IDENTIFICATION OF SENSITIVE AREAS AND VULNERABLE ZONES IN TRANSITIONAL AND COASTAL PORTUGUESE SYSTEMS

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Application of the United States National Estuarine Eutrophication Assessment to the Minho, Lima, Douro, Ria de Aveiro, Mondego, Tagus, Sado, Mira, Ria Formosa and Guadiana systems

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The data required for this study exist for many Portuguese estuaries and coastal lagoons. However, data producers often do not make this information widely available; as a result, very limited datasets are sometimes extrapolated to describe the pressures and state of a particular system.

INAG, the Portuguese Water Institute, has strongly endorsed open standards in access to water quality data, and has promoted many initiatives which help Portugal have a modern outlook on the relevance of public data dissemination. We thank INAG for the opportunity which this work has given us to play a part in information sharing in estuarine research.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

This study was carried out to address the potential classification of sensitive areas and/or vulnerable zones in ten Portuguese systems, the Minho, Lima, Douro, Ria de Aveiro, Mondego, Tagus and Sado, Mira and Guadiana estuaries, and the Ria Formosa coastal lagoon. The evaluation presented in this document applies the U.S. National Estuarine Eutrophication Assessment, developed by the National Oceanic and Atmospheric Administration of the United States.

This work examines the ecological quality of the ten systems, and asks six fundamental questions:

- **Sensitive areas**
  Directive on urban wastewater treatment UWWTD (91/271/EEC)
- **Vulnerable zones**
  Nitrates directive ND (91/676/EEC)

FIGURE 1. EUTROPHICATION STATUS OF THE PORTUGUESE SYSTEMS.

	Overall Eutrophic Condition (OEC)	Overall Human Influence (OHI)	Definition of Future Outlook (DFO)
Minho	There is insufficient information to fully apply the NEEA index in this estuary, but the analysis of available data shows that there are no problems with eutrophication symptoms		
Lima	There is insufficient information to fully apply the NEEA index in this estuary, but the analysis of available data shows that there are no problems with eutrophication symptoms		
Douro	There is insufficient information to fully apply the NEEA index in this estuary, but the analysis of available data shows that there are no problems with eutrophication symptoms		
Ria de Aveiro	Moderate low ✓	Low ✓	No change ✓
Mondego	There is insufficient information to apply the NEEA index in this estuary, but a partial analysis shows that there are problems in the south arm of the system		
Tagus	Moderate low ✓	Low ✓	Slight improvement ✓
Sado	Low ✓	Low ✓	Substantial improvement ✓
Mira	Low ✓	Low ✓	No change ✓
Ria Formosa	Moderate Low ✓	Moderate ✓	Substantial improvement ✓
Guadiana	Moderate ✓	Moderate low ✓	No change ✓

SIX KEY QUESTIONS

1. What is the eutrophication status of each of the ten systems, as a whole and in sections; how does it compare with other estuaries and coastal waters in Portugal and elsewhere?
2. Which systems or parts of systems should be classified as sensitive areas and/or vulnerable zones?
3. What are the potential management solutions, for example through effluent treatment or improvement of agricultural practices?
4. What will be the trends in nutrient loading to these systems, from urban and agricultural sources, over the next few decades?
5. Where are the main data gaps, and what are the recommendations for monitoring and research for the ten systems studied?

6. How can this assessment be used as the basis for a national strategy?

The results obtained for the ten systems are presented below.

EUTROPHICATION STATUS

Figure 1 shows the results of the NEEA assessment of the ten systems. No eutrophication problems are identified in the Minho, Lima, Douro, Ria de Aveiro, Tagus, Sado and Mira estuaries. In the Mondego, existing data for the South channel suggest the occurrence of eutrophication symptoms associated with macroalgal (seaweed) growth. In the Ria Formosa, periodic blooms of macroalgae have been detected in the Faro-Olhão channels. In the tidal freshwater and mixing zones of the Guadiana estuary, the eutrophic symptoms are associated with medium to high chlorophyll *a* values.

The study carried out by NOAA on 138 estuaries in the United States, identified 34% with high expression of eutrophication conditions, 37% with moderate conditions and 29% with low conditions – 17 of the 138 estuaries did not have enough information available to apply the NEEA methodology. Given the level of development of the European Union, we would expect the application of NEEA to European estuaries to give similar results or perhaps even to identify a greater proportion of systems with high eutrophication conditions. Comparatively, the Portuguese systems for which adequate data exist have low eutrophic conditions when considered on an EU-wide scale.

