DEVELOPMENT OF GUIDELINES FOR THE APPLICATION OF THE EUROPEAN UNION WATER FRAMEWORK DIRECTIVE

Typology and Reference Conditions for Portuguese Transitional and Coastal Waters

A. M. Bettencourt, S. B. Bricker, J. G. Ferreira, A. Franco, J. C. Marques, J. J. Melo, A. Nobre, L. Ramos, C. S. Reis, F. Salas, M. C. Silva, T. Simas, W. J. Wolff

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Acknowledgements

The Water Framework Directive represents a paradigm shift for water management in the European Union and addresses a broad range of issues and systems. This book is the product of an interdisciplinary study led by the Portuguese Water Institute, INAG, and focuses on two areas of the Directive: Transitional waters and coastal waters.

Portugal participated actively in the European Commission COAST working group, set up to provide interpretation and guidance on the specific aspects of the Directive concerning transitional and coastal waters, and INAG translated words into action by establishing this one year project, designed to provide a timely response from Portugal in the areas of typology and reference conditions. This book is a result of that effort, one of several products which are indicated in later chapters.

This work relied heavily on available data for Portuguese estuarine and coastal systems, at many different levels. The databases developed as a result of this effort contain over half a million records, and in some cases span a period of over seventy years.

Our thanks, both institutionally and to individual scientists, go to IPIMAR, Instituto Hidrográfico, Instituto de Ambiente, and many universities and respective research centres, including the full IMAR partnership. Some of these data are part of ongoing research projects, and we have taken great care in ensuring that other usage of the data is conditioned for a period, pending publication.

The team is grateful to Teresa Álvares of INAG, who gave us important insights into the issues of Heavily Modified Water Bodies, as applied to transitional waters.

We are thankful for discussions with several of our colleagues from the EC COAST group and also to the feedback from the freshwater projects, in particular to Isabel Pardo from Galicia and João Bernardo from Évora.

Finally we thank Manuel Lacerda and Laudemira Ramos of INAG, for their support throughout the project.

This book is dedicated to the memory of Martin Sprung. An excellent scientist, colleague and friend, who helped us readily on every occasion, he will be sadly missed.

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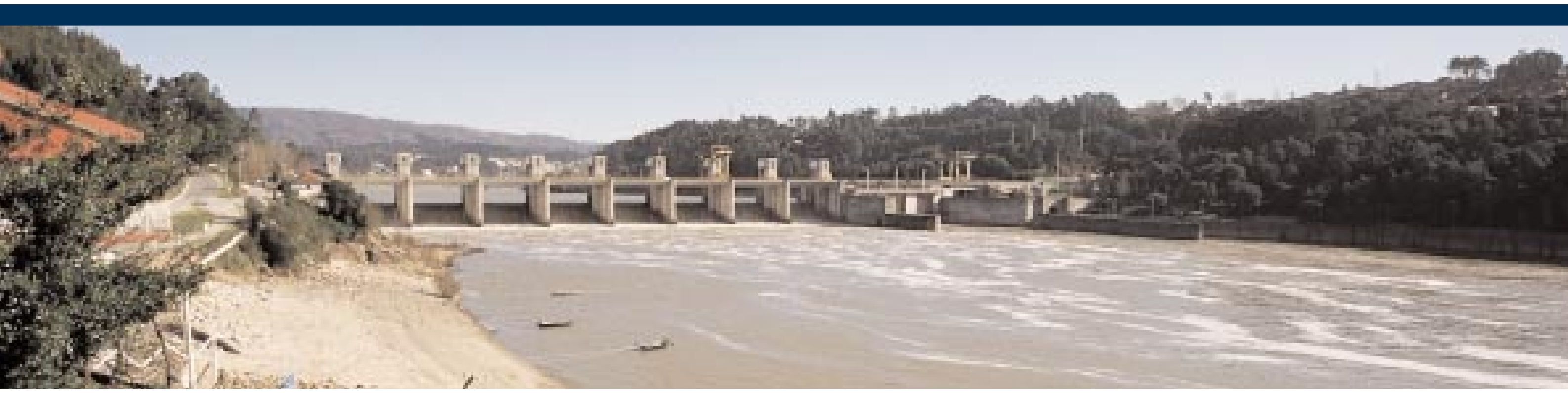
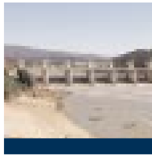




Executive Summary

Portugal has a number of important estuaries, which fall under the category of transitional waters – two of these, and parts of the rivers which flow into them, form the northwestern and southeastern borders with Spain. Portugal has an extensive coastal area, which delimits the country to the west and to the south.

The Typology and Reference Conditions (TICOR) study aimed to provide a framework for appropriate coastal management in Portugal, following the requirements of the Water Framework Directive. The team carrying out this work reviewed a broad range of issues, ranging from classification of different systems, division into system types, and examination of approaches to ecological quality status and the definition of reference conditions for transitional and coastal waters.

In order to address some of these issues, the TICOR project was carried out.

The key outputs of TICOR are presented in this book, which begins with a brief introduction to the WFD, and to the main aspects concerning transitional and coastal waters, and follows with a further seven chapters. Every effort has been made to allow each chapter to be readable on its own,

TICOR objectives

- Develop an integrated approach for all Portuguese coastal and transitional waters for the application of the Water Framework Directive (WFD)
- Provide the data framework and methodology for delimiting and typing Portuguese coastal and transitional systems
- Assemble the data required for WFD typology and first generation (G1) reference conditions, based on WFD criteria and on the guidance provided by the Common Implementation Strategy working group COAST
- Deliver a set of maps for typology of a key subset of Portuguese coastal and transitional waters
- Derive a set of G1 reference conditions for Portuguese coastal and transitional types
- Review the special issues of *Heavily Modified Water Bodies* and of *Pressures* and their application to Portuguese coastal and transitional waters

by including the basic components of the theme, from concepts to methods and results. The *tools* chapter provides an overview of the techniques used for the different parts of the work.

Introduction
WFD and guidance & key objectives

Methodology
Details on the TICOR process

Tools
Summary of tools used in TICOR

Systems, limits & morphology
Definitions for transitional & coastal waters, GIS presentation of areas and volumes

Typology
Classification of transitional & coastal waters into seven types

Pelagic reference conditions
Review of the state of the art for classification tools, and suggested approaches for defining first generation pelagic reference conditions

Benthic reference conditions
Review of the state of the art for classification tools, and suggested approaches for defining first generation benthic reference conditions

Special issues
Heavily Modified Water Bodies and general approach to environmental pressures

A summary of the key outputs and findings of TICOR are presented below.

Data

Over 600,000 records of data for Portuguese transitional and coastal waters have been archived in relational databases during the project. These are available on the internet, and contain parameters ranging from water and sediment quality to species lists, covering ten

Figure 1. Areas and volumes of TICOR systems.

System name	Classification	Area (km²)	Volume (10^6 m³)
Minho estuary	Transitional	23	67
Lima estuary	Transitional	5	19
Douro estuary	Transitional	5	39
Ria de Aveiro	Transitional	60	84
Mondego estuary	Transitional	9	21
Tagus estuary	Transitional	330	2 200
Sado estuary	Transitional	170	850
Mira estuary	Transitional	3	17
Guadiana estuary	Transitional	18	96
Ria Formosa	Coastal	49	92
Exposed Atlantic coast	Coastal	3 200	195 000
Moderately exposed Atlantic coast	Coastal	4 200	295 900
Sheltered Atlantic coast	Coastal	1 000	27 600

Note: Different colours correspond to different types.

transitional and coastal waters, and in some cases spanning over seventy years. These data were the foundation for the work which has been developed, and are an important reference collection of historical information on which future monitoring and research activities may build.

Systems, limits and morphology

TICOR addressed ten transitional and inshore coastal systems, as well as the coastline of continental Portugal (Figure 1). The project did not consider the areas of Madeira and Azores. A geographic information system (GIS) was developed for all the systems, and was used as a framework for the subsequent definition of limits, areas and volumes.

From a total of 44 transitional or coastal systems in Portugal, about half are in class A (≤ 0.3 km²). The other 48% are distributed in other classes. Class D (≥ 1.0 km²) is the most representative of these.

The systems studied in TICOR, together with their classification into transitional or coastal waters and morphological data, are shown in Figure 1.

Typology

Seven different types of transitional and coastal waters were defined for Portugal, based on the consideration that the number of types should be relatively small but should accurately reflect the existing diversity of systems (Figure 2).

Two transitional water types were defined, corresponding to estuarine systems from the northern and southern parts of Portugal. Type A2, *mesotidal well-mixed estuary with irregular river discharge*, is envisaged to be almost unique in the European Union, due to the combination of highly variable freshwater discharge and mesotidal regime. Additionally, two semi-enclosed coastal types were defined, as well as three open coastal types, which were judged to be sufficient to describe the entire Atlantic coastline. Of these three, type A6, *mesotidal moderately exposed Atlantic coast*, is considered to be unique to the European Union, because it combines colder north-east Atlantic and warmer Mediterranean influences with the dynamics of a narrow shelf. The type names and descriptions are shown in Figure 2.

The rationale for each type is explained in the *Typology* chapter, and the areas and volumes for the different types were determined with basis on the GIS. Some results are presented also on the distribution of these morphological data among types, and a discussion of types which may potentially be common to other EU member states is made. The most likely candidate types are: A1, A3, A5 and A7.

Figure 2. Proposed typology and classification of systems larger that 1 km^2.

Type	Descriptor	Systems larger than 1 km^2
A1	Mesotidal stratified estuary	Minho estuary Lima estuary Douro estuary Leça estuary
A2	Mesotidal well-mixed estuary with irregular river discharge	Ria de Aveiro Mondego estuary Tagus estuary Sado estuary Mira estuary Arade estuary Guadiana estuary
A3	Mesotidal semi-enclosed lagoon	Óbidos lagoon Albufeira lagoon St. André lagoon
A4	Mesotidal shallow lagoon	Ria de Alvor Ria Formosa
A5	Mesotidal exposed Atlantic coast	From the Minho estuary until Cabo Carvoeiro
A6	Mesotidal moderately exposed Atlantic coast	From Cabo Carvoeiro until Ponta da Piedade
A7	Mesotidal sheltered coast	From Ponta da Piedade until Vila Real de Sto. António

Note: TICOR systems shown in blue.

Main findings for pelagic reference coditions

- There are sufficient data in most cases for establishing reference conditions for phytoplanton abundance, biomass and composition. Some gaps exist for type A1 and for open coastal waters
- The supporting quality element *nutrients* should be measured in order to monitor elemental ratios, and to support the evaluation of pressures, but no clear link between dissolved nutrients in the water column and phytoplankton biomass and abundance could be established
- Phytoplankton composition differs clearly between transitional water types. Some questions are raised about the Sado estuary, which behaves like a coastal lagoon for this element
- Phytoplankton composition in transitional waters is potentially linked to water residence time. This should be further explored, and if appropriate taken into account when establishing reference conditions
- Phytoplankton abundance may be adequately represented by biomass, using chlorophyll *a* as a proxy
- Phytoplankton biomass and abundance should be assessed using an integrated methodology, because organic enrichment effects may be manifested also in changes to benthic flora. The use of the ASSETS approach, developed from the U.S. National Estuarine Eutrophication Assessment procedure is recommended
- Ecological status for fish is potentially best evaluated using Indices of Biotic Integrity (IBI)

Pelagic reference conditions

A review was carried out of the approaches that may be used for determination of ecological quality status in phytoplankton and fish, the latter quality element only for transitional waters. The relevance of the various supporting quality elements was also analysed, using relationships developed from the TICOR databases and other sources.

Benthic reference conditions

A review was carried out of the approaches that may be used for determination of ecological quality status of benthic quality elements, both for aquatic flora and fauna. A potential method for establishing a scale for reference conditions of benthic plants based on relative areal distribution and biomass of opportunistic and long-lived species is outlined. The method needs to be refined and tested.

The data collected on benthic macrofauna were used extensively to explore a number of different indices, across a range of transitional water types.

Figure 3. Application of indices as a function of data requirements and data availability.

<table>
<tr><th colspan="5">DATA AVAILABILITY</th></tr>
<tr><th colspan="2">Qualitative data</th><th colspan="3">Quantitative data</th></tr>
<tr><th>Metadata</th><th>Rough data</th><th>Numeric density data</th><th colspan="2">Numeric density and biomass data</th></tr>
<tr><td rowspan="2"></td><td rowspan="2">Shannon-Wiener
Margalef</td><td rowspan="2">Shannon-Wiener
Margalef
AMBI</td><td>Identification of individuals down to species level</td><td>Identification of individuals down to family level</td></tr>
<tr><td>ABC
Margalef
AMBI</td><td>Shannon-Wiener
Margalef
ABC</td></tr>
</table>

Figure 3 shows a synthesis of the work carried out. A first generation approach to ecological quality status may be carried out by using a combination of appropriate indices, based on data availability.

Special issues

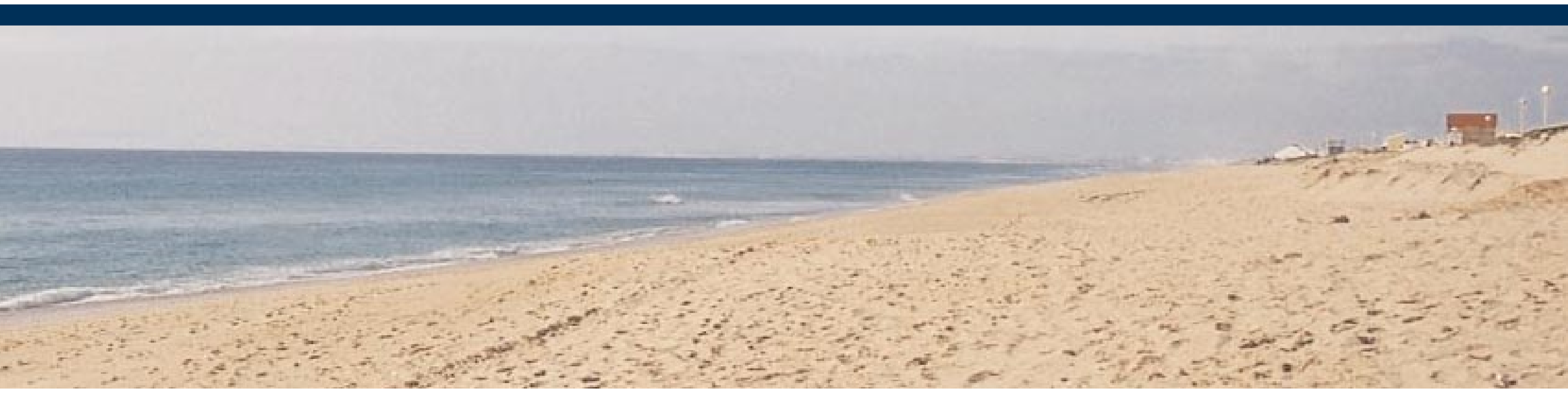
Two key areas were examined in the *Special Issues* chapter: *Heavily Modified Water Bodies* and *Pressure* elements.

One key finding of this part of the work is that there does not seem to be a basis for type differentiation of reference conditions for benthic fauna in transitional waters, in the application of the AMBI index and W-statistic. However, diversity indices may be regarded as type-specific, and will help to differentiate types in future developments of this method.

For the first issue, TICOR results are based on data developed by the relevant guidance group, defining the evaluation process that should be followed for classification.

The pressures guidance document was also used as a framework for discussion of this issue, the focus of the TICOR work is on the development of localised guidelines for the most relevant pressures on Portuguese transitional and coastal systems.

Introduction



THE WATER FRAMEWORK DIRECTIVE

General aspects

In December 2000, as a result of a long process of discussion and negotiation between policy makers, experts and others, the Water Framework Directive (WFD) of the European Commission was finally approved.

This directive establishes a framework for community action in what concerns water policy and management, 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, namely in what concerns 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

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".

All transitional and coastal waters have to be classified in types, according to System A or System B, as defined in Annex II of the WFD.

System A

- Mean annual salinity
- Tidal range (transitional), depth (coastal)

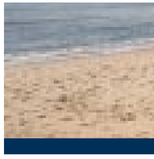
System B

- Obligatory factors for transitional and coastal waters: Latitude, longitude, tidal range and salinity
- Optional factors for transitional and coastal waters: Current velocity, wave exposure, mean water temperature, mixing characteristics, turbidity, mean substratum composition, water temperature
- Optional factors only for transitional waters: Depth, residence time and shape
- Optional factors only for coastal waters: retention time of enclosed bays

For System A all the descriptors are pre-defined. System B establishes obligatory factors and some optional factors. The number of types found using system B has to be equal to or greater than the number obtained using system A.

For each type of water characterised, type specific conditions shall be established in accordance with Annex V of the WFD, using hydromorphological, physicochemical and biological quality elements. Type specific reference conditions may be spatially based, based on modelling or may be derived using a combination of these methods. If it is not possible to use these methods, Member States may use expert judgement to establish such conditions, as is the case in the U.S. under EPA regulations.

Member States have also to collect and maintain information on type and magnitude of the significant anthropogenic pressures to which surface water types are liable to be subject.



COMMON UNDERSTANDING STRAGEGY

Reasons and objectives

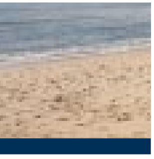
The implementation of the WFD raises challenges, which are widely shared by Member States. The complexity of the text and the diversity of possible solutions to scientific, technical and practical questions, the extremely demanding timetable, incomplete technical and scientific basis, with some fundamental 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, are examples of these challenges. That justifies the preparation of a common strategy.

Elements for a common strategy for the WFD

- **The need to share information between Member States and the European Commission**
- **Information and involvement of the public, and public awareness on the implementation of WFD**
- **The need to ensure coherence between the implementation of WFD and other sectorial and structural policies**
- **The need to ensure coherence between the implementation of WFD and other water directives**
- **The need to integrate activities on different horizontal issues for the effective development of river basin management plans and implementation of the WFD**
- **The necessity for capacity building in Member States**
- **The need to involve stakeholders and the civil society**
- **The establishment of working groups and the development of informal guidance and support documents**

The aim of this common strategy document is to allow a coherent and harmonious implementation of the WFD. Most of the challenges and difficulties are inevitably common to all Member States, and many of the European river basins are shared, crossing administrative and territorial borders, where a common understanding and approach is crucial to successful and effective implementation.

Emphasis is placed on methodological questions related to a common understanding of the technical and scientific implications of the WFD. The aim is to develop supporting technical and scientific information to clarify and assist in the practical implementation of the directive. The guidance documents and recommendations for operational methods produced for that purpose



have only an informal and non-legally binding character, and will be used by Member States on a voluntary basis.

A modular structure has been chosen, the modules being the following key activities:

Activity 1: information sharing

Activity 2: development of guidance on technical issues

Activity 3: information and data management and reporting

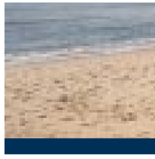
Activity 4: application, testing and validation

Working groups were created for the different activities, and their objectives, mandates, expected outcomes and timetables were established.

The first phase of the process is now concluded, and these working groups have ended their mandates. The guidance documents are now available and will be tested in some river basins chosen by Member States, in order to identify any difficulties. For Portugal, the choice was the Guadiana river basin.

Working Groups Established in the First Phase of the Strategy

- WG on the analysis of pressures and impacts
- WG on designation of heavily modified waters
- WG on classification and reference conditions of surface waters
- WG on classification and reference conditions for coastal and transitional waters
- WG on inter-calibration
- WG on economic analysis
- WG on monitoring
- WG on assessment and classification of groundwater
- WG on best practices in river basin management
- WG to develop a shared geographical information system
- WG on streamlining and reporting process



OBJECTIVES

In order to address these issues, the TICOR project was carried out. TICOR brought together an interdisciplinary team, for a period of one year, with the following objectives.

- **Develop an integrated approach for the application of the Water Framework Directive to all Portuguese coastal and transitional waters**
- **Provide the framework and methodology for classifying and delimiting Portuguese coastal and transitional systems**
- **Assemble the data required for WFD typology and first generation reference conditions, based on WFD criteria and on the guidance provided by the Common Implementation Strategy working group COAST**
- **Deliver a set of maps for typology of a key subset of Portuguese coastal and transitional waters**
- **Derive a set of first generation reference conditions for Portuguese coastal and transitional types**
- **Review the special issues of *Heavily Modified Water Bodies* and of *Pressures* and their application to Portuguese coastal and transitional waters**

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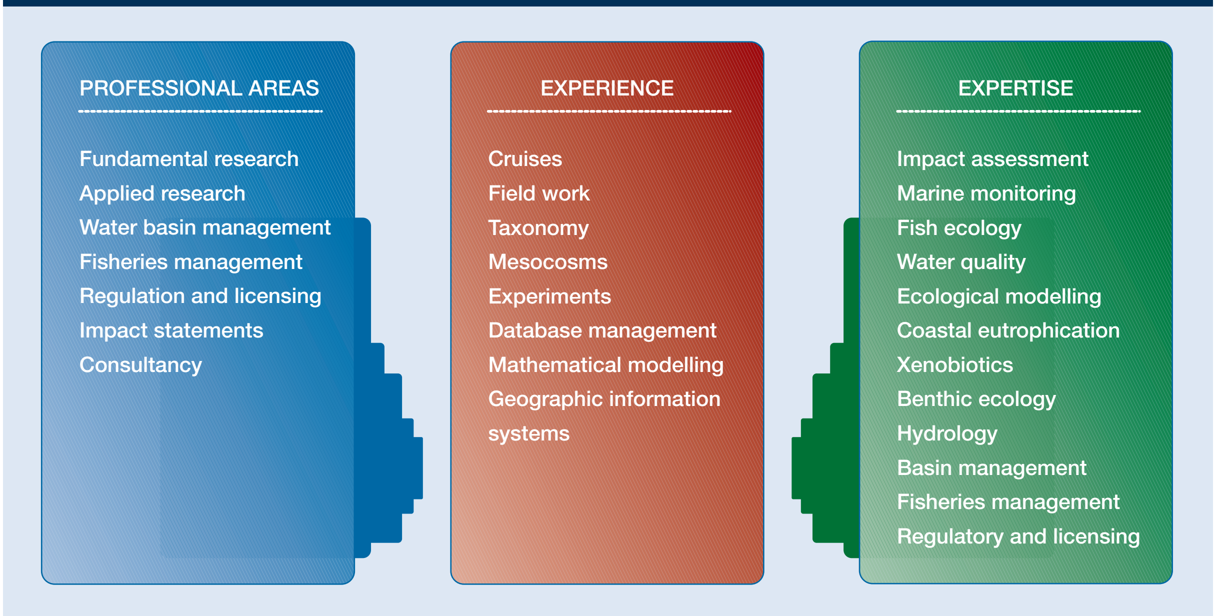
Methodology

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

TICOR TEAM AND EXPERTISE

This work was carried out by nine team members and four consultants, covering a wide range of areas in marine science (Figure 4). A consultant from Northern Europe helped to provide a more balanced approach to the work from an EU-wide perspective, and one from the U.S. Federal Agency NOAA allowed us to put this work into a wider context, by taking into account the approaches being followed in the European Union and in the United States.

Figure 4. Expertise, experience and professional areas of the TICOR team.



STRUCTURE AND TIMING

The TICOR workplan was divided into three workpackages, the first of which dealing with system definitions and data collection, and the second with typology and reference conditions. Workpackage three was concerned with coordination, product delivery and dissemination. The project started on the World Environment Day, 2002, and had a duration of one year.

TICOR considered a meaningful subset of Portuguese transitional and coastal waters (see Figure 25) which together account for about 100% of the area of transitional waters, corresponding to 9 estuaries, and 75% of restricted coastal waters. All the continental open coastal area was included, but the coastal areas of the Azores and Madeira were explicitly excluded.

Work packages, deliverables and products

The list of tasks to be carried out for each workpackage is shown in Figure 5.

Figure 5. TICOR workpackages and tasks.

Workpackage	Tasks
WP1	1.1 Listing of systems and basic definitions
System definition and historical data	1.2 Information for database loading
	1.3 GIS implementation
	1.4 Linking relational databases to GIS
	1.5 Web-driven database and metadatabase
WP2	2.1 Application of WFD criteria for typology definitions
Typology and reference conditions	2.2 First generation (G1) reference conditions
	2.3 Synthesis of reference conditions
	2.4 Artificial and heavily modified water bodies
	2.5 Special issues, designation of water bodies
WP3	3.1 Coordination
Coordination	3.2 Product delivery
	3.3 Dissemination

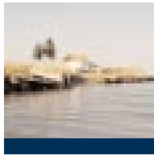
The first task consisted of listing the systems and providing the basic definitions for areal coverage, which effectively corresponds to an overall inventory. This allowed the project to be aware of the range of coastal and transitional systems in Portugal to which the WFD is applicable, which was an essential precondition for a comprehensive national typology.

TICOR was organised around monthly meetings of the project team, which were roughly split along two workpackages, the first of which dealt with system definitions and data collection, and the second with typology and reference conditions.

There were multiple challenges in accomplishing

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.



a programme of this nature in a period of one year, including data issues, integration and transnational questions.

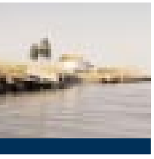
The deliverables identified for the two workpackages are shown in Figure 6. These deliverables were consolidated into four types of products, designed to maximise the utility of the work carried out for the decision-makers and water managers who must implement the WFD at a national level.

Figure 6. Deliverables for each TICOR workpackage.

Workpackage	Deliverables
WP1 System definition and historical data	• Criteria for definition and division of systems • Website with systems and baseline information • GIS with zone identification and delimitation • Databases and web implementation
WP2 Typology and reference conditions	• GIS for coastal zone with sampling stations • GIS for typology • First generation reference conditions • Synthesis of reference conditions for ecological quality ratios

The final products of TICOR are:

1. A digital set of raw data for all the TICOR ecosystems, which supported the work carried out during the project, and forms the basis for the historical dataset which will be developed upon by the different WFD monitoring initiatives which must now be implemented. This takes the form of ten different relational databases, distributed on the internet, and accompanying software for data entry, mining and output;
2. A geographical information system for the typology of Portuguese coastal and transitional waters;
3. A minimum of three scientific papers published in peer-reviewed international journals, with the objective of scientifically validating the methodologies explored or developed in TICOR;
4. A book describing the objectives, approach and main outcomes of the project, designed to appeal to a broad technical readership.

