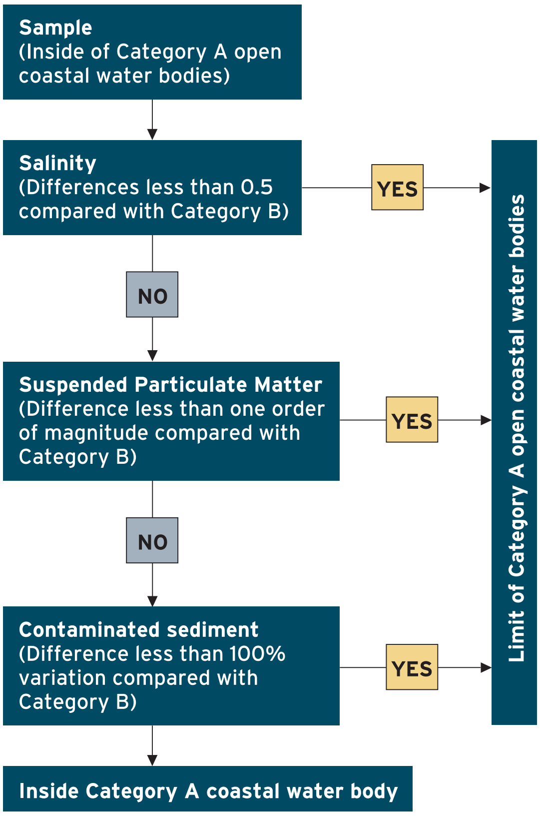
Merging coastal zones contiguous to estuaries

In certain regions the distance between estuarine outlets may be shorter than the size of Open Coastal Water Bodies if the individual influence of each estuarine system is considered. This overlapping effect may result from either strong freshwater discharges or coastal water circulation. In these cases coastal regions adjacent to contiguous estuarine systems should be merged into a single Open Coastal Water Body.

Approach for Category B Open Coastal water bodies

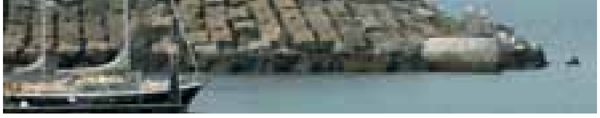
Open Coastal Water Bodies that are not directly influenced by material derived from land should be defined taking into account the typology of the coast and the existence of morphological features that export material to the coastal waters (size of Category A Open Coastal Water Bodies).

Figure 25. Definition of Category A open coastal water bodies.



Monitoring units

To avoid a large number of Open Coastal Water Bodies in zones of small perturbations it may be convenient to consider individual monitoring units within both types of Open Coastal Water Body. Examples of possible monitoring units are areas in the proximity of submerged sewage outfalls or areas of coastal upwelling that show rapid increase of nutrients and of consumption by phytoplankton blooms.



DEFINITION OF TRANSITIONAL AND RESTRICTED COASTAL WATER BODIES

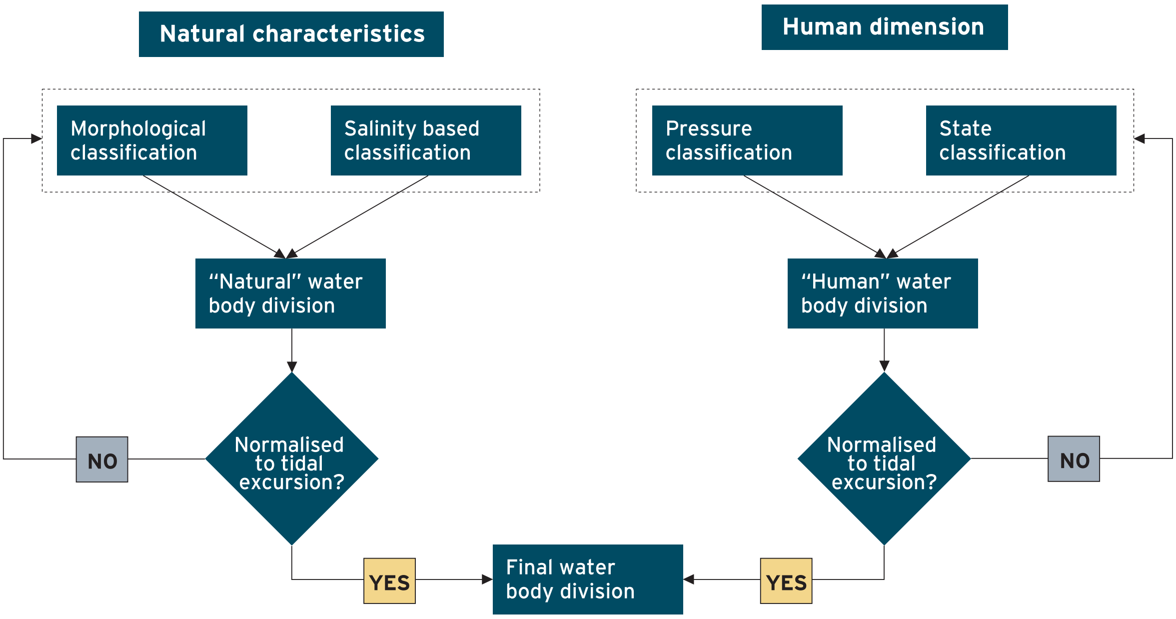
A semi-quantitative methodology was developed tested and verified to allow the division of estuaries (transitional waters) and inshore coastal waters (e.g. coastal, lagoons, embayments, rias) into a meaningful set of water bodies, bringing together both natural criteria and the human dimension. Due to the differences in the scales of ecological processes and in the management of ecosystems it may not be possible to develop a deterministic method that leads to just one final set of water bodies, instead the objective is to use a multi-criteria approach to provide an indication of the number and limits of water bodies which would be appropriate for a particular system. The end result of this analysis will always be subject to final policy decisions by managers, both as regards numbers and limits of water bodies.

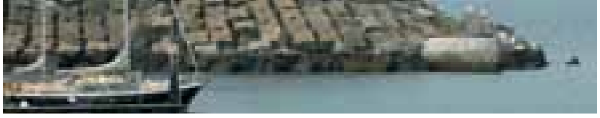
In order to test the methodology, we have applied a range of data handling and modelling techniques to three coastal systems of different characteristics:

- A "tubular" estuary, which has a one-dimensional circulation pattern: Mondego;
- A wide estuary with a markedly two-dimensional (X-Y) circulation: Sado;
- A "dendritic" coastal barrier island system: Ria Formosa.

Vertical stratification is not considered in this classification since a water body by definition includes the whole water column. The methodology for division of transitional and restricted coastal waters into water bodies is illustrated in Figure 26. The application of the natural and human influence criteria used for the water body division and the harmonisation processes are detailed below.

Figure 26. Stepwise definition of water bodies in transitional and restricted coastal waters.





Natural characteristics

Morphology and salinity are natural factors that strongly influence the processes controlling the effect of human pressures on the state of water bodies. Morphological characteristics affect hydrodynamics and mixing, and salinity is a controlling parameter for biogeochemical processes. As a result, these factors were considered primary dividers for the delimitation of water bodies. The morphological and salinity attributes are combined to identify the set of water bodies defined by these natural system characteristics.

Morphology

An adimensional shape factor (Eq. 1) was used for morphological classification. This parameter reflects the dominance of interface or water column processes. For instance, when the ratio σ_i is high, benthic processes and water-atmosphere exchanges tend to control state.

A logarithmic transformation was used due to the wide range of ratios obtained, which can vary by two orders of magnitude. The final morphological classification is obtained through an iterative process of (a) sub-division; and (b) analysis and aggregation.

$$\sigma_i = \log \frac{W_i}{|\bar{z}_i|} \qquad \textbf{(Eq. 1)}$$

Where:

W_i : Mean width of section i (m);
Z_i : Mean depth of section i (m).

Sub-division

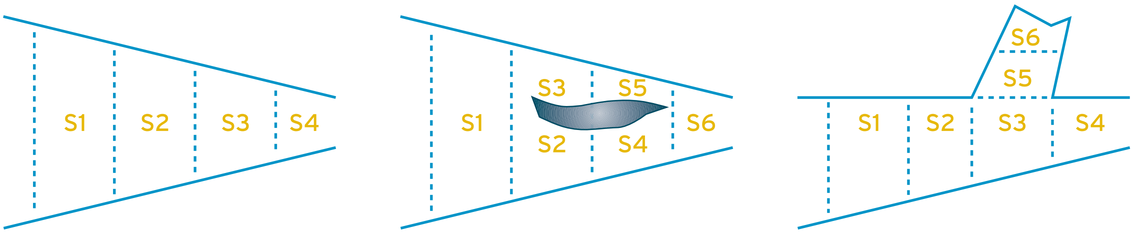
Cross-sectional profiles are drawn from bathymetric data using a geographical information system (GIS). The distance between sections is established as a function of the shape of the system – for a tubular estuary these are equidistant, but for systems with a more complex topography they may be heuristically determined (Figure 27).

$$\phi_{i,i+1} = \log \frac{|\Delta\sigma_{i,i+1}|}{(\sigma_i + \sigma_{i+1})/2} \qquad \textbf{(Eq. 2)}$$

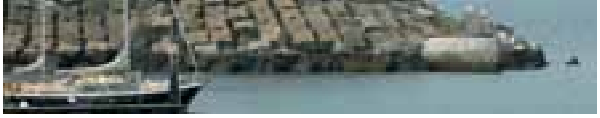
Where:

$\phi_{i,i+1}$: Aggregation factor (no units);
$\Delta\sigma$: Absolute difference between σ_i and σ_{i+1} (no units).

Figure 27. **Plan view of longitudinal division into sections for different estuaries.**



a) Tubular estuary **b)** Tubular with island **c)** Complex topography



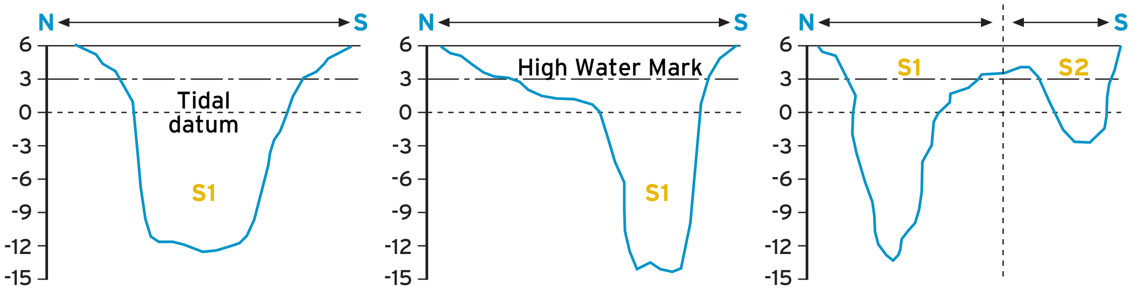
The variable ϕ in Eq. 2 is sensitive to the number of sections used in the calculation: for a very small or very large number of sections the number of water bodies defined by $\phi > 30\%$ tends to 1. A sensitivity analysis was carried out to determine the appropriate number of sections (illustrated for the Mondego estuary in Figure 28) - the number of sections resulting in the highest number of water bodies is used. This provides the most detailed morphological division of a system, which may subsequently be aggregated through the application of other criteria.

Figure 28. **Sensitivity analysis of the number of morphology-derived water bodies as a function of the number of sections applied to the Mondego Estuary.**

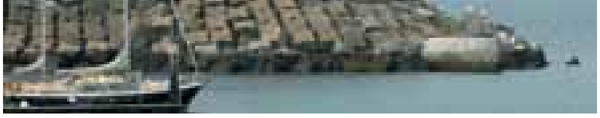
Nº of sections (comments)	Nº of water bodies defined by ϕ > 30%
2 (estuary limits at the head and mouth)	1
4	1
7	1
20	2
40 (sections very close together)	1

The cross-sectional profiles are analysed in order to identify sub-units (Figure 29): these would normally be considered separate when two (or more) deeper channels with an intertidal or island area between them occur (Figure 27b and Figure 29c).

Figure 29. **Lateral division based on morphology, using transverse sections in a hypothetical estuary.**



a) One section **b)** One section **c)** Two sections



Analysis and aggregation

The mean width w_i and mean depth z_i are determined by GIS for each section of the estuary. In areas where the system is split laterally into two or more sections (e.g. S2 and S3 in Figure 27b and S1 and S2 in Figure 29c) these are considered separately.

The shape factor σ_i is calculated for each section, and compared pair-wise to determine an aggregation index ϕ (Eq. 2). Sections are aggregated longitudinally into water bodies when ϕ is below a threshold value. This critical value was defined heuristically to be 30%.

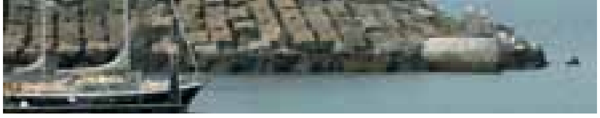
Salinity

A spatial framework based on salinity zonation was applied to provide an additional natural sub-division of water bodies within an estuary, complementing the morphological division. Three salinity classes were defined, based on the NOAA National Estuarine Inventory; tidal fresh (0 - 0.5), mixing (0.5 – 25) and seawater (>25) zones, which broadly correspond to the Venice classification. However, the threshold between the seawater and mixing classes (Venice system euhaline/mixohaline) was adjusted to reflect changes in species distribution of floral and faunal communities along the salinity gradient.

Salinity for each station was determined from long-term salinity records and represents annual average values over the water column. The salinity zones were obtained using an inverse distance interpolator in the GIS, based on the averaged salinity values for each station: tubular estuaries will normally be split into three zones and estuaries with a more complex topography and circulation may additionally be divided laterally. Although not all systems have all three zones, this allows a consistent approach for comparisons among highly diverse systems.

Harmonisation of the natural characteristics division

The results obtained through the application of morphology and salinity dividers are combined into a pre-final set of "natural" water bodies. In cases where the limits derived from morphology



and salinity are close together, the pairs are considered as "bands", and a centreline is defined as a water body separator. In other cases, the combination of the two factors will potentially lead to more water bodies.

However, the tidal excursion is first used as a normalization test: if the length of a water body defined through morphology, salinity, or a combination of the two factors is less than the tidal excursion, its size is increased appropriately, which may lead to a decrease in the number of water bodies. The rationale for this test, which is also applied in the *Human dimension* division, is to ensure that small areas are not considered as water bodies, since tidal circulation will cause the same water mass to be in two or more different water bodies. Given that a water body is defined in the WFD as a management unit, where control measures on the significant pressures potentially result in a change in state, excessively small water bodies will be scientifically meaningless.

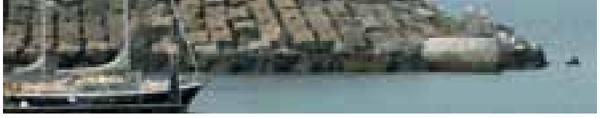
Human dimension

A guidance document on the application of the WFD to transitional and coastal waters provides the following orientation: "The need to keep separate two or more contiguous water bodies of the same type depends upon the pressures and resulting impacts. (...) Such an area of one type could therefore be divided into two separate water bodies with different classifications. If there were no impact from the discharge it would not be necessary to divide the area into two water bodies as it would have the same classification and should be managed as one entity." Both aspects are considered herein for water body division from an anthropogenic standpoint. The pressure factor provides an assessment of loading of the relevant substances to an estuary, and the state assessment allows a division in terms of impact of such discharges, based on a sub-set of appropriate metrics. These metrics are chosen from the list of WFD *Biological Quality Elements* (BQE) and *Supporting Quality Elements* (SQE). These are the same variables that are monitored for fulfilment of US Clean Water Act requirements and used for the EU OSPAR Comprehensive Procedure and thus the methodology detailed here should be broadly applicable.

Pressure

Determination of pressure on an estuarine system for the purpose of defining water bodies involves the following steps:

- Selection of the significant pressure, and choice of representative variables;
- Assessment and partitioning of loads;
- Normalisation, analysis and aggregation.



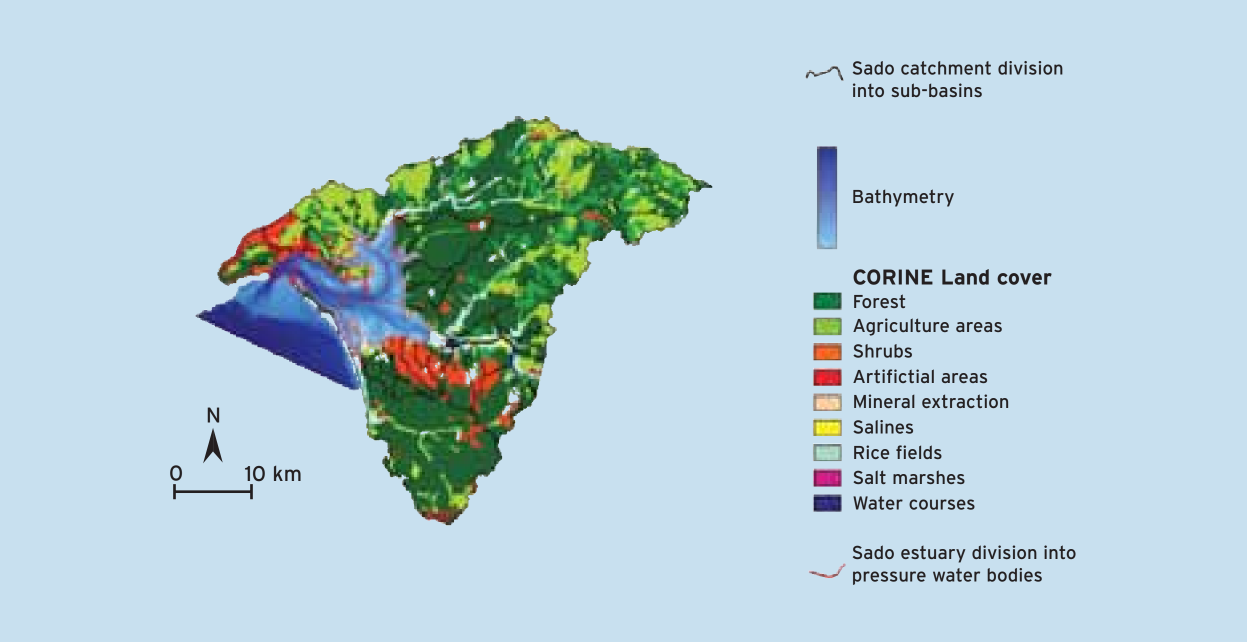
Selection of the significant pressure and representative variables

A variety of pressures may be considered in the application of the WFD for the purpose of defining water bodies and it appears appropriate that the most significant pressure should be selected. In the examples presented below we have chosen nutrient loading, with eutrophication symptoms in the water bodies as a potential impact on state.

Assessment and partitioning of loads

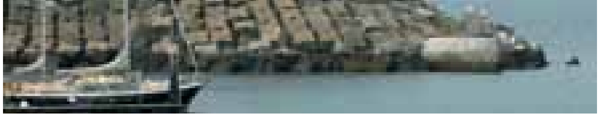
This may be done through a combination of different techniques, such as source inventories or modelling. For our work the Corine land cover database was used (Figure 30), and land use coefficients were applied to determine nitrogen and phosphorus loads. In order to partition the load discharging to different parts of an estuary, the watershed was divided into sub-basins using a digital terrain model (Figure 30), and the final N and P loadings were then determined for each section of the watershed.

Figure 30. **Pressure aggregation based on CORINE land cover mapping for the Sado estuary.**



Normalisation, analysis and aggregation

In order to determine the "pressure-defined" zones of an estuary, the following approach was used: (a) extend the section of each watershed to the estuary; (b) the N and P loading for each watershed sub-basin was normalised by dividing by the estuary shoreline length of the sub-basin; (c) the limiting nutrient for primary production was calculated from the Redfield ratio in the water column; and (d) a similarity index τ was defined heuristically, and used to aggregate contiguous lengths of the shoreline with similar pressure.



$$\tau_{i,i+1} = \frac{|\,\Delta\lambda_{i,i+1}\,|}{(\,\lambda_i + \lambda_{i+1}\,)/2} \qquad \textbf{(Eq. 3)}$$

Where:

$\tau_{i,i+1}$: Aggregation factor (no units);

λ_i : N (or P) load normalised per length of shoreline (kg y^{-1} m^{-1});

$\Delta\lambda$: Absolute difference between λ_i and λ_{i+1} (kg y^{-1} m^{-1}).

This index was calculated using Eq. 3; it is analogous to the approach used in the morphology component, but differs with regard to the selection of an optimum number of sections. Since the watershed sub-basin limits are defined hydrologically, thus establishing the respective shoreline lengths (Figure 30) and the comparison is normalised to unit length there is no pre-selection procedure. Contiguous sub-basins with a value of $\tau < 100\%$ were aggregated pair-wise, providing a pressure-derived definition of water bodies.

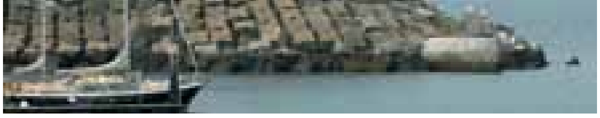
The normalization of watershed loads using shoreline length instead of estuarine area or volume was adopted in order to establishing uniformity of loading (or not) along the shoreline to permit possible aggregation. The differential effects of such an aggregated loading (e.g. due to morphology or mixing) may lead to a subsequent separation based on the indicators of State.

State

The use of appropriate metrics of state to contribute to water body definition is justified because the relationship between pressure and state is strongly influenced by estuarine geomorphology, hydrodynamics and ecological structure. For instance, estuaries subject to similar nutrient-related pressure often exhibit totally different eutrophication symptoms, and in some cases, no symptoms at all. Factors such as water residence time, tidal range, stratification, turbidity and grazing play a major role in determining the nature and magnitude of symptom expression.

The approach followed in the present methodology consists of two steps:

- Selection of a sub-set of appropriate parameters;
- Data analysis and aggregation.



Parameter selection

Appropriate parameters are chosen from the list of BQE and SQE. The relevance is determined from:

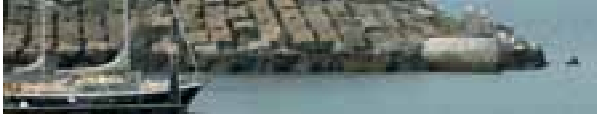
(a) Significant pressures – for instance, if these result in N and P discharge, water column chlorophyll *a* (chl *a*) might be considered appropriate, whereas if the main issue is xenobiotic emissions, lead or mercury in sediments might be the elements of choice;

(b) Key characteristics of the estuarine system – for instance, if eutrophication symptoms are the general category under consideration, opportunistic benthic macroalgae might be more appropriate than chl *a* for fast-flushing or strongly light-limited estuaries. For xenobiotics, benthic diversity or tissue contamination might provide relevant state characteristics.

Data analysis and aggregation

Data on the relevant variables collected for an estuary (e.g. from field measurements or remote sensing) are assimilated at an appropriate time scale and plotted as GIS surfaces. Aggregation may be carried out by establishing concentration dividers for each variable, and using the overlapped surfaces to define the state component of water bodies. This may be done on the basis of established classification systems, or where these do not exist, using a heuristic approach.

In the present study, chlorophyll *a* and dissolved oxygen (D.O.) were used as eutrophication symptoms, with data assimilated over a period of one year. Published classification thresholds were applied, using 90th and 10th percentile cut-off points for chl *a* and D.O. respectively, as indicators of typically elevated (for chl *a*) and low (D.O.) values.



Harmonisation of the human dimension division

Harmonisation of the *human dimension* is carried out in a similar way to the *natural characteristics* division: pressure and state results are combined into a pre-final set of water bodies reflecting the *human dimension*. The water bodies defined through the analysis of state are used in two ways: (a) to link opposite shorelines where there is no significant gradient in state; and (b) to divide (or join) contiguous sections based on pressures when there is (no) significant change in impact, following the WFD guidance. As indicated previously, tidal excursion is also used as a normalization test (Figure 26).

Final definition of water bodies

The final definition of water bodies for an estuary is obtained by combining and harmonising the natural and human components. Boundaries that are close together are aggregated as described previously, by considering a boundary "band" which is then reduced to a centreline. If required, the tidal excursion is used as a "common sense" test to define a final set of water bodies.

Case studies and discussion

Three contrasting systems from Portugal are presented as case studies to test the methodology, in order to highlight the various aspects of its application, including practical difficulties. These systems include two estuaries and one sheltered coastal system, belonging to two different WFD types. They are all well studied systems, for which appropriate data exist at adequate spatial resolution for a period of several years.

Description of test systems

The three systems selected to apply the methodology are shown in Figure 31. The main characteristics of the three systems are presented in Figure 32 including (i) physical parameters which summarise the morphology and circulation, and provide an indication of system susceptibility; and (ii) population data, nutrient loading, Redfield ratios and ASSETS eutrophication status.

The three systems differ substantially in morphology, salinity structure, mixing characteristics, and water residence time. Anthropogenic pressure and state are also different, but in all three systems nitrogen appears to limit primary production (Figure 32).

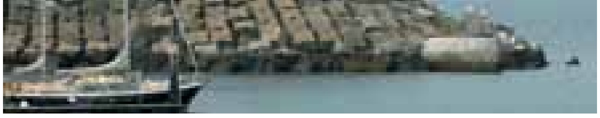
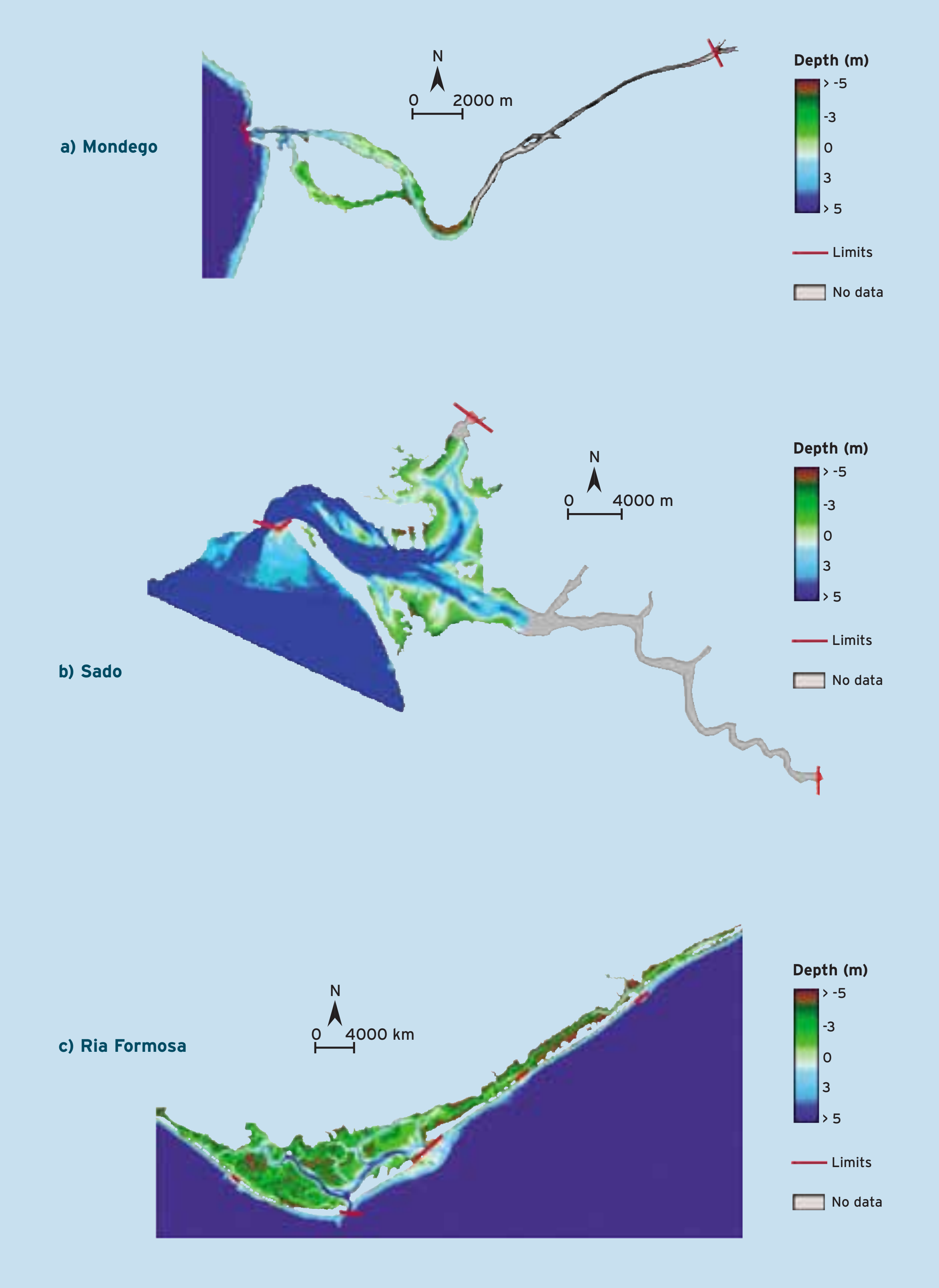


Figure 31. Map of the systems used for case studies: a) Mondego, small tubular estuary, b) Sado, large coastal lagoon estuary, c) Ria Formosa, coastal lagoon.