CLASSIFICATION OF VULNERABLE ZONES AND/OR SENSITIVE AREAS

Designation of vulnerable zones

On the basis of the application of the NEEA index to the ten systems, there is no justification for designating vulnerable zones in the Minho, Lima, Douro, Ria de Aveiro, Tagus, Sado, Mira

and Ria Formosa. In the Mondego estuary, available data suggest that the South channel is a problem area, and the measures required to reduce macroalgal blooms and restore the ecosystem balance should be urgently examined. The designation of vulnerable zones in the Guadiana estuary is dependent on the changes in agricultural practices promoted by the future availability of water for irrigation from the Alqueva reservoir.

Designation of sensitive areas

On the basis of the application of the NEEA index to the ten systems, there is no justification for designating sensitive areas in any of them, under the terms of the UWWTD Directive (91/271/EEC), as regards eutrophication.

MANAGEMENT RECOMMENDATIONS

Minho, Lima and Douro estuaries

Due to the lack of information for these estuaries no conclusions could be drawn on management recommendations.

Mondego estuary

Improve the agricultural practices in the Pranto river basin, and propose the application of ecotechnology solutions. A comprehensive list would include:

(i) Optimisation of the management of the Pranto discharge;

(ii) Construction of artificial wetlands between the upstream farmland and the Pranto sluice connection to the Mondego Southern channel.

Guadiana estuary

The effective implementation of good agricultural practices according to the EU agro-environmental rules is essential to prevent environmental quality degradation as regards eutrophication.

Other estuaries

The management measures currently being applied in the estuaries of the Ria de Aveiro, Tagus, Sado, Mira and Ria Formosa, with respect to effluent treatment and discharge to the receiving body, agricultural practices and soil protection, appear to be adequate for preserving and improving environmental quality as regards eutrophication.

FUTURE OUTLOOK

The future trends are positive in the case of the Douro, Tagus, Sado and Ria Formosa and neutral in the case of the Lima, Ria de Aveiro and Mira. No conclusions were drawn on possible trends for the Mondego and Minho due to lack of information. Negative future trends should be considered in the case of the

Guadiana estuary if appropriate management recommendations are not implemented.

DATA GAPS AND RECOMMENDATIONS

All the systems except the Tagus exhibit data gaps, which should be filled by means of an adequate monitoring programme. These programmes should be implemented following the recommendations of the Water Framework Directive (WFD, Directive 2000/60/CE).

Minho estuary

The information on water quality parameters for the Minho estuary is very limited. Some of the parameters are only available as metadata and the spatial and temporal coverage is not sufficient to carry out an analysis of the system as a whole. A *Surveillance Monitoring* programme is recommended, following the definition set out in the Water Framework Directive.

Lima estuary

The areas near the banks of the Lima estuary, particularly the saltmarshes and saltpans, have been studied, but there is a requirement for an integrated approach to the whole system from the head of the estuary to the mouth. Due to the lack of information for this estuary, particularly in what concerns hydrology, macroalgae, epiphytes and submerged aquatic vegetation dynamics, a *Surveillance Monitoring* programme should be developed.

Douro estuary

The information for the Douro estuary is also scarce concerning water quality, macrophytes and nuisance and toxic blooms. For this estuary a *Surveillance Monitoring* programme is necessary.

Ria de Aveiro

Some data gaps were detected for Ria de Aveiro concerning spatial coverage for chlorophyll *a*,

macrophyte dynamics and nuisance and toxic blooms. An adequate *Surveillance Monitoring* programme should be developed to rectify these gaps. Aditionally two investigative monitoring programs should be carried out to determine the reasons for general SAV loss and high chlorophyll concentrations in the extreme of Mira channel.

Mondego estuary

The South channel of the Mondego estuary is well studied, but there is a requirement for an integrated approach to the whole system, from the head of the estuary to the mouth, considering both the North and South channels. For this estuary, apart from the *Surveillance Monitoring* indicated in the WFD, an *Investigative Monitoring* programme has now been implemented, in order to respond to the outstanding issues.

Tagus estuary

The Tagus estuary is well characterized, and the fulfilment of national obligations with regard to WFD *Surveillance Monitoring* is sufficient.