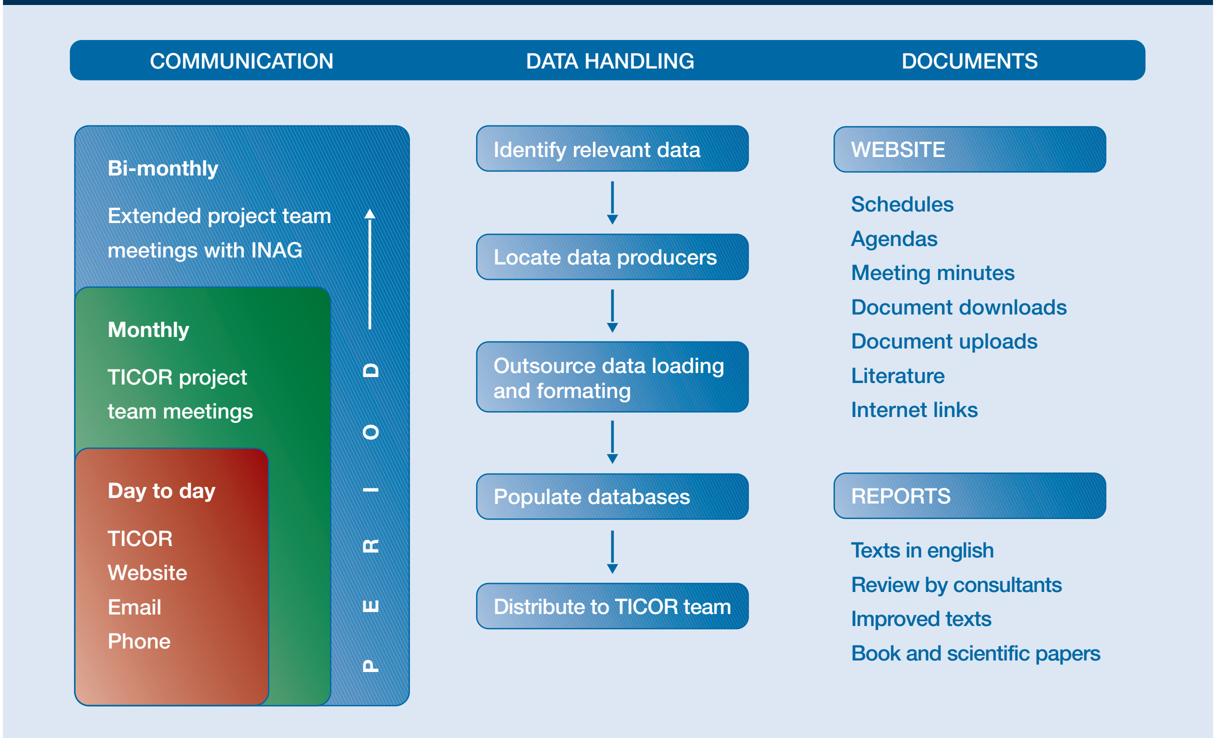


PROJECT MANAGEMENT

The approach taken for project management is shown in Figure 7. Management was divided into three key areas: team communication, data handling and dissemination and 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, and the information which was produced during this process formed the backbone of the work presented herein.

Figure 7. Management approach for TICOR.



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

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Tools

INTRODUCTION AND OBJECTIVES

This chapter reviews the tools used and developed in TICOR. The TICOR tools may be divided into three categories based on their role in the project.

OVERVIEW OF TOOLS

Role in project

The correspondence between the objectives to be achieved and the tools to be applied is presented in Figure 8.

TICOR tools

Data analysis tools

Supply the framework for the project as a whole.

Typology tools

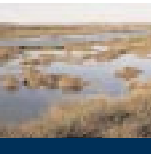
Are used to apply the criteria for type definition.

Ecological status evaluation tools

Provide the methods to define first generation WFD reference conditions.

Figure 8. Application of tools to each of the TICOR objectives.

Tool applied	TICOR objective
All	Develop an integrated approach for the application of the Water Framework Directive to all Portuguese coastal and transitional waters
Data analysis tools	Provide the framework and methodology for classifying and delimiting Portuguese coastal and transitional systems
	Assemble the data required for WFD typology and G1 reference conditions, based on WFD criteria and on the guidance provided by the Common Implementation Strategy Working Group COAST
Typology tools	Deliver a set of maps for typology of a key subset of Portuguese coastal and transitional waters
Ecological status evaluation tools	Derive a set of first generation reference conditions for Portuguese coastal and transitional types
Not applicable	Review the special issues of *Heavily Modified Water Bodies* and of *Pressures* and their application to Portuguese coastal and transitional waters



Brief description

Relational database

For the relevant transitional and coastal water bodies relational databases were built for water quality data assimilation and management, using the Barcawin2000™ software.

Geographic information system

For the analysis and management of spatially distributed data a geographical information system (GIS) was implemented for each water body.

Typology tools

For the application of the set of obligatory and optional factors defined under classification system B (WFD Annex II), in order to define the different types of transitional and coastal waters.

Ecological status evaluation tools

The aim of this toolset is to provide the means to evaluate the state of the water bodies. For each of the biological quality elements in Annex V of the WFD, the methodology and metrics for ecological status classification were defined.

DATA ANALYSIS TOOLS

Relational database

Data assimilation was done using the Barcawin2000 software. For each system a relational database was built (Figure 9) except for the Atlantic coast. The software in use has been developed from 1985 onwards and has been used by this team in multiple research projects with widely varying data storage requirements.

The main advantages of this database can be summed up as follows:

- Organisation of information in a state-of-the-art relational database;
- Security for five levels of user access;
- Easy input of data, by mapping MS-Excel spreadsheets to database fields, followed by automatic import and validation;

Figure 9. Number of stations, parameters, samples and results for TICOR system databases.

System	Stations	Parameters	Samples	Results
Minho estuary	18	34	322	3 538
Lima estuary	31	70	603	8 096
Douro estuary	39	42	292	5 006
Ria de Aveiro	84	91	1 441	13 499
Mondego estuary	48	290	726	18 317
Tagus estuary	146	151	8 702	81 003
Sado estuary	299	60	3 801	24 164
Mira estuary	119	178	6 469	30 704
Guadiana estuary	118	39	35 677	133 896
Ria Formosa	70	165	97 021	139 932
Totals	972	1 120	155 054	458 155
Overall total				615 301

- Numeric listings and search results are output to an Excel compatible spreadsheet, or to graphs created directly in Excel.

Geographic information system

GIS was used to store and analyse spatial data. For each system a GIS was implemented based on bathymetric data layers. The main properties of these layers are indicated in Figure 10. A schematic representation of a bathymetry layer is shown in Figure 11.

For the data analysis and map production the GIS

Figure 10. Properties of bathymetric layers.

Surface water body category	System	Bathymetry resolution (m)	Bathymetry coverage (% total area)	Source type	Conversion/ interpolation
Transitional water	Minho	30 x 30	51%	Irregular grid	MCI
	Lima	5 x 5	72%	Paper bathymetric chart	Digitising
	Douro	30 x 30	56%	Irregular grid	MCI
	Ria de Aveiro	30 x 30	100%	Irregular grid	MCI
	Mondego	30 x 30	60%	Irregular grid	MCI
	Tagus	30 x 30	95%	Irregular grid	MCI
	Sado	30 x 30	80%	Irregular grid	MCI
	Mira	30 x 30	22%	Irregular grid	MCI
	Guadiana	30 x 30	100%	Irregular grid	MCI
Coastal water	Atlantic Coast	50 x 50	100%	Bathymetric isolines (10 m)	Triangulation
	Ria Formosa	30 x 30	100%	Irregular grid	MCI

*[1] MCI - Minimum curvature interpolation

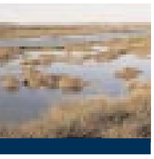
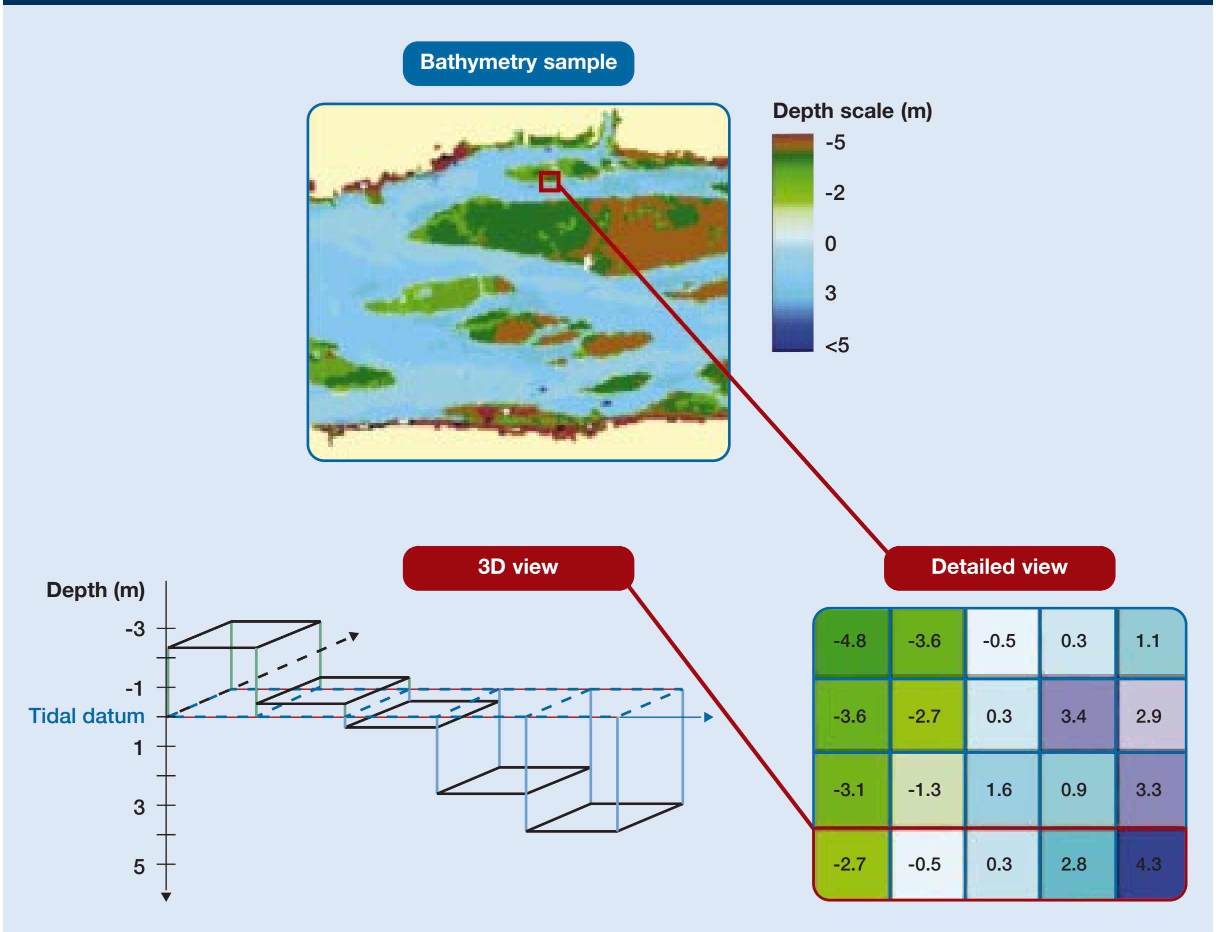


Figure 11. Bathymetry layer representation.



functions used were:

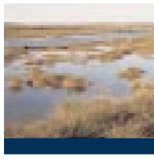
- Reclassification of grid cells;
- Geostatistical analysis;
- Map algebra.

APPLICATION TO SYSTEM DELIMITATION AND MORPHOLOGY

Transitional water upstream limits

The upper limits of the transitional water bodies were established according to the particular features of each system and to data availability. The alternative approaches were:

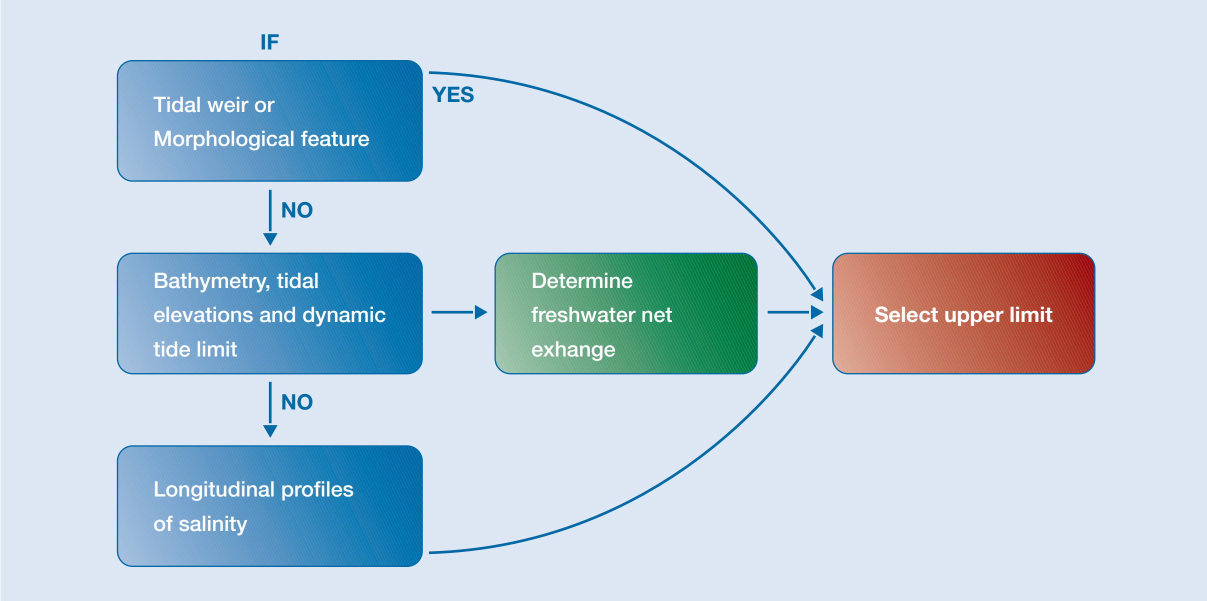
- Presence of morphological / physical features, which are a barrier to saltwater intrusion;



- The identification of the limit of saltwater intrusion, either on the basis of salinity observations or by determining the theoretical upper limit of net saltwater exchange;
- The selection of the method followed the decision rule shown in Figure 12.

The cross section upstream of which there is no net exchange between salt and fresh water is determined as a function of the flow and tidal amplitudes and is designated as the theoretical upper limit of net saltwater exchange. The methodology is fully described in the chapter *Systems, Limits and Morphology*.

Figure 12. Decision rule to identify upper limit of transitional water bodies.



Transitional water downstream limits

The downstream limit is defined on the basis of:

- Morphological / physical features such as a “barrier” (sand bar) with influence on water exchange processes;
- Conspicuous points defining a closure line;
- Traditional limits established by the maritime authorities.

Coastal water limits

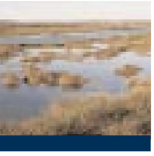
The coastal water limits were determined on the basis of the WFD definition (Article 2.7):

- The **offshore limit** is a line defined in the WFD by points “at a distance of one nautical mile on the seaward side from the *nearest point of the baseline from which the breadth of territorial waters is measured*”;
- The **inshore limit** is defined by the high water limit at maximum spring tide, except at the offshore limit of transitional waters.

Morphological parameters

The water volume and area were calculated using GIS techniques from the bathymetric data, considering three situations for water height.

- **Z_0 (mean tide level at the tide gauge)**
- **Equinoctial spring tide high water;**
- **Equinoctial spring tide low water.**



TYPOLOGY TOOLS

Two main tools were used in the typing process of transitional and coastal Portuguese waters: a top-down approach, based on expert knowledge, and a bottom-up approach developed as a follow-up to the LoiczView tool, which is currently being used for clustering transitional and coastal waters in the United States.

The variables considered in both approaches were those proposed in the WFD **system B** classification for obligatory factors and optional factors.

Obligatory factors	Optional factors
latitude/longitude,	mixing conditions,
salinity,	wave exposure,
tidal range.	depth.

The results obtained using the two different typing approaches were compared and a final typology was determined. A general description of each type was then made, based on the system B variables and on other information considered relevant and specific for each type. An analysis in terms of areas and volumes by type was also carried out and is presented in the *Typology* chapter of this book.

ECOLOGICAL STATUS EVALUATION TOOLS

Pelagic classification tools

A number of tools were evaluated for classification of pelagic quality elements, and the subsequent definition of type-specific reference conditions. Details of these are given later on in this book in the *Pelagic reference conditions* chapter, but a brief overview is provided here of the most promising methodologies for this purpose.

For the phytoplankton composition, abundance and biomass elements, the species composition was considered separately from the abundance and biomass. The latter two were aggregated by using biomass as a proxy for abundance.

The relationship between composition and supporting quality elements such as tidal range and freshwater discharge was explored for transitional waters.

Symptoms of organic enrichment are not necessarily pelagic, but may include potential developments of opportunistic seaweeds and/or other ecosystem modifications. The most appropriate approach for phytoplankton abundance and biomass should therefore be integrated with phytobenthic biological elements, and include relevant supporting quality elements.

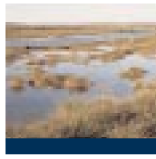
The steps taken for selection of appropriate tools were (a) to use the available dataset for testing the relevance of the various supporting quality elements; (b) to examine the capacity of the various methods for integration of the different elements; and (c) to evaluate the data requirements and validation status of each approach.

A subset of the U.S. National Estuarine Eutrophication Assessment approach (Overall Eutrophic Condition) was selected as a tool for evaluating *phytoplankton abundance and*

For **species composition**, the approach used phytoplankton species lists collected over a period of over 50 years (1930-1980), for all proposed transitional and coastal water types.

A relational database was built and queried to identify commonality and differences among types in order to:

- examine the ecological correspondence of type definitions to the phytoplankton biological quality element
- provide a metric for ecological quality status based on numbers and types of species present.



biomass, together with composition and abundance of other aquatic flora, and key supporting elements such as dissolved oxygen.

For fish, which were considered in the pelagic chapter, six indices were reviewed.

CDI - Estuarine Community Degradation Index

BHI - Estuarine Biological Health Index

FHI - Estuarine Fish Health Index

EBI - Estuarine Biotic Integrity Index

FRI - Estuarine Fish Recruitment Index

FIR - Estuarine Fish Importance Rating

The EBI was selected as the most promising method for assessing the quality status of fish communities. Detailed suggestions are made for the application of EBI to Portuguese transitional waters, and a review of available data and requirements was carried out.

Benthic classification tools

The benthic quality elements composition and abundance, as well as presence/absence of disturbance sensitive taxa, were evaluated with biological indices.

The selected indices integrate the quality elements defined in the WFD. All of them have been applied to wide geographical areas and to zones disturbed by different types of pollution.

This first generation of benthic reference conditions / ecological classification tools is not strictly type-specific. The AMBI index and the W-statistic are universal in terms of their applicability, i.e. the interpretation of measurements is independent from the geographic area or the type of system. However, diversity measures and their interpretation are strongly dependent on the geographic variation and on the type of system, in the sense that a value estimated using a given diversity index does not have the same significance in warm temperate and boreal systems, or in an open coastal area and an estuary located at the same latitude. A decision rule was developed for application of indices as a function of data requirements and data availability (Figure 13).

- Shannon-Wiener index
- Margalef index
- AMBI Marine Biotic Index
- ABC curves method, using the W-statistic

The description of the indices and the joint valuation resulting from the combination of two or three of them (depending on the type of data available) is detailed in the *Benthic Reference Conditions* chapter.

Information on macrophytobenthos in Portuguese transitional and coastal waters is scarce. This means that although macrophyte species composition and abundance can be found for some systems, the dynamics of macroalgae, seagrass and saltmarsh

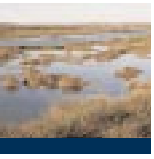


Figure 13. Benthic biological indices as a function of data availability.

What type of available data?				
Qualitative data		Quantitative data		
			Numeric density and biomass data	
Metadata	Rough data	Numeric density data	Identification down to species level	Identification down to family level
	Shannon-Wiener	Shannon-Wiener	Method ABC	Shannon-Wiener
	Margalef	Margalef	Margalef	Margalef
		AMBI	AMBI	Method ABC

vegetation is not well understood. For this reason it was not possible to test the different approaches and to examine the possible associations between biological descriptors and supporting elements in the Portuguese types. However some guidelines for the establishment of reference conditions are presented in the *Benthic Reference Conditions* chapter.

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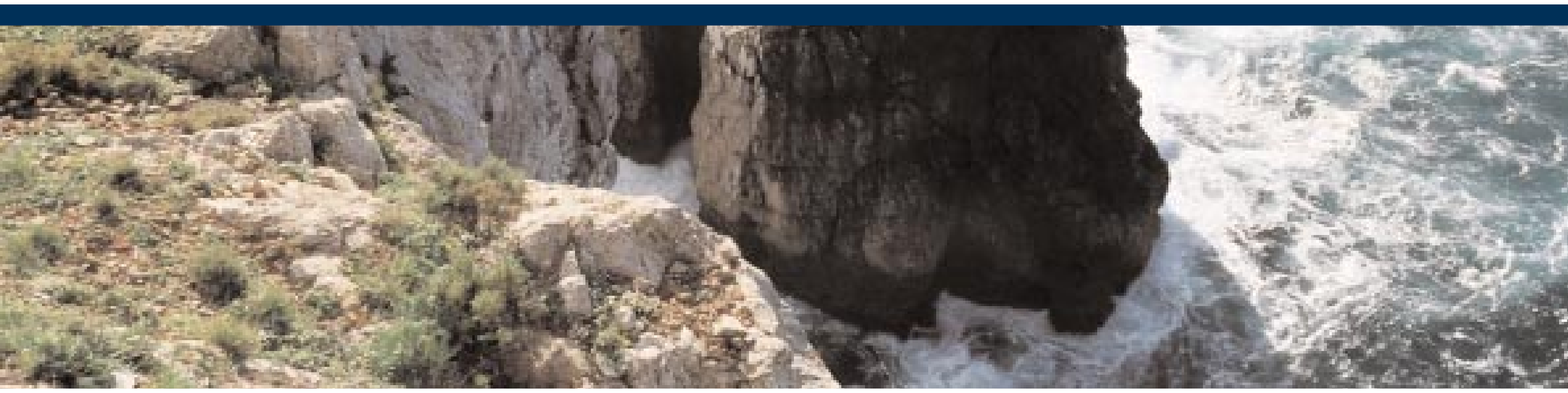
Systems, Limits and Morphology



INTRODUCTION AND OBJECTIVES

The WFD defines "transitional waters as: *bodies of 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*".

Their delimitation has to take into consideration this dual influence of fresh and coastal waters, which is translated into characteristic salinity gradients. The problem of establishing limits for transitional waters derives from the fact that these gradients are variable as a function of a combination of factors, acting at different time scales, the more relevant being tidal situation and range and fresh water flows.

Nevertheless, there is a need to define geographic boundaries, since the application of the WFD implies:

- **The calculation of morphological parameters (areas and volumes);**
- **The identification of a spatial domain for application of:**
  - **- Reference conditions**
  - **- Environmental quality objectives**
- **The design of monitoring programmes.**

METHODS AND CRITERIA

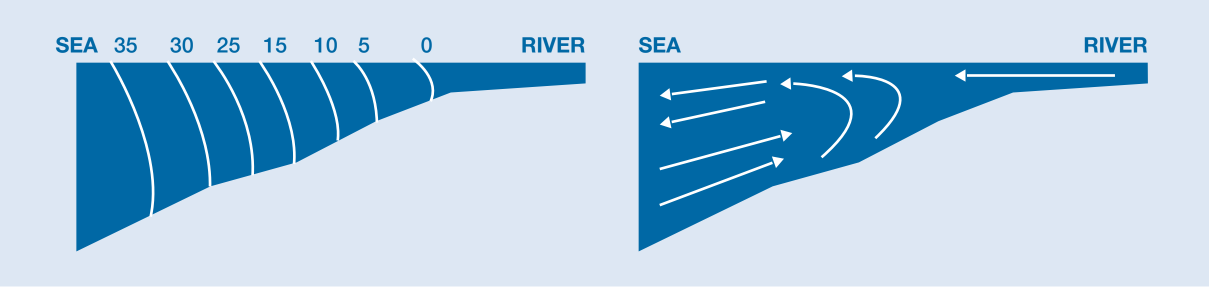
Review of available approaches

The definition of *transitional waters* agrees with the simple concept of "estuary" as proposed by Nelson-Smith. On the basis of this "fuzzy" definition it is difficult to establish clear criteria to locate the boundaries of transitional waters. The most relevant characteristics of transitional waters are the cyclical variations of water level and salinity, which drive changes in other ecologically relevant variables. For a variety of reasons, including administrative and historical ones, the estuary head or upstream limit has been adopted as the limit of tidal influence. For the sea boundary the most common criterion is the open coast line. These options have limited practical use in the context of the WFD, since the limit of transitional waters must be related to salinity values. At the head of the estuary, the tide may be advecting fresh water, and for large river flows, the influence of fresh water in the coastal salinity may be noticeable. For practical reasons, we have adopted a definition of the seaward limit based on the identification of a limiting section, as other options based on salinity distributions in the immediate coastal vicinity present feasibility issues.

Theoretical basis

The proposed methodology for the identification of the upstream boundary of transitional waters is based on concepts derived from simplified mixing models of estuarine circulation and salinity distribution.

Figure 14. Schematic representation of the estuarine circulation.



In a typical estuary, the mixing of fresh and salt water is not complete, due to the buoyancy of the less dense fresh water tending to float so that there is a vertical gradient of salinity as well as a longitudinal one. The net circulation of the estuary, over a sufficiently large number of tidal cycles, is established in such a way that a movement of saltwater upstream balances the seaward movement of freshwater. Schematically the "equilibrium circulation" is illustrated in Figure 14. The slope of the salinity isolines shows the degree of vertical stratification.

The concept of the limit of net exchange of saltwater

The schematic presentation of the circulation of estuaries leads to the concept of "limit of saltwater exchange". Early studies on this type of water bodies address the theoretical basis of this concept and propose a methodology for its determination.

A transitional water body is a region where the mixture of seawater and freshwater is measurable: therefore its inner end can be defined as *the cross section above which the volume which raises the water level from low tide to high tide is totally contributed by the river flow*. On the flood tide there will be no net exchange of water through this section as the river flow contributes all the water required to fill the intertidal volume. Thus, the water above this section should be completely fresh. On the ebb tide there is a net loss through this cross section of a volume of fresh water equal to the volume introduced by the river during a tidal cycle.

It should be noted that this is a dynamic rather than a geographical boundary and implies that the head of the estuary moves upstream and downstream with changes in river flow and tidal range.

The method to determine this section was developed in studies of estuarine flushing. It uses a segmentation technique: on theoretical grounds the full validity of this implies that a steady state is observed when there is a net seaward transport over a tidal cycle of a volume of fresh water equal to the volume introduced by the river in the same period. When such a steady state cannot be assumed to occur, the method is not valid. For practical reasons, this limitation is not considered in this study, which means that the assumptions of the methodology may not be completely met in all the systems.

Advantages of the proposed definition

The proposed definition for the upper limit of transitional waters has clear advantages. It is conceptually simple and has a clear physical meaning. It has no intrinsic difficulty of application and requires simple data on morphology and tidal elevations. Nevertheless, it is the availability of simple data, identified below, that creates the main difficulties for the application of the method.

Data requirements

The determination of upstream limits of transitional waters requires information on:

- Location of dynamic tidal limit. This limit is often defined by using the discharge curve to establish the end of the influence of tidal elevation or through local anecdotal evidence.
- Morphology of upper reaches. Most bathymetric data is obtained for navigational purposes. This may exclude upper reaches, although cross-sections are commonly available for the tidal fresh water zones. Shoreline elevation and shape are also needed.
- Tidal elevations in the upper reaches.
- Freshwater flows over a section representing the discharge into the system.