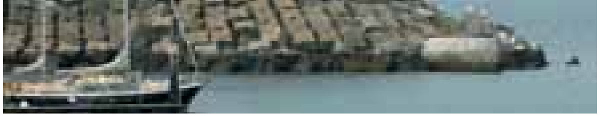


Figure 32. Key features of the Mondego Estuary, Sado Estuary, and Ria Formosa.

Parameters	Mondego Estuary	Sado Estuary	Ria Formosa
Volume (10^6 m^3)	22	500	92
Surface area (km^2)	6.4	180	49
River flow (m^{3}s^{-1})	80	40	-
Tidal range (m)	3.0	2.7	2.0
Mean water residence time (d)	North channel: 2 South channel: 9	32	1
Population	66 000	128 000	145 000
Nitrogen load (t yr^{-1})	143	3 788	421
N load per unit area (g m^{-2} yr^{-1})	22.3	21.0	8.6
Phosphorus load (t yr^{-1})	27	837	83
P load per unit area (g m^{-2} yr^{-1})	4.2	4.7	1.7
Mean Redfield N/P (molar) ratio in the water column	11	4	14
ASSETS[1] grade	Moderate	High	Good

[1] A description of the ASSETS methodology and its application to the three systems is given in the *Key References*.

Natural characteristics

The division based on morphology is shown in Figure 33, providing a first approach for the definition of water bodies. The morphological analysis of the similarity between contiguous sections using the ϕ criterion (Eq. 2), results in the identification of five water bodies both in Mondego and Sado (Figure 33a and Figure 33b).

In shallow systems such as the Ria Formosa, with branched channels and large intertidal areas, it is rather biased to define cross-sections such as the ones drawn for the tubular systems. Figure 33c and Figure 33d show two possibilities for drawing sections and illustrate the difficulties, since the resulting sections would be meaningless for the division of intertidal areas. Additionally, the subsequent division into intertidal and channel areas and application of an adimensional shape factor and aggregation into a final morphological water bodies definition is not adequate due to the heterogeneity of channels and intertidal zones, leading to an unmanageably large set of small water bodies. Instead it is proposed that the division of dendritic systems such as the Ria Formosa should be made using a heuristic criterion using drainage patterns evidenced by the bathymetry (Figure 33e), resulting in this case study in 10 water bodies.

The salinity surfaces were calculated using data that covers all seasons and tidal situations. In the case of Sado and Ria Formosa, the salinity distribution in the estuary is typical of a coastal lagoon and a single water body with salinity greater than 25 is considered in both cases. In the Mondego Estuary (Figure 34) the morphologically defined WB1 and WB2 were merged into the natural WB1 using the tidal excursion criteria and also in agreement with the salinity division. On the contrary the morphological WB4 was split into the natural WB3 and WB4 due to the salinity criteria.

The combination of the two natural factors led in Sado and Ria Formosa examples to a set of water bodies dictated by the morphology. In

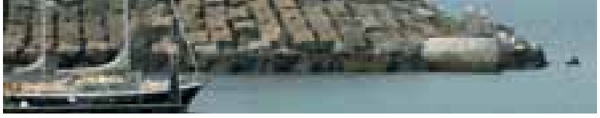
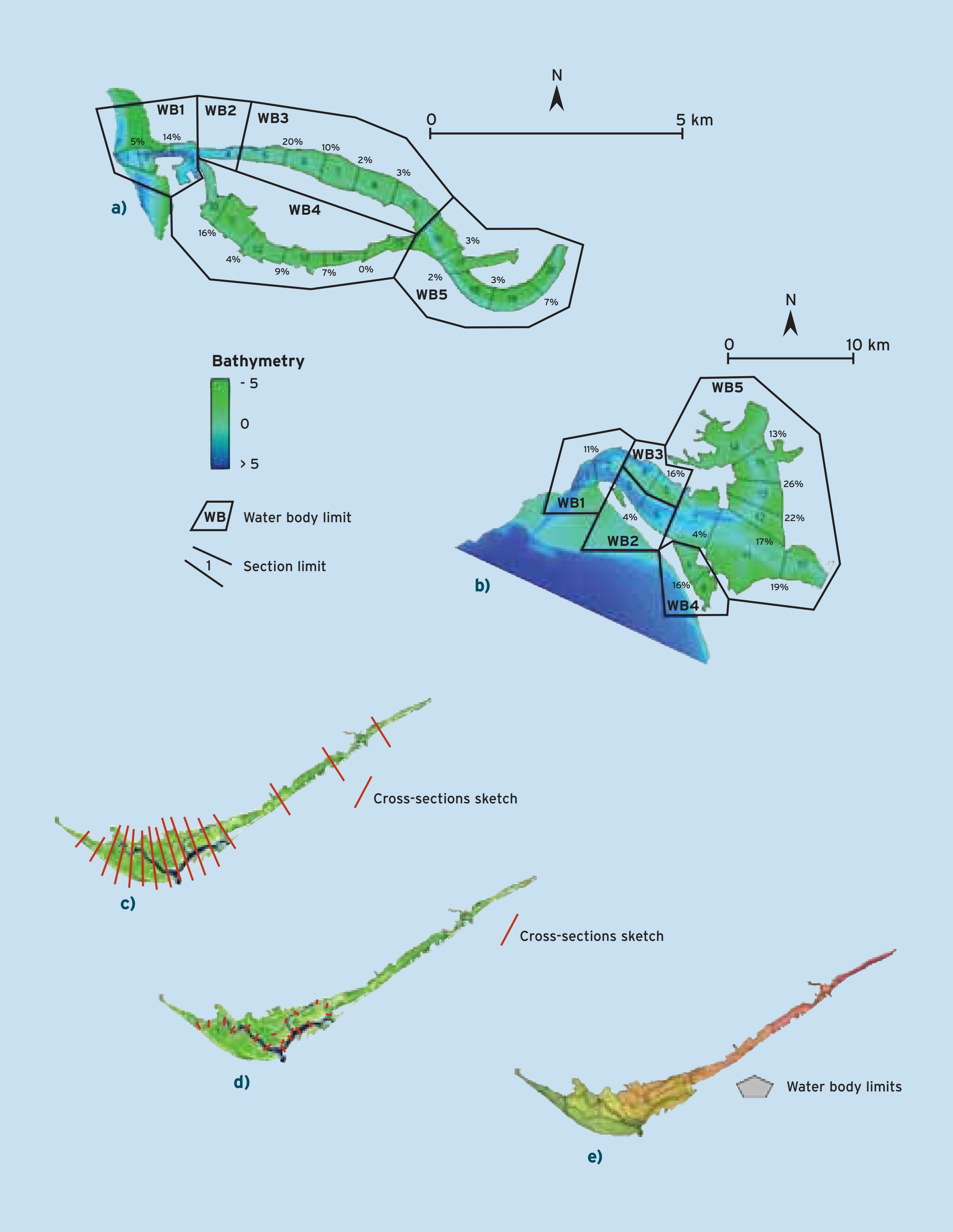


Figure 33. Longitudinal division of the Mondego (a) and Sado (b) estuaries as an example for morphological analysis, showing GIS sections, ϕ values and definition of water bodies based on morphology. Three approaches are shown for the Ria Formosa, due to the difficulty in applying a quantitative approach to this type of system: a cross-sectional division based on (c) the whole system including intertidal areas; (d) only the sub-tidal channels; and (e) the final heuristic division.



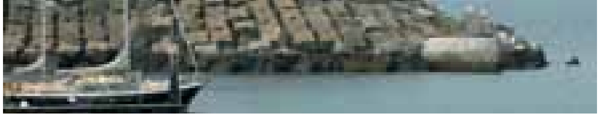
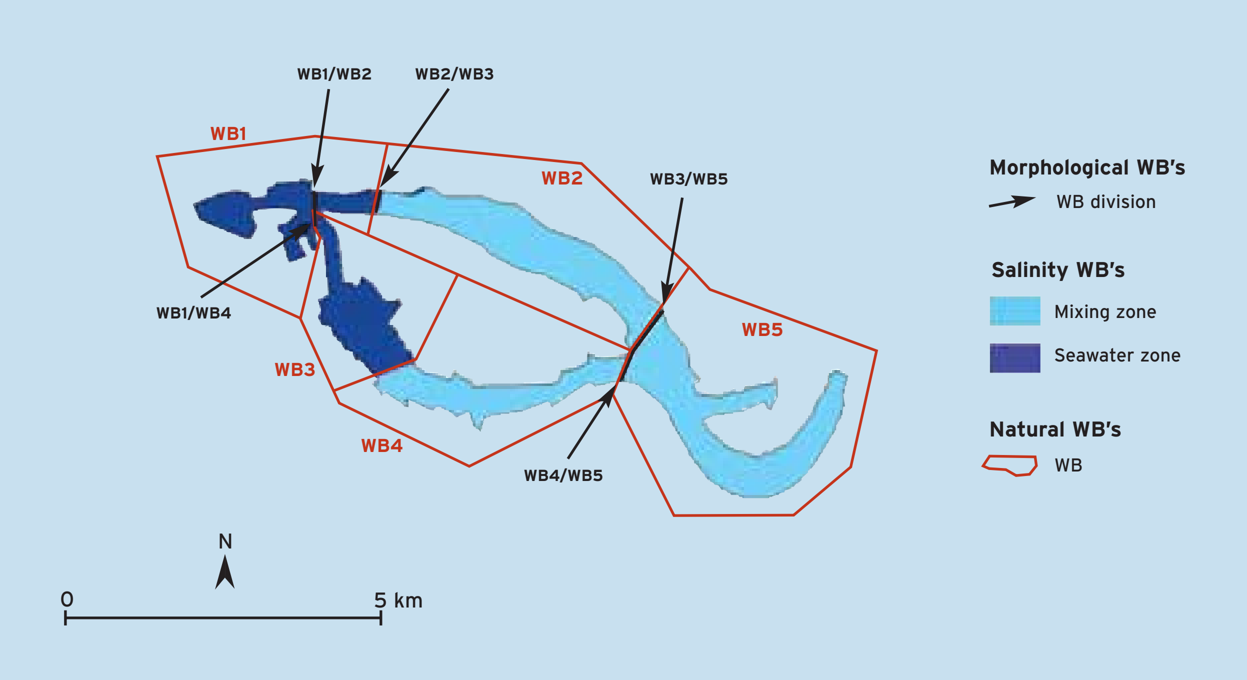


Figure 34. Division of the Mondego Estuary into natural water bodies, combination of the morphological and salinity criteria.



Mondego the natural water bodies result from the combinations of the morphological and salinity criteria.

Human dimension

Figure 35 shows the application of the pressure metric for Mondego and Sado estuaries. In both cases the water column Redfield ratio (in atoms) was below 16, suggesting the use of N as the element for analysis. For the Mondego, the τ threshold (Eq. 3) distinguishes between sub-basins 1 and 2, and 1 and 5, with a τ value of about 160% in both cases. In the case of the Sado, all the contiguous sub-basin values have values of τ > 100%, suggesting the definition of six separate water bodies. In the case of the Ria Formosa this metric provides a division into eleven zones.

The state was determined through the selection of appropriate BQE and SQE; since nutrient input was chosen as the relevant pressure, state was evaluated using chl *a* and D.O. as eutrophication symptoms as described in the *Methodology*. The Ria Formosa case study is exemplified in Figure 36. Both chl *a* and D.O. show that as regards state there is a distinct zone with lower water quality in the western

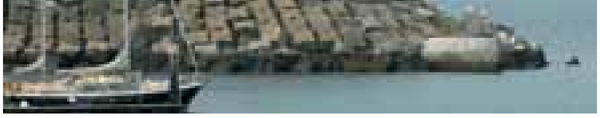
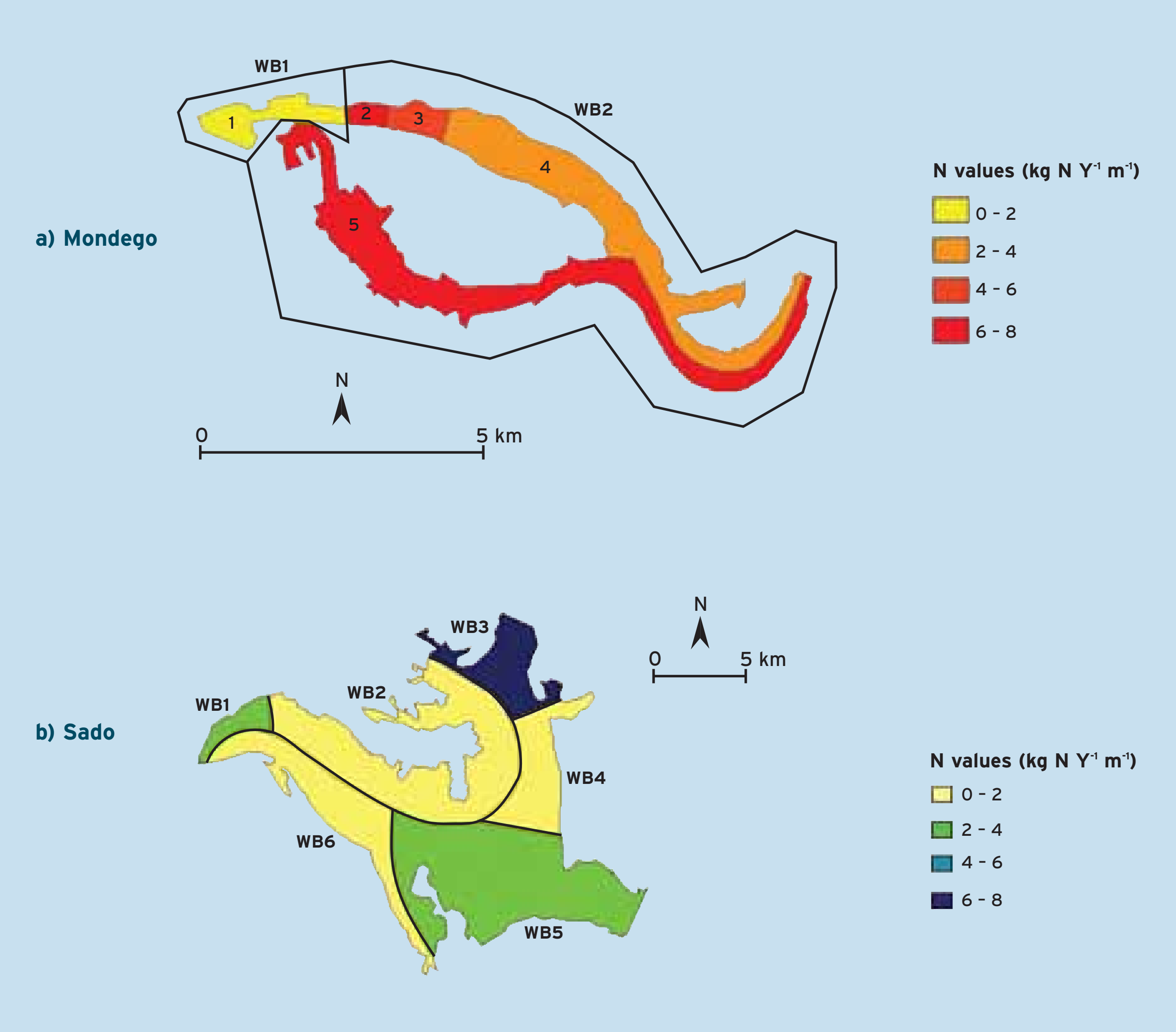
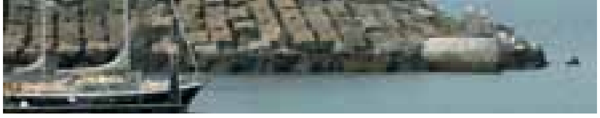


Figure 35. Division of the a) Mondego and b) Sado) estuaries based on watershed nutrient pressure.



part of the Ria (Figure 36a and Figure 36b). A state assessment was made by combining chl *a* and D.O. using map algebra (Figure 36c). Pre-processing of the maps was done in order to convert continuous concentration data into binary data, *No problem* or *Problem*, regarding the ASSETS threshold of the *No Problem* class for these variables. The resulting state water bodies are shown in Figure 36d. The distribution of chl *a* and D.O. in the Mondego and Sado generate a straightforward division into state water bodies since a single zone is defined using D.O. (all percentile 10 values are above 5 mg L^{-1}). Chl *a* defines two zones in the Mondego (shown by the State divider in Figure 37a. In the Sado the complex distribution of chl *a* generates five distinct zones (see State assessment in Figure 37b).

In the Ria Formosa and Mondego it would be useful to include benthic primary producers in the state analysis as these have well-known issues of opportunistic macroalgal blooms but



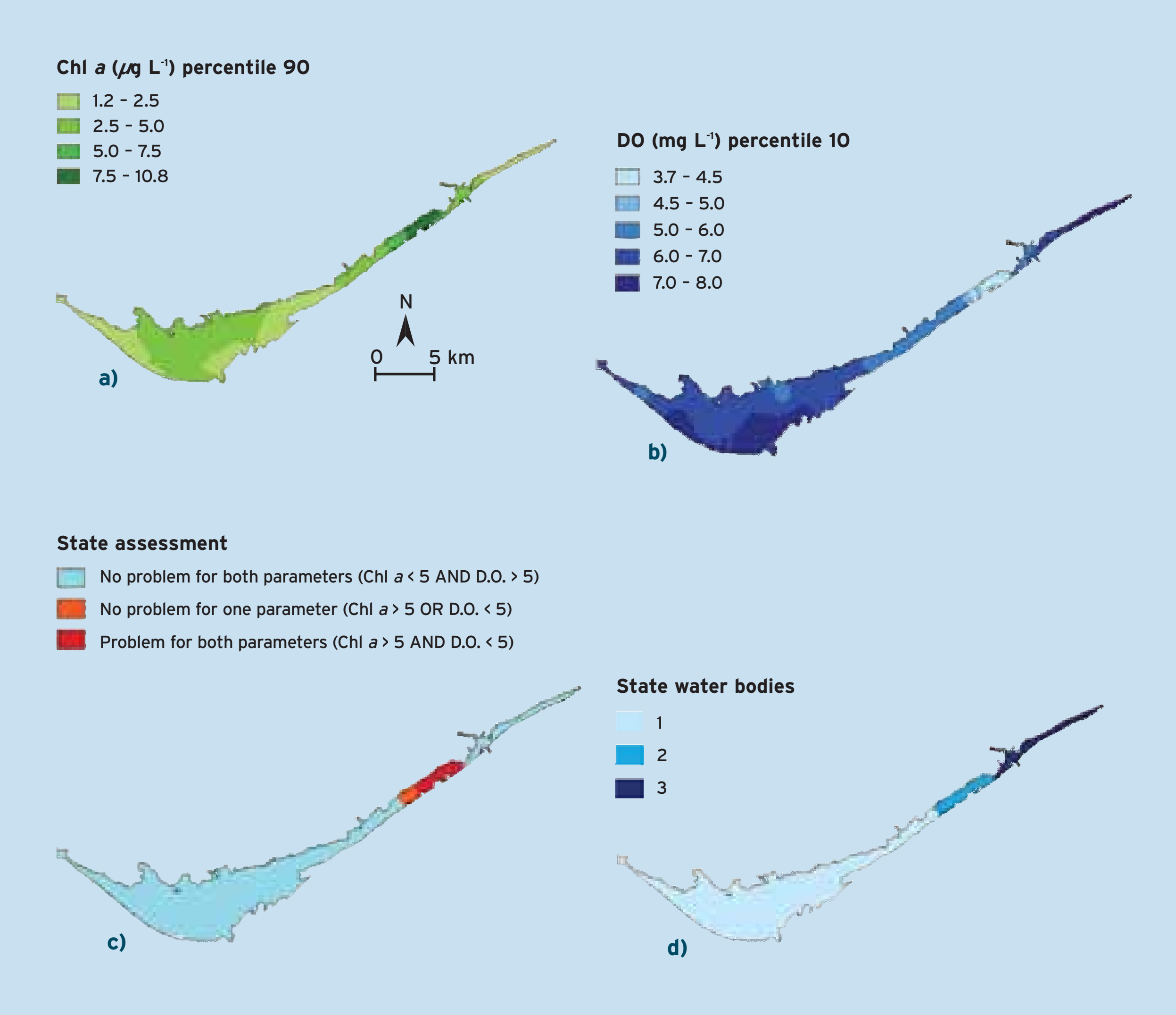


Figure 36. Division of the Ria Formosa for State based on chl *a* and D.O. thresholds: Distribution of a) chl *a* concentrations and b) D.O. concentrations; c) map algebra analysis results, d) state water bodies.

estuary-wide data were not available for this parameter.

In the Mondego Estuary and Ria Formosa the combination of pressure and state leads to the human dimension water bodies, three and eleven respectively as shown in Figure 37a and Figure 37c. In the Sado Estuary the complex zones generated by the state criteria were used to divide or aggregate the ones obtained by the pressure criteria as illustrated in Figure 37b, resulting in five human dimension water bodies.

Synthesis of natural and human characteristics

The aggregation of both natural and human dimension factors into the final water bodies is shown in Figure 38 for the three case studies.

For the Mondego Estuary, the natural water body divisions correspond roughly to the human water bodies, except between WB3 / WB4 (shown in Figure 34), leading to a set of four water bodies. As shown in Figure 38a, the

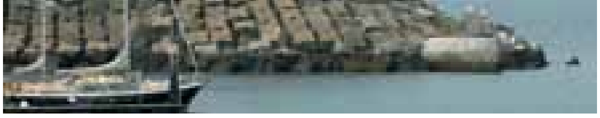
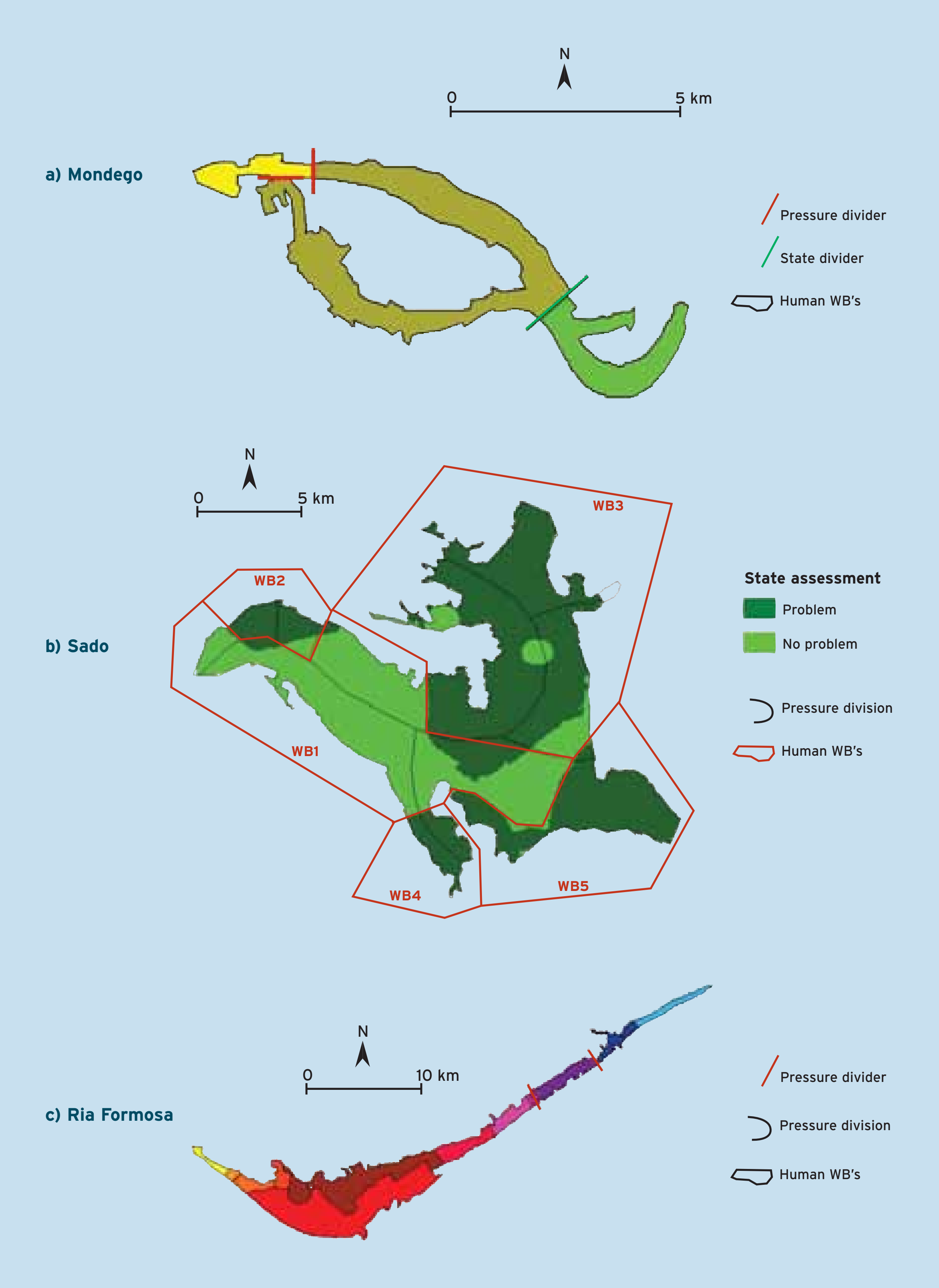


Figure 37. **Division of a) Mondego, b) Sado and c) Ria Formosa, into human dimension water bodies, combination of the pressure and state components.**



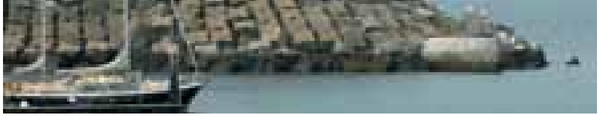
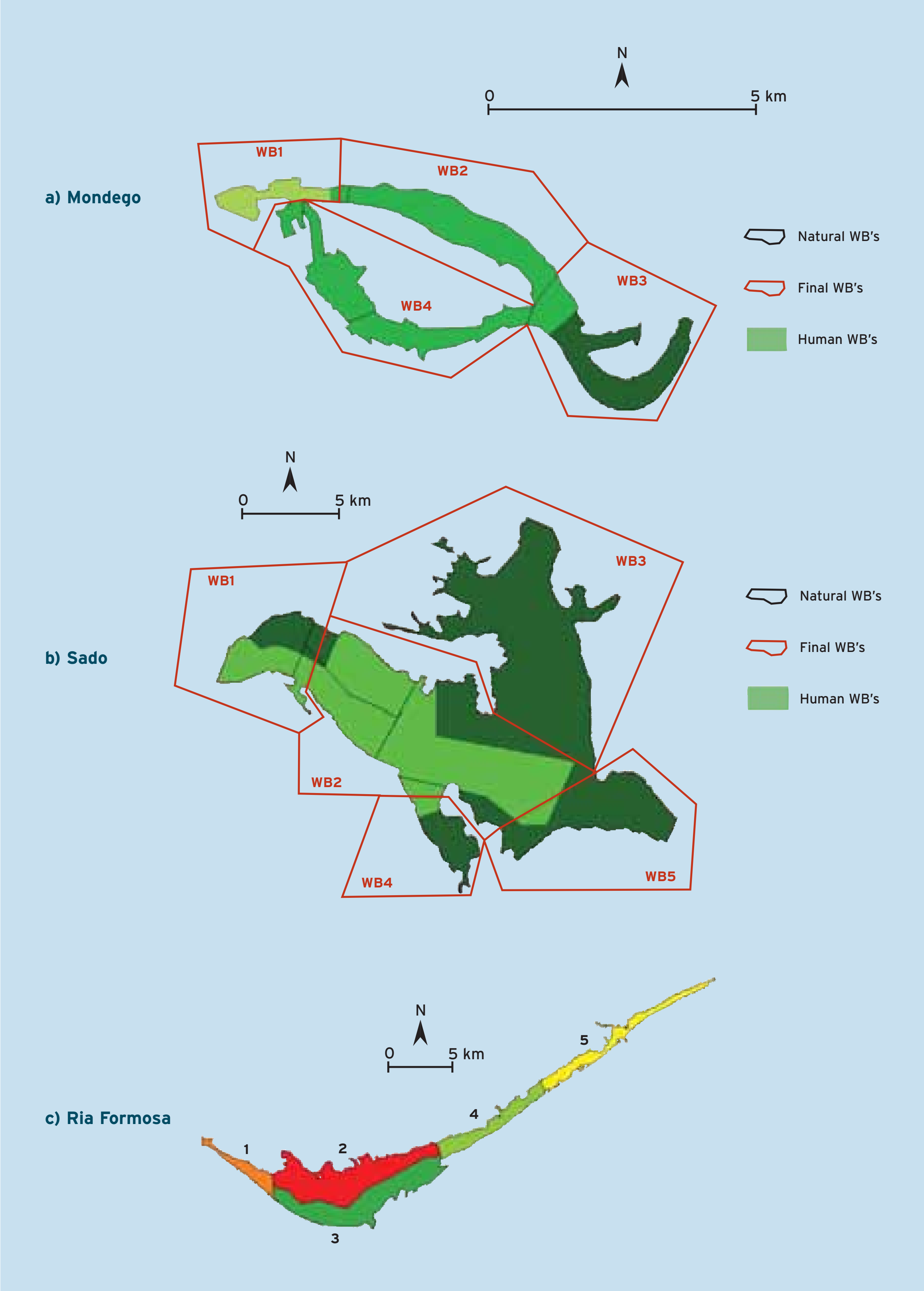
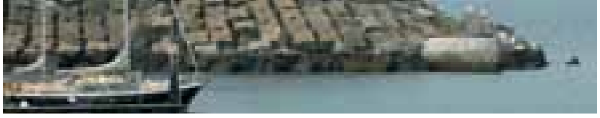


Figure 38. Final definition of water bodies for the three case study systems.





divider between WB1 / WB2 changed to the centreline of the natural and human divisions. The dividers between WB2 / WB3 and WB3 / WB4 were kept the same as in the natural water bodies, in this case the centreline would generate an additional small water body that would be eliminated using the tidal excursion criterion. The divider between WB1 / WB4 exemplifies another exception where the centreline might not be used; instead the human division was used to avoid generating an awkward division due to the morphology of the system in this zone. The natural WB3 and WB4 (Figure 34) were merged into WB4 since the human dimension criterion showed no difference between these.