Sado estuary

Some areas of the Sado estuary are not very well known, particularly the upper part. These knowledge gaps may be filled by an adequately designed *Surveillance Monitoring* programme. Elevated chlorophyll *a* peaks were identified on one sampling date in February 2000, which are clearly inconsistent with the overall dataset. As a precaution, *Investigative Monitoring* is suggested for the area in question.

Mira estuary

Sections of the Mira are poorly known, particularly the upstream part. There is also a need to improve the description of temporal and spatial variation of chlorophyll *a*. The monitoring programme falls clearly into the *Surveillance Monitoring* area of the WFD.

Ria Formosa

The data gaps detected for the Ria Formosa concern macrophyte dynamics, particularly seaweeds and seagrasses. Efforts should be made to obtain the necessary information by means of an *Investigative Monitoring* programme.

Guadiana estuary

Although an extensive database for salinity and dissolved oxygen is available for the Guadiana estuary, the information on other biogeochemical parameters is much more limited. The analysis for chlorophyll *a* is the most obvious case, where an uneven distribution of observations in space and time may bias the data. A comprehensive and carefully designed *Surveillance Monitoring* programme (sensu WFD) is recommended, to help to fill the gaps in the database.

DEFINITION OF A NATIONAL STRATEGY

This study brings together valuable information on the state of eutrophication of nine estuarine systems and one coastal lagoon in Portugal, and is a useful support for decision-making and management of these systems. The existence of a comparative methodology and results at an international level reinforces the utility of this approach. The general application of the NEEA index to a large number of Portuguese estuaries and coastal lagoons was shown to have the following advantages:

- Contribution to the definition of priorities and decision-support at a national level
- In estuaries with serious problems, application of management measures. In systems considered to be at risk, promotion of monitoring and preventive measures
- In estuaries where serious knowledge gaps exist, identification of the monitoring requirements for quality assessment

INTRODUCTION

The objective of this document is to outline the key methodological aspects and results for the implementation of the Urban Waste Water Treatment Directive - UWWTD (91/271/EEC) and the Nitrate Directive - ND (91/676/EEC) in transitional and coastal waters in Portugal. It specifically excludes freshwater and groundwater.

FIGURE 2. SUMMARY OF THE URBAN WASTE WATER TREATMENT AND NITRATE DIRECTIVES.

Directive	Classification	Type of water body	Criteria
ND (91/676/EEC)	Vulnerable zones	Surface freshwater and groundwater	• Nitrate > 50 mg l-1 (75/440/EEC) • Eutrophic conditions
		Freshwater lakes, other freshwater bodies, estuaries, coastal waters and marine waters	
UWWTD (91/271/EEC)	Sensitive areas	Freshwater lakes, other freshwater bodies, estuaries, coastal waters	• Eutrophic conditions • System with poor water renewal • High nutrient discharge
		Surface freshwaters	• Nitrate > 50 mg l-1 (75/440/EEC)
	Less sensitive areas	Estuaries and coastal waters	• Good water exchange • Not subject to eutrophication • Not subject to O_2 depletion

These directives (Figure 2) stipulate that Member States must indicate sensitive areas (UWWTD) and/or vulnerable zones (ND) for water bodies based on the application of criteria, which focus on eutrophication, interpreted as a process rather than a state.

Since several aspects are left open to interpretation by Member States, particularly in what concerns the assessment of eutrophication status, the Portuguese authorities established a list of factors which were used in characterising and identifying sensitive and less sensitive areas, and vulnerable zones.

Only the Tagus estuary had designated sensitive areas: Seixal, Coina, Moita and Montijo (Dec. Lei nº152/97 of 19th June), and no estuarine zones were designated as vulnerable.

FIGURE 3. ESTUARINE AREAS IDENTIFIED BY ERM (2000) AS REQUIRING DESIGNATION AS SENSITIVE AREAS AND / OR VULNERABLE ZONES.

Estuary	Criteria	Vulnerable zone	Sensitive area
Mondego	Eutrophication	x	-
Sado	Eutrophication in Marateca Bay and Álcacer channel Nitrate contamination in Setúbal peninsula	x	-
Tagus	Eutrophication in Cala do Norte	x	x

A report produced for the European Commission in February 2000 by Environmental Resources Management (ERM) concerning Portugal identifies three estuarine systems (Mondego, Tagus and Sado) as requiring designation under either or both directives (Figure 3), based on data published or available on the web.