METHODS

Upstream limits

The proposed methodology adopts as the upper limit of the transitional waters a cross section

upstream of which there is no net exchange between salt and fresh water for a pre-defined flow.

This section is established using a stepwise procedure (Figure 15):

1. Determine the dynamic upstream tidal propagation limit A. This can be done either by considering this limit to be an appropriate weir, or in cases where a weir does not exist, by examining the water height records.
2. Calculate the total volume B discharged by the river during a tidal cycle T. **Guidance**: The *modal flow* as published by INAG is adopted here in as the reference river flow Q.
3. Determine what equivalent length L of the estuary downstream of A is required to fit the volume B (above low water level). Data on the estuarine bathymetry and local tidal elevations are required for this.
4. The downstream limit C is the estuary limit at the head.
5. The cross section C is determined by plotting the cumulative volume upstream of consecutive sections against a linear dimension (the distance to the limit of dynamic tide propagation), and entering the discharge volume on that curve.

Practical questions

The application of this methodology to the TICOR systems revealed some difficulties:

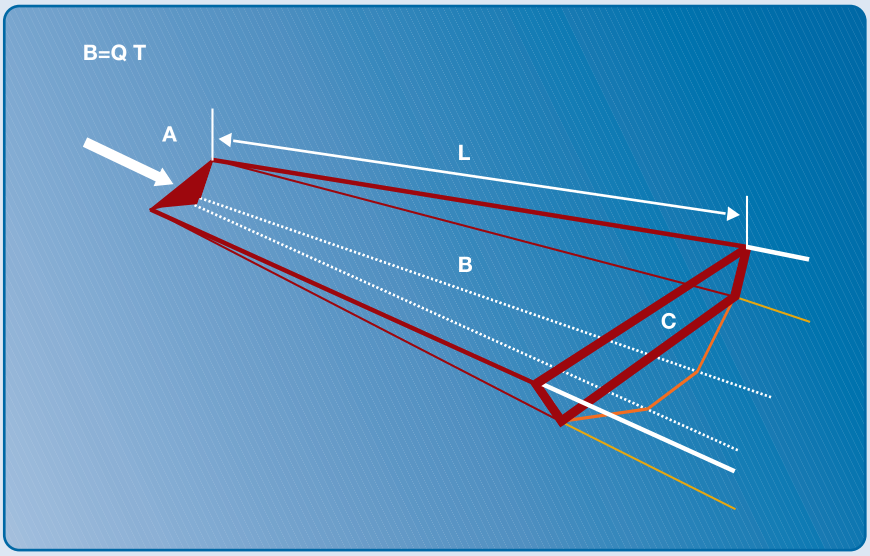
- Uncertainty regarding the dynamic tide limit, coupled with contradictory information in the available literature;
- Morphology of the upper reaches not easily available, incomplete and/or outdated;
- No information on tidal elevations in the upper reaches.

Alternative approaches

When data availability difficulties do not allow the application of this methodology, it may be still possible to apply alternative models to estimate longitudinal salinity distributions.

When neither of these alternatives is possible, the definition of the upper limit has to rely on heuristic approaches e.g. information on water uses with salinity requirements.

Figure 15. Schematic representation of the estuary.



Downstream limits

The methodology for identifying downstream limits of transitional waters relies on a combined approach, which is based on morphological features and historical or traditional seaward limits.

Particular morphological features such as sandbars or other barriers influencing the free exchange of seawater with estuarine brackish water were identified, and a survey of the jurisdiction of local maritime and port authorities was carried out. The limit lines were identified and represented in appropriately scaled maps: they are generally associated with lines defined by conspicuous points (landmarks) and reflect a "traditional" knowledge of limits of characteristic physical parameters.

Other possibilities were analysed, such as the identification of salinity gradients, but this is not feasible in most of the systems, because measurements of longitudinal salinity profiles are not commonly available and the lack of adequate morphological and tidal data did not allow the application of models to simulate such longitudinal distributions.

The different approaches given above were combined to obtain the proposed delimitation.

SYSTEM SELECTION METHODOLOGY

According to the WFD Guidance on the Common Understanding of Terms - Part B, a minimum area of 1 km^2 is recommended for consideration of transitional waters. On this basis, not only transitional waters but also coastal waters such as lagoons were identified according to the following approach:

1. Listing of all Portuguese rivers, estuaries and coastal lagoons shown on 1:25000 military charts;
2. Classification of these systems according to size classes:

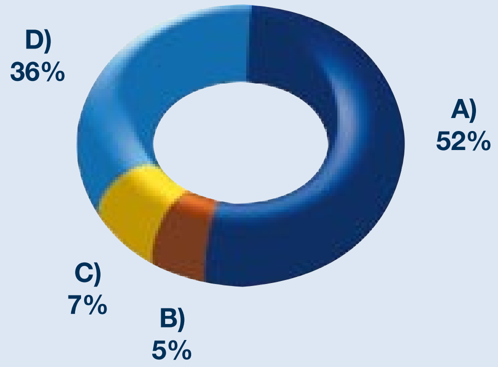
   Class A: < 0.3 km^2;

   Class B: ≥ 0.3 to < 0.7 km^2;

   Class C: ≥ 0.7 to < 1.0 km^2;

   Class D: ≥ 1.0 km^2;
3. Selection of the TICOR systems from the class D list;
4. Characterisation of the TICOR systems using area, volume, freshwater discharge, salinity, tidal range, tidal prism and limits as the main descriptors.

Figure 16. Relative number of transitional and coastal systems in each size class.



RESULTS

From a total of 44 systems identified as transitional or coastal, about half of them are classified within class A (≤ 0.3 km²) systems. The other 48% are distributed over the other classes. Class D (≥ 1.0 km²) is the most representative of these (Figure 16).

Figure 17 presents the total list of Portuguese transitional and coastal systems according to size classes, including minor estuaries, estuaries, coastal lagoons and artificial structures (ports and marinas). Class A is mainly composed of minor estuaries and class D of estuaries. Intermediate classes B and C have fewer systems, consisting mainly of artificial structures and coastal lagoons.

The system area, resident population, economic and ecological importance and geographical location were the main factors considered in

Figure 17. List of the Portuguese transitional and coastal systems according to size classes.

Types of systems	< 0.3 km²	≥ 0.3 to < 0.7 km²	≥ 0.7 to < 1.0 km²	≥ 1.0 km²
Minor estuaries	Ancora, Cabanas, Lis, Alcobaça, Alcabrichel, Sorraia, Sizandro, Safarujo, Cuco, Lisandro, Colares, Manique, Parreiras, Fontainhas, Odeceixe, Aljezur, Bordeira, Bensafrim, Alcantarilha, Quarteira, Alamo	-	-	-
Estuaries	Neiva, Ave	-	Cávado	Minho, Lima, Douro, Ria de Aveiro, Mondego, Tagus, Sado, Mira, Arade, Guadiana
Coastal lagoons	-	Melides	S. Martinho do Porto	Ria de Alvor, Ria Formosa, Sto. André, Albufeira, Óbidos
Artificial structures	-	Vilamoura Marina	Port of Póvoa de Varzim	Port of Leixões (Leça estuary)
Total number of systems	23	2	3	16
Overall total				44

selecting the TICOR systems. The following systems were chosen from class D: Minho, Lima, Douro, Ria de Aveiro, Mondego, Tagus, Sado, Mira, Ria Formosa and Guadiana (Figure 25).

COASTAL LIMITS

The coastal water limits were determined on the basis of the WFD definition (Article 2 (7)) for coastal waters: *"…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*".

The national legislation regarding the baseline from which the breadth of territorial waters is measured is D.L. nº 495/85, which was previously defined by D.L. nº 47771 (Figure 18). The line between points is the baseline defined by points in D.L 495/85 (green circles in Figure 18). The baseline boundaries at the NW and SE limits follow the tidal datum contour.

For the inshore limit the maximum spring high water mark was considered. Figure 19 shows the limits for the Atlantic coastal waters considering one nautical mile from the straight baseline to the inshore limit.

Figure 18. Points that identify the straight baseline (D.L. nº 495/85).

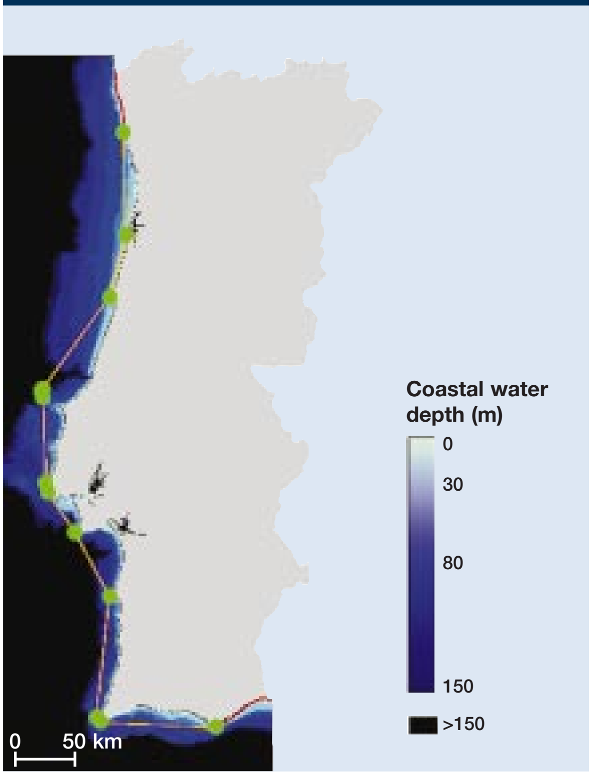
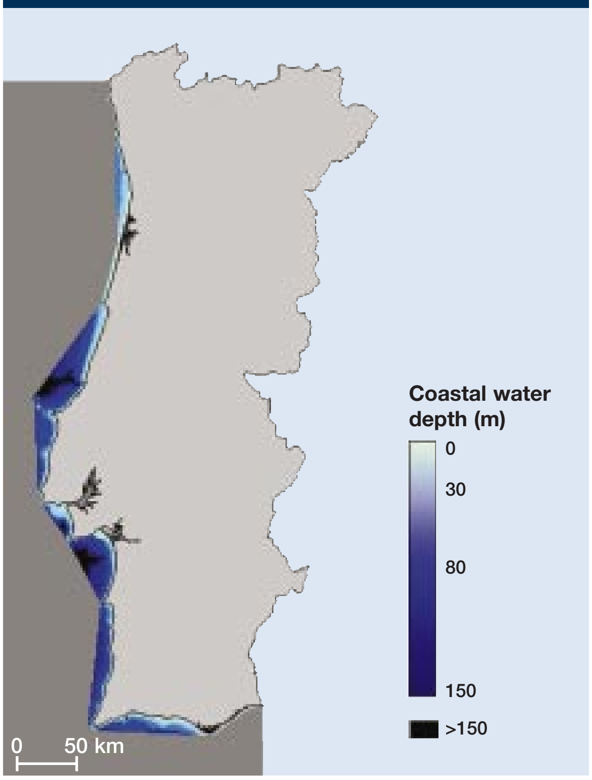


Figure 19. Atlantic coast limits.



APPLICATION TO TICOR SYSTEMS

The application to TICOR systems is shown in Figure 20 and Figure 21.

MORPHOLOGICAL PARAMETERS

Methods

For each system, the surface area and water volume were calculated using the bathymetry grid stored in the GIS. The area was calculated by multiplying the total number of grid cells by the cell area. The water volume was determined by multiplying the water height of each prismatic element (Figure 22) by the

Figure 20. Transitional system limits (only TICOR systems shown).

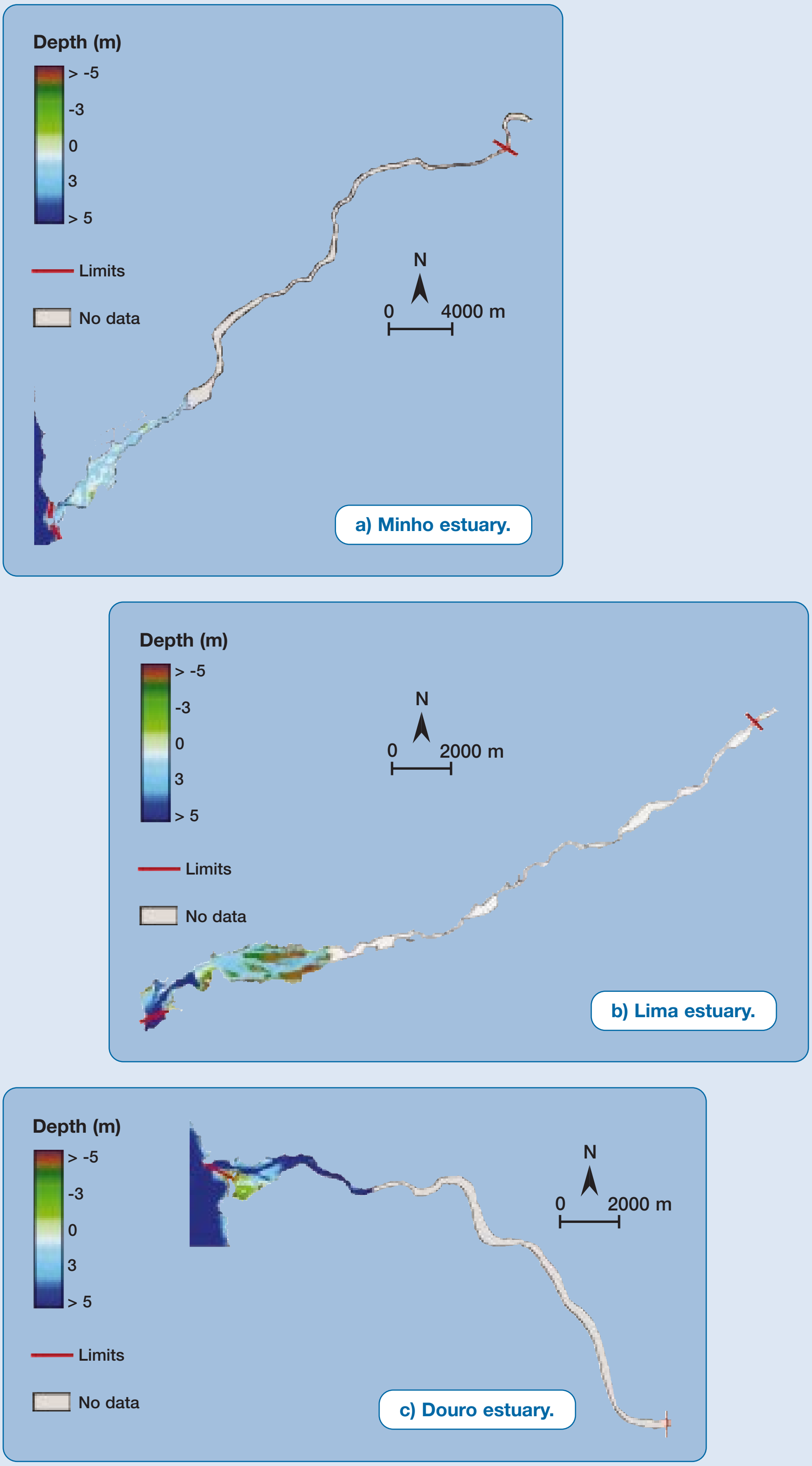


Figure 20. (cont.) Transitional system limits (only TICOR systems shown).

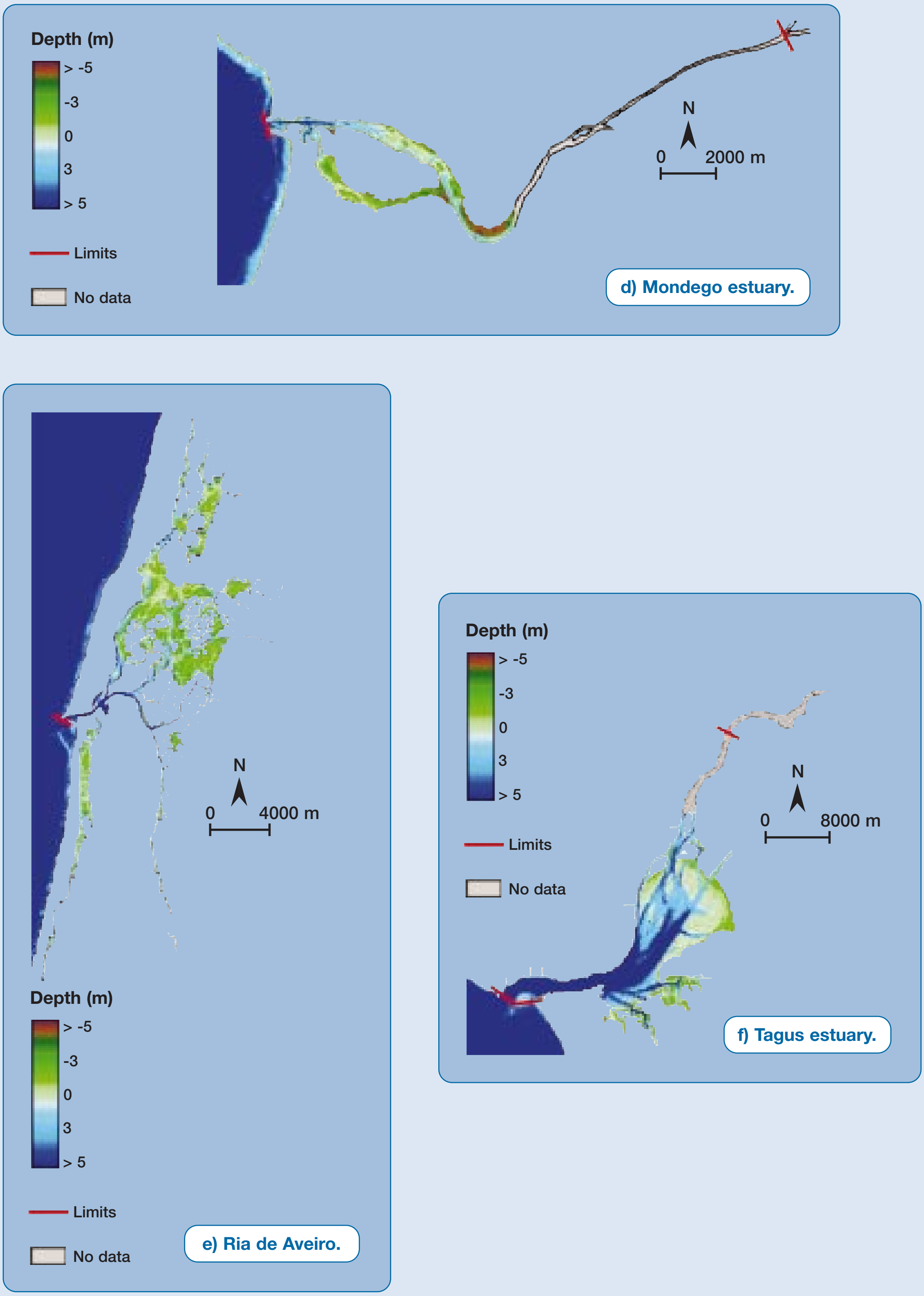


Figure 20. (cont.) Transitional system limits (only TICOR systems shown).

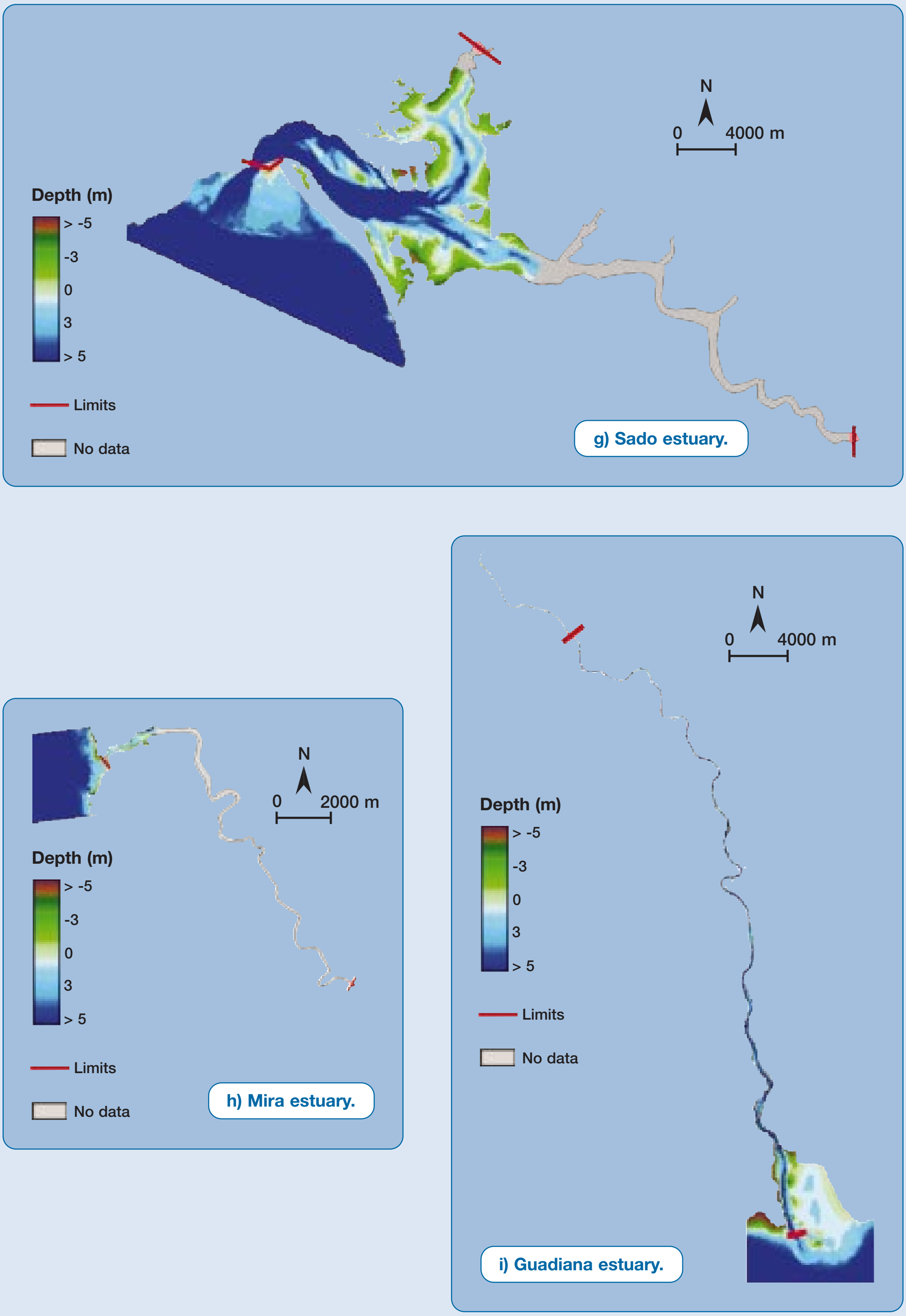
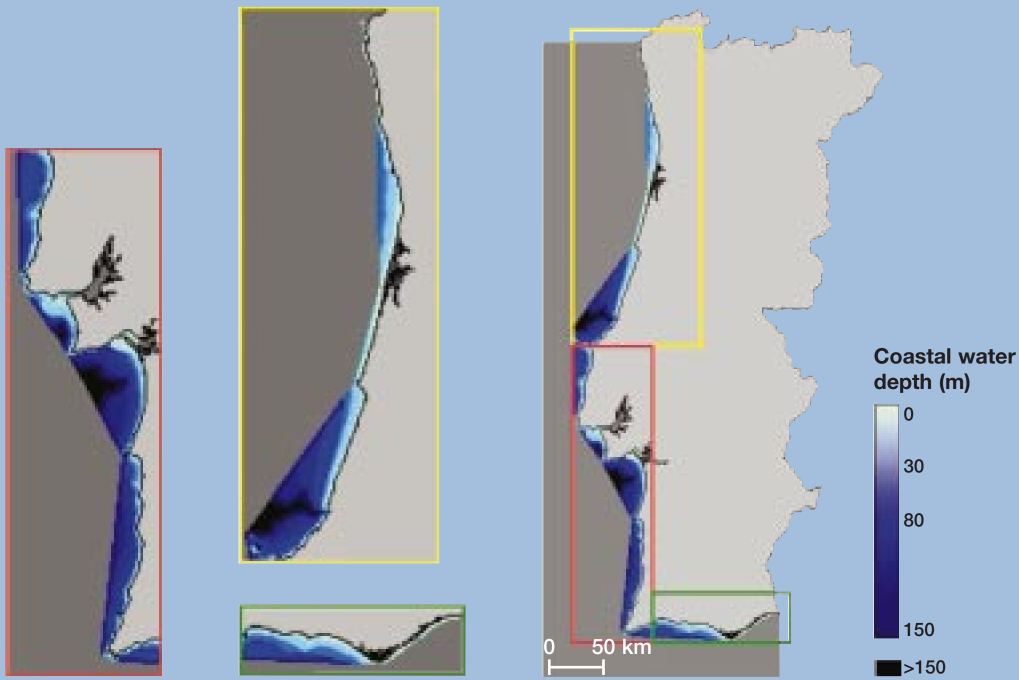


Figure 21. Limits for coastal systems.

a) North Atlantic coast.



b) Ria Formosa.

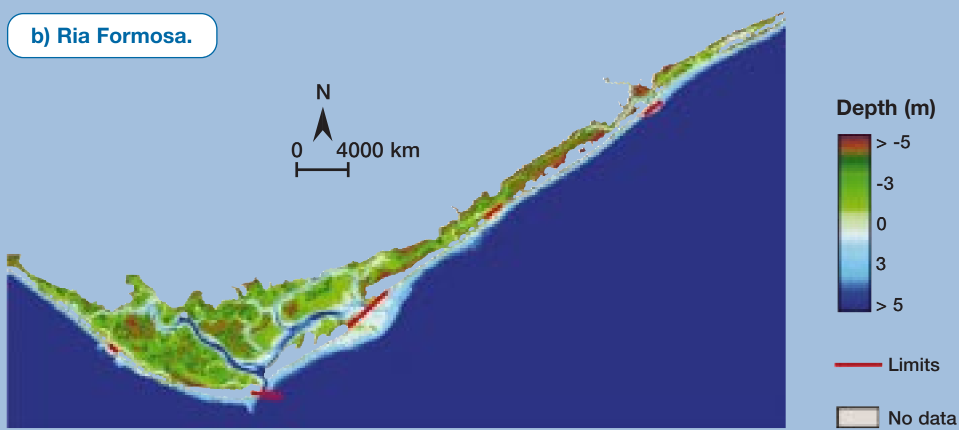
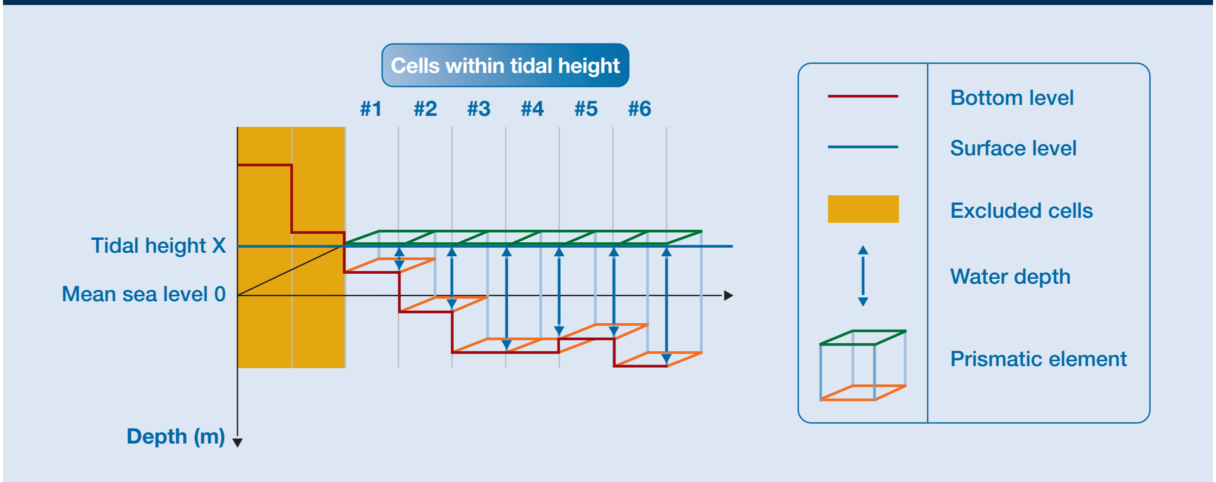


Figure 22. Volume calculation based on the bathymetry.



cell area and then integrating for the whole system.