In the case of the Sado Estuary, five water bodies are identified, the complex human dimension water bodies were harmonized with the natural ones as shown in Figure 38b, aggregating the boundaries close together and using the tidal excursion to eliminate small water bodies. The complex zones defined by the state criterion were simplified into a final set of water bodies (WB3 and WB5).

In the Ria Formosa the combination of the natural (Figure 33e) and human (Figure 37c) water bodies would generate a large number of small water bodies. The final set of five water bodies (Figure 38c) was obtained using the natural water bodies (defined according to drainage patterns) as a basis and the human dimension criteria for aggregation (e.g. WB2, WB3 and WB4 of Figure 38c). The small water bodies that would be generated at the system limits were merged resulting in WB1 and WB5 (Figure 38c).

PORTUGUESE TRANSITIONAL AND COASTAL WATER BODIES

Based on the methodologies described earlier, the sections below present MONAE results for the division of Portuguese TCW into Open Coastal Water Bodies and Transitional and Restricted Coastal Water Bodies.

Open Coastal Waters

The following Open Coastal Water Bodies are proposed (Figure 39).

Category A (light blue in Figure 39)

(a) I-1, between the Minho and Douro adjacent coastal areas. The salinity and suspended particulate matter (SPM) concentration fields successfully trace the dynamics of this region. The Douro plume is dominant until it merges with the Minho in spite of the other small discharges to the coast. Consequently,

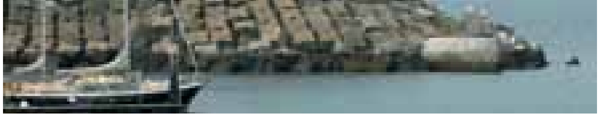
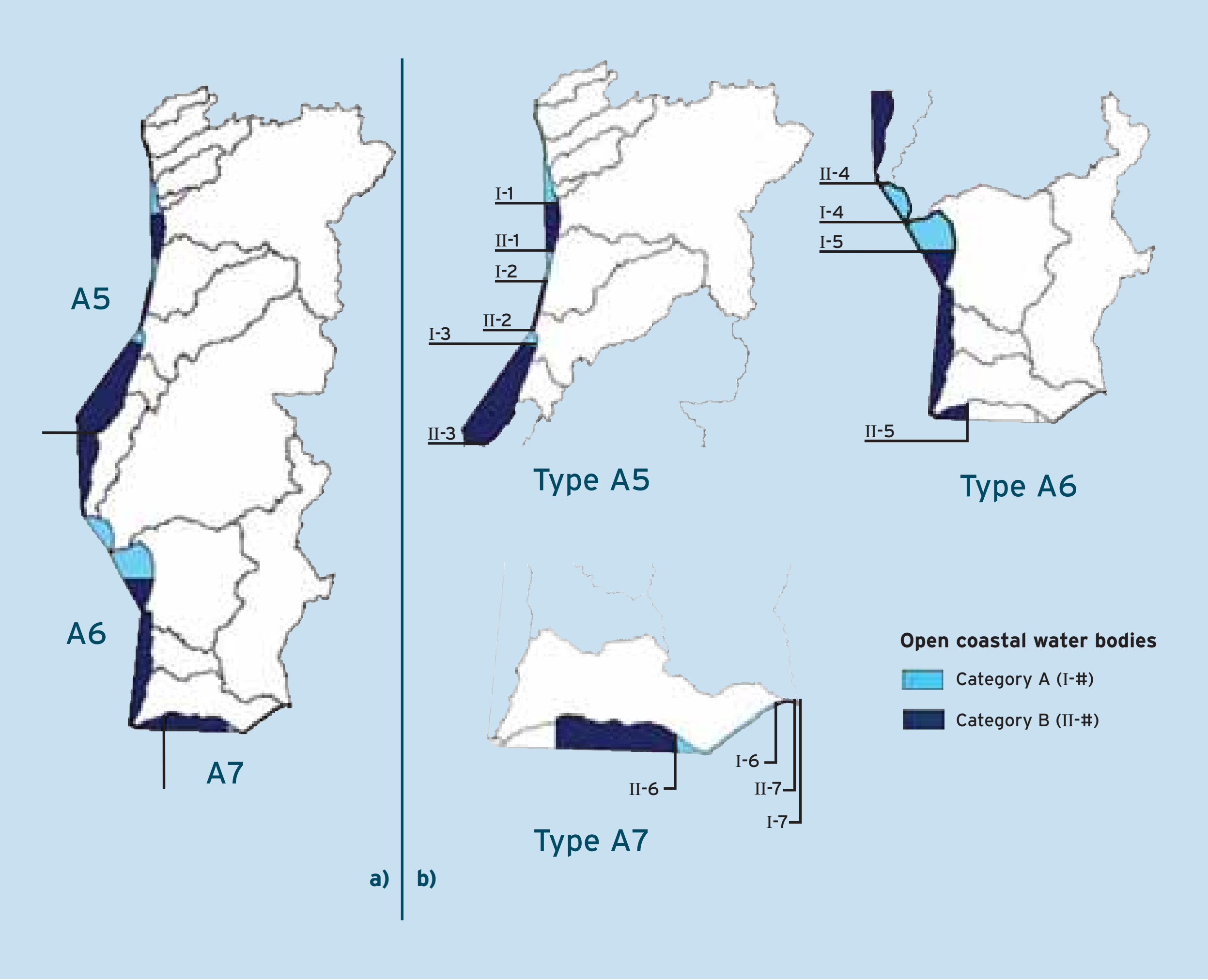


Figure 39. Coastal Water Bodies proposed for the Portuguese coast (a), listed per type (b).



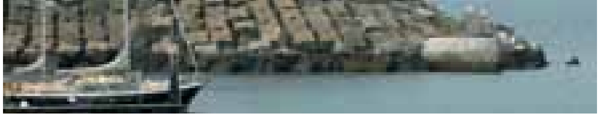
homogeneity may be assumed in this area, and it may be considered a coastal water body.

(b) I-2, adjacent to the Ria de Aveiro. The Ria de Aveiro exchanges dissolved and particulate material with the adjacent coastal zone, particularly during winter when the lagoon receives large quantities of freshwater.

(c) I-3, adjacent to the Mondego estuary. There is evidence of export of material to the sea during periods of high flow, which includes nutrients and potential contaminants incorporated in the sediments that may be resuspended in the water column.

(d) I-4, adjacent to the Tagus estuary. Many authors show the influence of this estuary on the adjacent coastal area in terms of suspended sediments, contaminants, nutrients and plankton.

(e) I-5, adjacent to Sado estuary. The Sado estuary receives nutrient and contaminant inputs from industrial activities, domestic sewage and diffuse sources. In periods of high flow there is evidence of contaminant export as well as



interactions between the environmental variables and benthic communities.

(f) I-6, adjacent to Ria Formosa. Although freshwater inputs to Ria Formosa are negligible during most of the year, substantial loads of anthropogenic material derived from domestic sewage enter directly into the lagoon, causing eutrophication in confined areas. Because the lagoon is shallow and strongly influenced by tides, about 75% of the water volume is renewed at spring tides. Recent work has shown the seasonal variation of nutrient exchange with the adjacent coastal areas.

(g) I-7 – adjacent to the Guadiana estuary. The Guadiana estuary is very sensitive to heavy rain and runoff. During these episodes the estuary is filled with freshwater and measurements show the export of substantial quantities of dissolved and particulate matter to the adjoining coastal area.

Category B (dark blue in Figure 39)

(a) II-1, between Douro (CWB-I-1) and Aveiro (CWB-I-2), where no direct influence of significant freshwater input has been recorded.

(b) II-2, between Aveiro (CWB-I-2) and Mondego (CWB-I-3) where no direct influence of significant freshwater input has been recorded.

(c) II-3, between Mondego (CWB-I-3) and the Cape Carvoeiro, corresponding to an exposed area as defined previously and including the Nazaré canyon.

(d) II-4, between Cape Carvoeiro and Cape of Roca, a moderately exposed area.

(e) II-5, between Sado (CWB-I-5) and Ponta da Piedade, including the southwest coastal area of Portugal where most freshwater systems do not reach the coast and several land-locked coastal lagoons are formed. The criteria to extend this Open Coastal Water Body to Ponta da Piedade on the South coast are based on similarities of meteorological and wave conditions.

(f) II-6, between Ponta da Piedade and Ria Formosa (CWB-I-6), where no direct influence of significant freshwater input has been recorded.

(g) II-7, between Ria Formosa and Guadiana (CWB-I-7), where no direct influence of significant freshwater input has been recorded.

Transitional and Restricted Coastal Waters

The following figures itemise the water bodies for all the transitional and restricted coastal systems (types A1 to A4). These were obtained

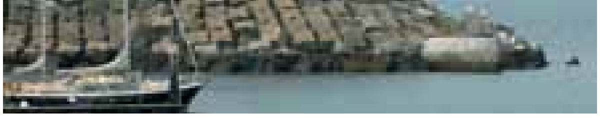
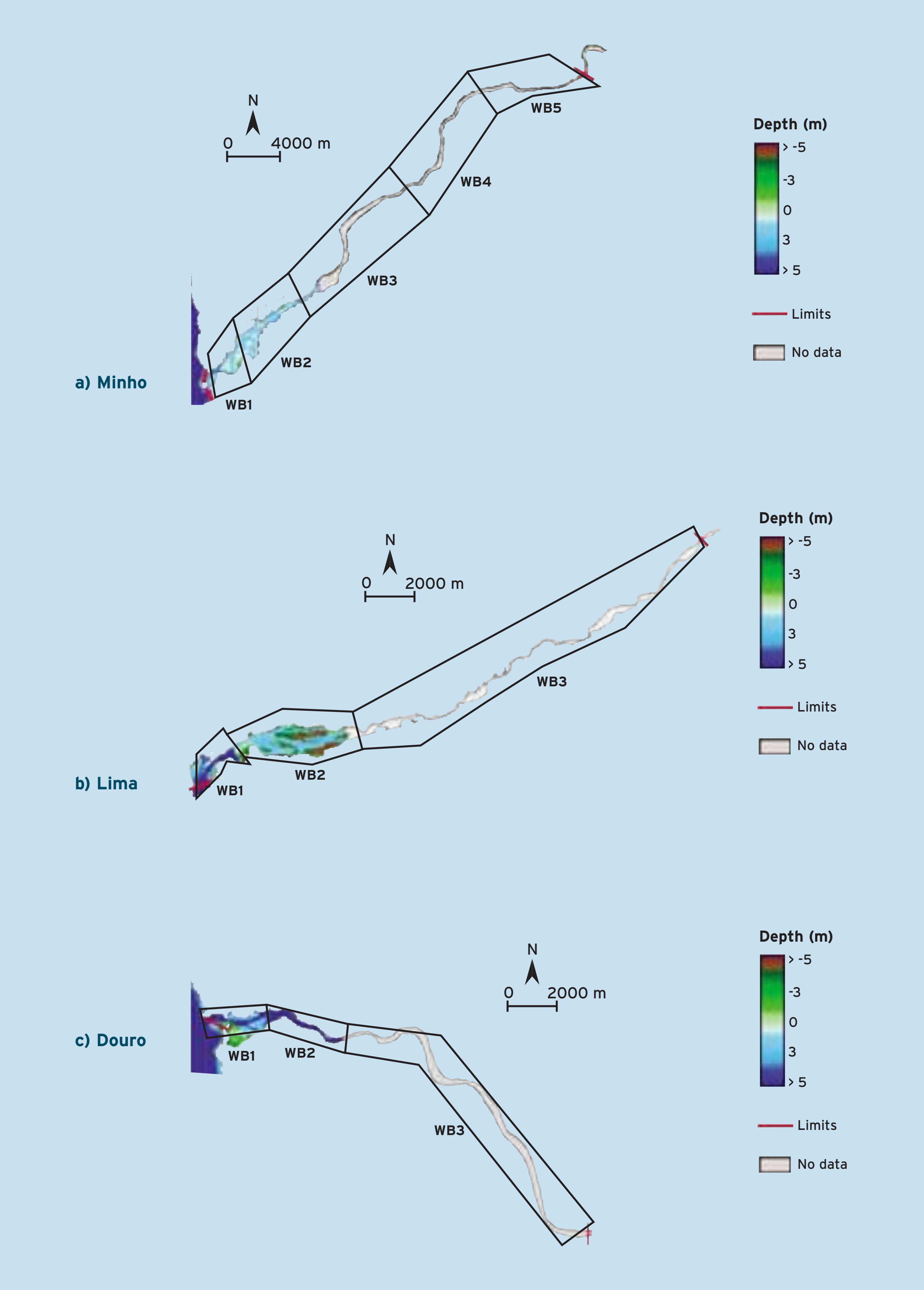


Figure 40. Water bodies for the a) Minho, b) Lima, and c) Douro estuaries.



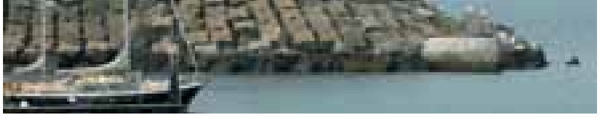
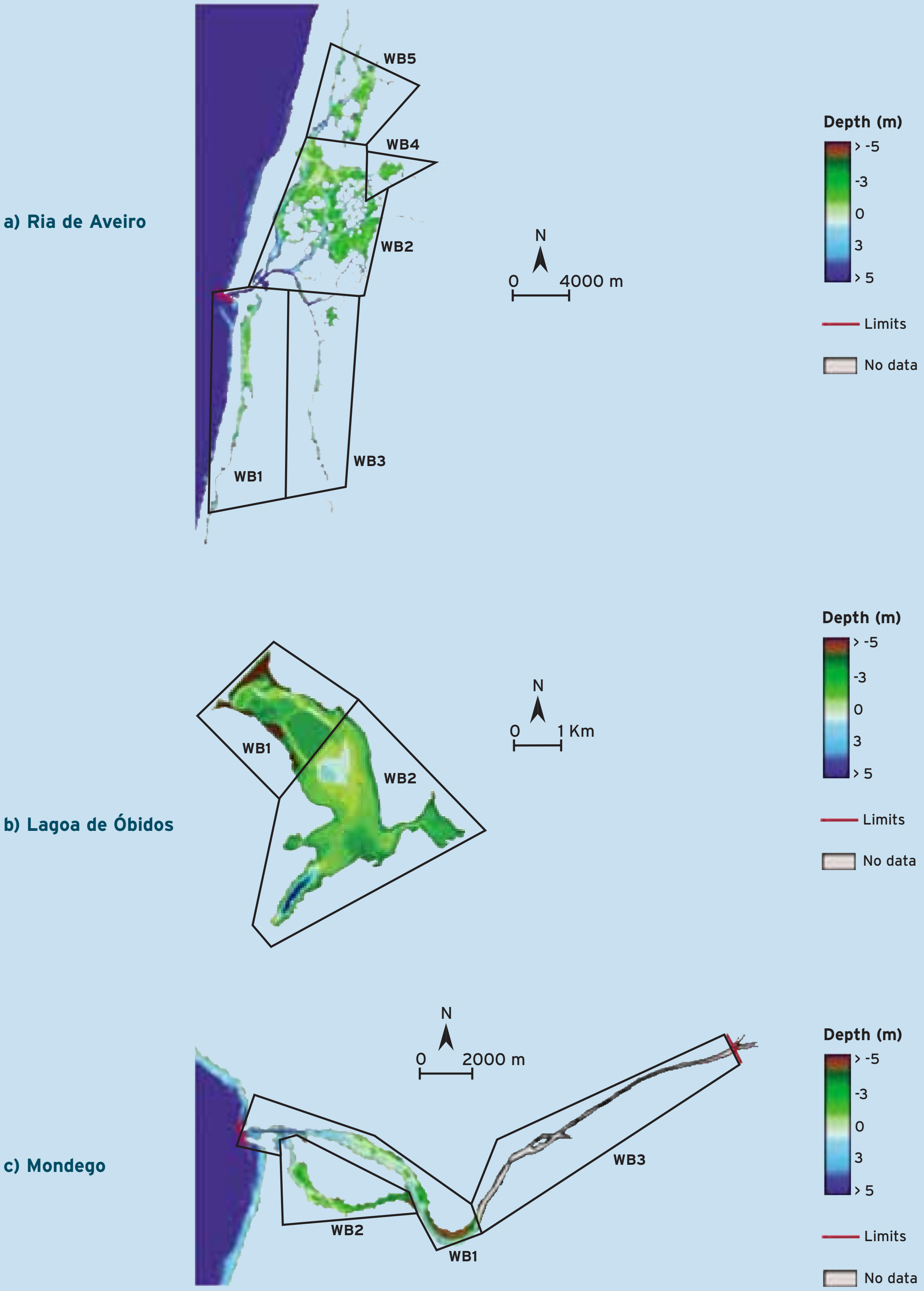


Figure 41. Water bodies for the a) Ria de Aveiro, b) Lagoa de Óbidos, and c) Mondego estuary.



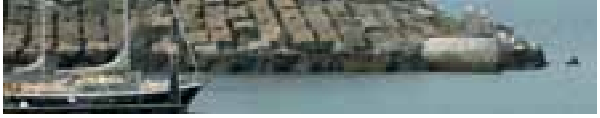
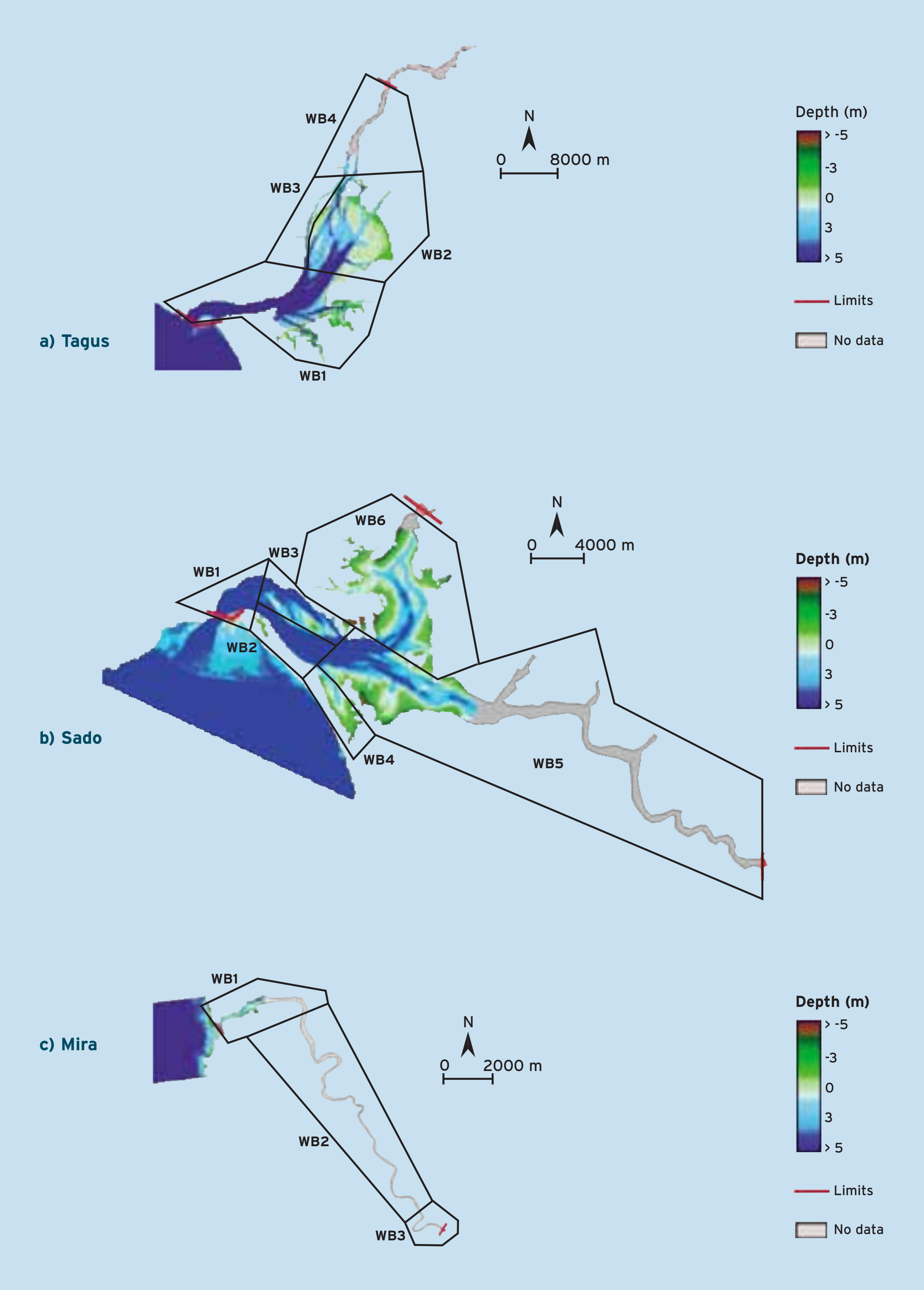


Figure 42. **Water bodies for the a) Tagus, b) Sado and c) Mira estuaries.**



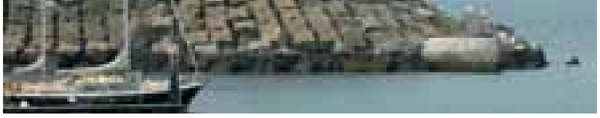


Figure 43. Water bodies for Ria Formosa.

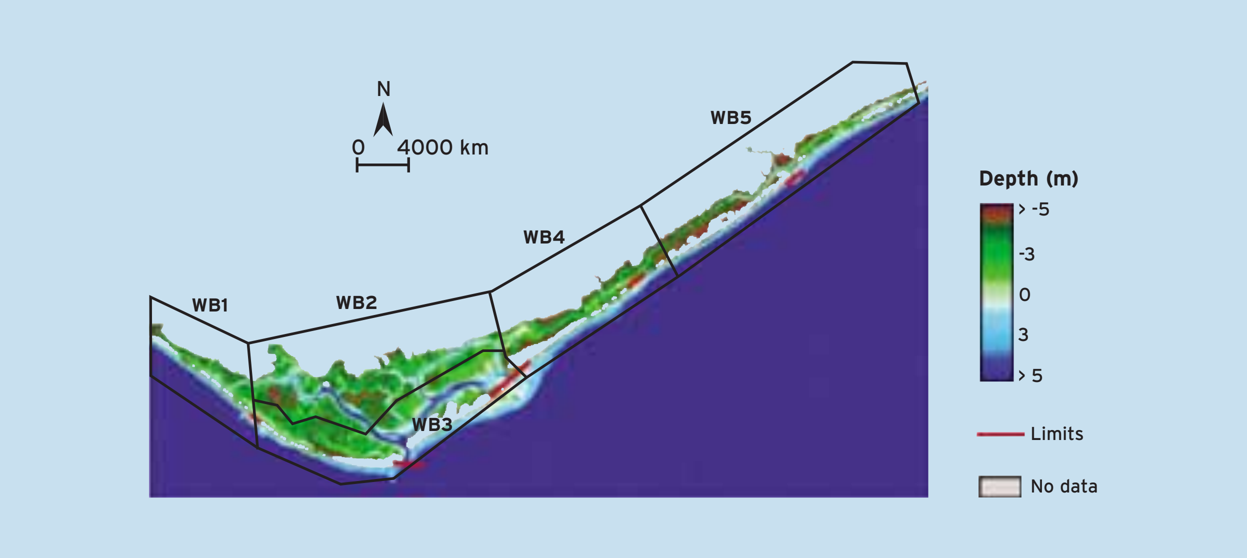
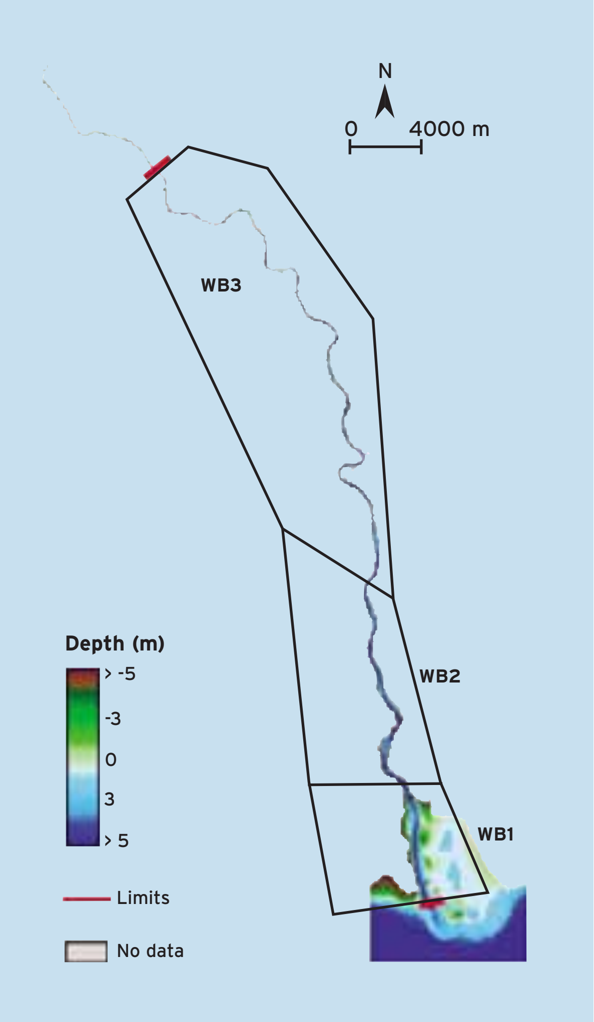


Figure 44. Water bodies for the Guadiana estuary.



using either the semi-quantitative analysis described in the *Definition of transitional and restricted coastal waters* section, or using a heuristic approach, depending on the available data for each system.