Additionally, a generic report produced by the same company on *Criteria for the definition of eutrophication in marine/coastal waters* referred a further estuary (Mira) as an example of a system where large biomasses of macrophytes occurred at certain locations.

In order to address the problem from a rigorous scientific perspective, to provide a methodology, which will clarify the identification of vulnerable zones and sensitive areas for estuarine systems in Portugal, and provide a yardstick for comparability throughout Europe, a twofold approach was developed by a national task team.

One part of the approach, described herein, relies on the assimilation of key data for the different systems and the application of a eutrophication assessment procedure. The second part, which is complementary, is described elsewhere, and uses mathematical modelling as a tool for describing and forecasting trophic conditions in the different systems.

Results are presented on the application of the NEEA index to the main Portuguese systems: Minho, Lima, Douro, Ria de Aveiro, Mondego, Tagus, Sado, Mira, Ria Formosa and Guadiana (Figure 4). The conclusions on the designation of sensitive areas and vulnerable zones are based on the results of the index.

FIGURE 4. LOCATION OF THE TEN SYSTEMS ON THE PORTUGUESE WESTERN SEABOARD.

METHODOLOGY

This section briefly describes the methodology used for eutrophication assessment for the different systems.

A review was carried out of the different approaches currently available, including different indices, the OSPAR discussion documents on *Common assessment criteria and their application within the comprehensive procedure*, and the NOAA National Estuarine Eutrophication Assessment (NEEA).

Following the review, a decision was taken to apply the latter approach, for three reasons.

Reasons to choose NEEA

- It was applied to 138 estuaries in the whole of the United States, over a seven year period;
- It reflects a diversity of environmental conditions in estuarine use, morphology, river discharge (magnitude and regime) and tidal ranges;
- It was consolidated through intense peer-review within the scientific community, and has been published in the open literature.

Four stages were identified by this working group as key milestones for the success of this task:

- **Assembly and loading of a relational database for each system, consolidating all the raw data available over the past twenty-five years. These databases provide the support for loading the index, trend analysis and decision-making;**
- **Application of the index to the different systems, and presentation of results on a custom-built website, located at http://tejo.dcea.fct.unl/assets/**
- **Involvement of regional experts on each estuary to provide guidance on local interpretation issues, and of a NOAA expert to provide guidance in the application of the NEEA;**
- **Where applicable, identification of vulnerable zones and sensitive areas on the basis of the results.**

Some information is given below on the database and NEAA methodologies.

DATA ASSIMILATION - WATER QUALITY DATABASES

The BarcaWin2000™ software was used for building relational databases for the ten systems. This team has extensive experience with water quality databases; the software in use has been developed from 1985 onwards, and has been used for a wide range of data storage and exploitation projects in estuaries and coastal areas: these include Carlingford

Lough in Ireland, Marennes-Oléron in France, the Northern Adriatic, S. Francisco Bay in the U.S. and coastal embayments in China and South Africa. More information may be found at http://tejo.dcea.fct.unl.pt/b2k/

NOAA'S NATIONAL ESTUARINE EUTROPHICATION ASSESSMENT

NEEA methodology

The National Estuarine Eutrophication Assessment (NEEA) was carried out for 138 estuaries in the U.S., during a period of over seven years. It is the most comprehensive survey of eutrophication in estuarine systems carried out to date, encompassing over 90% of the U.S. estuarine surface area.

It has a diverse set of outputs, including an eutrophication index which has been implemented for the different estuaries, based on a stepwise procedure. The different components are briefly reviewed in the next sections.

Homogeneous areas

The first step in applying the methodology is a physical classification of an estuarine system, with the objective of dividing each system into three zones. In the U.S. study this was based on NOAA's National Estuarine Inventory (NEI):

- **Tidal freshwater (<0.5)**
- **Mixing zone (0.5-25)**
- **Seawater (>25)**

Data for each parameter are aggregated using spatial rules, which are used for weighting values at different sampling stations to provide a fair representation of conditions within each system.

These salinity zones are determined for the various systems using a relational database with measured salinity data at different sampling stations and a geographic information system (GIS) to calculate surface areas.

Dataset

In order to be able to compare different systems, an analysis of data completeness and reliability (DCR) is carried out, with the objective of intercalibrating the spatial and temporal quality of the datasets (completeness) and the confidence in the results (reliability – *sensu lato*, includes sampling and analytical quality).