Three tidal situations were considered for the area and volume calculations:

- Z_0 (mean tide level at the tide gauge reference);
- Equinoctial spring tide high water;
- Equinoctial spring tide low water.

The same tidal height was used for the whole system: different surface heights due to delays in tidal propagation were not considered.

Areas and volumes per system

Figure 23 shows the calculated areas and volumes for each system using the WFD criteria.

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Figure 23. Areas and volumes for all TICOR systems.

	Area (km^2)			Volume (10^6 m^3)		
System name	High water	Z_0	Low water	High water	Z_0	Low water
Minho estuary*	23	23	21	105	67	38
Lima estuary*	6	5	5	24	19	15
Douro estuary*	6	6	6	83	65	49
Ria de Aveiro	74	60	16	184	84	39
Mondego estuary*	11	9	6	35	21	10
Tagus estuary*	340	330	230	2 800	2 200	1 700
Sado estuary*	180	160	120	1 060	770	550
Mira estuary*	3	3	3	18	17	16
Guadiana estuary	21	18	17	135	96	74
Ria Formosa	91	49	19	210	92	45
Atlantic coast			8 400			518 500

* - Systems with incomplete bathymetry on the upstream part. Parameters were calculated based on mean estimates of channel structure.

Note: Different colours correspond to different types.

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Typology

INTRODUCTION AND OBJECTIVES

The definition of water body types is one of the first stages in the implementation of the Water Framework Directive, as outlined in Annex II. The aim of typology is to separate surface waters into water types in order to produce a simple physical characterisation, ecologically relevant and practical to implement. This process should be finalised in the year 2004 (Article 5 (1)). The typology is intended as a tool to assist the overall purpose of the Water Framework Directive established in article 1: the protection of both water quality and water resources preventing further deterioration and promoting the improvement of the aquatic environment.

Limitations for number of types

Surveillance Monitoring is one of the national obligations established in the Water Framework Directive concerning the reference conditions defined for each transitional and coastal type. In the WFD there is no guidance on the specific number of types each Member State must have. However, a large number of types will result in a requirement for a large number of type-specific reference conditions. Furthermore, the costs of monitoring a large number of types should also be taken into account. Although it is recognised that a simple typology system will need to be complemented with a more sensitive reference condition framework, a smaller number of types will be more amenable to management.

WFD Typology elements

In Annex II of the WFD, the differentiation within the transitional or coastal waters should be made according to type. Types may be defined using either “system A”, which identifies types according to a fixed typology or “system B”, an alternative typology based on physical and chemical factors that determine the characteristics of the transitional water and hence the biological population structure and composition. Typology defined under system A consists of identifying geographical ecoregions and using (a) mean annual salinity and tidal range classes to characterise transitional waters or (b) mean annual salinity and depth classes to characterise coastal waters. The alternative system B characterisation uses both obligatory and optional factors, as shown in Figure 24.

The Guidance for Typology in Transitional and Coastal Waters suggests the use of system B, building on a consensus of the EU Member States, and refers that each country should use those obligatory and optional factors that are most applicable to their own ecological context.

Figure 24. Typology according to system A and system B.

	Descriptors	
System A - Fixed Typology	**Transitional waters**	**Coastal waters**
Ecoregion	Baltic sea	Baltic sea
	Barents Sea	Barents Sea
	Norwegian sea	Norwegian sea
	North Sea	North Sea
	North Atlantic Ocean	North Atlantic Ocean
	Mediterranean Sea	Mediterranean Sea
Type	Based on mean annual salinity	Based on mean annual salinity
	< 0.5 psu Freshwater	< 0.5 psu Freshwater
	0.5 to < 5 psu Oligohaline	0.5 to < 5 psu Oligohaline
	5 to < 18 psu Mesohaline	5 to < 18 psu Mesohaline
	18 to < 30 psu Polyhaline	18 to < 30 psu Polyhaline
	30 to < 40 psu Euhaline	30 to < 40 psu Euhaline
	Based on mean tidal range	Based on mean depth
	< 2 m Microtidal	Shallow waters: < 30 m
	2 to 4 m Mesotidal	Intermediate: 30 to 200 m
	> 4 m Macrotidal	Deep: > 200 m
System B – Alternative Characterisation	**Transitional waters**	**Coastal waters**
Obligatory factors	Latitude	Latitude
	Longitude	Longitude
	Tidal Range	Tidal Range
	Salinity	Salinity
Optional factors	Current velocity	Current velocity
	Wave exposure	Wave exposure
	Mean water temperature	Mean water temperature
	Mixing characteristics	Mixing characteristics
	Turbidity	Turbidity
	Mean substratum composition	Mean substratum composition
	Water temperature range	Water temperature range
	Residence time	Retention time (of enclosed bays)
	Depth	
	Shape	

Note: Adapted from the Annex II in the Water Framework Directive text.

Context for Portuguese waters

About 50% of Portugal's border is with the Atlantic Ocean. Transitional waters, or estuaries, are distributed along the coast, a number of them with an area greater then 1 km^2.

Coastal Portuguese waters include semi-enclosed and shallow lagoons located mainly in the southern part of the country, and open coastal waters, oriented North-South and East-West (Algarve coast). Coastal systems cover an area about fourteen times greater than transitional systems.

Studies on transitional and coastal Portuguese waters have been made over the last four decades. Although several spatial and temporal data gaps were detected, particularly in coastal waters, the information necessary to identify types has been assembled. Expert knowledge and metadata were used as a complement to raw data.

Objectives and approach

The main objectives of this chapter are:

- To describe the methodologies used for typology definition;
- To present the final typology for transitional and coastal Portuguese waters, including the description of each type;
- To classify the transitional and coastal Portuguese systems into types.

Figure 25. Main coastal and transitional Portuguese systems.

METHODS

Two main tools were used in the typing process of transitional and coastal Portuguese waters: a top-down approach, based on expert knowledge, and a bottom-up approach developed as a follow-up to the LoiczView clustering tool developed by LOICZ, and entitled "Deluxe Integrated System for Clustering Operations" (DISCO), which is currently being used for clustering transitional and coastal waters in the United States.

Top-down approach

In the top-down approach, systems larger than 1 km^2 were grouped into types based on a common characterisation for obligatory and optional factors.

The classification of transitional and coastal Portuguese waters was made using system B (Figure 24). This classification was found to be the most appropriate for defining national types since the biological composition and community structure usually depends on more descriptors

than those listed in System A (Figure 24). Prior to typing, the identification of the Ecoregion for Portuguese transitional and coastal waters was made using map B from Annex 11 of the WFD. Based on the "Guidance for Typology in Transitional and Coastal Waters" the obligatory factors for systems larger than 1 km^2 were selected. The same approach was made for the optional factors suggested in the guidance document (Figure 26).

Figure 26. Classification system and optional factors used for the typology of transitional and coastal Portuguese waters.

Category	System of classification	Obligatory factors	Optional factors used for typology
Transitional waters	B	Latitude Longitude Salinity Tidal range	Mixing characteristics
Coastal waters	B	Latitude Longitude Salinity Tidal range	Wave exposure Shape Depth

The systems were then grouped into types based on a common description. A preliminary typology list was intensively reviewed and discussed by the national experts and international consultants and a final list was then approved by consensus.

Bottom-up approach

The bottom-up strategy was made by means of the DISCO on-line clustering tool. This system uses a web-based interface and has been developed from the LoiczView package. An ASCII file was prepared containing available data on system B obligatory and optional factors (Figure 26), which describe each of the transitional and coastal Portuguese systems, and uploaded to DISCO. The number of clusters was set to the same number of types defined in the top-down strategy and a number of K-means cluster analyses were performed, each considering a combination of the relevant variables.

The names of the variables used in each DISCO run are given in Figure 27. Run 3 includes all obligatory and optional factors considered in the

Figure 27. DISCO clustering process for transitional and coastal Portuguese types.

	Variables	
Run number	Obligatory factors	Optional factors
1	• Latitude • Median salinity	• Depth
2	• Latitude • Median salinity	• Depth • Shape (volume and area)
3	• Latitude • Median salinity	• Depth • Shape (volume and area) • Mixing characteristics (estuary number [1])

[1] Modular flow ($m^3 d^{-1}$) / Normalized tidal prism ($m^3 d^{-1}$)

top-down approach both for transitional and coastal types, excluding longitude and tidal range. Longitude-based clusters provide a potentially artificial division, and tidal range is uniform throughout the Portuguese coast and is therefore not a suitable type discriminant.

RESULTS AND JUSTIFICATION

National typology for transitional and coastal waters

According to map B of WFD Annex XI, the transitional and coastal Portuguese waters fall within the Atlantic Ocean Ecoregion, which is included in the Atlantic / North Sea Ecoregion complex proposed in the WFD guidance. The Portuguese typology, defined using a top-down approach, consists of seven types identified from A1 to A7. The first two are types of transitional waters and types A3 to A7 belong to the coastal waters category (Figure 28).

The results obtained in the bottom-up approach are shown in Figure 29. In this analysis three different types were recognized for coastal waters and a further three for transitional waters.

The results for the final DISCO run were compared with the top-down typology in Figure 30. In both typing methodologies, three different coastal types are identified for open coastal waters: Exposed Atlantic Coast, Moderately Exposed Atlantic Coast and Sheltered Atlantic Coast. In the bottom-up typology, although Ria Formosa is discriminated from all the transitional systems, it is grouped with the Sheltered Atlantic Coast type. However, due to its specific characteristics (shallow enclosed coastal water) it may be heuristically distinguished as a separate type.

Figure 28. Results of the Portuguese typology for transitional and coastal waters using a top-down approach.

Type	Descriptor	Obligatory factors	Optional factors
Transitional waters			
A1	Mesotidal stratified estuary	Latitude: 41° 50’ N to 41° 08’ N Longitude: 08° 41’ W to 08° 53’ W Tidal range[1]: 3.5 m (Mesotidal) Salinity: Polyhaline (24)	Mixing conditions: Stratified
A2	Mesotidal well-mixed estuary with irregular river discharge	Latitude: 40° 37’ N to 37° 09’ N Longitude: 08° 43’ W to 07° 23’ W Tidal range: 3.3 to 3.8 m (Mesotidal) Salinity: Polyhaline (20)	Mixing conditions: Well-mixed
Coastal waters			
A3	Mesotidal semi-enclosed lagoon	Latitude: 39° 26’ N to 38° 05’ N Longitude: 09° 13’ W to 08° 47’ W Tidal range: 2 m (Mesotidal)[2] Salinity: Mesohaline[3]	Shape: Semi-enclosed Depth: < 2m
A4	Mesotidal shallow lagoon	Latitude: 36° 58’ N to 37° 08’ N Longitude: 07° 51’ W to 08° 37’ W Tidal range: 3.4 m (Mesotidal) Salinity: Euhaline (35)	Depth: 2m
A5	Mesotidal exposed Atlantic coast	Latitude: 41° 50’ N to 39° 21’ N Longitude: 08° 41’ W to 09° 24’ W Tidal range: 3.3 to 3.5 m (Mesotidal) Salinity: Euhaline (35)	Wave exposure: exposed
A6	Mesotidal moderately exposed Atlantic coast	Latitude: 39° 21’ N to 37° 04’ N Longitude: 09° 24’ W to 08° 40’ W Tidal range: 3.4 to 3.5 m (Mesotidal) Salinity: Euhaline (35)	Wave exposure: moderately exposed
A7	Mesotidal sheltered coast	Latitude: 37° 04’ N to 37° 11’ N Longitude: 08° 40’ W to 07° 24’ W Tidal range: 3.4 m (Mesotidal) Salinity: Euhaline (35)	Wave exposure: sheltered

[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 29. Results of the portuguese typology for transitional and coastal waters using the DISCO bottom-up approach.

	Variables		
	Run 1	Run 2	Run 3
Types	• Latitude • Median salinity • Depth	• Latitude • Median salinity • Depth • Shape (area, volume)	• Latitude • Median salinity • Depth • Shape (area, volume) • Mixing characteristics (estuary number)
1	• Minho • Douro	• Minho • Douro	• Douro
2	• Lima • Ria de Aveiro • Mondego	• Lima • Ria de Aveiro • Mondego	• Minho • Lima • Ria de Aveiro • Mondego
3	• Tagus • Sado • Mira • Ria Formosa • Guadiana	• Tagus • Sado • Mira • Ria Formosa • Guadiana	• Tagus • Sado • Mira • Guadiana
4	• Exposed Atlantic Coast	• Exposed Atlantic Coast	• Exposed Atlantic Coast
5	• Moderately exposed Atlantic Coast	• Moderately exposed Atlantic Coast	• Moderately exposed Atlantic Coast
6	• Sheltered Atlantic Coast	• Sheltered Atlantic Coast	• Sheltered Atlantic Coast • Ria Formosa

In the bottom-up approach the northern estuaries are distributed through two different types and separated from the southern estuaries, which integrate the third transitional type.

However, in the top-down approach only two main types of transitional waters are identified. Since one of the bottom-up transitional types only includes one system, and since there is a requirement to optimise the number of types, it was agreed that only two types should be defined for transitional waters, as defined in the top-down typology. The final typology for transitional and coastal Portuguese waters is presented in Figure 28 and is characterised below.

Characterisation of types

The characterisation of transitional and coastal Portuguese types is briefly described below, taking into account the factors used for type definition and other relevant information.

Transitional waters

A1 – Mesotidal stratified estuary

This type of estuary, located in the northern part of the country, is characterised by high river flows over the whole year, which promote

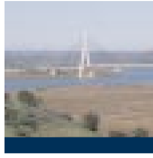
Figure 30. Comparison of the results obtained in both strategies used for Portuguese transitional and coastal waters typology process.

	Top-Down typology	Bottom-Up typology
1	• Minho estuary • Lima estuary • Douro estuary	• Douro estuary
2	• Ria de Aveiro • Mondego estuary • Tagus estuary • Sado estuary • Mira estuary • Guadiana estuary	• Minho estuary • Lima estuary • Ria de Aveiro • Mondego estuary
3	• Ria Formosa	• Tagus estuary • Sado estuary • Mira estuary • Guadiana estuary
4	• Exposed Atlantic Coast	• Exposed Atlantic Coast
5	• Moderately exposed Atlantic Coast	• Moderately exposed Atlantic Coast
6	• Sheltered Atlantic Coast	• Sheltered Atlantic Coast • Ria Formosa
7	• Óbidos lagoon • Albufeira lagoon • Sto. André lagoon	Not included in the typing process due to lack of data

stratification of the water column inside the estuary. The mean tidal range is about 2 m and mean annual salinities are about 20. The Minho, Lima and Douro are examples of this type of estuary.

A2 – Mesotidal well-mixed estuary with irregular river discharge

The river flow of this estuarine type depends strongly on the season. Generally the torrential river discharge is due to intense rainfall during the winter months. These estuaries are considered well-mixed during the whole year, with stratification being rare and occurring in specific situations such as extreme flood events. Examples of this type of estuary are the Tagus, Sado and Guadiana.



Coastal waters

A3 – Mesotidal semi-enclosed lagoon

Lagoons of this type have a direct but intermittent connection with the ocean, which is frequently closed by a sand bar. Artificial opening occurs mainly in the summer months. These systems are shallow, with a mean water depth less than 2 m. Salinity varies widely and is strongly influenced by evaporation, occasional freshwater inputs (precipitation and runoff) and by cycles of temporary communication with the sea. The tidal influence on the lagoons is moderate and only occurs during periods of free connection with the ocean. Sand dunes cover the coastal and lagoon shores and extensive reed beds colonise wetland areas. Santo André and Albufeira are two examples for this type.

A4 – Mesotidal shallow lagoon

The communication between the lagoon and the sea is permanent and occurs through several inlets located along the system. The shallow depth, strong tidal currents and high water renewal make this type of lagoon vertically well-mixed. The mean water depth is about 2 m and salinity values are always above 30 since the freshwater input can be considered negligible – in summer conditions this type of system may become an inverse estuary. This type encompasses a complex of coastal seawater lagoons on sandy or muddy soils, extensive mudflats, sandbanks, sand dune systems, salt marshes, wetlands and subtidal seagrass beds. Ria Formosa and Ria de Alvor are the most significant examples in Portugal of this type of lagoon.

A5 – Mesotidal exposed Atlantic coast

The western coast from the northern border with Spain to Cape Carvoeiro is divided in two main morphological parts. The first one, extending south from the northern border with Spain until 41° North is mainly rocky and shallow with cliffs alternating with small beaches. From 41° North to Cape Carvoeiro, beaches are the main morphological structures, interrupted only by Cape Mondego. Tides are semidiurnal with a spring tidal range of 3.8 m. This coastal type has high energy hydrodynamics and is struck by storms from the North Atlantic particularly from October to March. Dominant wave direction is West and Northwest with some occurrences from Southwest. Most frequent wave periods are in the range of 8 to 12 seconds and wave heights are in the range of 1 to 3 m. Under storm conditions waves of 8 m height and period exceeding 16 seconds may occur. At Leixões an extreme wave height of 14.6 m can occur for a return period of 50 years.

A6 – Mesotidal moderately exposed Atlantic coast

The moderately exposed coast is typical of the coastline from Cape Carvoeiro to Ponta da Piedade. Cliffs replace the beaches from Cape Carvoeiro to Cape Raso (Lisbon). From Cape Raso to Sines, two irregular coastal sectors alternate with two sandy sectors. From Cape Sines to Ponta da Piedade, cliffs, interrupted by small beaches, are the main morphological structures. The wave energy is slightly more attenuated than in the northern part, although peak wave heights vary between 14 m for a return period of 100 years in the Tagus, and 16.7 m at Sines for a return period of 50 years.

A7 – Mesotidal sheltered Atlantic coast

This type stretches from Ponta da Piedade in the western part of the Algarve to the Guadiana estuary, on the Southeastern border with Spain. From Ponta da Piedade to 8º West, cliffs interrupted by small beaches typically form the coast. Between 8º West and 7º30' West the main feature are the barrier islands of the Ria Formosa (type A4). Following this lagoon system a coastal plain formed mainly by beaches extends until the Guadalquivir estuary in Spain. The southern coast has a milder wave climate than the western coast, with long and frequent calm periods. Wave heights are seldom above 4 m with means between 0.6 and 1.5 m. Wave direction is from Southwest and Southeast and periods are similar to those of the western coast.

Typology application

The typology was applied to systems larger than 1km^2 (Figure 31). Considering the number of systems per type, A2, mesotidal well-mixed estuaries with irregular river discharge, is the most representative for transitional waters and A3, semi-enclosed lagoons, is the most representative for coastal waters. Figure 32 presents the location of each system identified by type. A total area of 618 km^2 was calculated for transitional waters while coastal systems, including open coast, cover an area fourteen times larger, with 8464 km^2.

About 93% of the total area for transitional waters (644 km^2) is covered by systems of type A2. For

Figure 31. Classification of the transitional and coastal Portuguese waters according types.

Category	Type	Systems larger than 1 km^2	Number of systems
Transitional waters	A1	Minho estuary Lima estuary Douro estuary Leça estuary	4
	A2	Ria de Aveiro Mondego estuary Tagus estuary Sado estuary Mira estuary Arade estuary Guadiana estuary	7
Coastal waters	A3	Óbidos lagoon Albufeira lagoon St. André lagoon	3
	A4	Ria de Alvor Ria Formosa	2
	A5	From Minho estuary until Cabo Carvoeiro	1
	A6	From Cabo Carvoeiro until Ponta da Piedade	1
	A7	From Ponta da Piedade until Vila Real de Sto. António	1

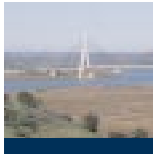
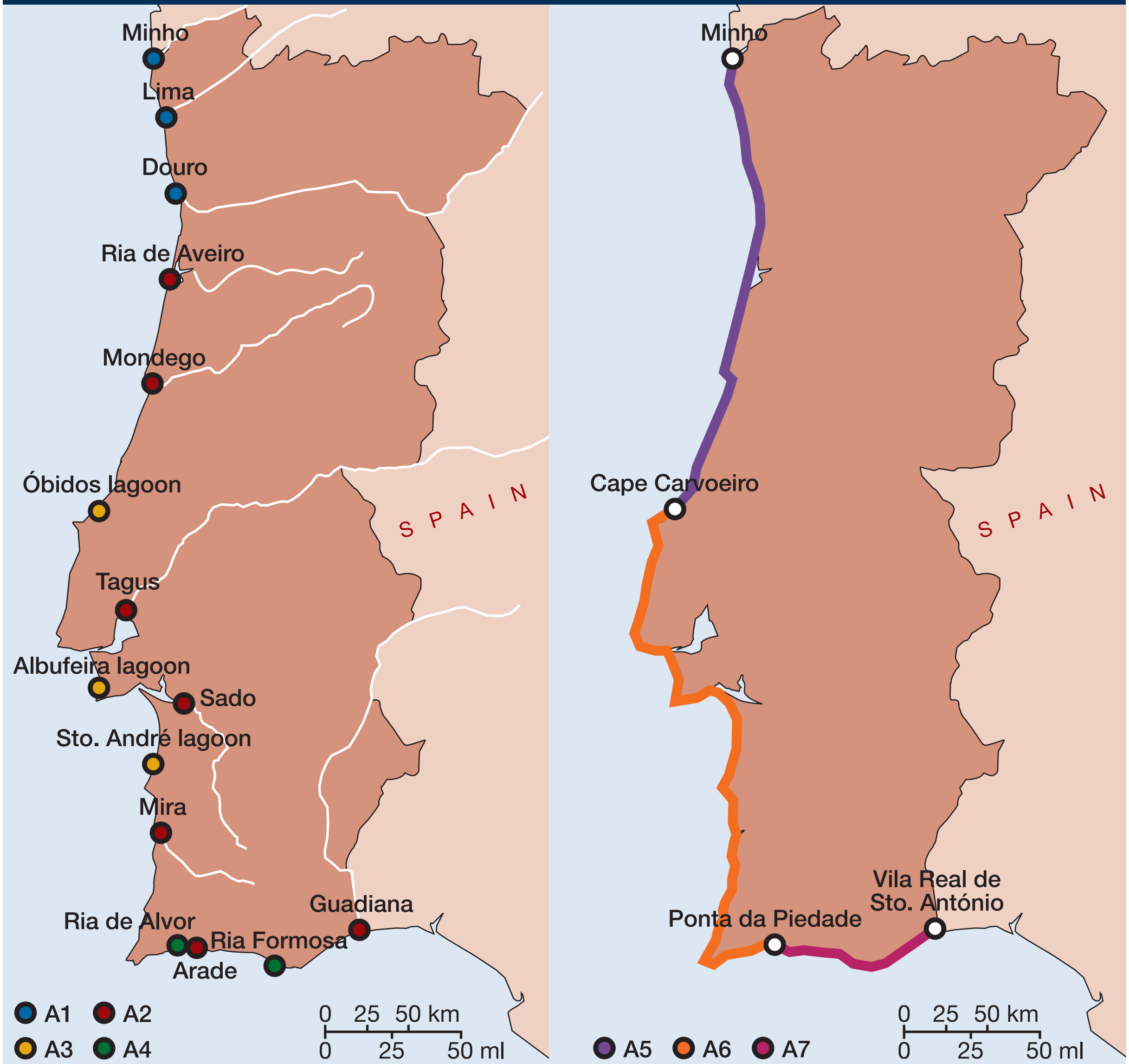


Figure 32. Location, areas and volumes of the transitional and coastal Portuguese types.



TYPOLOGY OF TRANSITIONAL WATERS AND SHELTERED COASTAL WATERS

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

TYPOLOGY OF OPEN COASTAL WATERS

	A5	A6	A7
Area (km²)*	3 200	4 200	1 000
Volume (10⁶ m³)*	195 000	295 900	27 600

* Only one value given since there are no appreciable differences due to tidal height.

coastal systems type A5 is the most representative, covering about 46% of the total area. In terms of water volume per type, similar proportions were obtained for transitional and coastal waters (Figure 32).

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Pelagic Reference Conditions

INTRODUCTION AND OBJECTIVES

The WFD defines (in Annex V) a number of quality elements, used for determination of ecological status, which may be considered to be pelagic, i.e. associated with the water column.

This chapter provides an overview of those elements, examines which metrics may best be used for their determination, and discusses possibilities for definition of type-specific reference conditions.

Finally, some points are made regarding integration of some of the biological quality elements, with particular reference to issues concerning organic enrichment.

Objectives

- **To collect and review available data;**
- **To assess the adequacy of the phytoplankton classification tools;**
- **To test and develop these tools in order to recommend the best techniques for establishing reference conditions for pelagic quality elements;**
- **To suggest some first-generation reference conditions, and make recommendations for future work.**

WFD pelagic quality elements

Figure 33 shows the pelagic quality elements for transitional and coastal waters. The list is abridged from the WFD Annex V to contain only those elements relating to the water column. Biological and supporting elements associated to the benthic environment are examined in the next chapter.

The key differences in quality elements between transitional and coastal waters are highlighted. The most important of these is the inclusion of the biological element *Composition and abundance of fish fauna* in transitional waters, but not in coastal waters.

Review of phytoplankton classification tools

A number of tools are available which may potentially be used for establishing type-specific reference conditions and ecological status of water bodies for phytoplankton composition, abundance and biomass.

Figure 33. Pelagic quality elements for transitional and coastal waters.

	Transitional and coastal waters	
Biological elements	• Composition, abundance and biomass of phytoplankton (6 months)	• Composition and abundance of fish fauna (3 years)
Hydromorphological elements supporting the biological elements	Morphological conditions: • Depth variation (6 years)	Tidal regime: • Freshwater flow • Direction of dominant currents • Wave exposure
Chemical and physico-chemical elements supporting the biological elements	General: 1. Transparency 2. Thermal conditions (3 months) 3. Oxygenation conditions (3 months) 4. Salinity (3 months) 5. Nutrient conditions (3 months)	Specific pollutants: • Pollution by all priority substances identified as being discharged into the body of water (1 month) • Pollution by other substances identified as being discharged in significant quantities into the body of water (3 months)

Note: Elements which are only applicable to transitional waters are shown in blue, elements applicable only to coastal waters are shown in red.