The results obtained were reviewed by experts in order to conjugate the scientific approach with local management expertise. An example is the Mondego estuary where the number of water bodies changed from four to three. Water bodies 1, 2 and 3 (Figure 38 a) were merged into a single water body WB1 (Figure 41 c) and a new water body was created (WB2 in Figure 41 c) for the area where no bathymetric data were available.

Figure 45 shows the number of transitional and coastal water bodies proposed for Portugal.

It is envisaged that future revisions of this list may allow the final number of water bodies defined for transitional and coastal systems in Portugal to be no greater than 50.

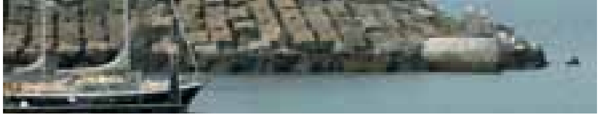


Figure 45. Summary of water bodies defined for Transitional and Coastal Waters in Portugal. The Leça estuary was excluded, since it is classified as an artificial structure.

Types	Water category	Systems	Nº of water bodies
A1 Mesotidal stratified estuary	Transitional	Minho estuary	5
		Lima estuary	3
		Douro estuary	3
		Leça estuary	-
A2 Mesotidal well-mixed estuary	Transitional	Ria de Aveiro	5
		Mondego estuary	3
		Tagus estuary	4
		Sado estuary	6
		Mira estuary	3
		Arade estuary	1
		Guadiana estuary	3
A3 Mesotidal semi-enclosed lagoon	Coastal	Óbidos lagoon	2
		Albufeira lagoon	1
		St. André lagoon	1
A4 Mesotidal shallow lagoon	Coastal	Ria Formosa	5
		Ria de Alvor	1
A5 Mesotidal exposed Atlantic coast	Coastal	Open coast	6
A6 Mesotidal moderately exposed Atlantic coast	Coastal	Open coast	4
A7 Mesotidal sheltered Atlantic coast	Coastal	Open coast	4
Total			**60**

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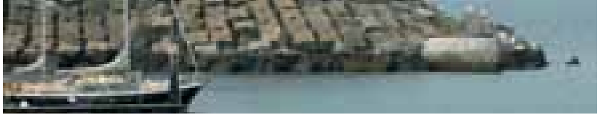

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MONITORING PLANS

DEFINITIONS AND GUIDELINES

- Definition of appropriate objectives
- Setting priorities and optimisation
- Implementation of quality control
- Assessment of monitoring success
- Reporting of results

This chapter comprehensively examines the preparation and execution of monitoring plans in Transitional and Coastal Waters. The initial sections address general issues relevant to any type of monitoring plan.

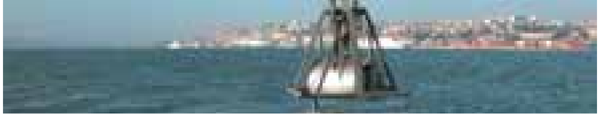
Later sections address surveillance, operational and investigative monitoring required by the WFD.

Definition of appropriate objectives

Although the general objective of monitoring specified in the WFD is to verify compliance with water quality objectives, or to establish the reasons for non-compliance so that appropriate measures may be put in place where applicable, a monitoring plan should examine these questions in broader terms, from the standpoint of ecosystem health.

Monitoring activities that address a broad set of aims use indicators as proxies for these. In the WFD, these indicators must include the appropriate Biological Quality Elements (BQE) and Supporting Quality Elements (SQE), and may include others.

The indicators shown in Figure 46 may have different levels of aggregation, ranging from, for example, combined indices of eutrophication or



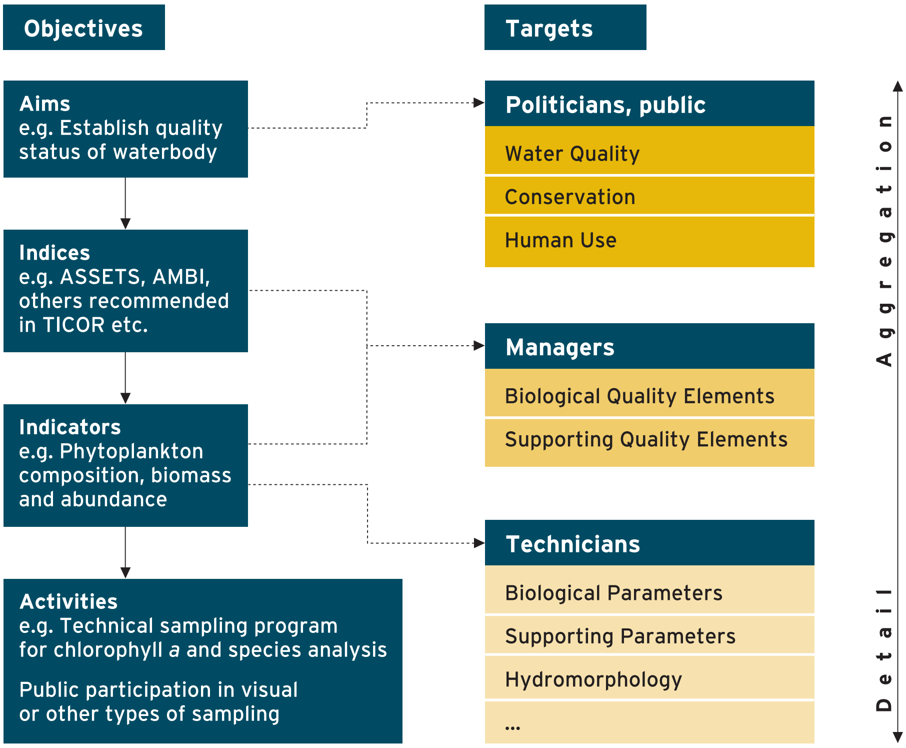


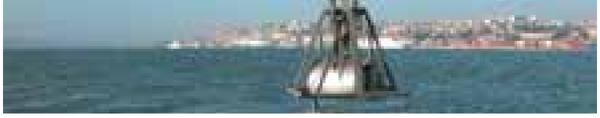
Figure 46. Conceptual relationship between aims, indices, indicators and activities.

benthic quality status to the concentration of a particular parameter such as dissolved oxygen, and may be defined collectively as Environmental Quality Proxies (EQP). In the WFD these correspond to different combinations of BQE and SQE.

Relevant objectives should be defined for management of Transitional and Coastal Waters, forming a set of goals, which may need to be harmonised in time, space, and within the allowable EQP thresholds.

Three broad groups of management objectives may be defined and are presented in the box below.

General objectives such as these have broad appeal, are easy to explain to a wide audience, and should be considered as bridges between



Management objectives

- **Water quality objectives** – e.g. (i) Restore and maintain a productive ecosystem with no adverse effects due to pollution; (ii) Minimize health risks associated with contact water uses; (iii) Estimate adverse impacts of eutrophication, including hypoxia resulting from human activities;
- **Conservation objectives** – e.g. (i) Maintain on a landscape level the natural environment of the watershed; (ii) Protect existing habitat categories within the watershed to preserve and improve regional biodiversity;
- **Human use objectives** – e.g. (i) Support water-related recreation whilst preserving the economic viability of commercial endeavours; (ii) Encourage sustainable lifestyles within the watershed, whereby human uses are balanced with ecosystem protection; (iii) Empower citizens in the protection and stewardship of the estuary and its watershed.

ecosystem management at a technical and scientific level, political decision-makers and the public at large. There is therefore a requirement that the monitoring plans developed in this chapter address these broad objectives, using EQP as assessment tools.

The box opposite provides examples of specific objectives that could be established as management targets for different systems.

These fit in with the concept of broad public appeal, and are included as an illustration for a few Portuguese systems.

Core and research biological and supporting quality elements

A number of monitoring plans for coastal systems in the E.U. and U.S. have identified several types of indicators that can be used, which may be applied in a complementary manner to address the issues under consideration. These are typically divided into core and research indicators, and are evaluated in distinct types of monitoring plans. This fits in well with the concepts outlined in the WFD and developed in various guidance documents, i.e. that for **surveillance monitoring** the full spectrum of BQE/SQE[1] needs to be covered, for **operational monitoring** the indicators need to be far more targeted, and in the case of **investigative monitoring** the focus is on the detailed understanding of a specific issue.

- **Tagus estuary** – Restoration of the oyster fishery to the levels of the 1960's
- **Sado estuary** – Conservation and expansion of the bottlenose dolphin population
- **Guadiana estuary** – Reappearance of sturgeon

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[1] - As required for the type-specific definition of reference conditions. Some elements may be excluded, e.g. due to high natural variability.

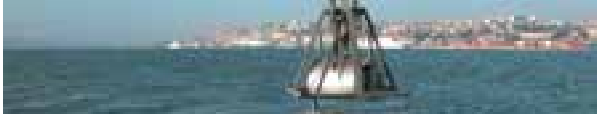


Figure 47. Indicator list (abridged) for the Barnegat Bay monitoring plan.

Primary Indicators (high-profile indicators)	Secondary Indicators (internal-use indicators)
• Submerged aquatic vegetation (SAV) distribution, abundance, and health	• Temperature and salinity
• Land use/land cover change	• Dissolved oxygen and nutrients
• Signature species	• Turbidity
• Watershed integrity	• Phytoplankton abundance and composition & chlorophyll *a* concentrations
• Shellfish beds	• Macrophyte abundance
• Bathing beaches	• Shellfish & finfish abundance
• Water-supply wells/drinking water	• Benthic community structure
• Harmful Algal Blooms (HAB)	• Toxic contaminants in aquatic biota and sediments
• Freshwater inputs	• Rare plant & animal populations

An example of the types of indicators used in the Barnegat Bay (New Jersey, U.S.) monitoring plan is shown in Figure 47. The distinction between primary (high-profile) and secondary (internal-use) is similar to the higher and lower levels of aggregation illustrated in Figure 46.

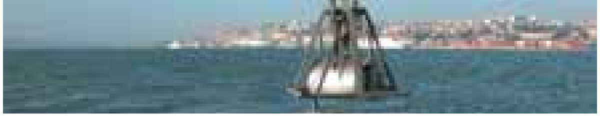
The use of indicators to define pressure, state and response characteristics and trends has grown in popularity. Indicators, particularly biological indicators that are more charismatic than chemical concentration data, for example, can provide more of an ecosystem perspective of conditions in estuarine and coastal waters, that scientists, managers, politicians and the public find relevant and useful.

The Barnegat Bay example identifies a mix of indicators that relate to this wide constituency of scientists (e.g., chemical pollution and biological effects), managers (e.g., pollutant sources and land cover changes), and politicians and the public (e.g., fish and shellfish abundance and value, beach closures, and toxic contaminants in seafood). The full picture of an estuary incorporates all these indicators to define cause and effect relationships that lead to necessary management outcomes.

Furthermore, monitoring programmes often need only slight modifications to ensure that a broad suite of useful indicators are built from the underlying parameter and media monitoring that meet both WFD and MONAE objectives for comprehensive monitoring to assess ecosystem health status of TCW.

Priorities and optimisation

Monitoring plans must be established for a comprehensive coverage of transitional and coastal water bodies. The monitoring activities to be carried out constitute a serious additional workload on the technical and scientific



community. The problems facing the successful implementation of monitoring plans for Portuguese Transitional and Coastal Waters are not trivial, and are conditioned both by logistics and finance.

This has partly been addressed by limiting the number of individual water bodies to be monitored to an optimal suite. Although the WFD states that not all water bodies will need to be monitored, all will need to be classified for ecological status. The option taken by the MONAE project team was to define a manageable set of water bodies and propose that all should be monitored.

However, it is recognized that due to logistic and/or financial constraints it may be necessary to prioritise different monitoring activities according to the management issues at hand. Additionally, models and prior monitoring efforts may provide enough insight into an ecosystem to improve efficiency by reducing sampling in time and space, using a more minimalist approach but still achieving monitoring objectives.

Figure 48 shows a decision-tree that may be used to define guidelines for prioritising monitoring activities. This approach takes into consideration:

(a) The definitions contained in the WFD for selection criteria of monitoring types – these definitions are sometimes ambiguous;

(b) The pressure (anthropogenic or non-anthropogenic) on the system;

(c) The susceptibility of the system, dependent on factors such as freshwater flushing time and tidal mixing;

(d) The state of the system, assessed by means of Environmental Quality Proxies, i.e. BQE and SQE.

The monitoring actions, whilst important to defining pressure and state conditions, are the **Response** component of this framework, and correspond to different types of monitoring. In Figure 48 these are discriminated by monitoring type, and colour-coded according to priority. Surveillance monitoring is not subject to ranking according to this scheme, since it is a requirement of WFD river basin plans.

Implementation of quality control

Data quality is an important consideration for any monitoring programme to ensure objectives are met and conclusions are not misled by inaccurate data. The U.S. Environmental Protection Agency provides detailed guidance

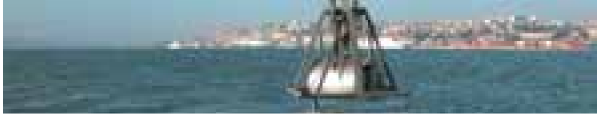


Figure 48. **Decision-tree for selection of different types of monitoring programmes.**

Pressure	Susceptibility	State	Monitoring response Surveillance	 Operational	 Investigative
H	H	H	✓		✓
H	H	G	✓	✓	
H	H	MPB	✓	✓	
H	L	H	✓		
H	L	G	✓	✓	
H	L	MPB	✓	✓	
M	H	H	✓		
M	H	G	✓	✓	
M	H	MPB	✓	✓	✓
M	L	H	✓		
M	L	G	✓	✓	
M	L	MPB	✓	✓	✓
L	H	H	✓		
L	H	G	✓	✓	
L	H	MPB	✓	✓	✓
L	L	H	✓		
L	L	G	✓		
L	L	MPB	✓	✓	✓

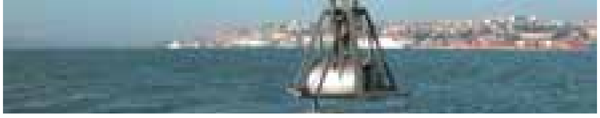
Pressure
H - High
M - Moderate
L - Low
If unknown consider High

Susceptibility
H - High
L - Low

State
H - High
G - Good
MPB - Moderate, poor and bad

Monitoring response
S - Surveillance
O - Operational (O1 to O3: higher to lower priority)
I - Investigative (I1 to I2: higher to lower priority)

for Quality Assurance Project Plans (QAPP) that cover all aspects of programme structure, quality assurance and control, and data analysis and reporting. EPA promotes a system that brings a final project design through policy, organisational, programmatic and, finally, project implementation components. The guidance documents include an evaluation of quality control in environmental modelling, a critical component of monitoring and assessment.



QAPPs need to consider all aspects of the monitoring activity, emphasizing standard and recognizable elements from planning through implementation and final assessment. As such, EPA approval requires compliance with the following checklist.

- The project technical and quality objectives are identified and agreed upon
- The intended measurements, data generation, or data acquisition methods are appropriate for achieving project objectives
- Assessment procedures are sufficient for confirming that data of the type and quality needed and expected are obtained
- Any limitations on the use of the data can be identified and documented

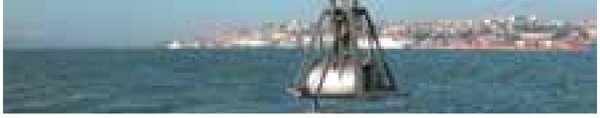
Within this framework, QAPPs need to define and justify an appropriate project management structure, sound data generation and acquisition methodologies, a reasonable and statistically validated assessment and oversight procedure for quality assurance and control, and a process for ensuring data are valid and usable for the stated purposes and objectives of the programme.

Of particular relevance to MONAE is sound experimental design. The traditional components of a programme answer questions about the type and numbers of samples, the design of the network, locations, frequencies of collection, media sampled, and the parameters included. Standard procedures need to be specified – sample methods, handling and custody, and analytical methods.

Adequate quality control and assurance measures specific to the programme design that quantify precision, accuracy, bias, procedural error, etc. must be included, together with plans to respond to any problems that arise. Typically, analytical programmes rely on duplicates, splits, blanks, spikes, and reference samples, among others, during both field and laboratory operations. Review is followed from field and laboratory procedures into data analysis and verification.

Appropriately validated banking of raw data is a fundamental component of the quality assurance process. Data collected in a monitoring programme must be stored in such a way as to allow a variety of treatments to be carried out. This includes, but is not limited to, statistical analyses, use in GIS and model calibration and validation. The following points should be considered as a set of minimum requirements.

- The data storage system should comply to an open standard (e.g. SQL) and allow easy export and import
- The database system should avoid redundancy and permit fast retrieval
- Data loading should incorporate quality assurance, by means of e.g. input validation, parameter range checking and pattern analysis
- The data storage should include both metadata and raw data, and incorporate analytical methods and detection limits



Finally, quality assurance for environmental models is an essential component of the complete monitoring process cycle. This becomes particularly significant as simulation results become progressively more integrated in regulatory activities. Key points highlighted by the EPA guidance and other sources include:

(a) Suitability for purpose

(b) Internal consistency

(c) Adequate calibration, validation and sensitivity testing

(d) Appropriate documentation

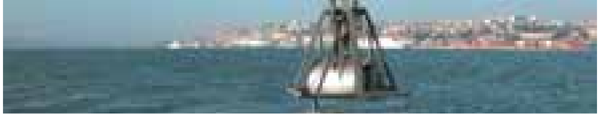
(e) Ease of use, including data input and output handling

Assessment of monitoring success

The success of each monitoring plan must be assessed in a clear way, providing a mechanism for evaluating the cost-benefit of the monitoring activity and for making necessary adaptations or corrections for future improvement.

Each monitoring plan must set out a number of objectives, which may be grouped into two different types: the first focuses on the **outputs**, and is effectively an internal audit - verification would include compliance with the various terms of reference for time, space, parameters, methodology, etc. The second type examines the success in terms of **outcomes**, i.e. it is the component that informs management action. As an example, for assessment of chlorophyll *a* (biological quality element) and dissolved oxygen (supporting quality element) which are respectively primary and secondary symptoms of eutrophication, monitoring success might be evaluated (i) at the **outputs** level by examination of compliance with monthly sampling within water bodies covering three estuarine salinity zones, considering appropriate depth profiling, analytical methods, etc.; and (ii) at the **outcomes** level by determining whether the data collected provided sufficient information to answer questions on whether the impacted areas and deviation from state at reference

- Programme implementation (outputs). These are verifiable targets which may be related to the MONAE terms of reference, i.e. Are the goals and objectives of the plan being met. This answers programmatic questions such as: (a) Is the sampling covering the estuaries/coastal systems specified in the plan? (b) Is the strategy defined for a particular system (e.g. sampling according to a salinity gradient, particular vertical profiles or seasonality being followed? (c) Are the parameters being measured as required by the WFD? (d) Are methodology issues (intercalibration of methods, etc.) being handled as recommended?
- Programme effectiveness, i.e. environmental success (outcomes). A distinct set of targets, based around specific ecological quality achievements, must answer questions such as: (a) Are shellfish/finfish areas increasing/decreasing? (b) Are salt marsh areas increasing/decreasing? (c) How is the frequency/spatial scope of elevated chlorophyll *a* evolving? (d) What are the observable trends for HAB events? (e) Are elevated nutrients correlated with elevated chlorophyll *a*? These questions should be centered around the BQE/SQE, and the indices into which these are aggregated.



conditions were increasing, and whether a correlation with nutrient loading could be established.

As stated, the first type of instrument (outputs) audits the monitoring plan internally, and certifies its quality and consistency, allowing the second type of instrument (outcomes) if successful, to be a reliable basis for policy decisions.

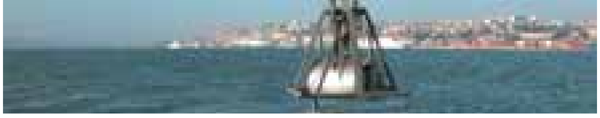
Reporting of results

The outcome of monitoring should, in relevant cases, lead to managerial or political action. Therefore, it is essential that sampling programmes are constructed in such a way that meaningful data, information and indicators can be reported to all levels of interested parties to effect intended change. Reports may take many forms depending on the intended audience – fact sheets, scientific reports, web sites, news media – and should convey a message of a good scientific foundation that supports a clearly articulated action agenda.

The reporting of results should be carried out at six different levels. The first level is preparatory, and all others report on the data collected at different levels of aggregation, and target specific sectors of the public.

The preparation of standard forms for each quality element is illustrated below with an example; all the other aspects are addressed in different parts of this book. The data storage guidelines for raw data and metadata have been reviewed in this chapter, GIS reporting is illustrated in the Tools and Spatial Domain Chapters, the production of bulletins and press releases is discussed in the Public Participation Chapter, and scientific publications follow the usual conventions of academic journals.

- Preparation of standard forms for each quality element describing the work to be carried out
- Measured values (raw data) and metadata inserted into a water quality database (e.g. the INAG SNIRH database is appropriate)
- GIS layers with WFD colours per BQE and overlap according to the ECOSTAT scheme (or successors), and/or a summary Ecological Quality Status Classification
- Bulletins (in paper and on the web) describing activities and compliance with high-profile monitoring objectives
- Press-releases
- Scientific publications, particularly reporting outcomes of Investigative Monitoring



Standard forms for each quality element

Figure 49 illustrates an (abridged) form taken from the Tillamook Bay (Oregon, U.S.) monitoring plan. This plan provides a good example of a programme that addresses many of the design and quality assurance concerns identified above.

The survey for eelgrass (*Zostera*) in Tillamook Bay is developed on the basis of the metadata presented in this form, which include a clear definition of the metrics used to evaluate monitoring success.

The form states the general objective (**outcome**, as defined above) of the survey, allowing hypotheses (here adapted and posed as null) such as "The distribution of eelgrass is unchanged over a historical time period" or "The abundance of eelgrass is not being affected by nutrient enrichment" to be tested by managers.

The form includes a management objective, "No net decline" – whilst this is not strictly a monitoring consideration, it is very useful to include the general management objective in such a list.

There are a number of logistic and administrative fields, and finally a sufficiently complete set of **output** indicators to allow a clear definition of the monitoring activity and subsequent internal audit.

SURVEILLANCE MONITORING

Definition and objectives

For each period to which a river basin management applies a surveillance monitoring shall be established. The objective of the surveillance monitoring is to provide information for:

(i) supplementing and validating the assessment of the likelihood that transitional or coastal waters will fail to meet the environmental quality objectives

(ii) the efficient and effective design of future monitoring programmes

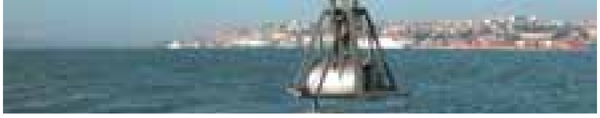
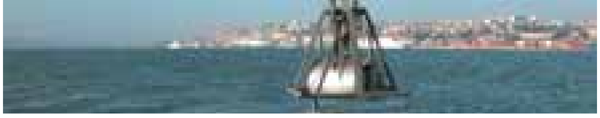


Figure 49. Submerged Aquatic Vegetation (SAV) survey, Tillamook Bay National Estuary Program (TBNEP), abridged.

Outcomes	**Program Objective (Core)**	Track the abundance and distribution of eelgrass beds in Tillamook Bay.
	Monitoring Question(s)	Is the spatial extent of eelgrass beds in the estuary changing over time scales of years to decades? Are there changes in eelgrass density or other visual indicators of changes in eelgrass health over time scales of years to decades?
	Plan Objective	No net decline in eelgrass beds (baseline = 363 hectares).
	Program Description	Eelgrass (Zostera spp.) meadows contribute to estuarine water quality and provide habitat for many aquatic species, including salmonids. Eelgrass has also been identified as Essential Fish Habitat. In 1995, the TBNEP used a prototype airborne imaging system to collect multispectral data for Tillamook Bay at a 1-meter spatial resolution to: (1) accurately map eelgrass beds throughout Tillamook Bay in order to establish an initial baseline of eelgrass bed density and distribution and (2) identify a means of monitoring the Bay environment in terms of cover and substrate that is both accurate and cost effective. Vegetation was assigned to one of six classes, and substrate was assigned to one of four classes. During this survey, eelgrass beds were found to cover nearly 11% of the area (approximately 363 hectares) of Tillamook Bay with the majority of the dense beds in the northern half of the Bay. Field surveys as part of the eelgrass monitoring project and as part of related benthic surveys verified the accuracy of this assessment.
Logistics	**Date Initiated**	1995.
	Coordinating Agency	TBNEP/TCPP.
	Funding Agency	TBNEP/TCPP.
Outputs	**Monitoring Parameters**	Terrestrial plants Sand/gravel, Green algae Mud/sand, Dense mixed algae Organic debris, Dense eelgrass Developed, Sparse eelgrass Water, Sparse mixed algae on dark substrates, Sparse mixed algae on light substrates
	Stations	The survey covers the extent of Tillamook Bay.
	Frequency	Aerial surveys at least every five years.
	Sample Collection	Multispectral sensor imaging mounted on light aircraft. Data collection requires over four hours during extreme low tide, during which high resolution (~1 meter) images are captured. Three spectral bands mimic bands 1 (blue), 3(red), and 4 (infrared) of Landsat TM. More than 300 separate frames are collected and georeferenced. Color photographs should be taken at the same time to provide an additional resource to improve the classification of digital files. Guidelines set for imaging specify that images may be taken only at low tide, during maximum delineation of submerged aquatic vegetation (SAV), during periods of low turbidity and low or no wind and clouds, and with sufficient identifiable land area to assure accurate plotting of beds. Ground-truthing for eelgrass extent and distribution to correlate with imaging will occur through the Eelgrass, Oyster, and Burrowing Shrimp Study and incidentally by other agencies, organizations, and individuals (e.g., during fish or benthic studies, or other research).
	Data Management	ArcInfo/ArcView GIS
	Related Monitoring Programs	Coordinate with Ecological Interactions Among Eelgrass, Oysters, and Burrowing Shrimp. Coordinate with Riparian Assessment. Coordinate with Tidal Wetlands Assessment. Benthic Invertebrate Inventory (Bay) Fish Use of the Estuary
	Anticipated Cost	$40,000/survey



WFD River Basin Management Plans

Article 13

6. River basin management plans shall be published at the latest nine years after the date of entry into force of this Directive.
7. River basin management plans shall be reviewed and updated at the latest 15 years after the date of entry into force of this Directive and every six years thereafter.

Annex V

Surveillance monitoring shall be carried out for each monitoring site for a period of one year during the period covered by a river basin management plan for:

- parameters indicative of all biological quality elements,
- parameters indicative of all hydromorphological quality elements,
- parameters indicative of all general physico-chemical quality elements,
- priority list pollutants which are discharged into the river basin or sub-basin, and
- other pollutants discharged in significant quantities in the river basin or sub-basin,

unless the previous surveillance monitoring exercise showed that the body concerned reached good status and there is no evidence from the review of impact of human activity in Annex II that the impacts on the body have changed. In these cases, surveillance monitoring shall be carried out once every three river basin management plans.

(iii) the assessment of long-term changes in natural conditions in order to distinguish between non-natural and natural alterations in the ecosystem

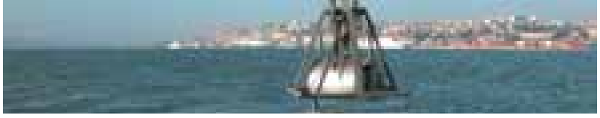
(iv) the assessment of long-term changes resulting from widespread anthropogenic activity

The results of surveillance monitoring shall be reviewed and used in combination with the impact assessment to determine or adjust requirements for current and other monitoring programmes in the river basin management plans.

On the basis of these results, the risk of failing to meet WFD environmental objectives shall be evaluated in the surveyed water bodies and an operational monitoring programme established. Before implementing operational programmes and to ascertain the causes of a water body failing to achieve the environmental objectives, investigative monitoring shall be considered, which may provide insight into reasons for any unknown excess.

Design of a surveillance monitoring programme

The foremost concerns in the design of a surveillance monitoring programme are that (i) transitional and coastal water sampling stations within each river basin district be sufficient in number and appropriately distribuced; and (ii)



observations are frequent enough to provide an assessment of the overall water status.

Surveillance monitoring shall be carried out for each monitoring site for a period of one year during the period covered by a river basin management plan, unless the previous surveillance monitoring exercise showed that the body concerned reached good status and there is no evidence of changes in impacts. In these cases, surveillance monitoring shall be carried out once every three river basin management plans, i.e. every eighteen years.

Monitoring shall include the quality elements listed in Figure 50, and indicated in the box above (WFD Annex V).

Spatial and temporal domain

The frequency of observations used over the surveillance monitoring period shall be sufficient to obtain a representative picture of the water body status. The number of observations at each station will depend upon the variability in parameters resulting from both natural and anthropogenic conditions. The understanding of the time scales of processes relevant to water quality status, obtained from previous monitoring programmes or literature reviews, informs an appropriate choice of monitoring frequency. It is recommended that the times at which monitoring is undertaken shall be selected in order to ensure that the results reflect changes in the water body due to anthropogenic pressure rather than other influences.

The minimum monitoring frequencies indicated in Annex V of the WFD may not be adequate or realistic for Transitional and Coastal Waters. There will generally be a lower level of confidence in most transitional systems when compared to freshwater because of the much higher natural variability and heterogeneity, therefore more samples may also be needed. Additionally, areas of special conservation interest, e.g. Natura2000 sites, may require a fuller sampling programme to verify compliance with complementary legislation such as the 92/43/EEC (Habitats) Directive.

Open coastal waters

These coastal waters are not directly influenced by river inputs or sewage discharges, and correspond to TICOR types A5, A6 and A7. Most of the changes in physico-chemical and biological parameters are due to natural conditions. Monitoring frequencies shall be chosen to achieve an acceptable level of long-term surveillance.

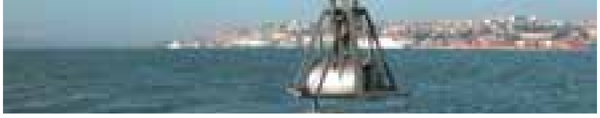


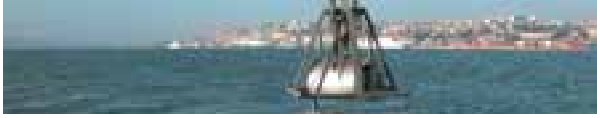
Figure 50. Surveillance monitoring frequencies of quality elements in open coastal water bodies.

Quality elements	No influence of freshwater	Submarine canyon	Influence of freshwater	Influence of urban outfalls
Biological				
Phytoplankton[1]	Seasonal	Every six months	Seasonal	Seasonal
Other aquatic flora	Annual if applicable	Not applicable	Annual if applicable	Every six months if applicable
Macro invertebrates	Annual	Not applicable	Every six months	Every six months
Fish	Not applicable	Not applicable	Not applicable	Not applicable
Hydromorphology				
Depth variation	6 years	18 years	6 years	6 years
Structure of the bed	6 years	18 years	6 years	6 years
Structure of the intertidal zone	6 years	Not applicable	6 years	6 years
Tides	Continuous	Not applicable	Continuous	Continuous
Currents and flows	6 years	18 years	6 years	6 years
Wave exposure	Continuous for one year every six years	Continuous	Continuous for one year every six years	Continuous for one year every six years
Physico-chemical				
Transparency/Turbidity	Seasonal	Seasonal	Seasonal	Seasonal
Thermal conditions	Seasonal	Seasonal	Seasonal	Seasonal
Dissolved oxygen	Seasonal	Seasonal	Seasonal	Seasonal
Salinity	-	Seasonal	Seasonal	Seasonal
Nutrient status	Seasonal	Seasonal	Seasonal	Seasonal
Special Pollutants				
Other pollutants[2]	Annual(2)	Annual(2)	Annual(2)	Annual(2)
Priority substances	Annual(2)	Annual(2)	Annual(2)	Annual(2)

[1] - In areas of bivalve production the presence of biotoxins in commercial bivalves and of toxic species of phytoplankton is monitored weekly-monthly due to food safety regulations; [2] - Sampling should be conducted in tissues of fish and shellfish and in sediments.

Figure 50 summarises the sampling frequencies of quality elements. The frequencies differ, but sampling should always take place synoptically, e.g. samples collected at three-month periods for a particular element should coincide with monthly samples for relevant elements.

The vertical sampling resolution should be determined according to the water temperature and salinity gradients, but always include at least a surface and a deep water sample (above and below the pycnocline for a stratified water column).



Transitional and inshore coastal waters

These include estuaries and coastal waters in the proximity of estuaries or lagoons, where water status is influenced by the magnitude of discharges as well as by their tidal and seasonal fluctuations, and correspond to TICOR types A1, A2, A3 and A4. Monitoring frequencies of pelagic biological quality elements and supporting quality elements shall take into consideration the tidal and seasonal variability.

At each station in estuaries and coastal lagoons with permanent connection to the sea it is recommended that all these parameters be measured at least at high and low tide, supplemented by sampling at mid-ebb and mid-flood where appropriate.

Guidelines for vertical sampling in transitional and inshore coastal waters

- At stations with depth less than 2m (with respect to tidal datum), only mid-water samples will be collected, unless there is clear salinity and/or temperature stratification
- At stations with depth of 2-4m (with respect to tidal datum), surface and bottom samples will be collected. If clear salinity and/or temperature stratification exists, an additional mid-water sample will be taken
- At stations with depth of 4-10m (with respect to tidal datum), surface, mid-water and bottom samples will be collected
- At stations with depth greater than 10m (with respect to tidal datum), appropriate vertical profiling will be used, based on salinity and/or temperature stratification

The spatial resolution will be determined on the basis of the water bodies defined for each system (see *Spatial Domain* chapter), with at least one station per water body. The vertical resolution will be determined (a) by the depth of the station and (b) by the degree of stratification.

Figure 51 summarizes the sampling frequencies for quality elements. The frequencies shown for quality elements differ, but sampling should always take place synoptically, e.g. samples collected at three month periods for a particular element should coincide with monthly samples for relevant elements.

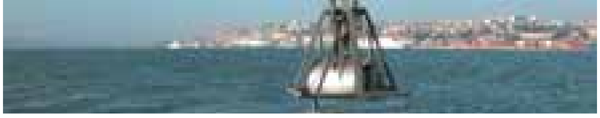


Figure 51. Surveillance monitoring frequencies of quality elements in transitional and inshore coastal water bodies.

Quality element	Frequency
Biological	
Phytoplankton (biomass and abundance)	Monthly
Phytoplankton species composition[1]	Every six months
Other aquatic flora	Seasonal
Macro invertebrates	Every six months
Fish[2,3]	Seasonal
Hydromorphology	Variable
Physico-chemical	
Thermal conditions	Monthly
Dissolved oxygen	Monthly
Salinity	Monthly
Nutrients	Monthly
Special Pollutants[4]	
Other pollutants	Every six months
Priority substances	Seasonal

[1] - In areas of bivalve production the presence of biotoxins in commercial bivalves and of toxic species of phytoplankton is monitored weekly-monthly due to food safety regulations; [2] - Applicable only to transitional waters; [3] - Observations shall where possible be synoptic with monitoring programmes related to the sustainable exploitation of commercial fish species; [4] - Sampling should be carried out in suspended particulate matter, sediments and tissues of fish and shellfish.

OPERATIONAL MONITORING

Definition and objectives

Operational monitoring (as defined in the *Problem Definition and Objectives* Chapter) focuses on two specific objectives. In both cases, the objectives are to verify the status of a water body or set of water bodies, with respect to one or more WFD quality elements.

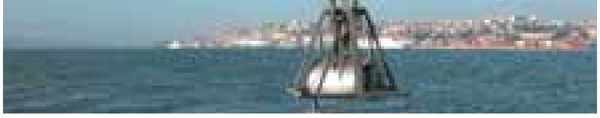
Except in extreme cases of pressure across a range of substances (nutrients, metals, organic micropollutants, etc.), this means that whereas surveillance monitoring is broader in scope, and as a rule less targeted, operational monitoring will generally focus on a sub-set of quality elements, e.g. primary and secondary eutrophication symptoms in the case of nutrient-related problems.

Operational monitoring

- Establish the status of those bodies identified as being at risk of failing to meet their environmental objectives
- Assess any changes in the status of such bodies resulting from the programmes of measures

Identification of water bodies at risk and verification of measures

The first objective (*screening*) of operational monitoring is concerned with further investigation into a water body which is at risk of non-



compliance with environmental objectives, i.e. which appears from surveillance monitoring data to be at moderate, poor or bad status for one or more quality elements. Operational monitoring is interpreted in MONAE to be applicable mainly for water bodies diagnosed as being at moderate status, where more detailed studies will help establish the status of the water body. Figure 48 presents guidelines for managers to decide on the inception of operational monitoring as regards the first objective. The figure is an overview, intended as a primer for detailed data analysis on a case by case basis, on which final decisions will be based.

The second objective (*verification*) is to verify *post-facto* if management measures are working, i.e. from a Pressure-State-Response perspective, if a reduction in pressure due to management response has resulted in the expected change in state.

Prediction of change in state resulting from measures

- Comparison to historical data
- Comparison to system(s) of identical type in pristine condition
- Application of ecological models
- Heuristic evaluation

The prediction of the change in state which will result from changes in pressure may only be made using the same approaches used for definition of reference conditions, listed in the box above.

The evaluation of the changes in status is made through the comparison of predictions and measurements.

Design of an operational monitoring programme

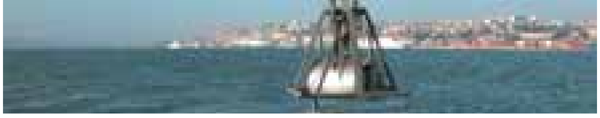
The guidelines for the design of operational monitoring will be determined by the quality elements that are under scrutiny, and whether the monitoring is being implemented to address *screening* or *verification*. The two objectives are discussed separately below, despite the fact that there are some common points.

Operational monitoring for screening

The decision to implement operational monitoring for screening purposes should be based on (a) the results of surveillance monitoring; (b) the pressures on a water body; or (c) both of these. Situations such as (i) *high* pressure combined with *good* state or (ii) *low* pressure combined with *bad* state (Figure 48) clearly need further interpretation. One of the key aspects in the design of this type of operational monitoring is the accurate assessment of anthropogenic pressure, including source apportionment, necessary in order to determine the possible responses in various situations.

Transitional and Coastal Waters exhibit changes in state that may appear to be decoupled from the pressure on the system. For instance, in the case of coastal eutrophication:

1. The symptoms are diverse, variable in time and space, may potentially be due to a range of causes, and vary greatly in severity.
2. Although there is an association between pressure and state, the relationship between them is strongly influenced by estuarine geomorphology and hydrodynamics: estuaries

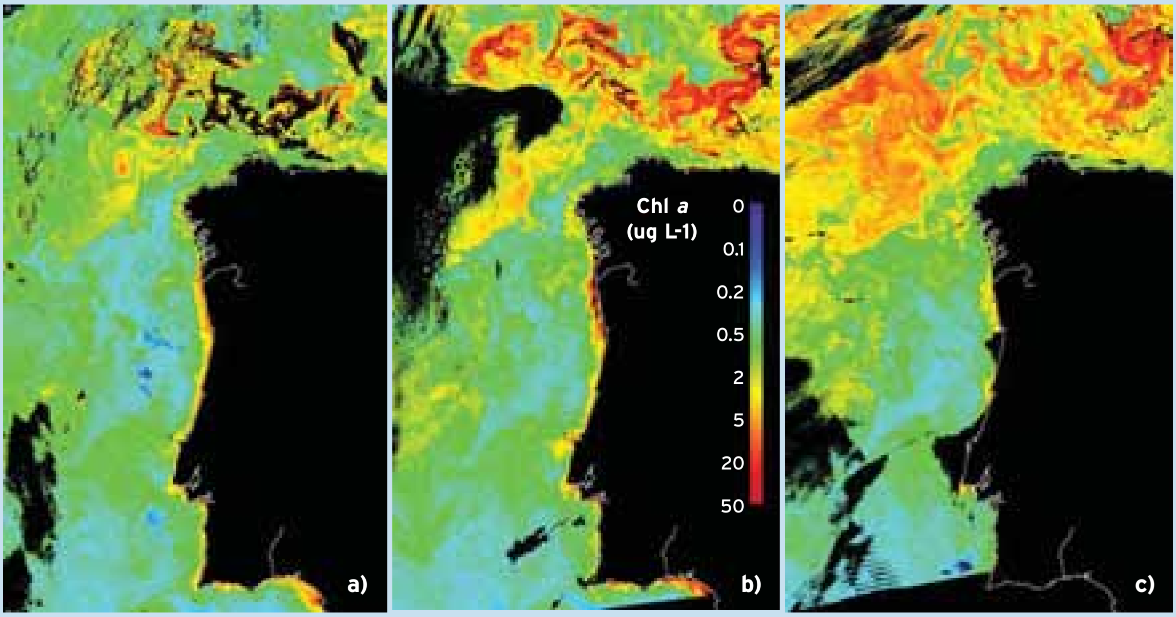


subject to similar nutrient-related pressure often exhibit totally different eutrophication symptoms, and in some cases no symptoms at all. Factors such as water residence time, tidal range and turbidity play a major role in determining the nature and magnitude of symptom expression;

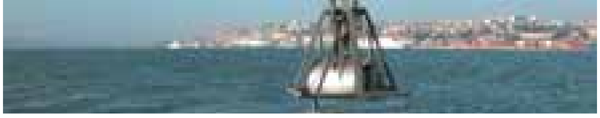
3. Biological interactions, particularly due to grazing, may provide a top-down control of eutrophication symptoms. These may occur in similar types of estuaries, due to natural variability, but also due to human activities such as shellfish aquaculture. In the latter case, selective filtration by bivalves may additionally affect biodiversity by altering the phytoplankton species composition.

Conversely, Figure 52 shows a situation where a potential HAB event causes impairment of coastal waters, but no reduction in pressure will correct the situation since this is a natural occurrence, caused e.g. due to upwelling relaxation.

Figure 52. Potential impairment of coastal waters by phytoplankton advected from offshore fronts (courtesy Plymouth Marine Laboratory).



The design of a monitoring programme of this kind, which aims to screen water bodies and systems, must therefore take into account (a) the measurement of state, where the design considerations are those indicated in the surveillance monitoring section as regards particular quality elements; (b) the determination of pressure to establish whether there is a match between pressure and state; (c) source apportionment if required, in order to inform appropriate management measures.



Operational monitoring for verification

The design of an operational monitoring programme for verification of compliance presupposes that there is a clear hypothesis that relates the anthropogenic pressure to the ecological status.

In all cases, the null hypothesis being tested for one or more quality elements is:

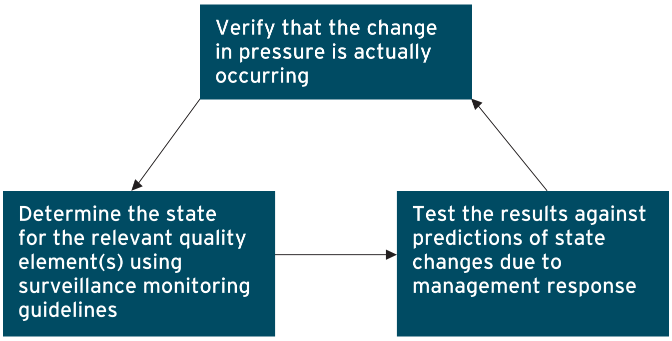
The change in anthropogenic pressure as a result of management response does not result in a change of state.

The hypothesis is tested e.g. to verify whether decreased pressure improves state, or if increased pressure deteriorates state. In many cases, a reduction in pressure will result in an improvement of state, but in some cases, such as the HAB example in Figure 52, it will not. The key design consideration is therefore the testing of this hypothesis, which must include a number of steps, following the operational monitoring programme. These are illustrated in Figure 53.

Case study

An analysis of the potential effects of reduction in nutrient loading for the Ria Formosa in southern Portugal is presented as a case study for implementation of operational monitoring for verification.

Figure 53. Steps in operational monitoring for verification.



The eutrophication status of the Ria Formosa was determined by means of the ASSETS screening model, fully described at http://www.eutro.org. The resulting eutrophication grade of *Moderate Low*, which corresponds to a WFD classification of *Good*, was determined on the basis of data collected over a number of years for primary and secondary eutrophication symptoms.

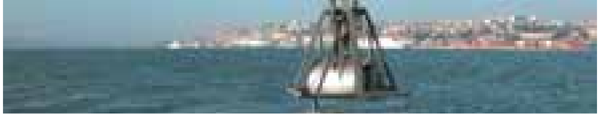
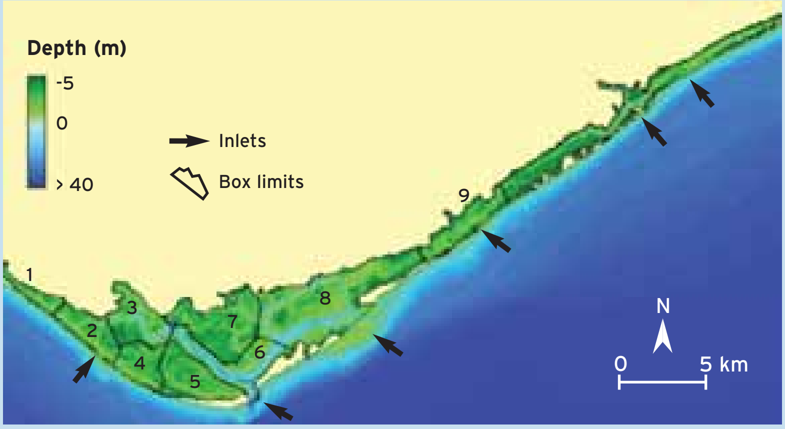


Figure 54. **Ria Formosa, showing ecological model boxes.**



In parallel, an ecological model was developed for the Ria (Figure 54), to simulate water exchange, nutrient dynamics, pelagic and benthic production, and clam aquaculture, a major use of the system. The outputs of this model were used to drive the screening model. Four scenarios were run on the research model: pristine, standard (simulates present loading), half and double the current nutrient loading.

The Ria Formosa has a short water residence time, and eutrophication symptoms are not apparent in the water column. However, benthic symptoms are expressed as excessive macroalgal growth and strong dissolved oxygen fluctuations in the tide pools. The standard simulation results showed an ASSETS grade identical to the field data application.

The application of the screening model to the other scenario outputs showed the responsiveness of ASSETS to changes in pressure, state and response, scoring a grade of High under pristine conditions, Good for half the standard scenario and Moderate for double the present loadings. The use of this hybrid approach allows managers to test the outcome of measures against a set of well-defined metrics for the evaluation of state.

Figure 55 shows the results obtained for the research model "green" scenario, corresponding to a 50% reduction in nitrogen loading. From an operational monitoring standpoint, the results generated by the research model could be compared to measured data after the implementation, using a variety of techniques, such as trend analysis or statistical comparisons. More importantly, the ASSETS screening model, which is indicated in TICOR as a potentially valuable tool for the implementation of the WFD in Transitional and Coastal Waters, could be applied on the data set collected in the verification programme, and the results compared with the screening model classification shown in Figure 55.

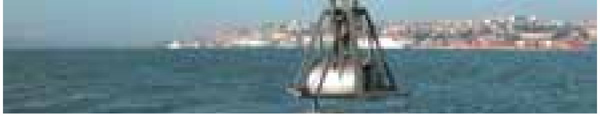


Figure 55. **Application of ASSETS to various research model scenarios.**

Index	Methods	Parameters	Value	Level of expression	Index
Field data Overall Eutrophic Condition (OEC) ASSETS OEC: 4	PSM	Chlorophyll *a* Epiphytes Macroalgae	0.25 0.50 0.96	0.57 Moderate	**Moderate low**
	SSM	Dissolved Oxygen Submerged Aquatic Vegetation Nuisance and Toxic Blooms	0 0.25 0	0.25 Low	
Research model Overall Eutrophic Condition (OEC) ASSETS OEC: 4	PSM	Chlorophyll *a* Epiphytes Macroalgae	0.25 0.50 1.00	0.58 Moderate	**Moderate low**
	SSM	Dissolved Oxygen Submerged Aquatic Vegetation Nuisance and Toxic Blooms	0 0.25 0	0.25 Low	
Model green scenario Overall Eutrophic Condition (OEC) ASSETS OEC: 4(5)	PSM	Chlorophyll *a* Epiphytes Macroalgae	0.25 0.50 0.50	0.42 Moderate	**Moderate low**
	SSM	Dissolved Oxygen Submerged Aquatic Vegetation Nuisance and Toxic Blooms	0 0.25 0	0.25 Low	

28% lower

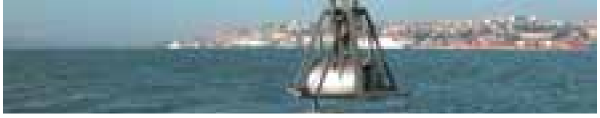
INVESTIGATIVE MONITORING

Cases where investigative monitoring is required

The Water Framework Directive specifies three cases where this type of monitoring is required.

The results of the monitoring would then be used to establish a programme of measures to achieve the environmental objectives and specific measures necessary to remedy the effects of accidental pollution.

- Where the reason for any exceedences (of Environmental Objectives) is unknown
- Where surveillance monitoring indicates that the objectives set under Article 4 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
- To ascertain the magnitude and impacts of accidental pollution



Investigative monitoring will thus be designed for the specific case or problem being investigated. In some cases it will be more intensive in terms of monitoring frequencies and focused on particular water bodies or parts of water bodies, and on relevant quality elements.

Ecotoxicological monitoring and assessment methods would in some cases be appropriate for investigative monitoring.

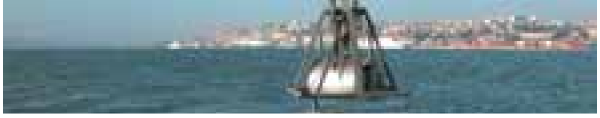
Investigative monitoring might also include alarm or early warning monitoring, for example, for protection against accidental pollution. This type of monitoring could be considered as part of the programmes of measures required by Article 11.3(a) and could include continuous or semi-continuous measurements of a few chemical (such as dissolved oxygen) and/or biological (such as fish) determinants.

Investigative monitoring may involve other determinants, sites and frequencies than surveillance or operational monitoring, as each programme will be designed to assess a specific stress or impact.

Approaches in investigative monitoring

Investigative monitoring relies by definition on a variety of approaches, which will generally be conjugated to provide answers to the research questions being asked.

Approach	Objective	WFD interpretation
In situ water monitoring	Identify specific mechanisms and substances	To ascertain the causes of a water body or bodies failingto achieve the environmental objectives. In the case of alarm or early warning.
Near-field monitoring	Reflects local exposure (history)	To ascertain the magnitude and impacts of accidental pollution.
Wider area monitoring	Ecological reference	To ascertain the magnitude and impacts of accidental pollution.



Estuaries and coastal zones are often highly energetic systems, due to the effects of river discharges, waves and tides, so the representation of physical processes is usually required to help clarify the phenomena of interest. These physical tools should be used in conjunction with chemical and biological techniques, which are selected according to the objectives of the work. The box above provides a useful indication of scale, covering a range from local to far-field effects.

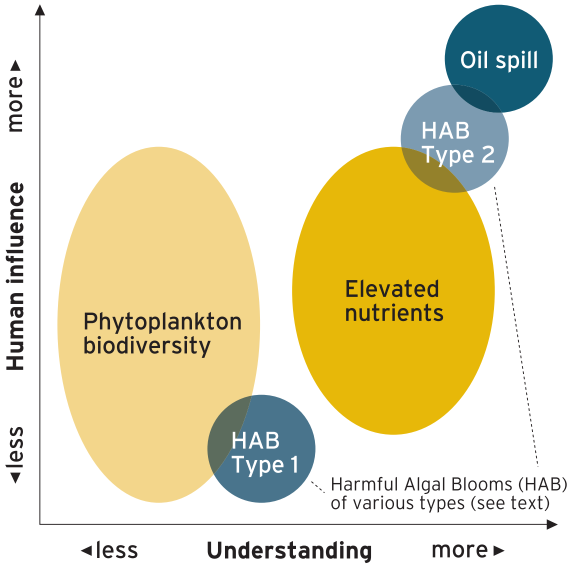
Investigative monitoring of the marine environment is by nature interdisciplinary, with the problems addressed being diverse, and constrained by different levels of understanding. Issues range e.g. from the interpretation of the effects of an accidental oil spill, where most processes are well understood, to the understanding of changes in biodiversity, affecting e.g. phytoplankton or benthic species composition, which are rather poorly understood (Figure 56).

The level of uncertainty in our understanding of underlying processes responsible for a particular environmental effect, and the corresponding apportioning of human influence (which conditions the possibility and adequacy of the response), is thus a major factor in the planning, execution and potential success of an investigative monitoring programme.

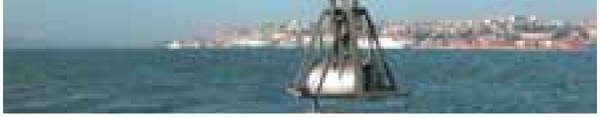
Overview of methodologies

Due to the constraints described above, it is therefore appropriate to provide only examples of methodologies that may be used to address research questions (i.e. perform investigative monitoring) for biological, supporting and hydromorphological quality elements.

Figure 56. **Examples of environmental problems in marine systems, scaled by human influence and process understanding.**



Additionally, it should be recognised that (a) methodologies are constantly under development (e.g. molecular probes, chemotaxonomic methods, improved *in situ* instrumentation, remote sensing); and (b) future paradigm shifts will potentially make some of these methods obsolete, as has occurred in the past for example



with the development of remote sensing applications or mathematical models.

MONAE is aimed at a WFD medium-term time horizon of about 20 years, and therefore recommends that investigative monitoring should always draw on the best available techniques, combining the state of the art in field determinations (*sensu lato*), laboratory experiments and simulation models in order to provide the answers to the investigative monitoring questions posed by managers and scientists.

Examples of techniques available for investigative monitoring

(a) At the local scale: field sampling and mooring deployment, *in situ* experiments; related laboratory work such as flumes for sediment-biota interactions, raceway devices for physiological studies or bioassays/ biomarkers for xenobiotics

(b) At a near-field to far-field scale: extended field studies, continuous shipboard profiling techniques, remote sensing, hydrodynamic models, water quality and ecological models

Application of biomarkers for investigative monitoring

Biomarkers are discussed below as an example of a powerful tool for use in investigative monitoring, targeted at xenobiotics.

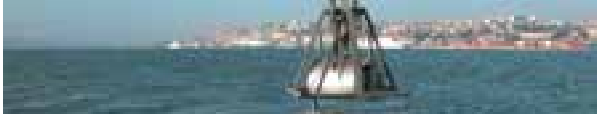
Biomarkers as an investigative monitoring tool

France and the U.K. have explored possibilities to include bioassays in the WFD; in most other countries bioassays and biomarkers are applied at a research level and/or in national monitoring programmes related to OSPAR. Moreover, in the U.S. bioassays are a federal requirement of state-delegated programmes for monitoring point source effluents as part of the discharge licensing process.

When warranted, field bioassays of water and sediment may be incorporated into state environmental monitoring programmes to ascertain causes of aquatic life use impairments and to track down toxic contaminant sources. Sediment bioassays are also an integral component of testing materials to be dredged if there is an expectation that the sediments are toxic based on bulk analyses.