Where applicable, the sampling frequency indicated in the WFD Annex V is shown in brackets.

Although all the phytoplankton components are considered together as one biological quality element, it is useful to consider individually the three phytoplankton descriptors indicated in the WFD.

There are a number of candidate methods for evaluating these three descriptors, although generally these tools focus on a sub-set of the three and/or combine these with other descriptors of ecosystem state. Based on the guidance developed by the CIS 2.4 (COAST) group, and on a review of additional possibilities, a list of potential approaches is shown in Figure 34, together with an evaluation of their usefulness.

The first two methods are integrated assessment procedures, which combine several WFD quality elements to either provide a semi-quantitative score (OSPAR) or a final calculation of state, known as overall eutrophic condition (NEEA/ASSETS). Both these approaches consider different stages in the eutrophication process, which result in progressively more severe impacts. Phytoplankton biomass is evaluated using chlorophyll *a* as a proxy, and combined with some of the supporting elements indicated in Figure 33, such as dissolved oxygen.

Both procedures extend the evaluation of quality

Composition

The phytoplankton species which make up the community

Abundance

The number of cells which exist in a sampling volume

Biomass

The mass of phytoplankton which exists in a sampling volume

elements that are considered individually in the WFD to address the effects of organic enrichment in transitional and coastal waters (TCW) using a more holistic approach. The effects of nutrient discharges to TCW may result in elevated phytoplankton biomasses, changes in phytoplankton composition or modifications to the phytobenthos, manifested through the shift in community structure from seagrasses and long-lived macroalgae to rapid blooms of opportunistic seaweeds.

A key difference between the two approaches lies in the use of nutrients as part of the assessment. NEEA/ASSETS uses nutrients only in the pressure part of the assessment, but not for determination of state. Although it is clear that human inputs of nutrients are the driver for the symptoms of organic enrichment which may occur in the coastal zone, dissolved nitrogen or phosphorus in the water column are often difficult to relate to phytoplankton composition, abundance and biomass. Moreover, the loading is more important than the observed concentration, although in many instances a clear relationship between nutrient loads and peak phytoplankton biomass is not observed.

IFREMER has developed a method for examining species composition (Figure 34) grouping species according to toxic events and organic enrichment. In the former case, a checklist of species is provided, whereas in the latter all species are considered. In both cases, cell number per unit volume is used as a descriptor, and high status results from lack of symptoms over a moving five-

Figure 34. Methodologies addressing the biological quality element phytoplankton composition, abundance and biomass, in whole or in part.

Method	Description	Positive	Negative
OSPAR Comprehensive Procedure	Symptoms-based approach identifying *direct* and *indirect* effects. Includes nutrients.	Integrated "EU accepted"	Non-exclusive, includes benthic components such as seaweeds Semi-quantitative (+/- scale) Draft standard, not well tested
NEEA/ASSETS Assessment of Estuarine Trophic Status	Similar to above, identifying *primary* and *secondary* symptoms. Contains elements of P-S-R. Excludes nutrients	Integrated Quantitative Well tested in U.S. "U.S. accepted"	Non-exclusive, includes benthic components such as seaweeds
IFREMER tentative classification	Composition approach based on: Toxic species (human, aquatic life) & Eutrophication species (all) over a moving 5 year period	One of very few approaches to composition	Not integrated Eutrophication is better assessed with biomass
South African "state of the estuaries" report	Multi-metric index based on suitability for aquatic life, human contact & trophic status	Integrated Applied to 250 South African estuaries	Excludes chlorophyll but includes nutrients

- High concentrations of suspended material in transitional waters may control light availability for phytoplankton production
- Phytoplankton blooms will not usually occur in transitional waters with a water residence time lower than the phytoplankton doubling time

year period. Toxic blooms advected inshore from ocean frontal systems present a problem for this classification, since this type of event is apparently unrelated to land-based pressures. On the other hand, eutrophication is probably better identified using biomass rather than abundance, and may not manifest itself at all in the phytoplankton.

The South African State of the Estuaries report develops an index for estuarine quality, which does not include a phytoplankton component, and therefore appears to be of limited use for the WFD.

Review of fish classification tools

The WFD specifies that the descriptors that should be used for establishing type-specific reference conditions and ecological status of water bodies for fish fauna are the following:

a) Fish assemblages and relative abundance

b) Relative abundance of sensitive species

Fish communities have often been used to illustrate changes in the condition of estuarine environments, despite the fact that these assemblages in transitional waters are usually dynamic.

A review of the literature Figure 35 shows six types of ecological indices that include the estuarine fish fauna component and may potentially be useful for the application of the WFD.

The first two methods are based on a comparison between the fish community present within an aquatic system and the reference community. The Estuarine Community Degradation Index (CDI) assumes that differences between the potential community and the present assemblage are due to habitat degradation. However this approach seems too simple because changes in fish communities are not only due to habitat degradation but also to pressures such as fisheries. Despite this, the CDI is a useful method because it can be used to monitor the recovery of

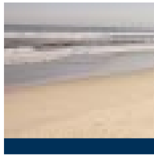


Figure 35. Methodologies addressing the biological quality element fish fauna composition and relative abundance.

Method	Description	Positive Aspects	Negative Aspects
CDI	Based on differences between a fish community and a reference	Condenses fish community information	Only refers presence/absence of species without proportions
BHI	Based on similarities between a fish community and a reference	Condenses fish community information	Only refers presence/absence of species without proportions uses two separate measures
FHI	Qualitative and quantitative comparisons with a reference fish community	Comparison between number of species inclusion of exotic or translocated species	Simulation of the reference conditions (mean value of each group)
EBI	Set of a scoring system of fish metrics using a reference	Integrated with representative metrics of fish community status	Difficulties in the establishment of the scoring system
FRI	Use of ichthyological information to assess changes in habitat integrity	Biologically meaningful	Lack of knowledge of some ecological factors affecting fish communities
FIR	Set of a scoring system of criteria reflecting the importance of estuaries to fish	Identifies which systems have a high fish conservation priority	Difficulties in the establishment of the scoring system

CDI - Estuarine Community Degradation Index; BHI - Estuarine Biological Health Index; FHI - Estuarine Fish Health Index;

EBI - Estuarine Biotic Integrity Index; FRI - Estuarine Fish Recruitment Index; FIR - Estuarine Fish Importance Rating

a system, to document its faunistic degradation over time and to support the identification of types where the fish communities are most endangered.

The Estuarine Biological Health Index (BHI) is derived from the CDI, and incorporates a measure of the degree of similarity between the potential community and the actual community (or present assemblage).

Although the BHI has been an important tool in condensing information on fish assemblages into a single numerical value, the index doesn't take into account the relative proportions of species present but only their presence/absence. Furthermore, the BHI formula combines two separate measures (health and importance) into a single index.

The Estuarine Fish Health Index (FHI) is based on both qualitative and quantitative comparisons with a reference fish community. The qualitative approach uses the number of species within each transitional waterbody, whilst the quantitative approach is based on the relative abundance of the species. In both approaches, a comparison is then made to the average number of species (qualitative) and percentage abundance of the species (quantitative) for the geomorphic group to which each water body belongs.

In qualitative and quantitative assessments, exotic and translocated fish species are included in the fish assemblages for each estuary type, but are not considered in the reference condition.

The Estuarine Biotic Integrity Index (EBI) reflects the relationship between anthropogenic alterations in the ecosystem and the status of higher trophic levels. The EBI includes the following eight metrics:

- **total number of species**
- **dominance**
- **fish abundance (number or biomass)**
- **number of nursery species**
- **number of estuarine spawning species**
- **number of resident species**
- **proportion of benthos associated species**
- **proportion of abnormal or diseased fish**

The usefulness of this index requires it to reflect not only the current status of fish communities but also be applicable over a wide range of estuaries, although this is not entirely achieved.

The Estuarine Fish Recruitment Index (FRI) was developed in an effort to use ichthyological information to assess changes in habitat integrity, especially the availability and suitability of estuarine nursery areas to marine migratory fishes. The FRI is a biologically meaningful management index, but the data requirements are critical.

The Estuarine Fish Importance Rating (FIR) is based on a scoring system of seven criteria that reflect the potential importance of estuaries to the associated fish species. This index is able to provide a ranking, based on the importance of each estuary and helps to identify the systems with major importance for fish conservation.

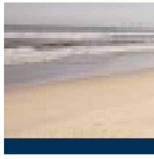
The indices described above condense information about fish fauna communities into a more functional format, which can be used to plan and manage the aquatic systems. The presence/absence of sensitive species is insufficient to determine the health of the community, but their relative abundance or the return of important species (diadromous species such as eel, shad and salmonids) could represent an important indicator for the determination of ecological status of water bodies.

METHODOLOGY

Phytoplankton and supporting elements

Data were collected for the three descriptors for this biological element (i.e. biomass, abundance, composition), together with a number of supporting quality elements, including hydrology and tides, water temperature and salinity, dissolved oxygen, nutrients, and some specific pollutants. The data cover the range of types proposed for Portuguese transitional and coastal waters, and usually span periods of several years.

Several different approaches were tested on the dataset, to examine the possible associations between biological descriptors and supporting elements. Some of the supporting elements, such as tidal range, river discharge, current velocity and salinity are part of the criteria for typology: thus, it



should theoretically be possible to establish some quantitative relationships, since reference conditions are considered to be type-specific.

Species composition

The dataset used in the analysis of species composition spans over six decades, and covers all seven TCW types proposed for Portugal. Due to this fact, it is considered to be a comprehensive listing of the phytoplankton species present, including those representative of pristine conditions.

Figure 36 shows a summary of this dataset, which was loaded in a relational database. Queries were used to (i) explore the number of species common to all or some of the types; (ii) perform a principal components analysis (PCA) of the distribution across types; and (iii) extract data subsets for comparison with supporting elements such as tidal range or freshwater discharge.

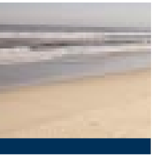
Abundance and biomass

A review of the available literature shows that phytoplankton abundance is very often determined

Figure 36. Number of species in a range of systems covering all types.

Type	System	Nº of species	% of total species
A1	Minho estuary	99	8.6
A2	Mondego estuary	174	15.2
A2	Tagus estuary	342	29.8
A2	Sado estuary	416	36.3
A2	Ria de Aveiro	293	25.5
A3	Albufeira lagoon	200	17.4
A3	Óbidos lagoon	403	35.1
A3	S. Martinho do Porto bay	264	23.0
A4	Ria Formosa	213	18.6
A5	Minho until Cabo Carvoeiro	514	44.8
A6	Cabo Carvoeiro until Ponta da Piedade	587	51.2
A7	Ponta da Piedade until V. R. Sto António	394	34.4
Total number of species		1 147	

Note: transitional waters in blue, coastal waters in green.



Key approaches

- To review the possible relationships between *abundance* and *biomass* and selected supporting elements;
- To determine the most suitable approach for an integrated assessment of ecological status for these descriptors.

by using biomass (i.e. chlorophyll *a*) as a proxy, due to the difficulty and cost of cell counts and biovolume determination; Abundance and biomass were therefore considered together.

The analysis was focused on transitional waters and semi-enclosed coastal waters - In Portuguese coastal ecosystems there are few (if any) concerns regarding these parameters in open coastal waters.

The following points were examined:

- Relationship between winter maxima for dissolved inorganic nitrogen and spring phytoplankton blooms (expressed as chlorophyll *a*);
- Relationship between turbidity and phytoplankton biomass;

The use of the U.S. National Estuarine Eutrophication Assessment (NEEA) and Assessment of Estuarine Trophic Status (ASSETS) procedures as a means of integrating phytoplankton biomass and abundance with relevant supporting quality elements.

Fish

In this chapter both pelagic and benthic species are discussed, despite the fact that biological and supporting elements which are associated to the benthic environment are examined in the next chapter. The WFD (Annex V) determines that type-specific reference conditions based on the composition and abundance of fish fauna should be established only in transitional waters.

The WFD stipulates the following conditions for fish fauna at high quality status:

- Species Composition and abundance correspond totally or nearly totally to undisturbed conditions,
- All the type-specific disturbance-sensitive species are present.

Composition

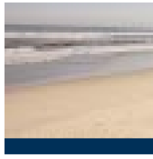
The fish species which make up the community

Abundance

The number of individuals which exist in a sampling area

In Portugal, as in most of the European Union, the definition of type-specific reference conditions based on data from undisturbed sites is extremely difficult, because such undisturbed types are rare or simply do not exist. Alternatively, some historical data and information concerning the fish fauna in specific sites may potentially be used to accomplish this goal. That information may then be compared with present data. The use of predictive or hindcasting methods could also be a useful tool to define type-specific reference conditions based on fish fauna, and will require an interdisciplinary approach. Expert judgement is rarely useful for quantitative assessment and therefore it should be used only when the other alternatives are not available, although it might be valuable as additional information.

The indices described previously condense information about fish fauna communities into a more functional format, which may be used in the management process. The presence/absence of sensitive species may not be sufficient to determine the health of the community, but their relative abundance or the recovery of important species (e.g. return of salmon to the Rhine) could represent



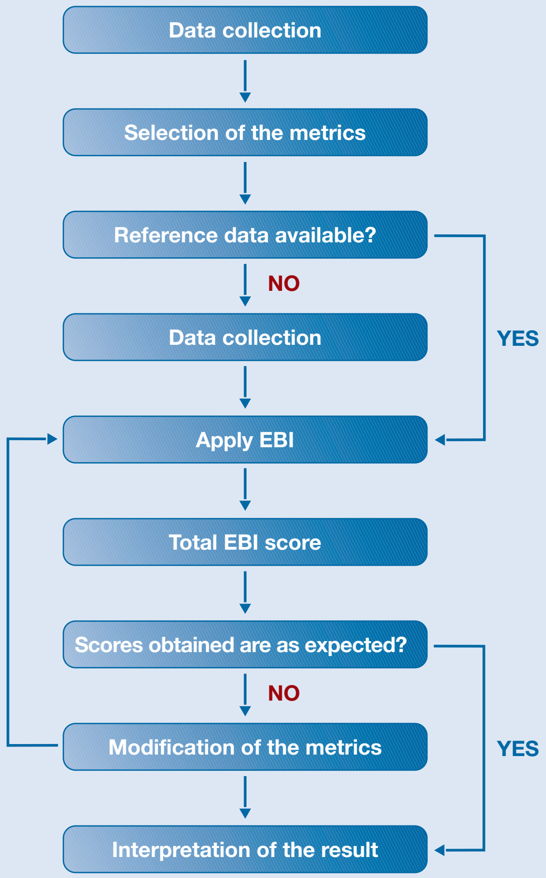
an important indicator on the determination of the ecological status of water bodies.

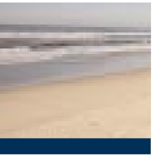
The various alternative methods described must therefore be assessed to identify the most suitable techniques for determining the ecological status of Portuguese transitional waters.

In this connection the development of an Estuarine Biotic Integrity Index based on fish communities could be useful for establishing the ecological status of the Portuguese transitional water bodies (Figure 37). This index could provide additional information on different quality aspects and potential causes. The EBI could also be helpful to identify impacts and to plan more efficient monitoring programmes. It is currently assumed that the first step in the development of an EBI index consists in the selection of appropriate metrics.

In the second step, the scores of the metrics are given, through the comparison of the values obtained to expected values (reference conditions). Following the original IBI metric, values approximating, deviating slightly from, or deviating greatly from those at the reference sites are scored as 5, 3, or 1, respectively. Finally, the

Figure 37. Sequence of steps involved in the application of the EBI.





scores of the metrics in each system are added, to give a result ranging from 60, the maximum value – excellent; to 12, the minimum - very poor.

Some of the problems associated to the creation of such an index are:

1. Which metrics should be included and at what level (systems, types or national)?

The selection of the appropriate metrics must be made on the basis of the ecological relevance of each possible metric to fish community biotic integrity, the most meaningful metrics being selected. Metrics which vary clearly in the presence of environmental stressors must be prioritized (e.g. sensitive species are the first to disappear when there is perturbation). These metrics should be related to several aspects of the fish communities, such as species richness and composition, trophic and reproductive composition, fish abundance and condition, among others. This implies the identification of relevant metrics among candidate metrics and presumes the application of some sort of discriminant analysis to previously collected reference data.

For the two Portuguese transitional water types, the selection of metrics should aim for a common set. However, the type-specific classification levels will differ, due to the physical, hydrodynamic and biogeochemical differences between types. The species which are sensitive in type A1 and A2 will quite probably differ, and differences in water temperature, freshwater discharge, stratification and water chemistry may lead to natural differences in dissolved oxygen concentration, which even at saturation values nearing 100% may not be sufficient to allow the survival of certain salmonid species in type A2.

2. In what way should the relative importance of metrics be considered?

The selection of appropriate metrics implies the identification of relevant metrics among candidate metrics. If the chosen metrics are not equally

important, then a weighting methodology should be applied or some of its descriptors eliminated.

Relative importance should be based on a significant relationship with the environmental stressors.

3. How can reference conditions be obtained in order to set the scoring criteria?

Among all problems in the conception of the EBI index, perhaps the most complex issue is the establishment of type-specific reference conditions. The WFD considers multiple alternatives to accomplish this goal, as discussed previously. Apart from the scarcity of historical data and information on systems (or types), transitional waters show high natural variability, which is difficult to dissociate from anthropogenic disturbance. Additionally, one of the main sources of human disturbance, i.e. fisheries, is not explicitly considered in the WFD.

The establishment of type-specific reference conditions using data from minimally-impaired systems may considered as acceptable, as long as it applies to systems belonging to the same type. It follows that this approach may only be used where such conditions exist. This is the case for type A2, but not for type A1.

4. How can the consistency of the results be guaranteed?

In order to compare the results obtained with the index in a system, through time, or between two different systems, a consistent sampling design is required. This means that the sampling effort and gear have to be the same for all systems and, in general, sampling effort should capture 90-95% of the species present at the site. This will also prevent the occurrence of bias due to different sampling conditions.

Finally, it seems that fish data analysis should be one component in a holistic approach, using hydrographical, physical, chemical and complementary biological data to interpret the results obtained.

RESULTS AND DISCUSSION

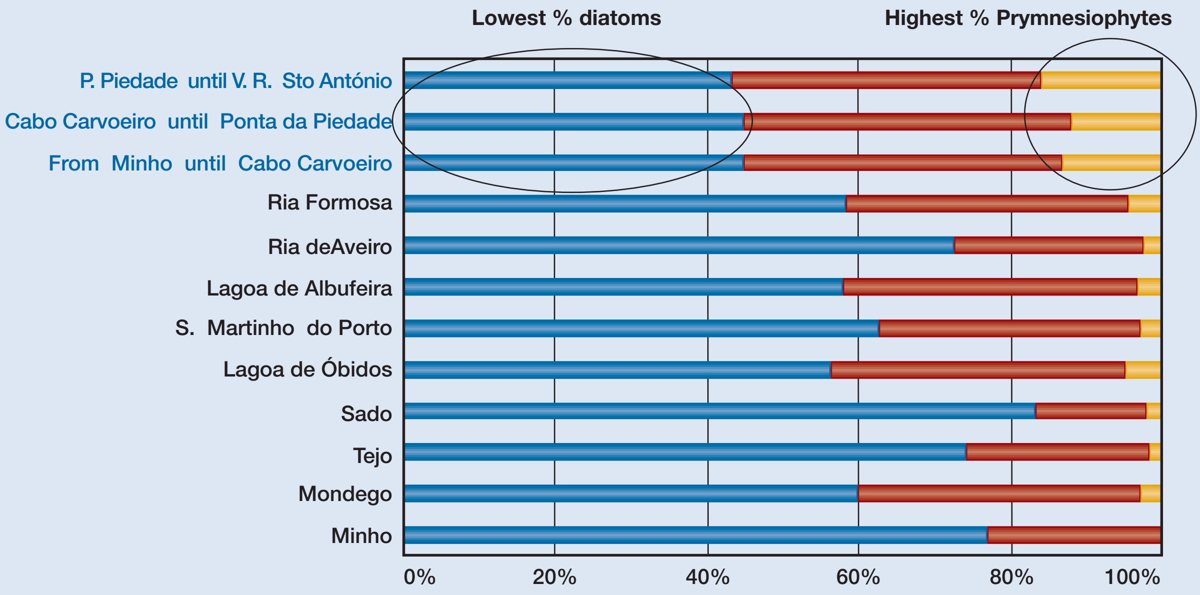
Phytoplankton and supporting elements

Species composition

The distribution of species across different types, grouped by major family, is shown in Figure 38. There is a clear difference between open coastal water and waters with restricted exchange, both coastal and transitional. Open coastal types have a significantly lower percentage of diatoms, and prymnesiophytes are far better represented.

Only 4% of species are common to all the systems, corresponding to a total of 45, of which 25 are diatoms and 16 are dinoflagellates. The analysis of the similarity of species composition within a type could only be carried out for two types (A2 and A3), where data exist for multiple systems. Figure 39 shows that the percentage of common phytoplankton species for each type varies between 20-50% for A2 and 30-70% for A3. It would therefore be reasonable to propose a list of species that should generally be present in water bodies belonging to each of these types.

Figure 38. Composition with respect to type.



Note: Open coastal water is shown in blue.

Figure 39. Species common to all systems of a type. Only data for types A2 and A3 are available.

Type	System	Nº of species	% of common species for type
A2	Mondego estuary	174	52
A2	Tagus estuary	342	26
A2	Sado estuary	416	22
A2	Ria de Aveiro	293	31
A3	Albufeira lagoon	200	67
A3	Óbidos lagoon	403	33
A3	S. Martinho do Porto bay	264	51

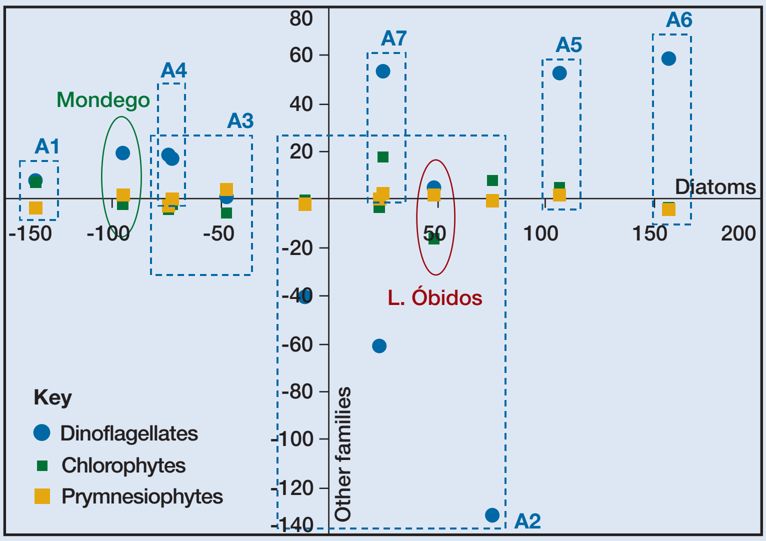
68 species are common to both types A2 and A3, corresponding respectively to 75% and 50% of the total of species common to these types.

Figure 40 shows the results of a principal components analysis (PCA) performed on the number of species from four of the thirteen phytoplankton families, using all the available systems.

The PCA shows a clear separation between the different types. Open coastal types A5, A6 and A7 are in the top right quadrant, coastal lagoon types A3 and A4 are in the left half of the figure, and transitional type A2 is in the lower part. Type A1 data are available only for the Minho, which is at the far left, but the Mondego, although classified in type A2 shows similarities to type A1, probably due to the low water residence time. In type A3, Óbidos lagoon does not appear to fit well with other systems, perhaps due to the fact that it is closed to the ocean for part of the year.

An analysis was made of the possible relation between water residence time and number of species present in each system.

Figure 40. Principal components analysis for species composition, using diatoms, dinoflagellates, chlorophytes and prymnesiophytes.



This analysis was considered to be relevant only for transitional waters, since in open coastal systems the combined forcing of tidal exchange and freshwater inputs is not applicable.

Figure 41 shows that there is a clear relation between the two variables for a dataset which includes estuaries from both types A1 and A2, and which cover the whole of Portugal from north (Minho) to South (Guadiana).

Water residence time in transitional waters integrates both the river inflow and tidal exchange, thus implicitly taking into account the

Figure 41. Number of phytoplankton species as a function of water residence time, for six transitional water systems, from two different types (A1 and A2).

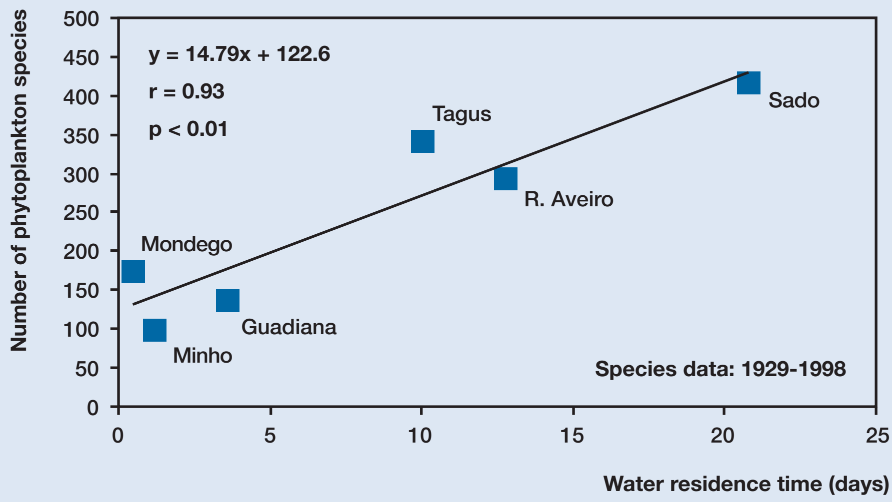
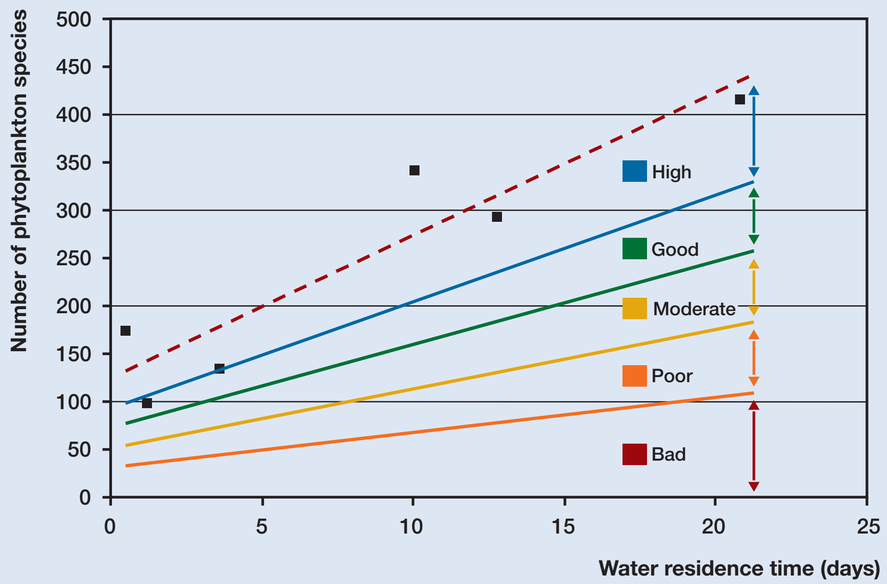


Figure 42. Scheme for defining the number of species that should be present at varying degrees of ecological status.