Although it is not specifically mentioned in the WFD, the Working Group on Biological Effects of Contaminants (WGBEC) determined in 2004 that there are clear opportunities for the use of bioassays.

Eco-assays: closing the gap between ecology and chemistry. Eco-assays are defined as the application of bioassays or biomarkers in a water body to:



(1) Predict whether the chemical quality is sufficient to achieve high ecological status, using risk analysis;

(2) Determine whether chemicals are the cause of not achieving a good ecological status.

Bioanalysis may be regarded as a partial replacement of chemical analyses of priority and/or other relevant substances, and prioritising locations for further chemical analysis. It is defined as the application of a small set of inexpensive and rapid assays representing various taxonomic groups and/or modes of action applied to an extract of a water (or sediment) sample.

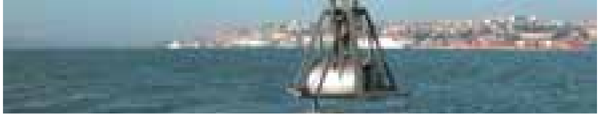
For bioassays, the WGBEC recommended whole sediment bioassays using the mud shrimp *Corophium* and the lugworm *Arenicola marina*, and bioassays of sediment pore waters, sea water elutriates, and sea water samples with bivalve embryos and the planktonic copepod *Acartia*. These two types of bioassays are non-contaminant specific and can provide a retrospective interpretation of community changes. Moreover, WGBEC in 2004 recommended different techniques for biological monitoring programmes, some of which are pollutant specific:

- The presence of organotin in coastal waters, for example, is detected by measuring the disruption to pattern of shell growth in the Pacific oyster *Crassostrea gigas* with the shell thickening method and/or by measuring the reproductive disorder in neogastropod molluscs by imposex or intersex.
- PAHs and other synthetic organic compounds can be measured through the bulky DNA adduct formation and PHA bile metabolism methods. Additionally, early toxicopathic lesions, pre-neoplastic and neoplastic liver histopathology in fish are indicators of these toxic substances.
- For certain metals such as copper and zinc, the metallothionein induction method measures the induction of metallothionein protein in mussels and fish.

Other methods like the lysosomal stability, the lysosomal retention and the "scope for growth" method, are not specific and respond to a wide variety of contaminants. The first two methods provide a link between exposure and pathological endpoints, and the "scope for growth" method is a sensitive measure of sublethal effects such as energy available for growth in bivalve molluscs.

Sampling procedures and frequency

The selected sampling procedures and their frequency of application will depend on the



method used to investigate the cause and the magnitude of specific stress or impact. In a general way, near-zone monitoring (e.g., caging of bivalves for testing purposes) and the wider area field surveys need to consider the biology of the target organism. In particular, periods of natural stress might need to be avoided, such as the spawning period when there may be large fluxes of contaminants out of the organism with the release of eggs.

The OSPAR Joint Assessment and Monitoring Programme (JAMP) has produced guidelines for general biological effects monitoring with technical annexes describing the methodology, sampling procedures and frequency of different bioassays and biological methods.

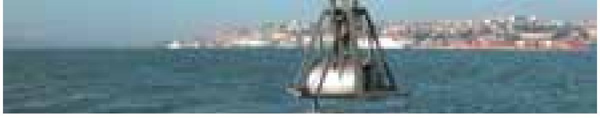
In the same way, several European projects like BEQUALM (Biological Effects Quality Assurance in Monitoring Programmes) have developed protocols and procedures for biological methods used in marine monitoring.

The role of target species

Bivalve molluscs have been one of the most frequently used indicators to determine the existence and quantity of a toxic substance. The advantages of using bivalves in environmental monitoring are: (1) wide distribution; (2) simplicity of sampling; (3) sedentary nature; (4) tolerance to a wide range of environmental conditions; and (5) high bioconcentration potential of environmental toxicants due to high filtration activity.

Due to their sessile nature, wide geographical distribution and capability to detoxify when pollution ceases, mussels such as *Mytilus*, cockles such as *Cerastoderma* and clams such as *Donax* have long been considered ideal for the detection of toxic substances in the environment. This broadly corresponds to the "Mussel Watch" concept, introduced in 1978.

Likewise, certain species of crustacea and some polychaete worms are considered capable of accumulating toxic substances.



Many fish species have also been used for the study of toxic pollution of the marine environment, due to their bioaccumulative capability and the existing relationship between pathologies suffered by benthic fish and the presence of polluting substances. Commercial and recreational fish species consumed by humans are also indicators of potential human health risk when specified thresholds for contaminant accumulation are exceeded, and the implications are readily understood by the general public.

Case studies

Harmful algal blooms

Harmful algal blooms (HAB) are caused by many different species of phytoplankton, and can have widely varying effects. They cause significant ecological and economic damage, for example through impacts on fisheries, aquaculture, human health and tourism. HABs may occur in open coastal waters and in semi-enclosed/enclosed systems, with a trend towards the occurrence of toxic algae in the former and high biomass blooms in the latter. The investigation of the causes and development of HAB events thus requires a range of methodologies (Figure 57).

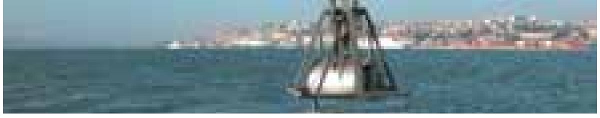
The ECOHAB programme, initiated in the U.S. in 1995, included three broad research themes. A general aim of ECOHAB was to develop reliable models to predict bloom initiation, development, duration and toxicity.

ECOHAB Research Themes

- Organisms – To determine physiological, biochemical and behavioural features influencing bloom dynamics
- Environmental regulation – To determine and parameterise the factors controlling the onset, growth and maintenance of HABs
- Food-web and community interactions – To determine the extent to which food webs and trophic structure affect and are affected by HABs

Figure 57. Examples of methodologies for investigative monitoring of HABs.

Methodology	Study objective
Physical oceanography (field studies, moorings)	Vertical migration, water column stability
Remote sensing	Biomass and primary productivity determination, bloom tracking, model validation
Micropaleontology	Cyst distribution in sediments
Molecular probes	Toxicity assessment of facultative HAB species
Numerical models	Prediction of HAB population development and distribution
Cost-benefit analysis	Evaluation of socio-economic costs of recurring HAB events



The EUROHAB initiative is a similar programme that has been carried out in the E.U. since 1999, clustering research projects such as BIOHAB and ECOHARM.

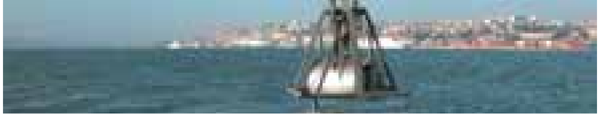
As an example of the application of currently available investigative monitoring techniques, field and simulation studies in the Gulf of Maine, U.S., revealed a number of physical and biological mechanisms which play a key role in the generation and maintenance of blooms of the toxic dinoflagellate *Alexandrium fundyense*.

1. Cysts of this species were found to germinate in bottom sediments far from shore;
2. Field mapping surveys revealed a large cyst repository situated offshore of Casco and Penobscot Bays, at a depth of 150m, at densities greater than 20 times those in inshore waters;
3. The role of these deep-water cysts in coastal HABs was studied by means of a mathematical model, which allowed the identification of an entrainment mechanism based partly on the behaviour of the toxic organism and partly on the wind-driven transport of a plume of low salinity water trapped in the surface layer;
4. The HAB cells germinated from deep-water cysts swim actively towards the light, enter the thin surface layer and are advected to the coast due to favourable onshore winds.

This case study illustrates the need to understand the cause-effect relationships that underpin HABs, through a combination of research tools. The affected area would in all likelihood violate environmental objectives, but conventional measures centered on the reduction of land-based nutrient discharges would not be an appropriate management response.

Accidental pollution

Accidental pollution in coastal systems can be of various forms, usually related to the discharge of xenobiotics. The magnitude, temporal and

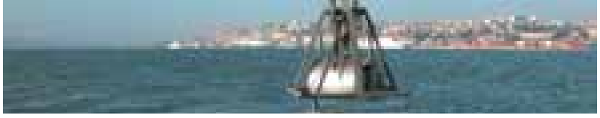


spatial scope of such accidental events vary widely, and they are not predictable in a deterministic sense.

The final case study in this chapter briefly reviews the potential investigative monitoring of accidental oil spills on coastal areas through the analysis of the studies carried out after the *Prestige* accident. The oil tanker *Prestige*, carrying 76 000 m^3 of fuel oil, sank off the north-western coast of Spain in November 2002. The tanker broke in half prior to sinking, discharging part of the oil as a surface slick, and fouling an area of 250 km of beaches and coves. The remainder of the oil was slowly released from the vessel's tanks from a depth of over 3 000 m.

The Special Action Plan carried out by the Spanish government to study the consequences of the *Prestige* shipwreck provides a good model for the study of the effects of an accidental oil spill. Actions taken to comprehensively assess and monitor the accident may be divided into three categories.

Background	Field/operational	Data/impact assessment
Identification and assessment of environmental risks in the area	Oceanographic survey of the shipwreck area and continental slope	Simulation of the evolution of fuel-oil and assessment of its physio-chemical properties
Implementation of an quality assurance system for analytic procedures	Oceanographic survey during the Spring bloom period	Assessment of the impact on communities and species with an ecological and economic importance in coastal areas
	Analysis and cartography of fuel-oil in water, sediments, organisms and pollution levels	Comparison of the measured concentration of PAHs in organisms with guidelines
		An ecotoxicological assessment applying appropriate methods to different taxa



This approach might equally apply to a wide range of spill accidents, allowing the planning of interdisciplinary studies which enable management measures to be taken as a reaction to such events. The adequacy of the approach may have a major impact on risk assessment, containment, mitigation and ecosystem recovery.

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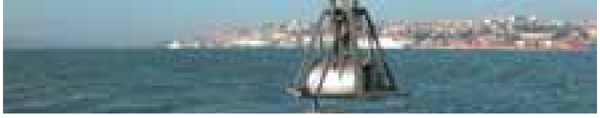

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ECONOMIC ANALYSIS

INTRODUCTION

The WFD establishes that monitoring programmes must be established in Transitional and Coastal Waters in order to verify ecological and chemical status. A hierarchical approach is proposed where cost-optimization with respect to informational requirements can be achieved. Environmental monitoring has evolved significantly over time, in response to legislation, monitoring tools and emerging threats, and consequently the measurement of the costs of such operations needs to take a flexible approach.

The objective of this chapter is to propose a framework for a cost-effective response to the requirements of the WFD. A full cost-effective analysis can be done by comparing the costs of monitoring options and assessing the risks and benefits of alternative management decisions.

Fixed costs are invariant to the rate of services delivered. *Variable costs* are related to the rate of service delivery. *Total costs* are simply the total of all fixed and variable costs, while *average total costs* are this sum divided by the number of services delivered. *Marginal cost* is the change in total (or variable) cost due to a one-unit change in the rate of service delivery.

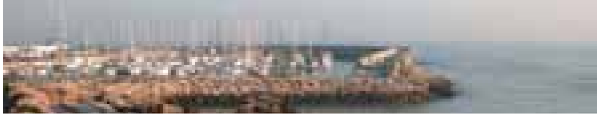
DEFINITION OF COST CONCEPTS

Economic and financial cost concepts

Costs are often used in different ways and it is therefore useful to define a few cost concepts.

Types of monitoring costs

This monitoring cost analysis considered three distinct actions: surveillance, operational and investigative monitoring. The analysis required an expression of the total cost per unit specific to each type of monitoring. This means that cost factors needed to be collected for all activities relevant to these three types of monitoring.



The following cost categories are proposed:

Fixed costs

These are the capital costs or the costs of investing in equipment specifically for the purpose of monitoring, and its installation. Equipment includes sensors, observation platforms, vessels and laboratories (fixed or mobile). Installation includes infrastructure construction and associated labour. Capital depreciation is counted as an annual expenditure governed by rules that indicate the expected remaining economic life of the capital employed. The following guidelines for total depreciation are suggested: 5 years for sensors used in the water and 8 years for sensors used outside the water.

Variable costs

Labour costs, or the costs of remuneration specifically for the purpose of monitoring, and operational and maintenance costs, including costs of chartering vessels and mobile laboratories, consumables, cost of training courses for system operators, spare parts and several levels of maintenance[1] are considered. Operational and maintenance costs also include the cost of specific logistical support such as 24-hour surveillance over the permanent monitoring networks with appropriate alarm systems and technical teams permanently available to repair equipment.

MEASUREMENT OF EXISTING COSTS

The determination of existing costs should ideally be carried out by sourcing from financial statements and budgets of the institutions responsible for monitoring activities. Data on work programmes could then be used to determine the unit cost per monitoring indicator (e.g. a BQE or SQE). However, financial statements do not specifically report on monitoring activities alone, making it impractical to use these as a basis for calculation.

As a consequence, a different approach was used, which determined the unit cost of a station-sample pair, which was subsequently used to evaluate overall sampling costs for different types of monitoring, based on the requirements defined in the previous chapter.

Station-sample pair

A sample taken at a station on one occasion, which may include only one depth or multiple depths. The entity is defined as a sampling visit to a particular geographic location.

The approach used for determination of station-sample unit costs is illustrated in Figure 58.

The information used to compile unit costs was drawn from work carried out in Portugal, the

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[1] - First level of maintenance: on-site technical support, especially in permanent stations, based on dedicated labour. Second level of maintenance: maintenance done on dedicated facilities. Third level of maintenance: maintenance executed by external support teams (manufacturers, outsourcing of special expertise).

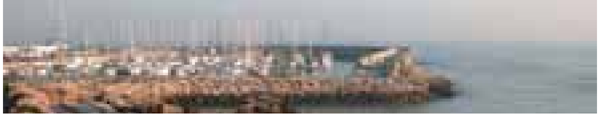
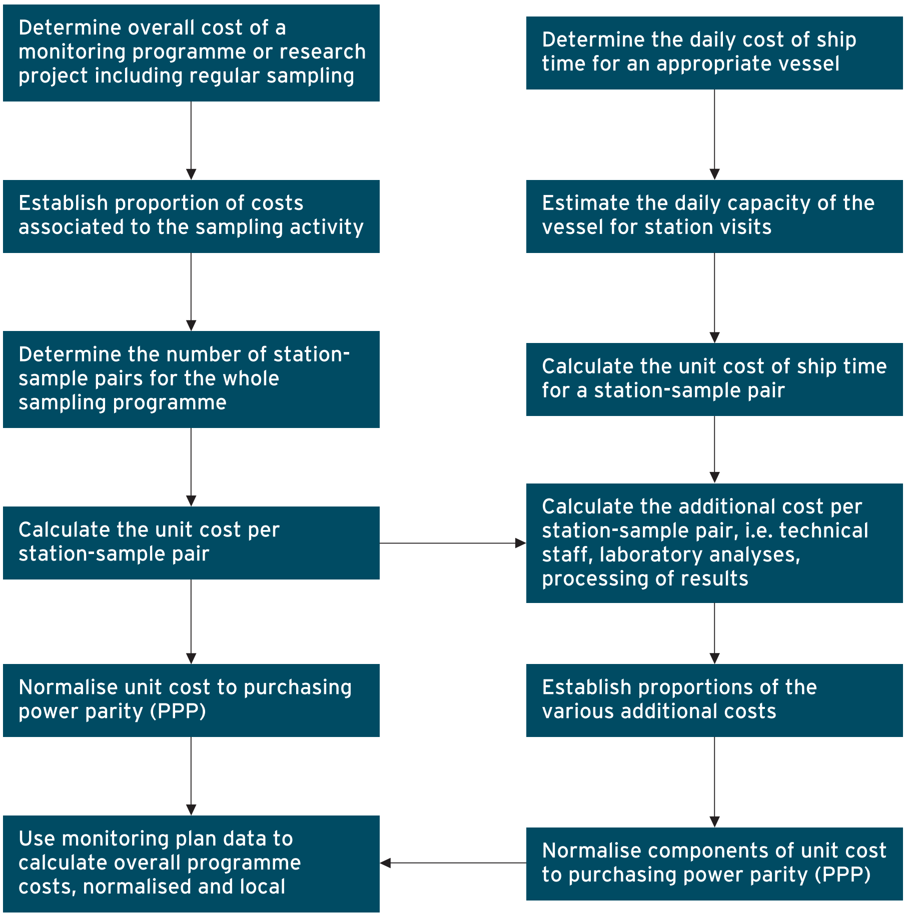


Figure 58. **Methodology for determining unit costs.**



United States and China, within the framework of monitoring activities and research projects. The data were then normalised to Purchasing Power Parity (PPP€). This approach allowed a comparison among different countries, both in terms of overall costs and the relative proportions of cost components. PPP€ measures the number of units of a country's currency required to buy the same amount of goods and services (in the domestic market) that the euro would buy in Europe. PPP€ has the same purchasing power in the domestic economy as €1 has in Europe.

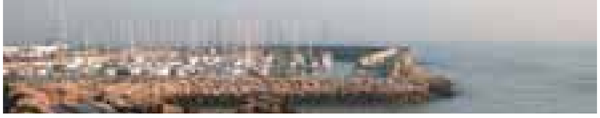
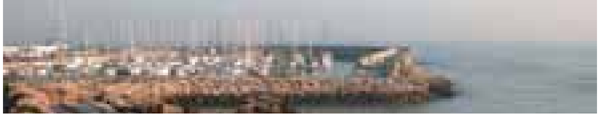


Figure 59. Cost calculation for transitional and inshore coastal systems.

	Portugal	United States	China
Project description	Environmental study of the Tagus estuary	Monitoring of Long Island Sound	Carrying capacity for aquaculture of Jiaozhou Bay and Sanggou Bay
Date/duration	1979-1983	Annual	1998-2001
Funding agency	UNDP, Portuguese government	U.S. Environmental Protection Agency	European Commission
Project cost for regular sampling activities (project time euros)	230,000	680,000	112,000
Stations	17	17 (31 in Summer)	7
Sampling events per station	54	35 (2 extra in Summer)	24
Total station-sample pairs	918	664	168
Unit cost for station-sample pair (project time euros)	250	1,024	667
Unit cost for station-sample pair (2004 euros)	**1,447**	**1,024**	**698**
Unit cost for station-sample pair (2004 PPP euros)	**1,447**	**530**	**3,061**
Ship (15-25m) cost per day (2004 euros)	2,500	2,924	2,611
Sampled daily	3	5	7
Sampling events per station	2	1	1
Total station-sample pairs	6	5	7
Ship cost per station-sample pair (2004 euros)	417	585	373
Additional cost per station-sample pair (2004 euros)	1,030	439	324
Percentage ship cost	29%	57%	54%
Percentage technician cost[1]	20%	20%	20%
Percentage analytical cost	51%	23%	26%

[1] - Technician cost is the cost of specialised shipboard staff for operation of sampling devices, conditioning of samples and in situ data acquisition – considered 20% of the total based on an average of various sources.



This has the advantage of being scalable in time and space, i.e. (a) allowing forecasting to be made for medium-term costs, taking into account inflation; and (b) proposing a methodology which is potentially applicable in different countries, and permits aggregated calculation of the costs of implementing the monitoring component of the WFD. A synthesis of results is shown in Figure 59.

The data in Figure 59 are used to provide average indications of cost, and are not corrected for variation in vertical resolution of sampling, or for the fact that cost estimates could differ between private and public companies. The selection of sampling programmes was however made on the basis that the biological and supporting quality elements measured had an 80-90% overlap among the three programmes.

Comparable data for programmes in open coastal water were more difficult to obtain, so an inverse analysis was carried out (Figure 60), using the daily ship costs, which are widely available, and the percentage unit cost allocations shown in Figure 59 to determine the overall unit cost.

For shallow water work, smaller (10-20m) vessels may be required, which will bring down the unit cost of sampling. Costs for an appropriate oceanographic platform for this type of sampling are in the range of 1,500-2,500 euros at 2004 prices in the United States, and about 50-75% of that in Portugal. Several issues arise from this, which are discussed more fully below, regarding cost adjustments, taking into account vessel range and mobility within and between estuarine systems.

The relative unit costs in 2004 PPP€ for the different countries are illustrated in Figure 61. Both transitional and inshore coastal and open coast monitoring is comparatively least costly in the United States, followed by Portugal and then China.

Although direct costs appear to be lowest in China, followed by the United States and then Portugal (see Figure 59 and Figure 60), when these costs are adjusted for the buying power a different picture emerges. Variations in direct unit costs may be related to differences in fuel costs, availability of appropriate monitoring platforms which affect cost competition, the degree of automation of laboratory analyses and

Figure 60. **Cost calculation for open coastal systems.**

	Portugal	United States	China
Ship (40-60m) cost per day (2004 euros)	7,000	9,310	3,896
Stations	5	5	5
Sampling events per station	1	1	1
Total station-sample pairs	5	5	5
Percentage ship cost	29%	57%	54%
Ship cost per station-sample pair (2004 euros)	1,400	1,862	779
Additional cost per station-sample pair (2004 euros)	4,862	3,260	1,456
Unit cost for station-sample pair (2004 euros)	**6,262**	**5,122**	**2,235**
Unit cost for station-sample pair (2004 PPP euros)	**6,262**	**2,649**	**9,814**

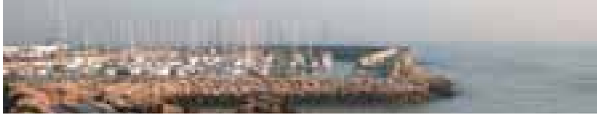
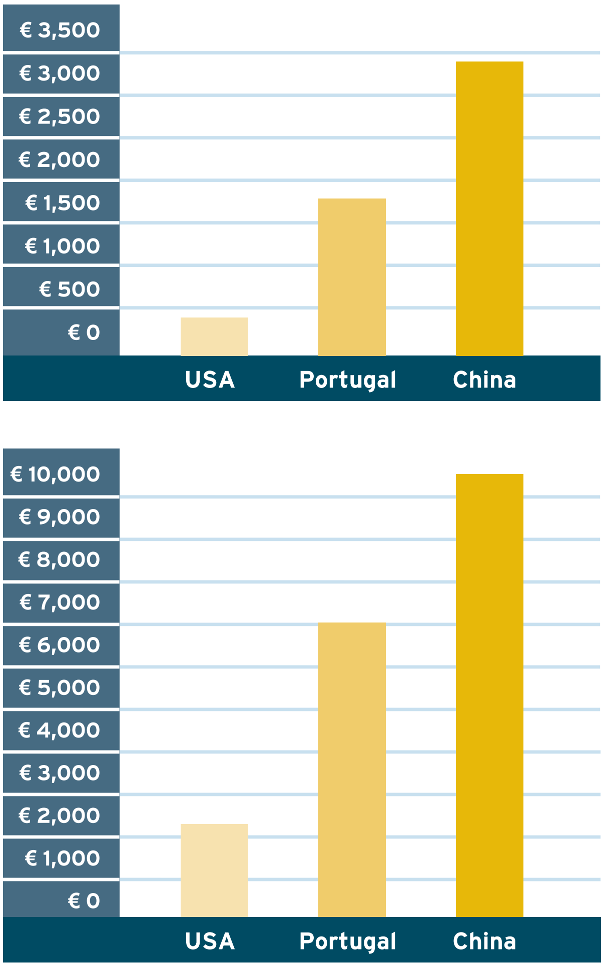


Figure 61. Comparative unit costs (station-sample pair) for inshore (top) and open coastal (bottom) monitoring in different countries (in PPP€).



the use of *in situ* measurements by means of oceanographic sensors.

PPP€ unit costs are useful for cross-country comparisons and direct unit costs for each country's own evaluation on monitoring costs.

MEASUREMENTS OF WFD MONITORING COSTS

Logistics

For inshore monitoring activities, 10-15m vessels with a semi-sheltered platform fitted with appropriate winches to lower rosettes and other equipment, and an appropriate shipboard work surface for sample processing, filtration, etc. would be suitable for the larger transitional systems (Figure 8). However, due to the limited mobility of such vessels among coastal systems due to navigational difficulties in the open ocean, three such vessels would be the estimated minimum to guarantee appropriate quasi-synoptic sampling coverage for the larger transitional waters in Portugal.

Such vessels could be based locally for daily operation and used in complementary tasks in order to optimize use and justify cost. For smaller estuaries, like the Lima, Mira or Ria de Aveiro, Óbidos and Formosa lagoons, smaller boats would be needed, for shallow water access. For some of the estuaries (Minho, Mondego) some locations may be reachable only with rubber dinghies deployed from a bigger boat or using a land-based mobile laboratory and trailer transport.

Cost estimates

To estimate WFD monitoring costs, frequencies for open coast and inshore surveillance

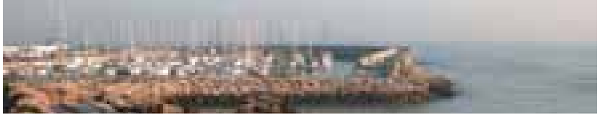


Figure 62. **Annual cost of monitoring for the application of the WFD in transitional and coastal systems in Portugal in 2004 PPP€.**

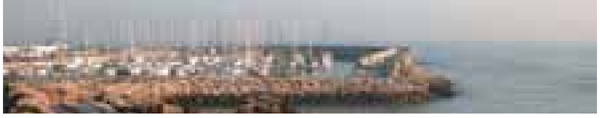
	Transitional and inshore coastal waters	Open coastal waters	Total cost (2004 PPP€)
Surveillance monitoring	1,736,000	250,000	1,986,000
Operational monitoring[1]	391,000	19,000	410,000
Investigative monitoring[2]	191,000	64,000	255,000
Total cost (2004 PPP€)	**2,318,000**	**333,000**	**2,651,000**

[1] - Calculated heuristically considering the following precautionary data: Spatial scope: 30% of transitional and inshore water bodies and 10% of open coastal water bodies. Workload: 25% cost reduction due to only half the analytical requirements; [2] - Calculated from research project budgets, see text for explanation.

monitoring (Figure 50 and Figure 51) need to be combined with the unit costs per sampling event. On the basis of a unit cost per sample-station pair of about €1,500 for transitional and inshore coastal systems and €6,300 for open coast monitoring it is estimated that annual surveillance monitoring costs required for WFD compliance will be almost €2,000,000 (Figure 62).

About 88% of this cost is associated to the inshore monitoring work (transitional and inshore coastal waters), the remaining 12% is for the surveillance monitoring of open coastal waters. This difference is partly due to the far greater number of transitional and inshore water bodies and associated sampling stations and also to the significantly higher monitoring frequency (Figure 45).

The unit costs of operational monitoring are based on the estimates for surveillance monitoring. The approach taken was to use the definition of operational monitoring, and in particular the application guidance discussed in the previous chapter, to heuristically estimate cases of suspected non-compliance or verification of measures which would create a requirement for operational monitoring. Using a precautionary approach, it is assumed that 30% of water bodies in transitional and inshore coastal waters, and 10% of water bodies in open coastal waters would require operational monitoring. Unit monitoring costs are additionally reduced by 25% (analytical costs are halved) because operational monitoring typically addresses a subset of biological quality elements and supporting quality elements.



Investigative monitoring is, by its very nature, difficult to value. This is compounded by the fact that it will include many emerging and new issues, for which there is no precedent and costs are unpredictable. The review presented on historical data identifies investigative monitoring principally as the activities of academic institutions and research institutes. The research budget funding to scientific projects in marine sciences and technology is thus a potential indicator of the scope and cost of investigative monitoring. This budget includes national research grants and projects financed by the European Union. The following assumptions have been used to calculate the investigative monitoring costs shown in Figure 62.

- Marine science research projects approved for funding in Portugal represent a recognition of the need to investigate unknown processes or complex system behaviour;
- The use of data from the previous ten years will include not only research driven by long-term questions but also integrate the costs of studying the effects of stochastic accidental events;
- A long-term average will dampen fluctuations due to economic cycles;
- Only the component of application to national systems of E.U. projects (Framework Programmes 4 and 5) is included, whereas for national programmes the full budget is used;
- The overall annual funding of investigative monitoring is weighted based on a research topic review – only a proportion of research projects will correspond to investigative monitoring.

The estimates shown for investigative monitoring considered 22 E.U. projects over the period 1996-2005, and 53 national projects, for an identical period. These were heuristically considered to address topics relevant to the WFD[1], and the total for the country was scaled up by considering that projects managed by IMAR correspond to a third of the national budget for WFD-relevant research in transitional and coastal systems – the distribution between the two was considered to be 75% and 25% respectively.

The annual costs shown in Figure 62 are applicable according to the monitoring periodicity indicated in the WFD, i.e. one year for every 6-year river basin management plan. The overall net present costs (at 2004 PPP€ prices) for an 18 year period, discounted at Portugal's long-term interest rate of 4.2%[2]

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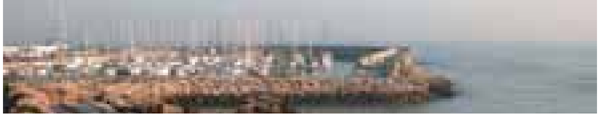
[1] - Out of the total list reviewed, 23 E.U. projects and 26 national projects were excluded, either because the topic was in appropriate for investigative monitoring (sensu WFD) or because the geographical context was not applicable to Transitional and Coastal Waters.

[2] - Europe's long term interest rate for 2004 is also 4.2%, which is measured as the weighted average of national 10 year government bond yields through 1998 and 10-year euro bond yields thereafter.



(OECD 2005), would indicatively be €7,000,000 at 2004 PPP€ prices, assuming operational and investigative monitoring is also carried out only for one year in every six. This is not necessarily a justifiable assumption, however it is difficult to determine how these will vary.

The total cost of monitoring over an eighteen year cycle (three river basin management plans) would be under 1€ per capita for the current ten million population of Portugal.

BENEFITS OF MONITORING

The additional benefits of monitoring requirements under the WFD are a subset of the total benefits of WFD system management. Although it would be feasible to calculate the cost-efficiency of alternative monitoring activities and programmes, the benefits of monitoring can only be viewed within a larger context. Better monitoring is necessary but not sufficient for the better management of inshore and coastal water resources.

Cost efficient and environmentally effective water body monitoring programmes play an important role in the improvement of water resources to the benefit of humans and ecosystems. The monitoring of inshore and coastal water bodies under the WFD includes at least the following benefits:

- Avoidance of non-compliance costs, including fines and other sanctions imposed by the European Commission;

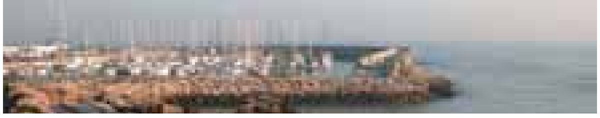
- Recreational and tourism benefits (e.g. coastal bathing, water sports, recreational fisheries);

- Improved quality and quantity of biomass produced in coastal and transitional systems (e.g. shellfish, finfish);

- Less expenditure on health services;

- Non-use benefits (existence values).

In a full cost-benefit analysis, these benefits need to be quantified up to a level where decision-makers can reasonably assess whether costs are disproportionate or not. The question of whether the economic costs in relation to benefits are disproportionate needs to be answered on a local level and informed by a cost-benefit analysis on the expected outcomes of the WFD. Disproportionate costs can occur when benefits are not sufficiently large, when the willingness to pay for benefits from the WFD is too low, or when affordability to implement the WFD is an issue. When such



disproportionate costs are evident, authorities may want to designate a system as a Heavily Modified Water Body or to seek derogation, requiring compliance with a subset of WFD requirements. The costs of limited compliance are not necessary financial, but are the benefits forfeited by not adhering to WFD standards.

In conclusion, the economic analysis of monitoring activities should take cognisance of:

- The types of monitoring that are required (surveillance, operational and investigative);
- The quality elements that need to be monitored (biological, physico-chemical, hydro-morphological and pollutants);
- The number of stations, number of sampling events per station and the required frequencies of different monitoring programmes;
- The unit costs per sampling event, if possible disaggregated for different quality elements and at different spatial scales.

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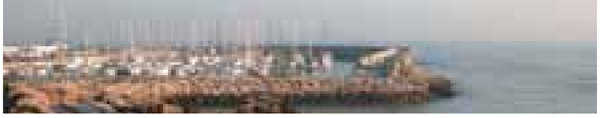

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PUBLIC PARTICIPATION

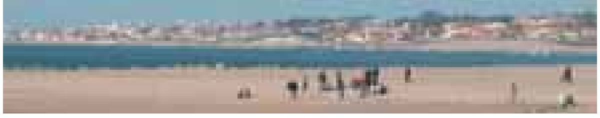
CONCEPTS AND SCOPE

The WFD identifies public participation as an integral component of water monitoring and assessment. Public participation is a two-way street: it means both that the public is the ultimate beneficiary of the WFD activities, and that the public has the right to have, and the means to exert, an influence in the conduct of public life.

Goals of public participation in coastal management

- Transparency: Relevant information should be made accessible to the public, and all non-classified information should be public record by default
- Hearing of interested parties: This is the core of public participation: stakeholders should be heard, their views duly considered, and addressed
- Citizenship and environmental education: Effective public participation must be learned, preferably through experience and action
- Data mining: Public participation may yield a large amount of useful data

Transparency and mandatory hearing of interested parties are commonplace and essential to the successful implementation of the WFD and Directive 2003/4/EC on the right of access to environmental information. However, promoting environmental and citizenship education is perhaps the most important goal in the long run, because coastal management has been a lesser branch of



environmental policy that would benefit from a better informed public opinion and support. Data from public participation, either from structured "collaborative monitoring" or from spontaneous citizens action or general knowledge, is a cost-effective source of low-tech, high-coverage information.

Steps in public participation

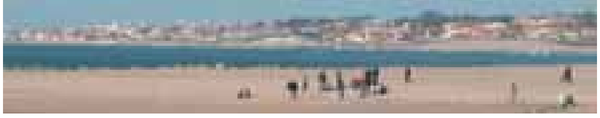
1. Awareness: Depending on the complexity of the issue, awareness may be raised by advertising or by environmental education actions
2. Information: Interested parties must be provided with useful information, in the form of paper publications, Internet access, CD-ROM, meetings or other means
3. Participation: Participation may range from elaborate written policy statements by a non-governmental organisation to mobile phone comments on the state of the beach by a surfer
4. Response: Contributions from the public should be considered by the authorities and must always be answered

PUBLIC PARTICIPATION ISSUES IN PORTUGAL

Public participation has little tradition in Portugal. The country has had a centralised system of government for eight and a half centuries, which did not encourage citizen participation in public life. Investment in education in the past two or three centuries has also been much lower than in most developed nations. This historical context has led to an ingrained habit of "following the leader", and a lack of independent thinking and self-reliance. The advent of democracy thirty years ago created political freedom and improved education opportunities, but did little about centralist government, or about promoting a more independent culture.

Despite these constraints, public participation has risen significantly in the last decades, due to a combination of political and social activity, higher levels of education, the integration in the European Union, the "information society", and a number of mandatory participation procedures, the most significant under the Environmental Impact Assessment (EIA) legislation. Whilst citizens' awareness and participation levels are still much lower in Portugal than in most of the European Union, there are signs of improvement.

Environmental information designed for public consumption is not overly abundant, but it is adequate for most purposes, though far from being used to its full potential. In other words, information availability is *not* the key issue



regarding public participation. The major hurdle is that public participation procedures are often seen in Portugal as *pro forma*, both by the authorities and by the citizens at large. Participation in any subject, and specifically under the WFD, will require a significant effort to raise the people's interest and awareness and to facilitate their say. People *will* participate if they feel that the issue at hand is relevant to their business, or that it has some bearing on their lives or their children's, and if they are convinced that their participation will have a meaningful effect.

PUBLIC PARTICIPATION IN COASTAL MANAGEMENT

Existing experience

International experience with public participation shows that public interest is a major driver in the creation of better coastal management practice. Public participation has a triple function here: direct action, from cleaning beaches to drafting of reports; environmental education "on-the-job"; and exerting pressure over the decision-makers. On the other hand, willingness of the authorities to embrace public participation generates a correspondingly higher interest from the public, depending on the methods used.

There are many examples worldwide of the benefits of such approaches. Among many others, the European Blue Flag initiative, managed at the European level by the Federation for Environmental Education (FEE) and in Portugal by Associação Bandeira Azul da Europa (ABAE), is a prime example. Despite being a purely private, voluntary initiative, the Blue Flag has become a standard for public participation and quality recognition regarding beaches and marinas throughout Europe. It should be noted that information for the Blue Flag is mostly provided by official agencies.

Methods

To promote public participation one must first recognise that the public is highly heterogeneous.

Organisations or individuals participate according to their interests, needs, agendas and convictions. The level of participation (both in quantity and in quality) is therefore highly dependent upon the perceived cost/benefit of the participation activity, thus on the

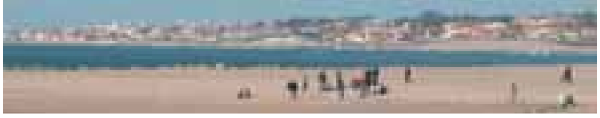


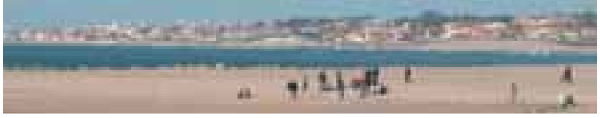
Figure 63. Preferred information and participation modes for selected publics.

Publics	Information	Participation
Environmental NGOs	Internet, executive reports, mailing list, focus or topical meetings	Internet, field campaigns, policy recommendations, positions in the media, work groups and steering committees
Schools	Mailing list, Internet, educational publications	Internet, environmental education, low-end field data, field trips
Scientists and Universities	Mailing list, Internet, CD-ROMs, seminars and conferences	Scientific publications, field data, seminars and conferences
Beach users	Posters, e-panels on the beach, leaflets	Mobile phone, e-kiosks, anecdotal field data
Fishermen (includes aquaculture)	TV, personal contact, focus meetings	Meetings, public hearings
Journalists	Press releases, Internet	Media: TV, radio, press, Internet
Government agencies (military, ports, police, health, environment, fisheries)	Meetings, Internet, executive reports, work groups and committees	Policy co-ordination, selected data made available (through the Internet), working groups and committees
Local authorities	Executive reports, web, focus meetings and training	Field activities, local campaigns
Decision-makers	Executive reports, Internet, briefings, legislative process, lobbying	Decisions, legislation, funding
General public	TV, Internet, newspapers, magazines, public hearings and meetings	Internet, mobile phone, public hearings and meetings

information and participation means and materials available (Figure 63).

One immediate conclusion is that the breadth of public participation is very large, so a wide range of communication tactics and information techniques must be available and targeted to each segment of the public.

Another fundamental conclusion is that to operate a public participation system is a full-time professional job. Serious public participation needs significant investment in money, hardware and personnel. Many useful data may come from public participation



Information and participation techniques

- Internet: The Internet is the cornerstone of any communication strategy, and is currently the best way to communicate and receive information from most interested parties. Websites must be of high quality, or most visitors will be discouraged from using them. Often, institutional sites tend to be irrelevant to stakeholder interests and user-unfriendly. Recently "blogs" have become an excellent way to express opinion and maintain informal communication among interested parties.
- Reports: There may be several types of these, for different publics. There should be an Internet and/or a paper version. The minimal requirement is an annual report (maximum 50 pages) synthesising results for key indicators (quality, pressure, impact), appropriate for non-technical readers. Graphics are preferable to listings, and "charismatic" animals (e.g. dolphins or otters) should be used as indicators to help capture public interest and imagination. A chapter on coastal waters should appear in the annual official report on the state of the environment. It is also helpful to create simplified versions, in brochure format, that can be distributed annually with a weekend newspaper.
- CD-ROM: Comprehensive digital products are essential for technical users such as researchers or consultants. These products should generally be released at marginal cost, or traded in kind as appropriate, e.g. with data from universities.
- Traditional marketing: This includes television advertisements, standing posters and leaflets to be distributed at the beach. TV advertising should either be broadcast as public service announcements, or negotiated with existing activities such as the "surf bulletin", in order to reduce cost.
- Press releases: This is the most important means of communication with the media, and usually requires professional staff. It is important to provide meaningful "news": press releases should be used, not abused.
- Public meetings and hearings: Public affairs can provide an opportunity for professional presentation and a dialogue with stakeholders in a transparent manner. There is no substitute for face-to-face talk.
- Closed meetings and committees: Regular meetings with stakeholders, in small groups, formal or informal, allow for better understanding and problem-solving than impersonal or public sessions.
- New information technologies: Portable technologies such as the multimedia mobile phone have a high potential to facilitate public participation, although it is a challenge to sort and use such information. Electronic multimedia kiosks, either fixed or mobile in beaches, environmental education centres or touring through schools, are useful tools for both transmitting information and gathering opinions.

(Figure 64). We should distinguish three main types: collaborative monitoring, anecdotal or spontaneous evidence, and emergency alerts.

The concept of collaborative monitoring is particularly appealing. National and international experience (e.g. Project CoastWatch Europe or

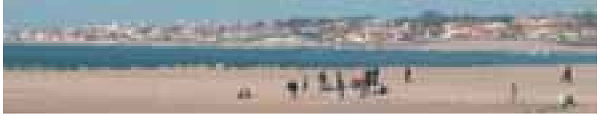
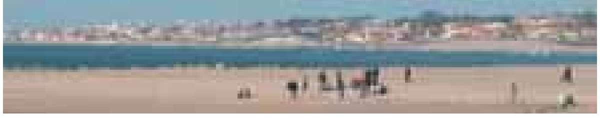


Figure 64. **Data from public participation.**

Mode of data gathering	Features	Techniques	Sources
Collaborative monitoring	Programmed data input with validated non-standard data	Bilateral protocols Custom made input interface Validation procedures	Environmental Non-Governmental Organisations (NGO) Research reports University field or lab training High school projects Government agencies (GO), e.g. border guard sightings of dolphins Companies, e.g. sensors attached to ships
Anecdotal evidence	"Input what you see" form	Internet or mobile phone link, with automatic data treatment	General public
	"Make a suggestion" form	Keyword filtering for automatic data treatment or personal attention	
	Open Forum	Screening for illegal use; Automatic statistical data treatment	
Emergency reporting	Police emergency-type receiving central	Identification and rapid verification	

the InfoZEE concept) indicates that different organisations may produce relevant data in a very cost-effective manner. These include environmental NGOs, schools and universities, local, regional and central government agencies, and private companies. However, to harness such information, data must be validated and pre-processed. Regularity, compatibility and quality of data may be assured by specific protocols.

Two modes of collaborative monitoring merit a comment. The first is the co-operation between environmental NGOs and schools. The second is the use of low-cost sensors, which dramatically improves the ability of a volunteer to gather scientifically valid data. Both have the potential to generate a huge amount of relevant, cost-effective information.



Other forms of participation may also generate relevant information. Anecdotal data may be gathered in a number of ways, from internet forms to telephone transcription. Although the average quality of such data may be low, it is certainly useful as a trend indicator and may also be used to monitor participation activity. The quality of data provided by non-organised but committed people can be improved by a certification procedure, that both qualify the data and improve willingness to respond.

Public intervention may also be important for emergency alert purposes, such as oil spills or dead dolphins, although in this case there must be a competent authority with permanent real-time response capacity.

Guidelines for collaborative monitoring protocols

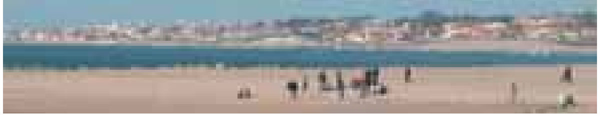
- Collaborative monitoring should result in a positive sum between data owner and database manager. Data exchange programmes or other reciprocal benefits should be clearly defined.
- The organisation that produces the data is the data owner. The data may be published or made available to third parties by the database manager, under the condition that the data source is acknowledged.
- The data owner should validate the data. A validation protocol may be agreed upon between the data owner and the database manager.
- The database manager should create an interface to facilitate the data input using an agreed format.
- The data owner should make the data gathering methodology available for consultation.

INFORMATION SYSTEM DESIGN AND IMPLEMENTATION

Features

The foundation for a strong participation strategy is a modern information system, designed from the ground up to meet very specific requirements. This cannot be achieved through a traditional “black box” approach, because the whole system must be conceived with full awareness and understanding of the field, the political goals and end-user needs. Otherwise, there is a risk of lack of flexibility and responsiveness to particular challenges, that might result in higher implementation and maintenance costs in the long run.

The objective of this section is to provide the terms of reference of an *Integrated Collaborative Monitoring Information System* for MONAE, with a focus on the public participation component but integrated with other functions and even pre-existing systems, that can serve as a base to produce a procurement statement. Cost estimation is beyond the scope of this document, since it depends on the precise quantification of the system's functional and scale parameters. This section to inform the discussion and decision on



parameters, usually involving a negotiation between the user viewpoint (institutional users, experts, end-user public representatives) and the provider viewpoint (budget constraints and scientific and political goals).

The objective is to provide an information system based on monitoring data that supports the WFD, as well as its permanent evaluation and reform, through collaboration between the public, experts, decision-makers and corresponding institutions (GO and NGO).

Bearing in mind the objectives and corresponding design criteria, we can list the most relevant uses (applications) and users (actors) for this information system (Figure 65). The concept of *user* as "*actor*" (and not just as a stakeholder) is important, since this is an "*action-oriented*" information system, whether the action is to be performed by a related institution or by interested citizens.

Some of the applications are "inner system" (e.g. interacting with sources), some are built-in targets (e.g. evaluating conformity to E.U. directives), but the system should also provide a clear interface to allow for private or public institutions to build other applications based on the system output.

Information system design criteria

- Versatility: It is essential to facilitate citizen input in casual circumstances, lowering the barriers to public participation, as well as delivering output to multiple entities with different functions. One of the more innovative facets of this system should be its ability to incorporate data in a wide variety of media carriers and formats, such as cell phone (SMS, pictures and video), audio calls, emails, web forms, as well as other more "traditional" media. But it should also be able to transmit information, from raw data to aggregated, analytical derivations of the system content, in equally flexible modes. This is not a trivial requirement.
- Robustness: When we facilitate raw, anecdotal input, there is a critical necessity to reinforce data validation filters and other strong consistency checks.
- Intelligence: Innovation often ventures into "uncharted territory" so it is essential that the system be able to incorporate the learning process that comes with user experience. This concerns, for instance, knowledge about validation filters and rules, multi-disciplinary content taxonomies and relations, dispatch procedures with different institutions, etc.
- Open architecture: Innovation notwithstanding, it is important to integrate with other pre-existing systems, and with future module add-ons for other functions and features. The system should not try to provide all possible "end-user" functions; instead, it should output a well-defined product with open specifications, allowing other actors who use that product to generate value-added products and services.
- Scalability: The potential of such a system is enormous, as can be its cost and implementation difficulties. The system must be able to adjust to different requirements, in terms of its dimensions (e.g. add more points of access), capacity (e.g. increase user handling ability, storage volume), scope (e.g. add more domains) and functions (e.g. add rapid response features).

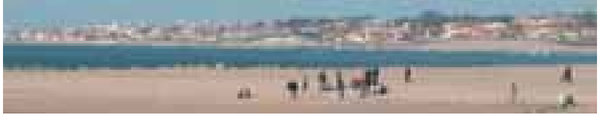


Figure 65. **Applications and actors in the information system.**

Application	Actors
Validation checks	MONAE system
Feedback to sources	MONAE system
Rapid response to relevant events/occurrences	Civil protection, others
Law enforcement	Law agencies
E.U. directive conformity evaluation	Water agencies, Government
Monitoring research	Universities, Research Centres, individual researchers
Policy and regulation debate, evaluation and reform	Water agencies, GOs and NGOs, Parliament, Political parties, Researchers, Citizens
Education/Raising the awareness of citizens	Water Agencies, Environmental NGOs, Schools, Citizens
Seeds for commercial/added-value products	Business, Public and Private Service providers

The specifications of the system input and output are summarised in Figure 66.

System architecture and functionality

In order to meet the expected input and output requirements, the system is defined in several modules. The overall system architecture is shown in Figure 67.

The following specifications are defined for the input-ouput modules of the system:

(i) Transducer (Input) - Automatic: forward SMS to email (contract service); parse email into digital structured text form (similar to web form); record phone calls (answering and message service); convert audio messages service to standard digital audio files; convert audio into digital structured text form (speech recognition for keywords from audio recordings); convert printed text into digital structured text form (Optical Character Recognition [OCR] for keywords in fax files); convert image/video signals into standard digital files. Human operator: converts all forms of input into structured digital text forms; scan images and printed text; digitise audio and video.

(ii) Transducer(Output) - Automatic: forward email to SMS (contract service); convert digital structured text into HTML (web

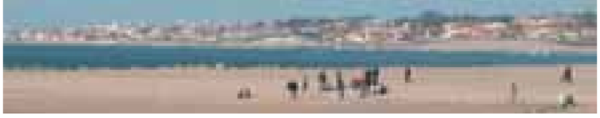


Figure 66. **System output and input.**

Output	Category	Input
(key examples) MONAE, INAG, Government, related Public Administration and Agencies, Environmental NGOs, Universities, Schools, Citizens.	Clients Sources	All "clients" for the system output are potential sources of the system as well. A special kind of "pre-certified" source, based on proven reliability and credibility should be included. In addition, the system should use source materials from other systems and projects.
Validated raw data (text, sound, image and video), Aggregated data (statistics, synthesis reports), Analytical data (reports, maps), Inferred data (knowledge-units – rules, FAQ, models, etc.).	Data types	Same as defined for "System output", plus possible geo-references concerning the source (such as cellular phone grid cell, caller ID, GPS).
Data descriptors (data-unit or knowledge-unit "ID card"), e.g. source, ownership, copyrights, terms of use, validation record, error margin, date, period of validity, processing/transformation steps, model assumptions, etc.	Metadata	Same as defined for "System output", plus information to provide an "ID card" for the source (name or handler code, contact).
SMS, digital text/audio/video files, mark-up text (e.g. XTML, HTML), analog audio/video, printed paper	Media format	SMS, digital text/audio/video files, mark-up text (e.g. XTML, HTML), analog audio/video, printed paper.
Public: Web, email, telephone, fax, regular mail, CD-ROM, DVD. **MONAE system staff only:** computer intranet.	Media delivery	**Public:** Web, email, telephone, fax, regular mail, CD-ROM, DVD. **MONAE system staff only:** computer intranet.
Public: Web portal with forum/blog and search engine, surrogate entities (e.g. distribution centres for printed material, CDs, DVDs, etc.), actors' "points-of-access" (phone number, email, etc.). **MONAE system staff only:** interactive terminals.	Points of transmission Points of access	**Public:** Web portal with structured forms, system's "points-of-access" (phone and fax number, email, postal address), surrogate entities (e.g. human assistance at police stations, port authorities and other public administration sites). **MONAE system staff only:** interactive terminals.
Free access to some Media delivery (e.g. Web-based publications, search engine and data-base queries), **fee-based access** to others (e.g. SMS news/alerts, printed reports, CDs, etc.).	Services provided	Friendly user interface through Internet, tools for anecdotal input, collaborative monitoring and reporting.
Seeds for added-value products (e.g. tools for aggregating data, simulation models, educational games, etc.).	Services enabled	

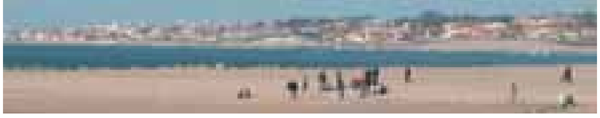
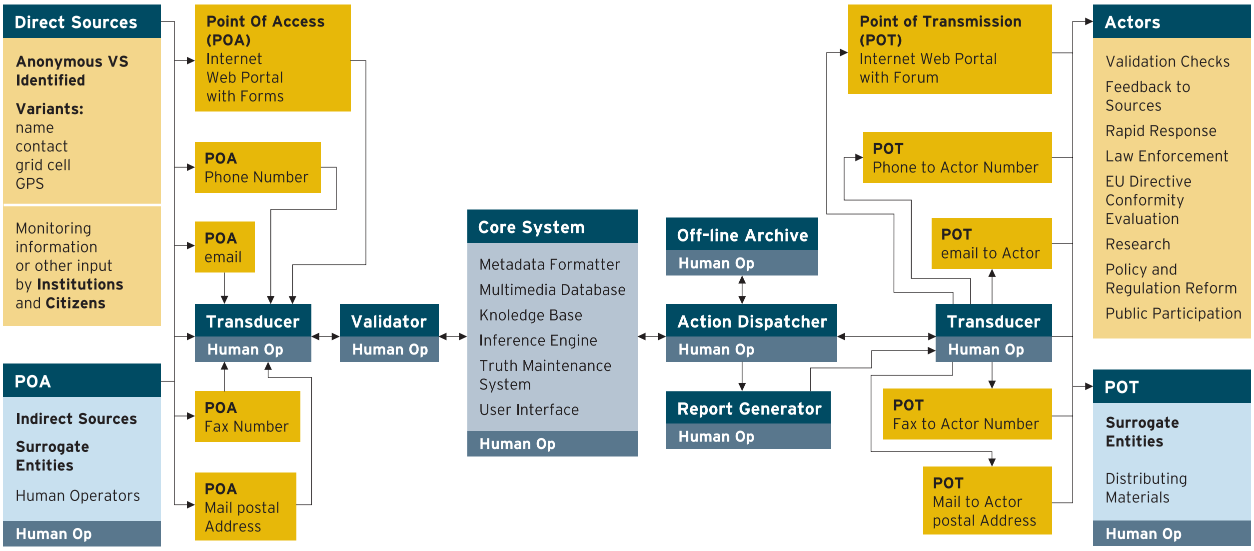


Figure 67. System architecture.

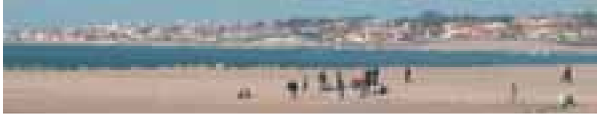


publication); upload text/image/audio/video files to Web server; convert digital structured text into audio files (Speech synthesis); generate phone calls from audio files; fax digital structured text; send image/video phone messages from standard digital files (contract service). Human operator: report all types of digital files to Actors (system clients), with multiple carriers (email, voice, etc.).

(iii) Data Validation - Automatic: rule-based consistency checks (e.g. claimed geographic location of the call checked against mobile phone grid cell, consistency between data serial input); rule-based relevance checks (e.g. irrelevant topic, joke calls); rule-based completeness checks (e.g. lack of image in image-dependent information, should originate an automatic request for added input); rule-based action requirement check (e.g. nature of info implies further validation check by human operator or outside agency). Human operator: all validation that fails to be solely satisfied by automatic procedures.

(iv) Off-line Archive - A multimedia system must handle very large volumes of data, in particular video, and this is further multiplied by the continuous nature of the input, producing a large backlog of historical data. It is not cost-effective to keep all of these files on-line, and therefore it is desirable to regularly transfer some of the less critical data to an off-line archive. To automate this procedure as much as possible, rules can be defined based on criteria such as period of validity, date, data "value" (from relevance, reliability, frequency of queries, etc.).

(v) Report Generator - Easy report programming by end users; standard reporting should be issued with selected indicators and indices



that are as clear and interesting as possible for the end-users of the system, e.g. using colour-coded maps and graphs rather than tables. Emphasis on significance: key indicators or indices rather than long lists. Different types of data: quality, pressures, impacts, monitoring effort, participation statistics; "charismatic" animal indicators, with pictures. Clarification on standards as appropriate, credit of sources.

Figure 68 defines the specifications of different modules, each representing a functionality of the system.

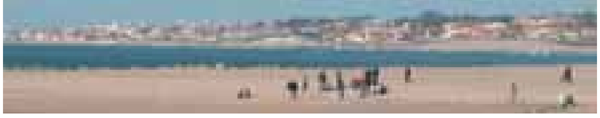
Implementation issues

A full-featured system should be able to produce the desired results and therefore requires several full-featured functional modules.