WFD supporting elements *salinity* and *freshwater discharge*. *Tidal range*, which is one of the descriptors for typology, is also included.

The ecological status classification for phytoplankton composition can therefore potentially be approached in two ways.

- **A type-specific list for key species may be defined based on existing data. Reference conditions and Ecological Quality Ratio (EQR) thresholds may be established on a presence/absence basis. The system may be refined by further categorising groups of species and using weighting schemes to arrive at overall indices**
- **For transitional water types, the number of species which should be present can be derived according to residence time, as shown in Figure 41, and EQR thresholds may be established using the type of approach illustrated in Figure 42**

Abundance and biomass

The application of the NEEA/ASSETS methodology to the evaluation of the phytoplankton abundance and biomass components allows the integration of the pelagic chlorophyll *a* metric with some important benthic descriptors of organic enrichment such as opportunistic macroalgae and alterations in submerged aquatic vegetation.

Additionally, the supporting element *dissolved oxygen* is included as a secondary symptom of enrichment, but other supporting elements listed in Figure 33 are not. Salinity and temperature are standard baseline parameters in transitional and coastal waters, but they are not phytoplankton indicators. Both salinity and temperature affect species composition, and temperature is a forcing function for primary production, but these parameters are not "manageable" at a local scale, and exhibit high natural variability.

Transparency is a supporting element shown to have a direct association with phytoplankton biomass and abundance in freshwater systems such as lakes or reservoirs, and in microtidal systems such as the Baltic Sea. However, in mesotidal transitional waters, the turbidity (and thus the transparency of the water column) is largely determined by erosion-deposition processes forced by the spring-neap cycle,

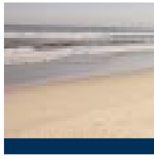
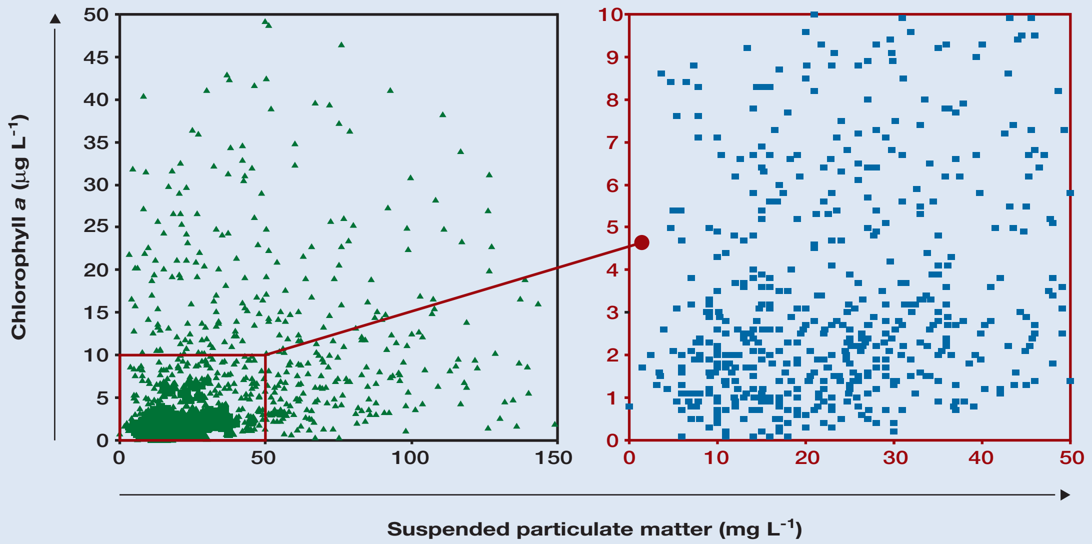


Figure 43. Chlorophyll *a* and suspended particulate matter (transparency proxy) for the Tagus estuary, a type A2 transitional water. 943 datapoints for surface samples taken over several years across the whole salinity range.



Note: The right-hand image zooms into the rectangular area on the left-hand image.

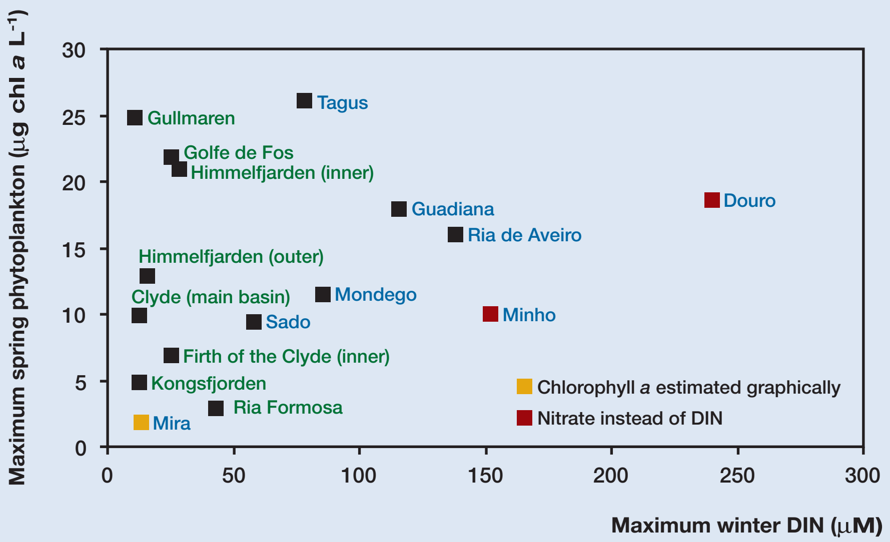
which is associated to variable bed shear stress and vertical mixing dynamics. Figure 43 shows a graph for the Tagus estuary, a type A2 transitional water: there is no dependence of water transparency on chlorophyll *a*; in mesotidal transitional and sheltered coastal waters in Portugal, this supporting element clearly has a high natural variability (sensu WFD) and therefore should be excluded from the assessment of ecological status.

The issue of the supporting element *nutrient conditions*, here interpreted to be nutrient (dissolved inorganic nitrogen and phosphorus) concentrations in the water column is particularly difficult. Although the relationship between dissolved nutrients (particularly phosphate) and phytoplankton blooms is well established in freshwater systems such as lakes, there is a growing body of evidence that both the nutrient loading and the concentration of dissolved nutrients in transitional waters is often difficult to relate to pelagic algal biomass. Data gathered for

a range of European systems is shown in Figure 44, using only dissolved inorganic nitrogen. In the systems shown, nitrogen dominates as the limiting nutrient for primary production. This is a well established pattern in many transitional and coastal systems, where the dissolved nitrogen to phosporus ratio is often below 16 (in atoms).

Figure 44 reveals that there is no clear relationship between phytoplankton and nutrient concentrations, for a broad range of European

Figure 44. Maximum spring phytoplankton as a function of maximum winter dissolved inorganic nitrogen (DIN).



Note: Percentile 90 for all data is used for the Portuguese systems, systems in green are from the EU OAERRE project, systems in blue are from TICOR.

transitional and coastal waters, suggesting the nutrients are not a good indicator for phytoplankton ecological status as regards abundance and biomass. The systems shown include estuaries, broad and narrow fjords, rias and lagoons. There are a number of reasons for the lack of association of nutrient concentration and phytoplankton biomass:

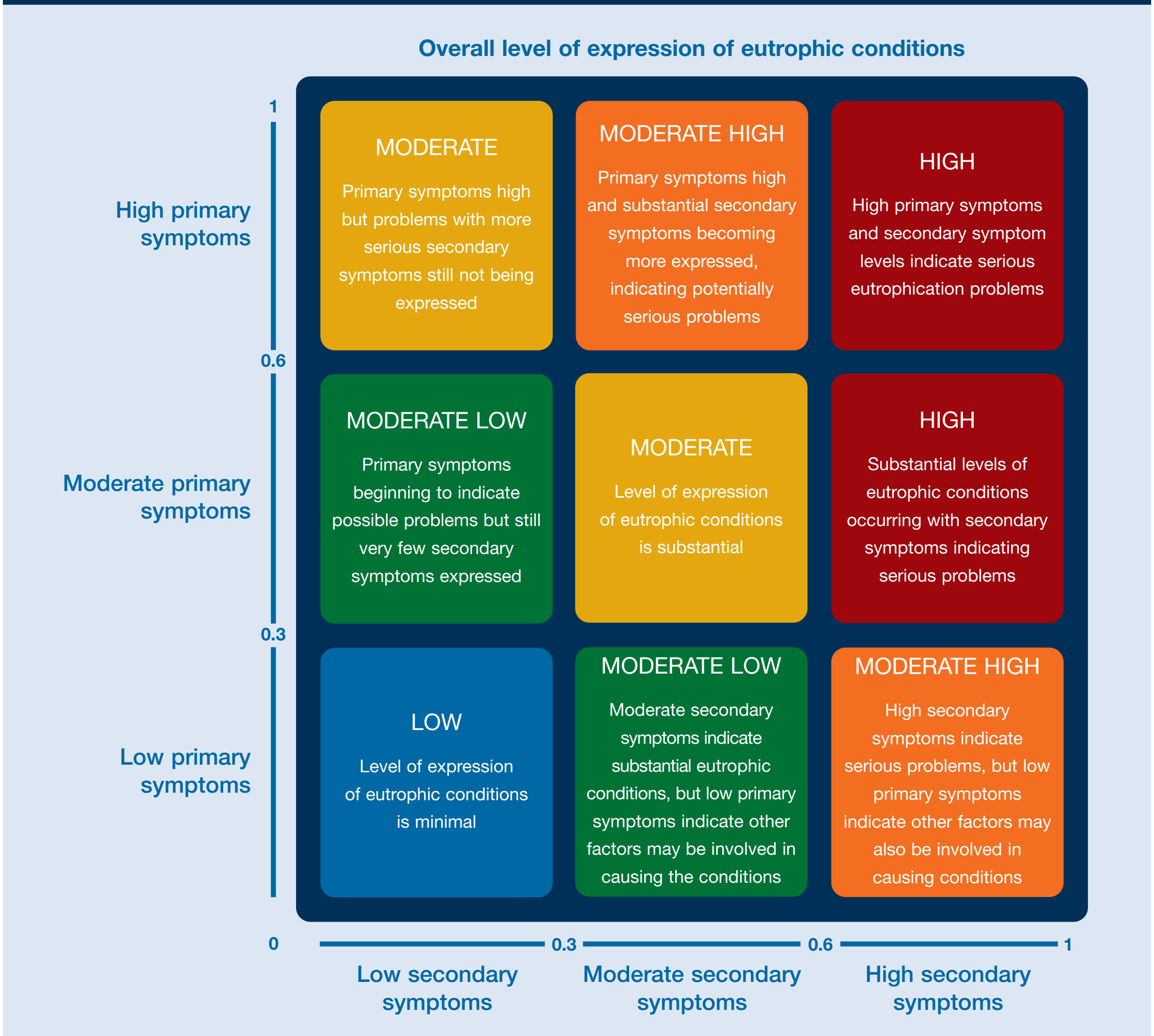
- Light availability may often be the limiting factor for pelagic primary production in turbid systems, whilst nutrients play a subsidiary role
- Strong pelagic-benthic coupling may mean that a top-down control of phytoplankton biomass exists e.g. due to bivalve filter feeding. This has been documented for estuaries such as S. Francisco Bay and coastal systems such as the Ria Formosa. Physical factors such as water column depth and vertical stratification may thus play a key role in the development of pelagic algal blooms
- Short water residence times do not allow the development of autochtonous phytoplankton blooms. Nutrient enrichment may lead instead to blooms of benthic algae such as *Ulva* or *Enteromorpha*, and to changes in seagrass communities

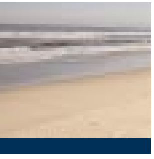
This is the basis for the exclusion of this element from the state component of the NEEA/ASSETS method, and is supported in a recent study by IFREMER on eutrophication in European waters. Studies carried out on the relationship between nutrient loading and phytoplankton biomass in a number of coastal systems are also inconclusive.

It is recommended that the supporting element nutrient conditions should be measured and used for monitoring pressure, and to explore the relationship between changes in nutrient ratios in the water bodies and species shifts, with a focus on the appearance of nuisance and/or harmful algae, but not as a supporting element for phytoplankton abundance and biomass.

The NEEA/ASSETS methodology (Figure 45) is envisaged to be the most suitable for assessing the ecological status for phytoplankton abundance and biomass, and the supporting quality element *dissolved oxygen*. Dissolved oxygen is used in NEEA/ASSETS as an indicator of advanced (secondary) symptoms of organic enrichment, following from enhanced chlorophyll *a* concentrations (pelagic or benthic). The inclusion of phytobenthic

Figure 45. NEEA/ASSETS - Overall level of eutrophic condition. Recommended as an integrated approach for the WFD biological elements of phytoplankton and phytobenthos.





components permits a fuller analysis of the range of potential eutrophication effects, which coupled to NEEA and ASSETS's quantitative approach and spatial and temporal discretisation make this a powerful tool for examining the WFD phytoplankton and phytobenthos biological quality elements.

However, NEEA/ASSETS currently use fixed ranges for pelagic chlorophyll *a* concentrations and for dissolved oxygen, which potentially fall short of a WFD requirement for type-specific reference conditions. This may be adapted if required e.g. by defining chlorophyll ranges varying with type, or by using percentage saturation of oxygen to "localise" oxygen data with respect to salinity and temperature.

Fish

Application of the EBI to Portuguese transitional waters

The application of EBI to define reference conditions for the two Portuguese transitional types will draw on both historical data and on systems which are presently undisturbed, or slightly disturbed. The historical data available for some Portuguese systems is shown in Figure 46.

It appears that some historical data exist concerning fish abundance and distribution for some systems of type A2, which would enable the application of an EBI index. However, the sampling conditions used to obtain those datasets have to be considered and reproduced in future data collection.

For the A2 systems, the Mira Estuary can be regarded as a relatively pristine estuary. The lack of information from this system must be resolved through the collection of missing data, the type of information depending on the metrics selected. In general, the metrics used rely on species richness, composition and condition, as referred.

On the other hand, for the systems which integrate type A1 it seems that there is no minimally impaired system suitable for use as a reference, although some historical data on fish abundance and distribution for the Douro estuary

Figure 46. Historical data for fish available to establish reference conditions for Portuguese systems.

Types	Systems	Composition (species list)	Abundance	Distribution	Presence of sensitive species
A1	Minho estuary	26 taxa	Unknown	Unknown	Yes
	Douro estuary	Unknown	Unknown	Yes	Unknown
A2	Ria de Aveiro	Yes	Yes	Yes	Yes
	Tagus estuary	> 100 taxa	Yes	Yes	Yes
	Sado estuary	Yes	Yes	Yes	Yes
	Mira estuary	Yes	Yes	Yes	Yes
	Guadiana estuary	> 28 taxa	Yes	Yes	Yes

may be useful. Since type A1 may well be trans-national, and occur also in Galicia in Spain, or in other Northeast Atlantic areas such as the Irish west coast, it is possible that a relatively undisturbed system outside Portugal may be used to establish reference conditions.

Additionally, there are historical data (fish abundance and distribution) for the Douro estuary, which may be suitable. As mentioned previously, care must be taken to normalise present and future sampling procedures when comparing with historical datasets.

Although historical data (species lists) exist in Portugal for some systems, in the majority of cases there is no information on community dynamics (number of individuals, biomass, etc), as well as on other descriptors such as dominance, proportion of benthic-associated species, or proportion of abnormal or diseased fish, which rules out the application of EBI to these datasets.

Supporting elements

There are a number of supporting elements which should be included in a definition of reference conditions for fish, of which the most important are abiotic factors such as dissolved oxygen, sediment organic content and bottom substrate modifications, and biotic factors such as the occurrence of harmful algal blooms. Although in the WFD no reference is made to the effects of fishing, it should be recognised that in transitional waters the main pressures which contribute to substrate changes are channel dredging and bottom trawling.

CONCLUSIONS

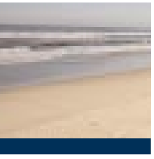
Phytoplankton

A review of the potential approaches for evaluating the phytoplankton quality elements suggests that the biomass and abundance components should be integrated with selected supporting elements by means of the NEEA/ASSETS approach, which additionally covers some of the benthic flora components. Thresholds for reference conditions should be type-specific, normalised in some cases by the use of fixed ranges, which account for differences between types. The best example is the use of dissolved oxygen expressed as percentage saturation, which reflects salinity and temperature differences between types.

The reference conditions for species composition may be based on an extensive historical dataset, taking into account the effects of water residence time on species number for transitional waters, as discussed previously.

Fish

A number of approaches simpler than the EBI index might be applied, as a first step, to Portuguese transitional waters in order to get some classification of their ecological quality in the framework of the WFD.



It is proposed that an investigative monitoring programme be put in place at selected systems, in order to apply an Estuarine Biotic Integrity index, analyse the suitability of the metrics and classification system, and make the necessary adaptations.

Such a program should last over a period of one year, synoptically in two systems, (e.g. the Minho estuary for type A1 and the Mira estuary for type A2). It should be followed by surveys of completion in other systems, which will allow the application of the metrics adopted and respective descriptors to the whole set of Portuguese transitional waters.

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Benthic Reference Conditions

INTRODUCTION AND OBJECTIVES

This chapter provides an overview of the benthic quality elements, tests different benthic classification tools, and suggests the best techniques for establishing benthic reference conditions

Objectives

- **To collect and review available data for benthic aquatic flora;**
- **To collect and review available data for benthic invertebrate fauna;**
- **To describe and discuss the benthic aquatic flora and benthic invertebrate classification tools;**
- **To present guidelines to establish reference conditions for benthic aquatic flora and benthic invertebrate fauna and recommendations for future work.**

WFD benthic aquatic flora quality elements

In Annex V of the WFD, the biological elements referred as typical flora of transitional and coastal waters are divided into two main groups: phytoplankton, which belongs to the pelagic category and is discussed in the previous chapter, and "other aquatic flora", which includes all the phytobenthic groups: microphytobenthos, macroalgae, seagrasses and saltmarsh vegetation. However, WFD Annex V indicates only ecological status definitions for macroalgae and angiosperms in the section on "other aquatic flora". These two groups are generally the most used in the evaluation of anthropogenic influence on transitional and coastal systems. For these reasons the further discussion on "other aquatic flora" refers to macroalgae and angiosperms, including seagrasses and saltmarshes. Figure 47 presents the WFD quality elements related to aquatic flora in transitional and coastal waters.

Review of benthic aquatic flora classification tools

A number of tools focusing on composition and abundance have been developed to establish the type-specific reference conditions and the ecological status of the aquatic flora. These tools evaluate the aquatic flora considering the equilibrium between macroalgae and angiosperms according to the quality status of the

Figure 47. Benthic aquatic flora quality elements for transitional and coastal waters.

	Transitional and coastal waters	
Biological element	**Composition and abundance of Macroalgae and Angiosperms**	
Supporting hydro-morphological elements	Morphological conditions: 1. Depth variation 2. Quantity structure and substrate of the bed 3. Structure of the intertidal zone	Tidal regime: • Freshwater flow • Direction of dominant currents • Wave exposure
Supporting chemical and physico-chemical elements	General: 1. Transparency 2. Thermal conditions (3 months) 3. Oxygenation conditions (3 months) 4. Salinity (3 months) 5. Nutrient conditions (3 months)	Specific pollutants: • Pollution by all priority substances identified as being discharged into the body of water (1 month) • Pollution by other substances identified as being discharged in significant quantities into the body of water (3 months)

Note: Elements which are only applicable to transitional waters are shown in blue, elements applicable only to coastal waters are shown in red.

Where applicable, the sampling frequency indicated in the WFD Annex V is shown in brackets.

Composition

The macroalgae and angiosperm species which make up the community

Abundance

The coverage of macroalgae and density of angiosperms which exist in a sampling area

environment. The rationale behind these methods can be summarised in the following assumptions:

- Angiosperms are mostly perennial species from late successional stages with low growth rates, long life cycles, and thus typical of consolidated ecosystems in a steady-state equilibrium
- Angiosperms, particularly the submerged aquatic species, are very sensitive to disturbed conditions such as decreases in water transparency, low oxygen conditions and organic enrichment
- In disturbed ecosystems angiosperms are gradually replaced by opportunistic species with high growth rates and short life cycles such as green algae and phytoplankton

Figure 48 presents the potential approaches as well as comments on their usefulness. The description of the first two methods as well as the main key differences between them is briefly presented in the "Pelagic Reference Conditions" chapter.

Although both procedures extend the quality elements evaluation by means of a holistic approach the individual assessment is also addressed. The OSPAR Comprehensive Procedure examines the shifts from long-lived to short-lived nuisance species (e.g. *Ulva sp.*). In the NEEA/ASSETS approach, macroalgal conditions are evaluated in terms of problematic growth frequency (episodic or periodic blooms), while submerged aquatic vegetation (angiosperms) is classified according to the magnitude of loss within the system.

The Swedish tool uses three substrate-specific classifications (soft-bottom, moderately exposed hard-bottom and exposed hard-bottom), according to the aquatic flora communities. Species composition and abundance is examined in five levels of deviation (little or none, moderate, significant, serious and eradication) from the pristine natural conditions assessed by historical data. This method was developed for coastal waters and still needs further testing.

IFREMER has developed a method for examining the eutrophication stages of aquatic flora communities assuming that, over an eutrophication gradient, perennial species decrease in density and biomass as the opportunistic species take over.

Five quality status classes are established according to the degree of human impact, from a situation where there is no significant impact of

Figure 48. Methodologies addressing the biological quality element other aquatic flora composition and abundance, in whole or in part.

Method	Description	Positive	Negative
OSPAR Comprehensive Procedure	Analyse seagrasses and seaweeds in terms of coverage and depth of occurrence and micro-phytobenthos biomass	Integrated "EU accepted"	Non-exclusive, includes pelagic components such as phytoplankton Does not consider saltmarshes Semi-quantitative (+/- scale) Draft standard, not well tested
NEEA/ASSETS Assessment of Estuarine Trophic Status	Submerged aquatic vegetation examined in terms of spatial coverage losses Macroalgae examined in terms of bloom frequency and spatial coverage	Integrated Quantitative Well tested in U.S. "U.S. accepted"	Non-exclusive, includes pelagic components such as phytoplankton Does not consider saltmarshes
Swedish classification tool for angiosperms and rocky shore communities	Classification of the shore communities in five levels of species abundance and composition	Adapted to the WFD levels of classification	Only for coastal areas Not well tested
IFREMER Eutrophication stages	Classification in five stages according to the oxygen conditions and species composition and abundance	Integrated Adapted to the WFD levels of classification	Not well tested
Ecological Evaluation Index (EEI)	Quantification of the relative species abundance (opportunistic and late successionals)	Semi-quantitative	Not well tested

human activities to a strong eutrophic condition when degradation of quality standards for aquatic flora and supporting elements decline due to human pressures. This is a semi-quantitative approach based on mapping data for macrophytes and sediments (organic matter distribution, nutrient concentrations). A quantitative development of this method is needed in order to improve the assessment.

The Ecological Evaluation Index (EEI), developed in Greece, quantifies the shifts in the structure of benthic macrophytes considering two Ecological State Groups (ESG): ESG I, which includes those genera with low growth rates and long life cycles (late successionals) and ESG II, which is composed of genera with high growth rates and short life cycles. After the division of the area into uniform permanent polygons (well-defined systems e.g. coastal lagoons) or lines (open coast) the mean spatial coverage of each ESG is determined. The overall EEI is then achieved using a heuristic set of categories, which corresponds to the levels of the WFD ecological status (high, good, moderate, poor and bad). This method has been tested only on Greek coastal and transitional waters.

Guidelines for the definition of reference conditions

Data on the Portuguese type-specific aquatic flora in transitional and coastal waters are scarce. Although composition and abundance of aquatic flora species can be found for some systems, the dynamics of macroalgae, seagrasses and saltmarsh vegetation are not well known. For this reason it was not possible to test the different approaches and to examine the possible associations between biological descriptors and supporting elements in the Portuguese types. However some guidelines for the establishment of reference conditions are presented.

Species composition

A comprehensive listing of the aquatic flora species present in Portuguese transitional and coastal types is needed. This list should identify, wherever possible, the historical presence of

Figure 49. Distribution of aquatic flora groups within transitional and coastal Portuguese types.

Types	Macroalgae	Seagrasses	Saltmarsh
A1	X	X	X
A2	X	X	X
A3	X	X	X
A4	X	X	-
A5	X	-	-
A6	X	-	-
A7	X	-	-

X indicates presence; - indicates absence.

perennial species as well as hydro-morphological and physico-chemical conditions, which effectively support those communities. Some of the standard baseline supporting elements, such as temperature, salinity and transparency, should not be used for this purpose due to their high natural variability, for reasons indicated in the "pelagic reference conditions" chapter.

The current data on aquatic flora identify three main groups for which reference conditions should be defined: macroalgae, seagrasses (including, when present, submerged angiosperms of the genera *Ruppia*, *Potamogeton* and *Chara*) and saltmarsh vegetation. Figure 49 shows the presence of these groups within the Portuguese types.