Naturally it is possible and advisable to implement these features in progressive,

Figure 68. **Functionality of System Core Modules.**

Module	Description
Metadata Formatter	Generate, validate and format data descriptors (data-unit or knowledge-unit "ID card"), such as described in "System output" The general principle is that it is always preferable to keep the original file format, or when not compatible, to store information that allows any authorised user to reproduce (and therefore check) all transformation steps that generated the current file from the original one
Multimedia Database	A relational database able to incorporate different raw media files (text, audio, image, video) and derived types (geo-referenced images, maps, etc.)
Knowledge-Base	Knowledge units (rules, frames, question-answer tuples, FAQ)
Inference Engine	Forward chaining, Query-Answer matching, pattern-matching
Truth Maintenance System	Logic truth consistency checks for the combined logic statements derived from current input and historical data
Action Dispatcher	**Automatic** Rule-based target institution identification (e.g. type of regulation violation, identifies corresponding agency or agencies) Rule-based urgency checks (e.g. dangerous occurrence requires notification of civil protection plus service responsible and able to provide further validation) Routine news report broadcast (e.g. SMS broadcast) Standard feedback to source (e.g. acknowledging reception of input) **Human operator** All data-suggested actions that fail to be solely addressed by automatic procedures
User Interface	Only for intranet access (MONAE system operators) Efficient computer-human interface paradigms (e.g. drag-and-drop, WYSIWYG), multi-platform operating systems



Scale and functional parameters

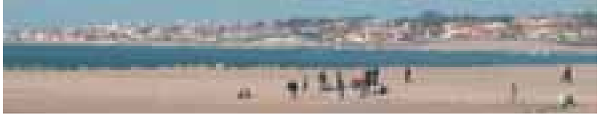
- Number of simultaneous users
- Number and kind of points of access (address, phone, fax, email, web forms, human operators and schedule)
- Number, kind and level of services contracted (SMS forward to email and vice-versa, grid cell report for mobile phone calls, GPS-based input devices, web search engines, surrogate points of access and points of transmission)
- Level of investment in automatic process (transducer and validation modules, algorithms, sensors and other input-output devices), correlated with level of intelligence to build into the system (number of rules, FAQ, inference engines, context knowledge-units)
- Number and qualifications of expert support staff for validation, and respective response time
- Volume of data to keep on-line and to keep off-line
- Response time to user requests
- Update frequencies: regular reports, database update, knowledge-base updates, web updates

gradual steps, as referred below (see "implementation path" box). In particular, scale and functional parameters must be quantified in order to evaluate system costs and upgrade path implications.

Designing the hardware architecture is only possible after deciding on many of the scale and functional parameters. Some components, however, are a standard requirement for this kind of system.

Furthermore, current experience shows that the best policy is to choose multi-platform systems (systems able to interact with many operating systems, software from different sources (proprietary software but also open-source software), as well as multiple hardware suppliers.

The proposed design allows for different levels of scale and services, depending on political will and budget constraints, but also depending on the evaluation of the results of the tests and experience accumulated with each stage implemented. Although ambitious in its more innovative aspects – like the ability to facilitate anecdotal input from modern individual



Implementation path

- First stage: Small, focused domain content, with only web form input (single point of access), no external output (does not require transducer modules, and has light requirements on validation, since it is pre-structured. Test the core system modules, off-line archive procedures, and report generation, with selected institutional users.
- Second stage: Add web-only output (single point of transmission), with simple web publication, open the system to general public use, then gradually introduce and test more web-based query and search features.
- Next stages: Add other forms of input (points of access), with gradual increments of requirements on transducer and validation. For each kind of transducer requirement, introduce and test the point-of-transmission, symmetrical to corresponding point-of-access.
- Development stages: Increase domain content, increase system capacity, add features.

communication devices used by common citizens – it is precisely the most innovative and challenging facets of this system that stand a better chance to stimulate public participation. In other words, rather than tone-down the system design and its features to correspond to low expectations due to current low levels of citizen involvement, we should adopt a proactive design philosophy rather than a reactive one.

Finally, it is important to emphasize that the key to the success of an information system like the one proposed here is the involvement of interested parties throughout the process, from the detailed specifications to the implementation stages.

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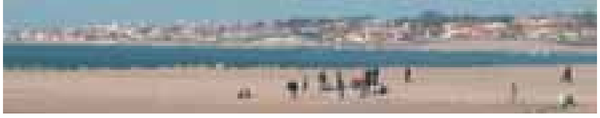

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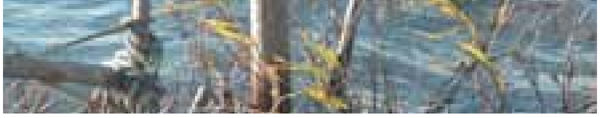
CONCLUSIONS

The E.U. Water Framework Directive (WFD – Directive 2000/60/EC) outlines the requirements for monitoring of surface waters in the European Union, within the general framework of river basin management plans. Three distinct types of monitoring are stipulated, in order to meet the overall goal of assessing the quality status of European waters. The focus of this book is only on transitional (estuarine) and coastal waters, for which the following monitoring types and objectives are defined in the WFD.

Monitoring type	Objectives
Surveillance monitoring	• Supplement and validate the assessment of the likelihood that transitional or coastal waters are failing to meet the environmental quality objectives • Efficient and effective design of future monitoring programmes • Assessment of long-term changes in natural conditions in order to distinguish between non-natural and natural alterations in the ecosystem • Assessment of long-term changes resulting from widespread anthropogenic activity
Operational monitoring	• Establish the status of those bodies identified as being at risk of failing to meet their environmental objectives • Assess any changes in the status of such bodies resulting from the programmes of measures
Investigative monitoring	• Where the reason for any exceedences of environmental objectives is unknown • Where surveillance monitoring indicates that the objectives set under Article 4 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 • To ascertain the magnitude and impacts of accidental pollution



The Monitoring Plan for Water Quality and Ecology for Portuguese Transitional and Coastal Waters (MONAE) was a project developed with the broad aim of setting guidelines for the development of WFD-compliant monitoring plans in Portuguese Transitional and Coastal Waters.

General objectives of MONAE

- Provide an integrated approach to monitor all Portuguese Transitional and Coastal Waters
- Have the potential to address management issues, i.e. to be hypothesis-driven
- Establish the guidelines for monitoring the water quality and ecology of Portuguese Transitional and Coastal Waters throughout the next decades
- Integrate the monitoring requirements of the WFD for Transitional and Coastal Waters
- Define and apply a methodology for the definition of water bodies in Portuguese coastal and transitional types
- Possess internal flexibility, in order to accommodate new methodologies that may be developed and/or applied over its life-cycle
- Use a hierarchical approach, allowing cost-optimisation with respect to information requirements

MONAE builds on previous work on typology and reference conditions published in TICOR (http://www.ecowin.org/ticor/) and in a number of supporting scientific papers.

The MONAE book begins with a brief general introduction and description of the problem, followed by a further seven chapters.

Problem definition and objectives

WFD context, problem definition, and general objectives

Methodology

Details on the MONAE process

Tools

Summary of tools used in MONAE, and end-product methodologies

Data overview

Review of historical data; Producers, metadata, WFD compliance and international comparison

Spatial domain

Spatial scope and typology; Methodology for water body definition and its application

Monitoring plans

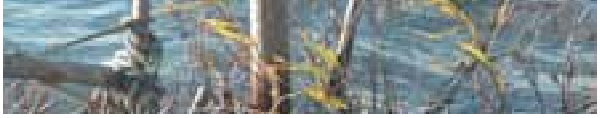
General considerations for all types of monitoring; Detailed guidelines for surveillance, operational and investigative monitoring

Economic analysis

Estimated costs of monitoring; Normalisation to Euro zone Purchasing Power Parity; Benefits

Public participation

Tools; Input regarding policy; Environmental education; Collaborative monitoring



Each chapter was written so as to be readable on its own, by including the key concepts, methodologies and results relevant to the theme. The tools chapter provides an overview of the techniques used for different parts of the work, together with those that may be applied for obtaining end-products, such as the definition of water bodies. We have chosen not to make any specific recommendations of software or other products, due to the progress anticipated in technology over the next decades. Where appropriate, we have indicated what tools were used to obtain the results presented herein.

A summary of the key outputs and findings of MONAE is presented below.

DATA OVERVIEW

Data collection in Portuguese Transitional and Coastal Waters (Figure 69) has been carried out regularly in several thematic areas, including hydromorphology, marine geology, water quality, phytoplankton, shellfish and specific pollutants.

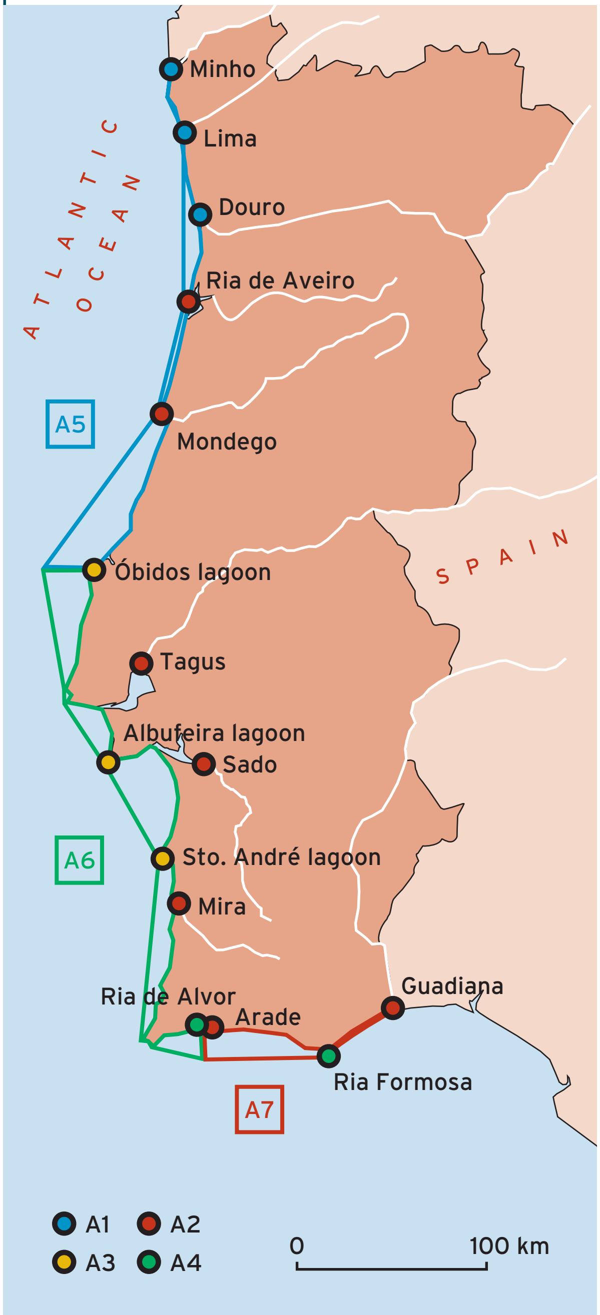
Most of the data collected by institutions in Portugal are stored in internal databases. The availability of historical data is thus compromised by data fragmentation, which stems from the lack of coordination of monitoring activities both at a system (e.g. estuary or lagoon) and at national level.

Figure 70 summarises the currently available historical datasets as well as other less accessible data.

There is a large quantity of data for Portuguese Transitional and Coastal Waters. However the datasets are concentrated both in time and space, which means that in most cases they are not representative of a comprehensive system survey, due to the nature of the sampling design.

In several systems the number of sampling stations, although high, covers only part of the

Figure 69. Map of the Portuguese typology for Transitional and Coastal Waters (transitional and restricted coastal types A1-A4 indicated in colour).



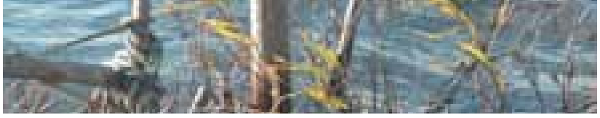


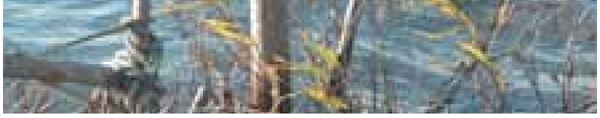
Figure 70. Available historical datasets for Portuguese Transitional and Coastal Waters.

	Type	Systems	Area (km²)	Sampling period	Number of records						
							Parameters				
					Stations	Samples	Physico-chemical	Biological	Other	Total	Results
Transitional waters	A1	Minho	23	1982 - 2002	17	322	25	7	2	34	3 538
		Lima	5	1984 - 2002	31	603	31	37	1	69	8 096
		Douro	6	1987 - 2002	39	292	34	7	1	42	5 006
	A2	Ria de Aveiro	60	1972 - 2002	84	1 441	45	40	6	91	13 499
		Mondego	9	1985 - 2002	48	726	17	261[1]	12	290	18 317
		Tagus	330	1971 - 2002	146	8 702	50	86	15	151	81 003
		Sado	160	1963 - 2002	299	3 801	39	5	16	60	24 164
		Mira	3	1983 - 2002	119	6 469	19	155[1]	4	178	30 704
		Guadiana	18	1977 - 2002	114	24 412	39	7	4	50	60 826
Coastal waters	A3	Óbidos	6	1962 - 2004	60	560	5	-	12	6	U
		St. André	2	1984 - 1986	17	1 239	11	3	0	14	9 760
	A4	Ria Formosa	49	1984 - 2002	70	97 021	78	74	13	165	139 932
	A5	From Minho estuary until Cabo Carvoeiro	3 200	1923 - 2003	987	1 730	3	U	U	3	U
	A6	From Cabo Carvoeiro until Ponta da Piedade	4 200	1923 - 2004	1 748	2 856	3	U	U	3	U
	A7	From Ponta da Piedade until Vila Real de Sto António	1 000	1923 - 2001	648	948	3	U	U	3	U

U - Unavailable information; [1] - Includes species list.

system. This issue must be addressed when designing future monitoring plans, since there is a need to choose representative sampling stations in accordance with the water bodies defined for an effective implementation of the WFD.

The data overview carried out shows that most datasets cannot be considered WFD compliant due to the lack of data availability for several of the biological quality elements (particularly aquatic flora, benthic invertebrate fauna and fish fauna) in most of the systems; the Ria de Aveiro, Tagus and Sado have the most complete datasets concerning biological quality elements. Apart from the spatial limitations referred above, particularly those observed in mesotidal stratified estuaries (type A1), the data for most of the hydromorphological and physico-chemical supporting elements are accessible for most systems. The fragmentation of monitoring outputs must be addressed for WFD compliant monitoring of Portuguese Transitional and Coastal Waters.



SPATIAL DOMAIN

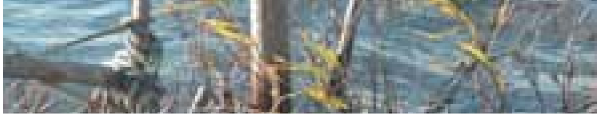
An approach for the division of Transitional and Coastal Waters in Portugal into water bodies for management and monitoring purposes was developed in MONAE.

Two distinct methodologies were used: for the definition of *Open Coastal Water Bodies* literature results were used, and for *Transitional and Restricted Coastal Water Bodies*, a bottom-up data analysis approach was carried out.

There are common points to both methodologies, since in both cases natural factors such as salinity or morphology are combined with the human dimension, using the significant pressures and/or key elements of state. The application of these methodologies has resulted in the definition of 60 transitional and coastal water bodies for Portugal, which are detailed in Figure 71. It is envisaged that

Figure 71. Summary of water bodies defined for Transitional and Coastal Waters in Portugal. The Leça estuary was excluded, since it is classified as an artificial structure.

Types	Water category	Systems	Nº of water bodies
A1 Mesotidal stratified estuary	Transitional	Minho estuary	5
		Lima estuary	3
		Douro estuary	3
		Leça estuary	-
A2 Mesotidal well-mixed estuary	Transitional	Ria de Aveiro	5
		Mondego estuary	3
		Tagus estuary	4
		Sado estuary	6
		Mira estuary	3
		Arade estuary	1
		Guadiana estuary	3
A3 Mesotidal semi-enclosed lagoon	Coastal	Óbidos lagoon	2
		Albufeira lagoon	1
		St. André lagoon	1
A4 Mesotidal shallow lagoon	Coastal	Ria Formosa	5
		Ria de Alvor	1
A5 Mesotidal exposed Atlantic coast	Coastal	Open coast	6
A6 Mesotidal moderately exposed Atlantic coast	Coastal	Open coast	4
A7 Mesotidal sheltered Atlantic coast	Coastal	Open coast	4
Total			**60**



future revisions of this list may allow the final number of water bodies defined for transitional and coastal systems in Portugal to be no greater than 50.

MONITORING PLANS

The general approach to the definition of guidelines for monitoring plans is shown in Figure 72.

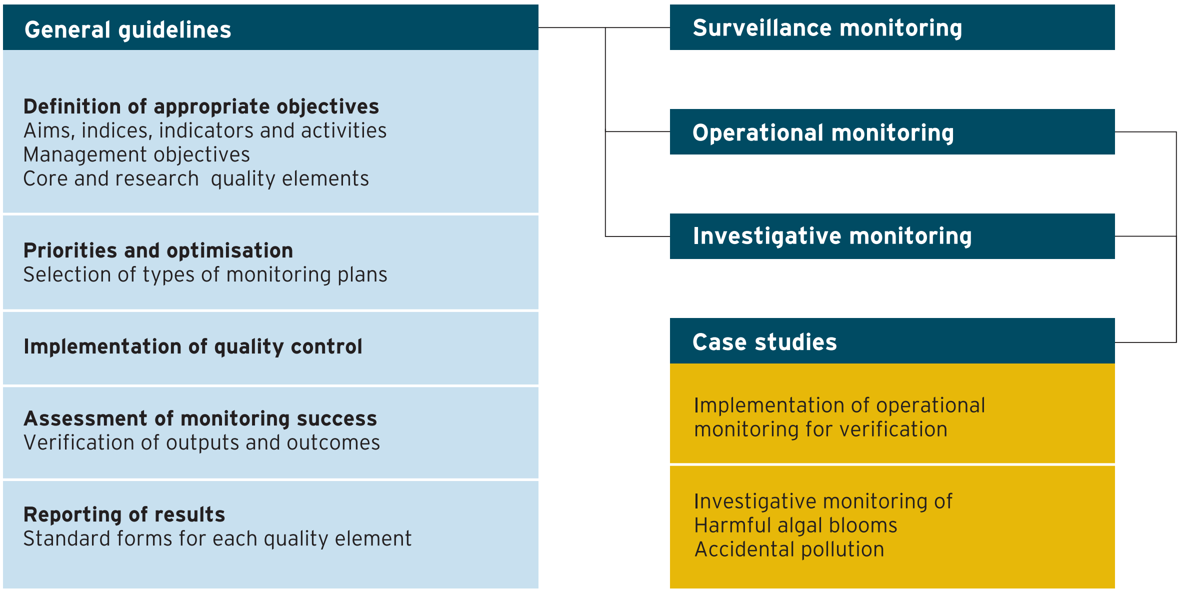
Key points are highlighted below for the three types of monitoring.

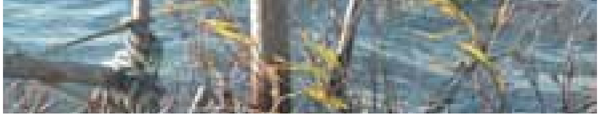
Surveillance monitoring

Appropriate frequencies for sampling biological quality elements and supporting quality elements are proposed for open coastal waters, inshore coastal waters and transitional waters. Guidelines are also provided for vertical resolution of water column sampling. The definition of water bodies shown in Figure 71 will result in a tentative network of 60-120 stations for all of Portugal, considering 1-2 stations per water body as an indicator of spatial resolution. Modifications to the number of water bodies will result in potential changes to the station network, both in number and distribution.

MONAE recommends that the following WFD "paradox" - *Member States must be sure that all*

Figure 72. **General guidance scheme for development of monitoring plans.**





Water Bodies have Good Ecological Status but only a subset may be sampled – should be addressed by sampling at least one station per water body for surveillance monitoring.

Operational monitoring

Two key objectives are indicated in the WFD for operational monitoring.

Operational monitoring

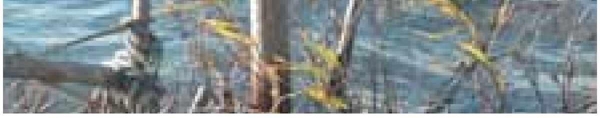
- Establish the status of those bodies identified as being at risk of failing to meet their environmental objectives
- Assess any changes in the status of such bodies resulting from the programmes of measures

The first objective (*screening*) of operational monitoring is concerned with further investigation into a water body which is at risk of non-compliance with environmental objectives, i.e. which appears from surveillance monitoring data to be at moderate, poor or bad status for one or more quality elements. This is interpreted in MONAE to be applicable mainly for water bodies diagnosed as being at moderate status, where more detailed studies will help establish the status of the water body.

The second objective (*verification*) is to verify *post-facto* if management measures are working, i.e. from a Pressure-State-Response perspective, if a reduction in pressure due to management response has resulted in the expected change in state.

In the first case (screening), the design of a monitoring programme must therefore take into account (a) the measurement of state, where the design considerations are those indicated for surveillance monitoring as regards particular quality elements; (b) the determination of pressure to establish whether there is a match between pressure and state; (c) source apportionment if required, in order to inform appropriate management measures.

In the second case (verification), the design of a monitoring programme for verification of compliance presupposes that there is a clear



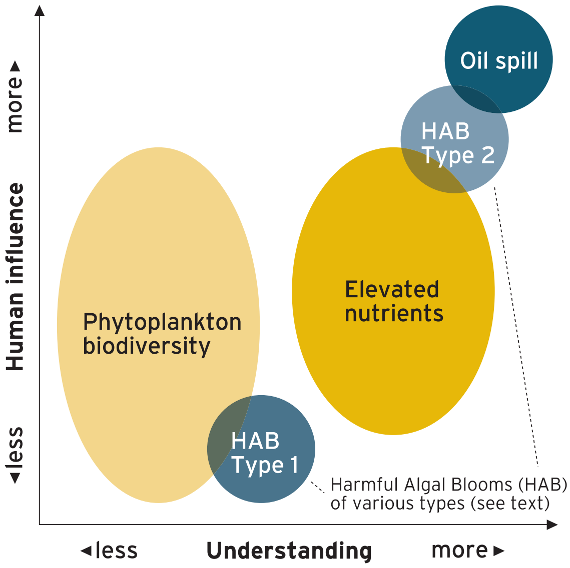
hypothesis that relates the anthropogenic pressure to the ecological status.

Investigative monitoring

This type of monitoring is research-oriented, and aims (i) to clarify unknown or poorly understood pressure-state relationships in order to inform an appropriate response; or (ii) to investigate accidental pollution events such as oil spills, and provide a blueprint for management measures, including mitigation and actions for future prevention.

Investigative monitoring of the marine environment is by nature interdisciplinary – the problems addressed are diverse, and constrained by different levels of understanding. Issues range e.g. from the interpretation of the effects of an accidental oil spill, where most processes are well understood, to the understanding of changes in biodiversity, affecting e.g. phytoplankton or benthic species composition, which are rather poorly understood (Figure 73).

Figure 73. Examples of environmental problems in marine systems, scaled by human influence and process understanding.



MONAE is set in the context of a WFD medium-term time horizon of about 20 years, and recognizes that (a) methodologies are constantly under development; and (b) future paradigm shifts will potentially make some of these methods obsolete. It therefore recommends that investigative monitoring should always draw on the best available techniques, combining the state of the art in field determinations, laboratory experiments and simulation models in order to provide the answers to the investigative monitoring questions posed by managers and scientists. Case studies on the research of naturally occurring harmful algal blooms and accidental oil spills are used as examples of the current state of the art in investigative monitoring.

ECONOMIC ANALYSIS

The general definitions of different cost concepts are reviewed, and an estimate of existing monitoring costs from systems in different countries is then used to estimate a unit cost for monitoring, based on a *station-sample pair*.

Station-sample pair

A sample taken at a station on one occasion, which may include only one depth or multiple depths. The entity is defined as a sampling visit to a particular geographic location.

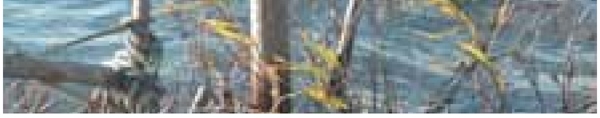


Figure 74. Annual cost of monitoring for the application of the WFD in transitional and coastal systems in Portugal in 2004 PPP€.

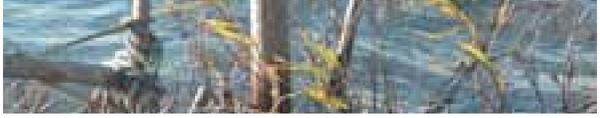
	Transitional and inshore coastal waters	Open coastal waters	Total cost (2004 PPP€)
Surveillance monitoring	1,736,000	250,000	1,986,000
Operational monitoring	391,000	19,000	410,000
Investigative monitoring	191,000	64,000	255,000
Total cost (2004 PPP€)	**2,318,000**	**333,000**	**2,651,000**

The information used to compile unit costs was drawn from work carried out in Portugal, the United States and China, within the framework of monitoring activities and research projects. The data were then normalised to Purchasing Power Parity (PPP€). This approach allowed a comparison among different countries, both in terms of overall costs and the relative proportions of cost components. These data were then used to extrapolate costs for all three types of monitoring under the WFD, and are summarised in Figure 74.

As regards surveillance monitoring, about 88% of this cost is associated to the inshore monitoring work (transitional and inshore coastal waters), the remaining 12% being that of monitoring open coastal waters. This difference is partly due to the far greater number of transitional and inshore water bodies and associated sampling stations and also to the significantly higher monitoring frequency.

The unit costs of operational monitoring are based on the estimates for surveillance monitoring. Using a precautionary approach, it is assumed that 30% of water bodies in transitional and inshore coastal waters, and 10% of water bodies in open coastal waters would require operational monitoring. Unit monitoring costs are additionally reduced because operational monitoring typically addresses a subset of biological quality elements and supporting quality elements.

Investigative monitoring is, by its very nature, difficult to value. This is compounded by the fact that it will include many emerging and new issues, for which there is no precedent and whose costs are unpredictable. The review presented on historical data identifies investigative monitoring principally as an



activity of academic institutions and research institutes. The research budget funding to scientific projects in marine sciences and technology is thus a potential indicator of the scope and cost of investigative monitoring, and has been used to estimate the values presented in Figure 74.

An analysis of the potential benefits of the successful implementation of WFD monitoring plans is also carried out, considering that these are a subset of the total benefits of WFD system management. Both use and non-use values are considered, and it is recommended that the detailed monitoring plans, which will be drawn up explicitly, consider these valuation issues on a case by case basis.

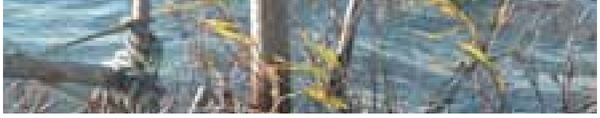
PUBLIC PARTICIPATION

Public participation is an integral part of the application of the WFD. An overview of concepts and scope is carried out, followed by an analysis of specific issues associated to public participation in Portugal.

Goals of public participation in coastal management

- Transparency: Relevant information should be made accessible to the public, and all non-classified information should be public recorded by default
- Hearing of interested parties: This is the core of public participation, stakeholders should be heard, their views duly considered, and addressed
- Citizenship and environmental education: Effective public participation does not grow out of thin air, it must be learned, preferably through experience and action
- Data mining: Public participation may yield a large amount of useful data

Two modes of collaborative monitoring merit a comment. The first is the co-operation between



environmental Non-Governmental Organisations and schools. The second is the use of low-cost sensors, which dramatically improves the ability of a volunteer to gather scientifically valid data. Both have the potential to generate a huge amount of relevant, cost-effective information. Public intervention may also be important for emergency alert purposes, such as oil spills or dead dolphins, although in this case there must be a competent authority with permanent real-time response capacity.

Finally, the specificity of public participation in coastal management is examined in detail, and a methodology is proposed for the design and implementation of an information system designed to deal with the two-way information flow between the management community and the public at large.

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OF PORTUGUESE TRANSITIONAL AND COASTAL WATERS
Development of Guidelines for the Application
of the European Union Water Framework Directive

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