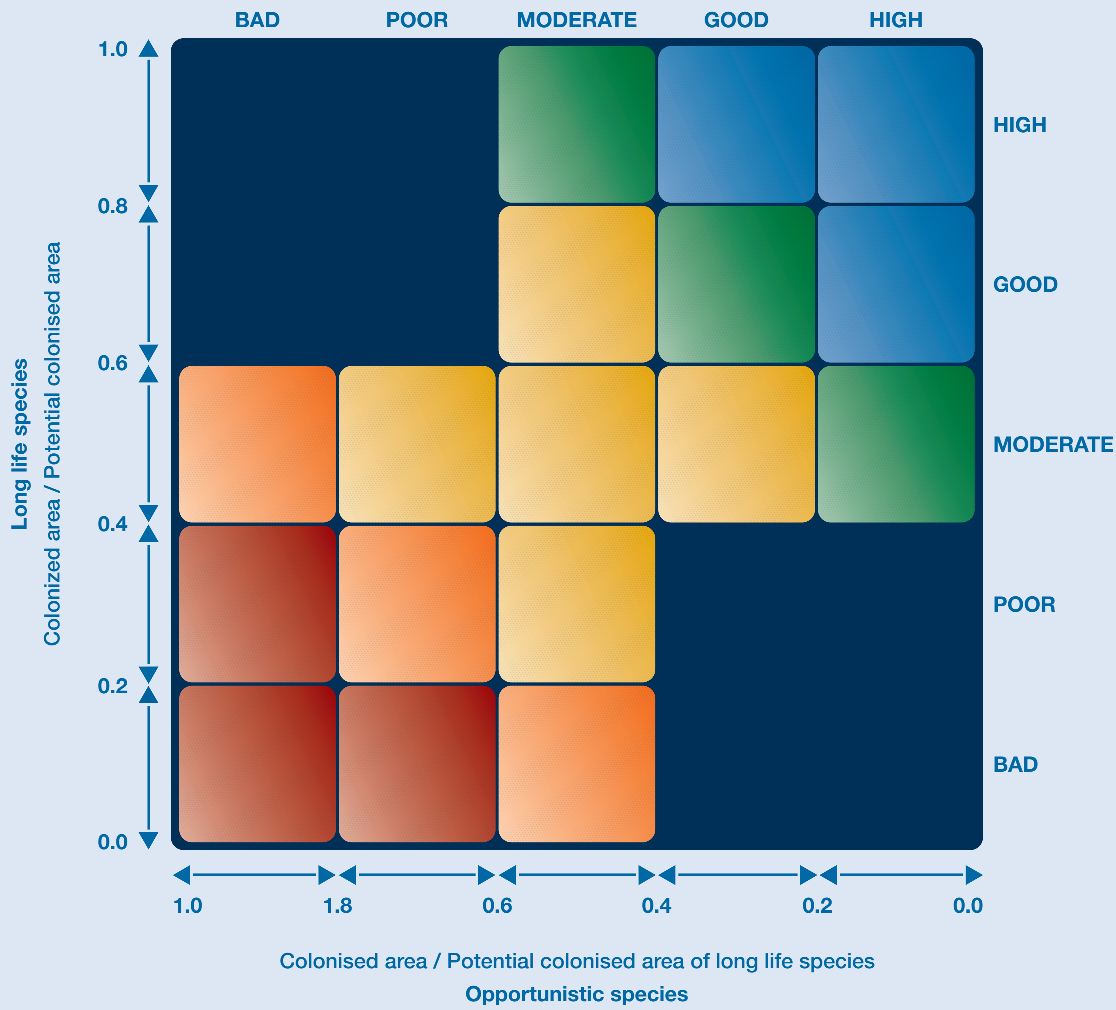
Species abundance

The percentage of macrophytobenthos loss or overgrowth in terms of colonised area can be used as a type-specific reference condition for species abundance. This could be addressed crossing historical and current data on the area of macrophytobenthos colonisation in order to calculate the percentage changes in the colonised area, using GIS. A heuristic set of categories for the percentage of loss / overgrowth can then be defined in order to assess the ecological status.

An integrated method based on the IFREMER and NEEA/ASSETS approaches is proposed in Figure 50 for long-lived and opportunistic macrophytes. In this approach the information for long-lived species is crossed with that for opportunistic macrophytes. An overall level for ecological status is then determined. It must be stressed that this method does not take into account saltmarsh vegetation.

Also, the application of the NEEA/ASSETS methodology for the evaluation of the abundance of macroalgae and submerged aquatic vegetation allows the integration of these components with the pelagic descriptors for phytoplankton. Dissolved oxygen is the only supporting element included in the analysis as a secondary symptom of organic enrichment.

Figure 50. Integrated method to evaluate the ecological status of long life and opportunistic macrophyte species.



Note: Ecological status levels: blue for high, green for good, yellow for moderate, orange for poor and red for bad.

WFD benthic invertebrate fauna quality elements

Figure 51 shows the biological and supporting elements that are associated to the benthic invertebrate fauna. Unlike those associated to pelagic environment, here all the elements related to the water column and sediment are taken into account, since one of the characteristics of the benthic communities is their ability to integrate everything that happens in the environment.

Benthic communities can be considered more adequate than those of the pelagic domain when evaluating the status of the ecosystem. Due to their limited mobility, they are more sensitive to local disturbance, and because of their permanence over seasonal time scales, they integrate the recent history of disturbances which might not be detected in the water column.

Review of benthic invertebrate fauna classification tools

Among the biological quality elements for the

The WFD establishes as pristine situations for the benthic communities in transitional and coastal waters those in which the diversity and abundance of invertebrate taxa is within the range normally associated with undisturbed conditions. Also, all the disturbance sensitive taxa associated with undisturbed conditions should be present.

WFD ecological status definitions are the composition and abundance of benthic invertebrate fauna.

Species composition and abundance of benthic organisms can be integrated in the formulation of biological indices, facilitating the task of the managers when interpreting the response of the system towards a specific impact on the environment.

Among the numerous indices found in the bibliography, there are different approaches in using each one of them when evaluating the status of a system. Some of them are focused on the presence or absence of indicator species. Others are based on the different ecological strategies followed by organisms, on the value of diversity (by means of indices that measure the species richness, models of species abundance, and indices based on the proportional abundance of species that aim to combine richness and uniformity in a simple expression) or on the energy variation in the system through changes in the biomass of individuals.

In theory, all indices described in the literature that consider those two parameters (species

Figure 51. Benthic invertebrate fauna quality elements for transitional and coastal waters.

	Transitional and coastal waters	
Biological elements	• Composition, abundance of benthic invertebrate fauna (3 months)	• Composition, abundance of benthic invertebrate fauna (3 months)
Supporting hydromorphological elements	Morphological conditions: • Depth variation (6 years) • Structure and substrate of the coastal bed • Structure of the intertidal zone	Tidal regime: • Freshwater flow • Direction of dominant currents • Wave exposure
Supporting chemical and physico-chemical elements	General: • Transparency • Thermal conditions (3 months) • Oxygenation conditions (3 months) • Salinity (3 months) • Nutrient conditions (3 months)	Specific pollutants: • Pollution by all priority substances identified as being discharged into the body of water (1 month) • Pollution by other substances identified as being discharged in significant quantities into the body of water (3 months)

Note: Elements which are only applicable to transitional waters are shown in blue, elements applicable only to coastal waters are shown in red.

Where applicable, the sampling frequency indicated in the WFD Annex V is shown in brackets.

composition and abundance) could be useful in detecting the environmental situation of a system. However, many were designed for the characteristics of a specific system (which invalidates them as widely applicable detection tools) and others have been rejected due to their dependence on parameters such as depth or sediment composition, and their unpredictable behaviour with regard to pollution. Likewise, the use of purely graphical methods is unacceptable, because they are highly subjective.

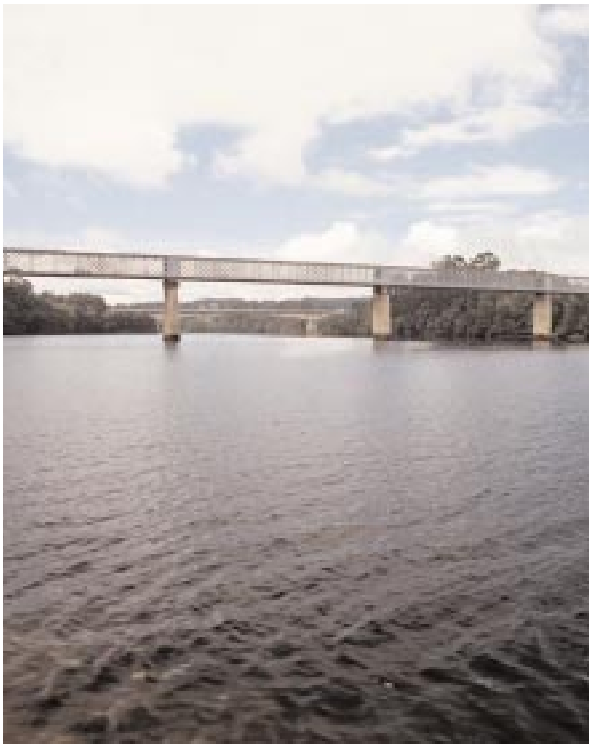
The guidance developed by the CIS 2.4 (COAST) group provides a list of tools currently available in Member States to classify benthic invertebrate fauna.

- Norway has a classification tool that includes both chemical and biotic aspects, using faunal diversity (Shannon-Wiener and Hulbert indices) and the total organic carbon in the sediment.
- Greece has developed a biotic index (BENTIX) applicable in coastal areas, and Spain has developed another biotic index (AMBI) applicable in European transitional and coastal waters.
- The OSPAR Comprehensive Procedure includes benthic invertebrates as a possible indicator of indirect eutrophication effects through mortality by oxygen depletion and/or long term changes in zoobenthos biomass and species composition due to nutrient enrichment.

Suitable indices for defining benthic reference conditions

The use of a single approach does not seem appropriate due to the complexity inherent in assessing the environmental quality of a system. Rather, this should be evaluated by combining a suite of indices which provide complementary information.

Additionally, even though the WFD does not take the biomass parameter into account, in enriched situations this is considered to be an important



metric for the effects of extra energy inputs into a system.

Following those principles, a combination of the Shannon-Wiener index, Margalef index, the AMBI Marine Biotic Index and the ABC curves method by means of the W-statistic is a good option for evaluating the conditions of a particular area. All these indices have been applied to wide geographical areas and to zones disturbed by different types of pollution, and they also take into account the different aspects which integrate the benthic community.

- **Shannon-Wiener index**
- **Margalef index**
- **AMBI Marine Biotic Index**
- **ABC curves method by means of the W-statistic**

All of them have been applied to wide geographical areas and to zones disturbed by different types of pollution.

The Shannon-Wiener and Margalef indices provide complementary diversity measures, as the former takes proportional abundance of species into account, whilst the latter is focused on species enrichment. Furthermore, the use of ABC curves compares the distribution in number of individuals of the different species of macrobenthic communities with the distribution of biomass.

Through AMBI, which is based on the presence of indicator species of polluted and unpolluted zones, the other aspect defined by the WFD has been considered. In this the importance of biological indicators is highlighted, in order to establish the ecological quality of transitional and coastal waters.

Although this index was based on the paradigm of Pearson and Rosenberg, which emphasises the influence of organic matter enrichment on benthic communities, it was shown to be useful for the assessment of other anthropogenic impacts, such as physical alterations in the habitat or heavy metal inputs. It has been successfully applied in the Atlantic (North Sea; Bay of Biscay; Southern Spain) and Mediterranean (Spain and Greece) European coastal waters.

METHODS

Application of indices as a function of data requirements and availability

Due to an uneven dataset, not all indices could be tested for all TICOR systems

For those where appropriate numeric density data were available, the Shannon-Wiener, Margalef and AMBI indices were applied. The ABC curves method was additionally applied in systems where numeric density and biomass data were available. However, as a combination of three indices is considered recommendable to evaluate a system, in this case the ABC, AMBI and Margalef indices were applied, as the information provided by the Shannon-Wiener index is already given by the ABC curves method.

In a large number of systems only qualitative metadata were available, so no indices could be

Figure 52. Application of indices to different systems (including all TICOR systems).

Category	Type	Descriptor	Systems	Type of data	Indices
Transitional surface waters	A1	Mesotidal stratified estuary	Minho Lima Douro Leça	No available data	
	A2	Mesotidal well-mixed estuary, highly variable discharge	Ria de Aveiro	Numeric density Data for crustaceans	Shannon Margalef
			Mondego	Numeric density data, biomass Data	Margalef ABC method AMBI
			Tagus	List of species	
			Sado	No available data	
			Mira	Numeric density data	Margalef ABC method AMBI
			Arade	No available data	
			Guadiana	No available data	
Coastal surface waters	A3	Mesotidal semi-enclosed lagoon	Albufeira Melides Sto André	No available data	
	A4	Mesotidal shallow ria	Ria Formosa	Numeric density data	Shannon Margalef AMBI
			Ria de Alvor	No available data	
	A5	Mesotidal exposed Atlantic coast	From Minho until Cabo Carvoeiro	No available data	
	A6	Mesotidal moderately exposed Atlantic coast	From Cabo Carvoeiro until Ponta da Piedade	No available data	
	A7	Mesotidal sheltered coast	From Ponta da Piedade until V. R. Sto António	No available data	

Figure 53. Summary of indices.

SHANNON-WIENER	MARGALEF	ABC METHOD	AMBI
$H' = -\sum p_i \log_2 p_i$ Where n is the number of species, and p_i is the proportion of abundance of species i in a community were species proportions are $p_1, p_2, p_3 \ldots p_n$.	$D = (S-1)/\log_e N$ Where S is the number of species found and N is the total number of individuals	$W = \sum (B_i - A_i)/50(S-1)$ Where B_i is the biomass of species i, A_i the abundance of specie species i, and S is the number of species.	BI={(0)(%GI)+(1,5)(%GII)+(3)(%GIII)+(4,5)(%GIV)+(6)(%GV)}/100 GI: Ecological group I GII: Ecological group II GIII: Ecological group III GIV: Ecological group IV GV: Ecological group V

applied, and only a qualitative assessment was carried out. Figure 52 shows the indices applied in each case.

The description of the indices is detailed in Figure 53. The definition of different ecological levels in the system according to the values of each index is shown in Figure 54.

Pearson's correlations were applied to analyse the response of each index as a function of different environmental variables, and to identify any significant parallels between the variation patterns of different indices.

RESULTS

The application of the different indices in the various systems showed that there is not a type-specific response.

The results of all the indices were similar, showing a significant correlation (P<0.01) in all cases between the values of the Margalef and Shannon-

Figure 54. Ecological levels according the values of each index.

	BAD	POOR	MODERATE	GOOD	HIGH
Shannon	0-1	1-2	2-3	3-4	>4
Margalef	<2.5	<2.5	<2.5-4	>4	>4
ABC method	-1- -0.1	-0.1- -0.1	-0.1- +0.1	+0.1- +1	+0.1- +1
AMBI	7-6	6-5.5	5.5-3.3	3.3-1.2	1.2-0.0

Wiener indices. This was expected, since both are diversity indices that provide complementary information.

However, none of the cases showed a significant correlation between the values of the indices and the various environmental parameters in the areas where this analysis was possible. The AMBI index, on the other hand, has only been significantly correlated with such indices when it was applied to subtidal communities in the Mondego estuary (Figure 55). In this system it has also been shown that this index does not vary with time, i.e. it is not influenced by changes in abundance. This is important because during the study period (1993-1994) there were no changes in environmental stressors.

Figure 55. Pearson correlations between the values of the different indices considering the sampling stations located in the two arms of the Mondego estuary.

	AMBI	Shannon-Wiener	Margalef
Shannon-Wiener	-0.73**		
Margalef	-0.69*	+0.83**	
W Statistics	-0.45*	+0.75**	+0.72*

(*) = $P \leq 0.05$; (**) = $P \leq 0.01$.

The results for the W statistic show that it is capable of distinguishing between non-disturbed, slightly disturbed and disturbed situations, although in some cases results were confusing due to the strong dominance of species that are not pollution indicators (e.g. the mudsnail *Hydrobia ulvae* and the cockle *Cerastoderma edule*). A similar situation has been observed in previous studies.

As regards specific composition, there is a common denominator among the systems of type A2. The dominant species are classified as belonging to Ecological Group III. These species are tolerant to pollution; they may occur under normal conditions, but their populations are stimulated by organic enrichment. Consequently, low diversity values in many of the systems taken into account in this study are due to the dominance of certain species such as *Leptocheirus pilosus*, *Corophium multisetosum*, *Cyathura carinata, Nereis diversicolor, Carcinus maenas*, *Cyathura carinata*, *Hydrobia ulvae*, *Scrobicularia plana*, and *Melinna palmata*.

In type A4 (Ria Formosa) species belonging to Ecological group II (species indifferent to enrichment, always in low densities with non-significant variations with time) mainly dominate, showing, in principle, a better system status.

As expected, this dominance leads to low values for the Shannon-Wiener index and in some cases, to a drop in species richness (measured in this case through the Margalef index). However, it is not necessarily affected by the dominance of certain species. Under certain circumstances, a higher resource exploitation or natural environmental variation may promote the development of these species and exclude others.

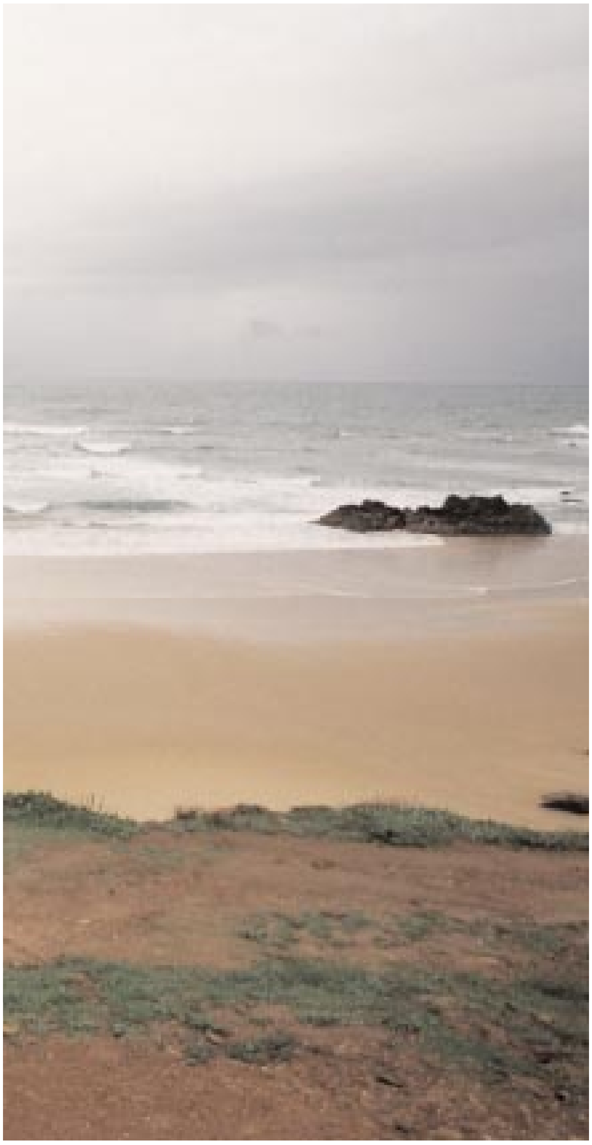
This study has shown satisfactory results along those lines, and it is therefore suggested that the definition of ecological status classes may be achieved by combining these indices, as shown in Figure 56.

For these reasons, the complementary use of different indices or methods based on different

Figure 56. Application of indices as a function of data requirements and data availability.

DATA AVAILABILITY

Qualitative data		Quantitative data		
Metadata	Rough data	Numeric density data	Numeric density and biomass data	
	Shannon-Wiener Margalef	Shannon-Wiener Margalef AMBI	Identification of individuals down to species level	Identification of individuals down to family level
			ABC Margalef AMBI	Shannon-Wiener Margalef ABC



ecological principles is highly recommended in determining the environmental quality of a system.

For those systems where adequate numeric density data exist, the Shannon-Wiener, Margalef and AMBI indices may be applied. For those with numeric density and biomass data it is additionally possible to apply the ABC curves method. However, as the combination of the three indices is recommended for system evaluation, in this case the ABC, AMBI and Margalef indices (if species level data exist) should be applied. As an alternative, if only family level data exist, the ABC curves method, Shannon-Wiener and Margalef indices should be used.

The combination of two or three of the indices (depending on the type of data available) provides a joint evaluation as shown in Figure 57.

CONCLUSIONS

Experience demonstrates that none of the available measures on biological effects of pollution may be considered ideal. The dominance of certain species produces low diversity estimates, although those species belong to ecological groups usually related to non-polluted environments. W statistics is capable of distinguishing between non-disturbed,

Figure 57. Classification of benthic reference conditions.

COMBINATION OF TWO OR THREE OF THE SELECTED INDICES Depending on the type of data available			STATUS
High	High		High
High	High	High	
High	High	Good	High/Good
High	Good		Good
Good	Good		
High	Good	Good	
Good	Good	Good	
Good	Good	Moderate	Good/Moderate
Good	Moderate		Moderate
Moderate	Moderate		
Good	Moderate	Moderate	
Moderate	Moderate	Moderate	
Moderate	Moderate	Poor	Moderate/Poor
Moderate	Poor		Poor
Poor	Poor		
Moderate	Poor	Poor	
Poor	Poor	Poor	
Bad	Poor	Poor	Poor/Bad
Bad	Bad	Poor	Bad
Bad	Bad	Bad	

and disturbed situations but nevertheless, the not so rare dominance of certain species small in size and characteristic of non-polluted environments will lead to erroneous evaluations. Finally, the classification of species as indicators of different grades of pollution, which constitutes the base of the AMBI, often contains subjective elements.

Nevertheless, we consider that the combination of these indices makes up for the defects of each one, and result in a good toolset for determining ecological quality status, due to the complementary nature of the ecological principles of each.

Moreover, the AMBI index and the W-statistic can be considered universal in terms of their applicability, i.e. the interpretation of measurements is independent from the geographic area or the type of system. Conversely, diversity measures and their interpretation are strongly dependent on geographic variation and on the type of system, in the sense that a given value estimated using a given diversity index does not have the same significance if one compares warm temperate and boreal systems, or an open coastal area with an estuary located at the same latitude.

Therefore, although in this work guideline values have been developed to establish ecological status, taking into account results from studies proceeding from various areas, these guidelines should be used with caution.

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HEAVILY MODIFIED WATER BODIES

Introduction and problem definition

Some water bodies may not achieve "*good ecological and chemical status*" by 2015 for different reasons. Under certain conditions the WFD permits Member States to identify and designate heavily modified water bodies (HMWB) according to WFD Article 4(3).

Less stringent objectives will be assigned to these water bodies: instead of "*good ecological status*" (GES), the environmental objective for HMWB is "*good ecological potential*" (GEP), which has to be achieved by 2015.

The concept of HMWB recognises that many water bodies have been subject to major physical alterations so as to allow for a range of water uses. Article 4(3) (a) lists types of activities which were considered likely to result in a water body being designated as a HMWB, from which the most relevant for transitional and coastal waters are:

• Navigation, including port facilities, or recreation;

• Flood protection and land drainage.

These uses tend to require considerable physical interventions which cause hydromorphological changes to water bodies of such a scale that restoration to GES may not be achievable even in the long-term without compromising the continuation of the specified use. The concept of HMWB was created to guarantee the maintenance or improvement of water quality, whilst allowing for the continuation of these uses, which provide valuable social and economic benefits.

Art. 2, n.º 9 of the WFD defines *Heavily Modified Water Body* as: *"a body of surface water which as a result of physical alterations by human activity is substantially changed in character"*.

The changes to be considered must be *significant* and *substantial* and must also be *permanent*, i.e. those that are limited in time or intermittent are not considered for the purpose of the definition of HMWB.

These alterations must also result in an obvious *change in character* of the water body as, in transitional waters when extensive morphological

To qualify as a *HMWB*, the water body must be:

• Physically altered by human activity;

• Substantially changed in character;

• Designated under Annex II (Art. 4(3)).

interventions (dredging and bank artificialization) are performed to create navigation and harbour conditions.

A key question for the identification of HMWB is the definition of *substantially changed in character*".

The WFD presents some general criteria [Art.4, (3)] for this identification as follows:

- The changes to hydromorphological characteristics needed for achieving GES would have adverse effects on:
  - The wider environment
  - Navigation, port facilities, recreation
  - Water supply, power generation
  - Regulation flows – flood protection, drainage
- The beneficial objectives served by the HMWB cannot (due to cost, technical feasibility, etc.) be achieved by other means representing a better environmental option.

On the basis of this general guidance, a "*substantial*" change in hydromorphology will be:

- extensive/widespread or profound, or
- very obvious in the sense of a major deviation from the hydromorphological characteristics present before the alterations.

Water bodies which have been substantially changed only in the morphology shall be considered as *substantially changed in character* when these changes are long term and affect hydrology. A substantial change in hydrology shall be considered as such when it is caused by a permanent structure, *e.g*. a dam, and the water body will be considered as *substantially changed in character* even if there are no significant morphological changes.

The environmental objectives for HMWB are GEP and *good chemical status*, less stringent than GES because it makes allowances for the ecological impacts resulting from those physical alterations. These objectives are also set in relation to reference conditions that may be defined in this context as the "*maximum ecological potential*" (*MEP*). This is a state where the biological status reflects, insofar as possible, that of the closest comparable surface water body, but taking into account the HMWB modifications. GEP accommodates "slight changes" in biological status from MEP.

Methodology

In the terms of the above concepts, the identification of sort out an HMWB is carried out after recognition that GES is not achievable due to physical transformations, taking into account the feasibility of the actions to restore the water body in order to achieve GES, and their effect on the wider environment. A full justification of the designation of a water body as HMWB has to be provided by Member States.

A flow chart with the methodology for identification of heavily modified water bodies is shown in Figure 58.

Step 4 is part of the characterisation of surface waters, which involves the identification and description of:

- **Main "specified uses" of the water body;**
- **Significant anthropogenic pressures [Annex II No. 1.4]; and**
- **Significant impacts of these pressures on hydromorphology [Annex II No. 1.5].**

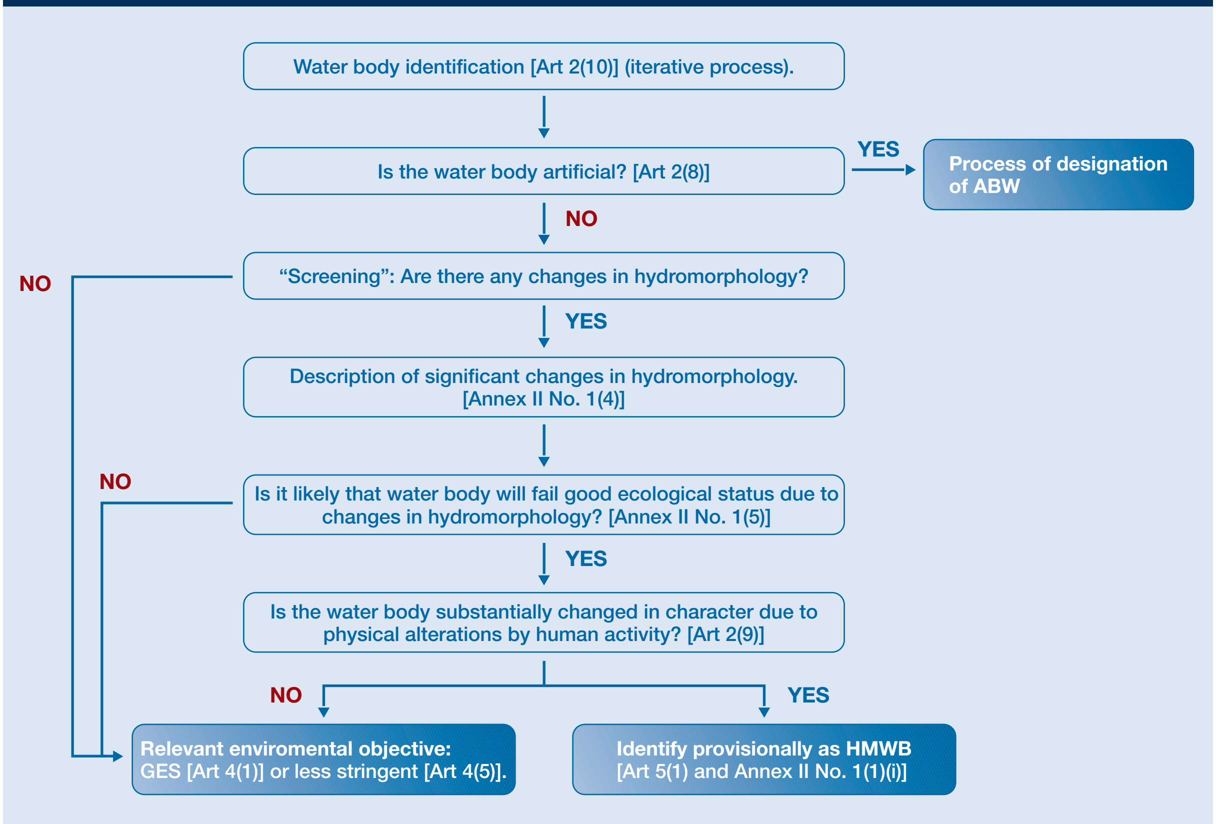
In Step 5, an assessment is made of the risk of failing GES due to hydromorphological changes, rather than other pressures such as toxic substances or other quality problems. This distinction from effects resulting from other impacts (e.g. toxic effects on macro-invertebrates, eutrophication symptoms in macrophytes) should be differentiated as far as possible using *e.g*. the following criteria, appropriate for transitional and coastal waters:

- disruption in river continuity assessment using long distance migrating fish species
- changes in flow downstream of reservoirs using macrophytes
- impacts of linear physical alterations such as coastal defence works using benthic invertebrates and macroalgae

A water body will be provisionally identified as HMWB (step 6) if it complies with the following criteria:

1. The failure to achieve *good status* results from physical alterations to the hydromorphological characteristics of a water body. It must not be due to other impacts such as physico-chemical impacts (pollution).

Figure 58. Methodology for provisional identification of heavily modified water bodies.



2. The water body must be *substantially changed in character*. This is the case when there is a major change in the appearance of the water body. It is a partly subjective decision as to whether a water body is (a) only *significantly* changed in character or (b) *substantially* changed in character, when provisional identification as an HMWB may be appropriate.

The body of water is *substantially* changed in character when:

- It is obvious that the water body is substantially changed from its natural condition in a permanent, extensive and profound way.
- The change is consistent with the scale of change that results from the activities listed in Article 4(3)(a):
- The substantial change in character is the result of the specified uses which represent equally important sustainable human development activities (either singly or in combination)

The final designation as HMWB of the provisionally identified water bodies implies the completion of the designation procedure as specified under Article 4(3) (a) & (b). These tests are designed to ensure that HMWB are only designated where there are no reasonable opportunities for achieving good status within a water body, and are therefore water body specific. The methodology and decision rules for final designation are presented in Figure 59.

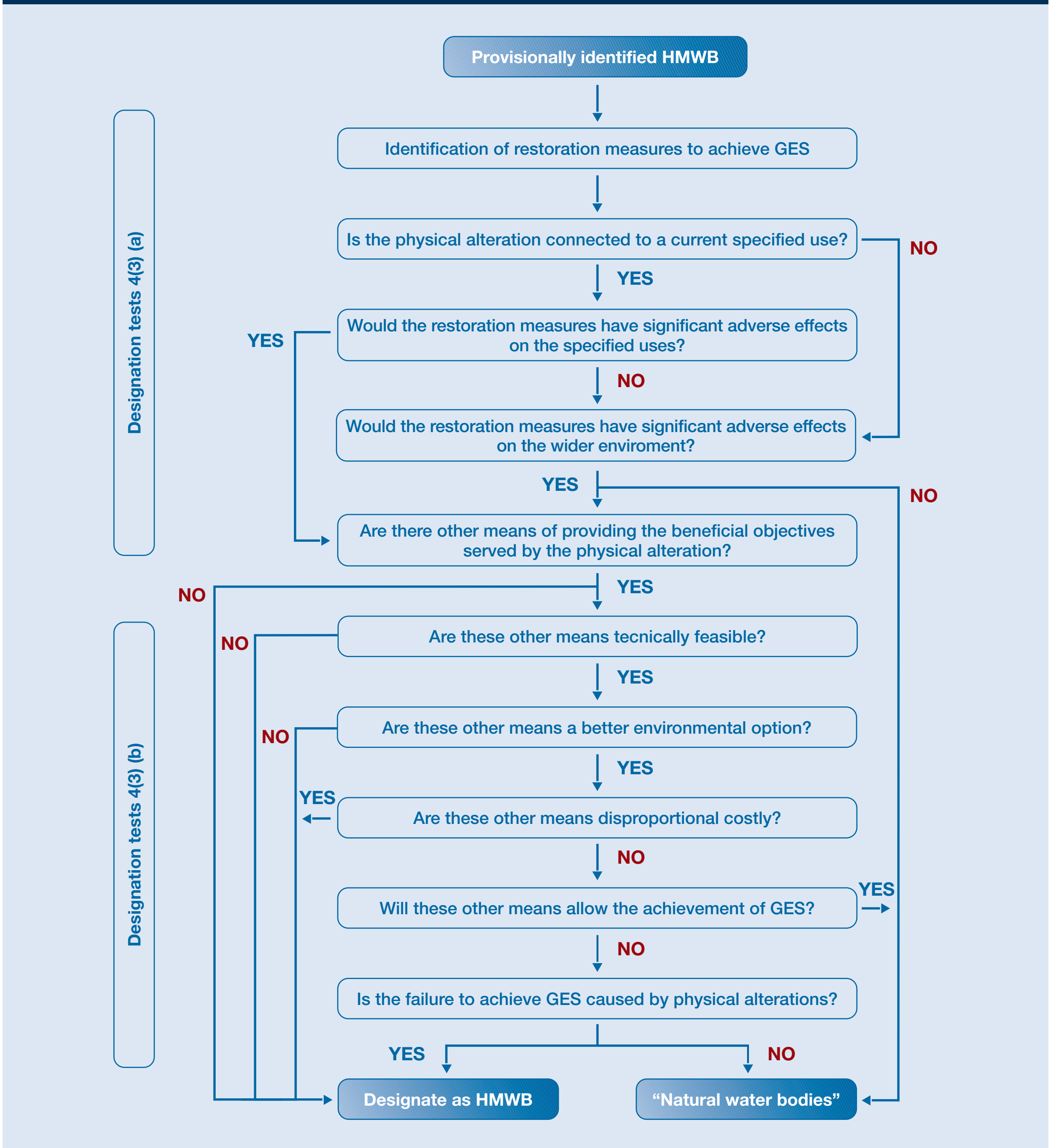
The designation test in Article 4(3) (a) has three components, dealing with “restoration measures” for achieving GES, with their “adverse effects” on the specific uses and on the wider environment.

The hydromorphological changes for achieving GES, i.e. the restoration measures to be analysed, may range from measures aimed at reducing the environmental impact of the physical alteration (*e.g.* increased compensation flows or fish passages) to measures resulting in the complete removal of the physical alteration. The second component requires an assessment of whether these restoration measures will have *significant adverse effects* on the specified uses such as losses of important goods and services (e.g. flood protection recreation or navigation), taking into consideration economic and social effects. The last component analyses the possibility of the occurrence of significant adverse effects of restoration measures on the wider environment, i.e. it tests whether the restoration measures required to achieve GES do not create environmental problems elsewhere.

The designation test in Article 4(3) (b) considers whether the beneficial objectives served by the modified characteristics of the water body can reasonably be achieved by other means which are:

- technically feasible
- a significantly better environmental option
- not disproportionately costly.

Figure 59. Final designation of heavily modified water bodies.



Water bodies for which other means that fulfil these three criteria can be found, and can achieve the beneficial objectives of the modified characteristics of the water body may not be designated as HMWB. The existing specified use may, in some cases, be abandoned and the physical alterations removed so that good status can be achieved.

A water body may be designated as HMWB if it has completed the designation procedure involving, if applicable, both designation tests (Figure 59).

If there are no significant adverse effects either on the specified uses or on the wider environment, or there are "other means" of delivering the

beneficial objectives then the water body should be regarded as natural.

Results

A preliminary exercise was carried out in order to identify possible candidates to the classification as HMWB within Portuguese transitional and coastal waters. The process should start with the assessment of whether some of the water bodies considered in TICOR are likely not to comply with the GES objectives. This is clearly not feasible at this stage, nor was it an objective of the TICOR project. Nevertheless, it was deemed useful to perform the exercise starting from the identification of the TICOR systems that, by expert judgement, were considered significantly modified on the basis of their physical characteristics. The Douro, Sado and Guadiana transitional waters were selected due to different reasons. The interventions, the uses associated with them and their effects on the hydrology, morphology and on ecological characteristics are summarised in Figure 60.

The tentative application of the designation tests is not fully feasible at this stage as the possible "distance" to GES is not identifiable. It is therefore also not possible to identify "restoration measures" to achieve GES.

Nevertheless, it appears that the physical alterations are connected with uses listed in the WFD and that most of the foreseeable measures/ physical interventions may have "*significant adverse effects*" on those uses.

The decision rule shown in Figure 59 will then imply the test (step 8.1) of whether there are *other*

Figure 60. Physical interventions and effects on candidate HMWB systems.

				Changes	
	Physical interventions	Associated uses	Hydrology	Morphology	Ecology
Douro	*Crestuma* dam Catchment intervention	Energy production Domestic water supply	River flow modification	Artificial weir limit of the estuary	Physical barrier to fish migration
Sado	Catchment intervention (regularisation index > 1) Artificial banks, dredging and land reclamation	Domestic and agricultural water supply Energy production Port activity Industrial settlement Conversion of salt pans for aquaculture	River flow modification	Possible change in current patterns Possible effects on sediment dynamics	Habitat change in (reduction of intertidal areas and wetlands) Possible change on water transparency
Guadiana	Catchment intervention (regularisation index > 1) *Alqueva – Pedrógão* and *Andévalo-Chanza* systems	Domestic and agricultural water supply Energy production	River flow modification	Possible effects on sediment dynamics	Physical barrier to fish migration

means of providing the beneficial objectives served by the physical alteration. The decision is both system and use dependent, although the following situations may be identified: (a) energy may be obtained from alternative sources; (b) water supply in the present climatic region will not be available by alternative means; (c) port facilities are dependent on natural conditions and may also have no alternatives.

The feasibility of the *other means* and, in particular, their declaration as a "*better" environmental option* would probably lead directly to the designation of all above listed systems as HMWB.

PRESSURES AND IMPACTS

The analysis of the pressures component of TICOR follows the "Guidance for the analysis of pressures and impacts in accordance with the WFD". Four groups of pressures, related impacts and data sources most relevant for Portuguese transitional and coastal waters have been reviewed.

Key approaches

- **Polluting emissions**
- **Water regime**
- **Morphology**
- **Biology**

Polluting emissions

Transitional and coastal waters in Portugal are subjected mostly from the following kinds of pollution:

- Organic biodegradable pollution, also associated with microbiological contamination, This results from untreated or undertreated urban and industrial sewage, and agricultural runoff. Resulting impacts, common in transitional waters and occasionally in coastal waters, include chemical and biological water quality degradation, with adverse effects on uses such as bathing water quality and fisheries. Further study is required on adverse effects on the biota and ecosystems;
- Toxic pollution. This results from a number of sources, including industry, urban areas, infra-structure, agriculture and navigation. Resulting impacts are often poorly understood for lack of detailed studies and data;
- Nutrients. These are associated mostly with agricultural run-off, although other sources may also be relevant (air pollution, urban sewage and run-off). The major impact associated with nutrients is eutrophication. This is a potential issue in more enclosed transitional and coastal waters, less so in open coastal waters.

It should be noted here that impacts resulting from a complex set of pressures (e.g. different and varying pollution sources) are best studied in living species that are most sensitive and/or natural integrators, such as top predators or benthic fauna.

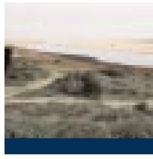
Quantification of pollution pressures should include a broad range of inputs into all transitional and coastal waters.

All polluting loads should be located with the aid of GIS, and accounted for at least on a yearly basis, to allow for a general trend analysis of polluting pressure. More detailed temporal discrimination should be used whenever necessary to model pressure-impact interactions.

Some impacts are readily visible, even if they are not the most worrisome - e.g. the international project CoastWatch, managed in Portugal by an environmental NGO, regularly produces information on the amount and type of garbage that appears

Quantification of inputs

- Rivers. Major rivers tributary to transitional or coastal water should be identified. Information of pollution load in these should be available from river water management, or must be collected. Small tributaries may be treated as non-point sources, if adequate modelling is available
- Industrial IPPC point sources. These should be fully inventoried and quantified according to European Pollution Emission Register (EPER) guidelines; OSPAR harmonised quantification and report procedures (HARP) should be added as appropriate
- Industrial non-IPPC point sources. The EPER guidelines should be used as possible. Industry with discharge permits should be fully inventoried. When relevant pollution information is not available for a source, the maximum allowed load derived from the emission permit should be used instead. Variables not included in the permit may be disregarded
- Urban point sources. Urban discharges, from both treatment plants and untreated sewage systems should be fully inventoried. Pollution quantification should be made for all discharges, based on actual measurements, permit limits (if the treatment is working apparently properly but there are no data), or computed from estimated loads of population and small industry
- Agricultural run-off. Research is required, because it is certain that it is relevant but existing scientific knowledge is not enough to quantify pressures, or to relate land use directly to such pressures. Land use information is more or less available, but that is not enough per se. Studies from other countries are not readily applied in Portugal due to major differences in soil, climate and agricultural practice
- Urban and infra-structure run-off. Research is also needed. Existing land use information is adequate, but it is not enough to quantify pollution pressure. Existing studies are scarce and unrepresentative, but they do indicate that the issue is relevant
- Navigation. Water pollution related to navigation is of high importance for Portugal, especially in the coastal waters, where the major navigation lane between Gibraltar and Northern Europe is located. About one hundred ships per day cross those waters, about half of those oil tankers. Several serious oil spills have highlighted in the worst possible way how vulnerable the Iberian coast is to maritime pollution hazards. However, a large part of maritime pollution is actually due to "operational", deliberate discharge of hydrocarbon-contaminated effluents



on the shoreline. Navigation-related pressures and impacts could best be monitored by implementing an integrated information system such as the InfoZEE model.

Water regime

Water regime comprehends a range of issues, from hard changes in the flow in the transitional and coastal waters, to freshwater inflow.

Changes in freshwater or sediment inflow, either by water abduction, sand extraction or flow regularisation with dams in the tributary watersheds, may profoundly change large tracts of the transitional ecosystem. This is particularly relevant in southern Portugal, because the rivers have a markedly torrential regime, and most wetlands that used to act as flow buffers no longer exist. Changes in freshwater flow and sediment flow (mostly sand) may also influence the coastal ecosystem if fish nurseries are affected.

Hard changes in the estuaries (e.g. estuary mouth damming) do not exist in Portugal. Nevertheless, flow in some transitional and closed coastal waters is heavily influenced by bar protection and harbour works. Coastal lagoons seasonally open to the ocean are often opened artificially to improve their water quality.

Water flow in open coastal waters in the Portuguese coast is not influenced by human action, although it does influence water quality, coastal erosion, and fisheries.

Pressure indices

- **Water abduction index = (upstream abduction) / (actual flow + upstream abduction) = 1 – (actual flow / natural flow)**
- **Regularisation index = (reservoir volume in the waterbasin) / (average annual freshwater discharge)**
- **Sediment abduction index = 1 – (actual sediment flow / natural sediment flow)**

The importance of freshwater and sediment flow change in transitional and closed coastal waters can be fairly easily perceived with three simple pressure indices.

The effects of bar and waterworks are more difficult to quantify, because they depend on very complex interactions between river water flow, solid flow and coastal dynamics.

Evaluation of impacts has to be performed on a case by case basis. As a guidance, the higher the value of these indices, the more likely there will be significant impacts from water regime change, meriting a correspondingly more thorough impact analysis. In the case of transitional waters, the sediment abduction index may be computed for upstream and downstream sections.

Pressure indices

- **Shoreline artificialisation index = (artificialised shore length) / (total shore length)**

Morphology

Common direct pressures regarding the morphology of coastal and transitional waters include:

- Harbour and bar protection works;
- Shoreline artificialisation;
- Coastal protection heavy works;
- Navigation channel dredging;
- Sand extraction, either in the catchment area or in the water body itself;

- Landfilling to create urban, infra-structure or agricultural area.

All pressures consisting in heavy works are readily identifiable on aerial or satellite photography. Additional information may be gathered from other parties, such as local authorities or environmental NGOs. Port authorities have adequate data on navigation channel dredging. Sand extraction is the worst covered sector, due to lack of adequate control, but can be swiftly remedied.

Shoreline artificialisation is correlated to a number of impacts, including coastal erosion and pollution from different human activities.

A simple index for evaluating the importance of these pressures is shown opposite.

The higher the value of the index, the higher the probability of impacts resulting from such pressures.

Other pressures such as dredging, sand extraction or landfilling have the immediate effect of destroying local ecosystems, and may also be related to coastal erosion. This may or may not have a significant impact depending on site sensitivity and size of the intervention as compared to total water body size. Actual impact is very site-specific and must be reviewed on a case by case basis.

Biology

Ecosystem quality is influenced by a number of factors, including the above mentioned pollution, water flow changes and morphology changes. Moreover, it can be directly affected by other human activities, namely:

- Fisheries. Although seldom associated with the concept of "water quality", fisheries are among the most important pressures imposed on transitional and coastal waters. Actual impact depends on a number of factors, but it is closely related to the degree of exploitation of fisheries stocks. There is much information on the impact of fisheries, but there is as yet no adequate management model. Portuguese fisheries (like European fisheries in general) are lacking both better research and better management policies.
- Aquaculture. This is an expanding activity, that may have a significant impact on the water body, mainly due to direct destruction of local ecosystems, introduction of alien species, and pollution related to fish-farming techniques. More research is needed for proper assessment of such impacts.

Reporting

For purposes of reporting, it is useful that information is presented using synthetic indicators that can be readily perceived by the public.

Environmental impacts are very difficult to aggregate. It is simpler to select a few key indicators that are representative of whatever issue is being communicated.

Environmental pressures, on the other hand, are easier to standardise and it is useful that they

should be presented in an aggregate form with methods such as the "Ecological Footprint" or "EcoBlock".

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General Conclusions

Portugal has a number of important estuaries, which fall under the category of transitional waters – two of these, and parts of the rivers which flow into them, form the northwestern and southeastern borders with Spain. Portugal has an extensive coastal area, which delimits the country to the west and to the south.

The Typology and Reference Conditions (TICOR) study aimed to provide a framework for appropriate coastal management in Portugal, following the requirements of the Water Framework Directive. The team carrying out this work reviewed a broad range of issues, ranging from classification of different systems, division into system types, and examination of approaches to ecological quality status and the definition of reference conditions for transitional and coastal waters.

In order to address some of these issues, the TICOR project was carried out.

The key outputs of TICOR are presented in this book, which begins with a brief introduction to the WFD, and to the main aspects concerning transitional and coastal waters, and follows with a further seven chapters. Every effort has been made to allow each chapter to be readable on its own,

TICOR objectives

- **Develop an integrated approach for all Portuguese coastal and transitional waters for the application of the Water Framework Directive (WFD)**
- **Provide the data framework and methodology for delimiting and typing Portuguese coastal and transitional systems**
- **Assemble the data required for WFD typology and first generation (G1) reference conditions, based on WFD criteria and on the guidance provided by the Common Implementation Strategy working group COAST**
- **Deliver a set of maps for typology of a key subset of Portuguese coastal and transitional waters**
- **Derive a set of G1 reference conditions for Portuguese coastal and transitional types**
- **Review the special issues of *Heavily Modified Water Bodies* and of *Pressures* and their application to Portuguese coastal and transitional waters**

by including the basic components of the theme, from concepts to methods and results. The *tools* chapter provides an overview of the techniques used for the different parts of the work.

Introduction
WFD and guidance & key objectives

Methodology
Details on the TICOR process

Tools
Summary of tools used in TICOR

Systems, limits & morphology
Definitions for transitional & coastal waters, GIS presentation of areas and volumes

Typology
Classification of transitional & coastal waters into seven types

Pelagic reference conditions
Review of the state of the art for classification tools, and suggested approaches for defining first generation pelagic reference conditions

Benthic reference conditions
Review of the state of the art for classification tools, and suggested approaches for defining first generation benthic reference conditions

Special issues
Heavily Modified Water Bodies and general approach to environmental pressures

A summary of the key outputs and findings of TICOR are presented below.

Data

Over 600,000 records of data for Portuguese transitional and coastal waters have been archived in relational databases during the project. These are available on the internet, and contain parameters ranging from water and sediment quality to species lists, covering ten

Figure 61. Areas and volumes of TICOR systems.

System name	Classification	Area (km^2)	Volume (10^6 m^3)
Minho estuary	Transitional	23	67
Lima estuary	Transitional	5	19
Douro estuary	Transitional	5	39
Ria de Aveiro	Transitional	60	84
Mondego estuary	Transitional	9	21
Tagus estuary	Transitional	330	2 200
Sado estuary	Transitional	170	850
Mira estuary	Transitional	3	17
Guadiana estuary	Transitional	18	96
Ria Formosa	Coastal	49	92
Exposed Atlantic coast	Coastal	3 200	195 000
Moderately exposed Atlantic coast	Coastal	4 200	295 900
Sheltered Atlantic coast	Coastal	1 000	27 600

Note: Different colours correspond to different types.

transitional and coastal waters, and in some cases spanning over seventy years. These data were the foundation for the work which has been developed, and are an important reference collection of historical information on which future monitoring and research activities may build.

Systems, limits and morphology

TICOR addressed ten transitional and inshore coastal systems, as well as the coastline of continental Portugal (Figure 61). The project did not consider the areas of Madeira and Azores. A geographic information system (GIS) was developed for all the systems, and was used as a framework for the subsequent definition of limits, areas and volumes.

From a total of 44 transitional or coastal systems in Portugal, about half are in class A ($\leq$ 0.3 km^2). The other 48% are distributed in other classes. Class D ($\geq$ 1.0 km^2) is the most representative of these.

The systems studied in TICOR, together with their classification into transitional or coastal waters and morphological data, are shown in Figure 61.

Typology

Seven different types of transitional and coastal waters were defined for Portugal, based on the consideration that the number of types should be relatively small but should accurately reflect the existing diversity of systems (Figure 62).

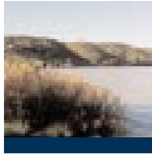
Two transitional water types were defined, corresponding to estuarine systems from the northern and southern parts of Portugal. Type A2, *mesotidal well-mixed estuary with irregular river discharge*, is envisaged to be almost unique in the European Union, due to the combination of highly variable freshwater discharge and mesotidal regime. Additionally, two semi-enclosed coastal types were defined, as well as three open coastal types, which were judged to be sufficient to describe the entire Atlantic coastline. Of these three, type A6, *mesotidal moderately exposed Atlantic coast*, is considered to be unique to the European Union, because it combines colder north-east Atlantic and warmer Mediterranean influences with the dynamics of a narrow shelf. The type names and descriptions are shown in Figure 62.

The rationale for each type is explained in the *Typology* chapter, and the areas and volumes for the different types were determined with basis on the GIS. Some results are presented also on the distribution of these morphological data among types, and a discussion of types which may potentially be common to other EU member states is made. The most likely candidate types are: A1, A3, A5 and A7.

Figure 62. Proposed typology and classification of systems larger that 1 km².

Type	Descriptor	Systems larger than 1 km²
A1	Mesotidal stratified estuary	Minho estuary
		Lima estuary
		Douro estuary
		Leça estuary
A2	Mesotidal well-mixed estuary with irregular river discharge	Ria de Aveiro
		Mondego estuary
		Tagus estuary
		Sado estuary
		Mira estuary
		Arade estuary
		Guadiana estuary
A3	Mesotidal semi-enclosed lagoon	Óbidos lagoon
		Albufeira lagoon
		St. André lagoon
A4	Mesotidal shallow lagoon	Ria de Alvor
		Ria Formosa
A5	Mesotidal exposed Atlantic coast	From the Minho estuary until Cabo Carvoeiro
A6	Mesotidal moderately exposed Atlantic coast	From Cabo Carvoeiro until Ponta da Piedade
A7	Mesotidal sheltered coast	From Ponta da Piedade until Vila Real de Sto. António

Note: TICOR systems shown in blue.



Main findings for pelagic reference coditions

- There are sufficient data in most cases for establishing reference conditions for phytoplanton abundance, biomass and composition. Some gaps exist for type A1 and for open coastal waters
- The supporting quality element *nutrients* should be measured in order to monitor elemental ratios, and to support the evaluation of pressures, but no clear link between dissolved nutrients in the water column and phytoplankton biomass and abundance could be established
- Phytoplankton composition differs clearly between transitional water types. Some questions are raised about the Sado estuary, which behaves like a coastal lagoon for this element
- Phytoplankton composition in transitional waters is potentially linked to water residence time. This should be further explored, and if appropriate taken into account when establishing reference conditions
- Phytoplankton abundance may be adequately represented by biomass, using chlorophyll *a* as a proxy
- Phytoplankton biomass and abundance should be assessed using an integrated methodology, because organic enrichment effects may be manifested also in changes to benthic flora. The use of the ASSETS approach, developed from the U.S. National Estuarine Eutrophication Assessment procedure is recommended
- Ecological status for fish is potentially best evaluated using Indices of Biotic Integrity (IBI)

Pelagic reference conditions

A review was carried out of the approaches that may be used for determination of ecological quality status in phytoplankton and fish, the latter quality element only for transitional waters. The relevance of the various supporting quality elements was also analysed, using relationships developed from the TICOR databases and other sources.

Benthic reference conditions

A review was carried out of the approaches that may be used for determination of ecological quality status of benthic quality elements, both for aquatic flora and fauna. A potential method for establishing a scale for reference conditions of benthic plants based on relative areal distribution and biomass of opportunistic and long-lived species is outlined. The method needs to be refined and tested.

The data collected on benthic macrofauna were used extensively to explore a number of different indices, across a range of transitional water types.

Figure 63. Application of indices as a function of data requirements and data availability.

<table>
<tr><th colspan="6">DATA AVAILABILITY</th></tr>
<tr><th colspan="2">Qualitative data</th><th colspan="4">Quantitative data</th></tr>
<tr><td>Metadata</td><td>Rough data</td><td>Numeric density data</td><td colspan="3">Numeric density and biomass data</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Shannon-Wiener
Margalef</td><td rowspan="2">Shannon-Wiener
Margalef
AMBI</td><td>Identification of individuals down to species level</td><td colspan="2">Identification of individuals down to family level</td></tr>
<tr><td>ABC
Margalef
AMBI</td><td colspan="2">Shannon-Wiener
Margalef
ABC</td></tr>
</table>

Figure 63 shows a synthesis of the work carried out. A first generation approach to ecological quality status may be carried out by using a combination of appropriate indices, based on data availability.

Special issues

Two key areas were examined in the *Special Issues* chapter: *Heavily Modified Water Bodies* and *Pressure* elements.

One key finding of this part of the work is that there does not seem to be a basis for type differentiation of reference conditions for benthic fauna in transitional waters, in the application of the AMBI index and W-statistic. However, diversity indices may be regarded as type-specific, and will help to differentiate types in future developments of this method.

For the first issue, TICOR results are based on data developed by the relevant guidance group, defining the evaluation process that should be followed for classification.

The pressures guidance document was also used as a framework for discussion of this issue, the focus of the TICOR work is on the development of localised guidelines for the most relevant pressures on Portuguese transitional and coastal systems.

TYPOLOGY AND REFERENCE CONDITIONS
FOR PORTUGUESE TRANSITIONAL AND COASTAL WATERS
Development of Guidelines for the Application
of the European Union Water Framework Directive

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