Indices

Following these initial steps, there are three indices which may be calculated from the datasets. These are:

Overall Eutrophic Condition (OEC) index

Overall Human Influence (OHI) index

Determination of Future Outlook (DFO) index

Although there is interaction between these different indices, they are not specifically combined into a final value. The susceptibility part of the evaluation (see OHI, below) is however used both in OHI and DFO.

The NEEA approach may be divided into three parts:

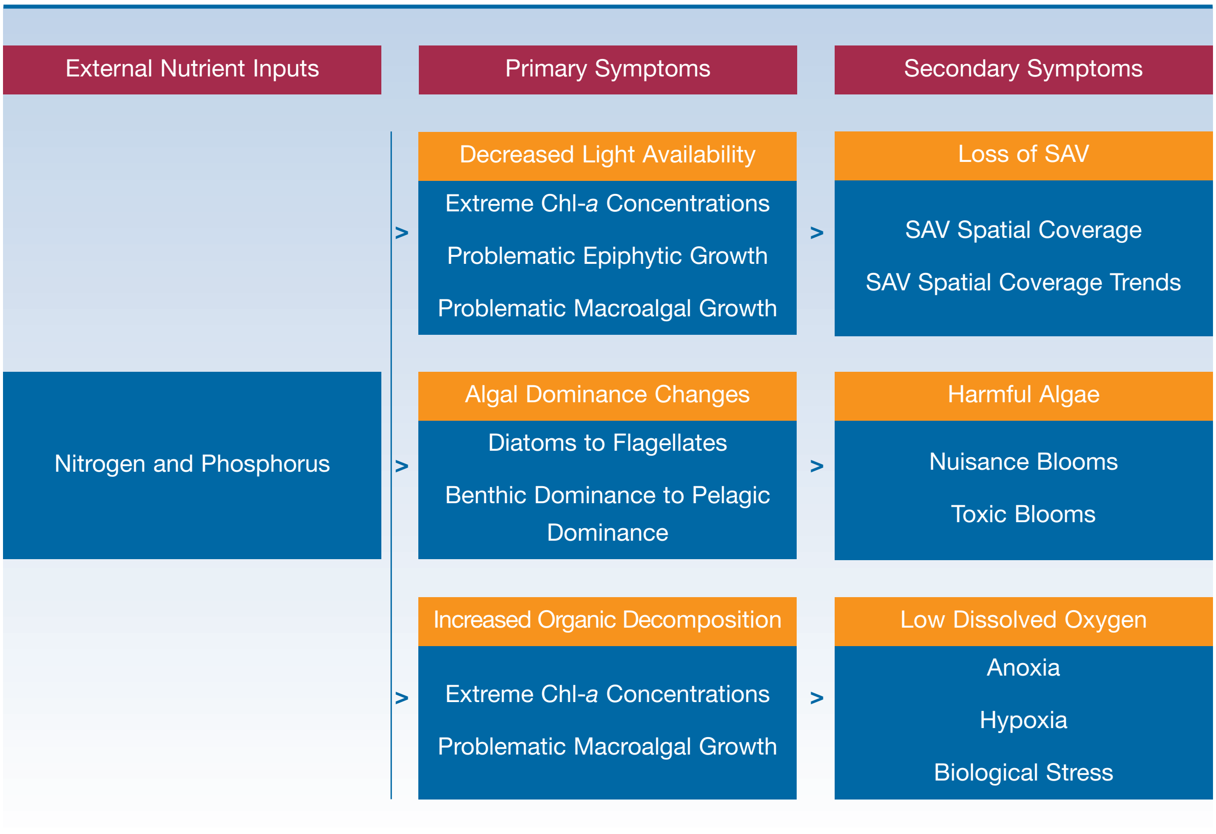
- Division of estuaries into homogeneous areas
- Evaluation of data completeness and reliability
- Application of indices

A short description of the methodology for each component is detailed below.

OVERALL EUTROPHIC CONDITION

The **Overall Eutrophic Condition (OEC) index** has a sequential (stepwise) approach based on 2 phases, which bring together six key parameters (Figure 5). The primary symptoms correspond to the first stage of water quality degradation and are examined through the analysis of chlorophyll *a* concentrations, epiphyte abundance and macroalgal blooms. In some systems the primary symptoms lead to secondary symptoms such as submerged aquatic vegetation loss, nuisance and toxic algal blooms and low dissolved oxygen (anoxia or hypoxia).

FIGURE 5. EUTROPHICATION MODEL (ADAPTED FROM NEEA).

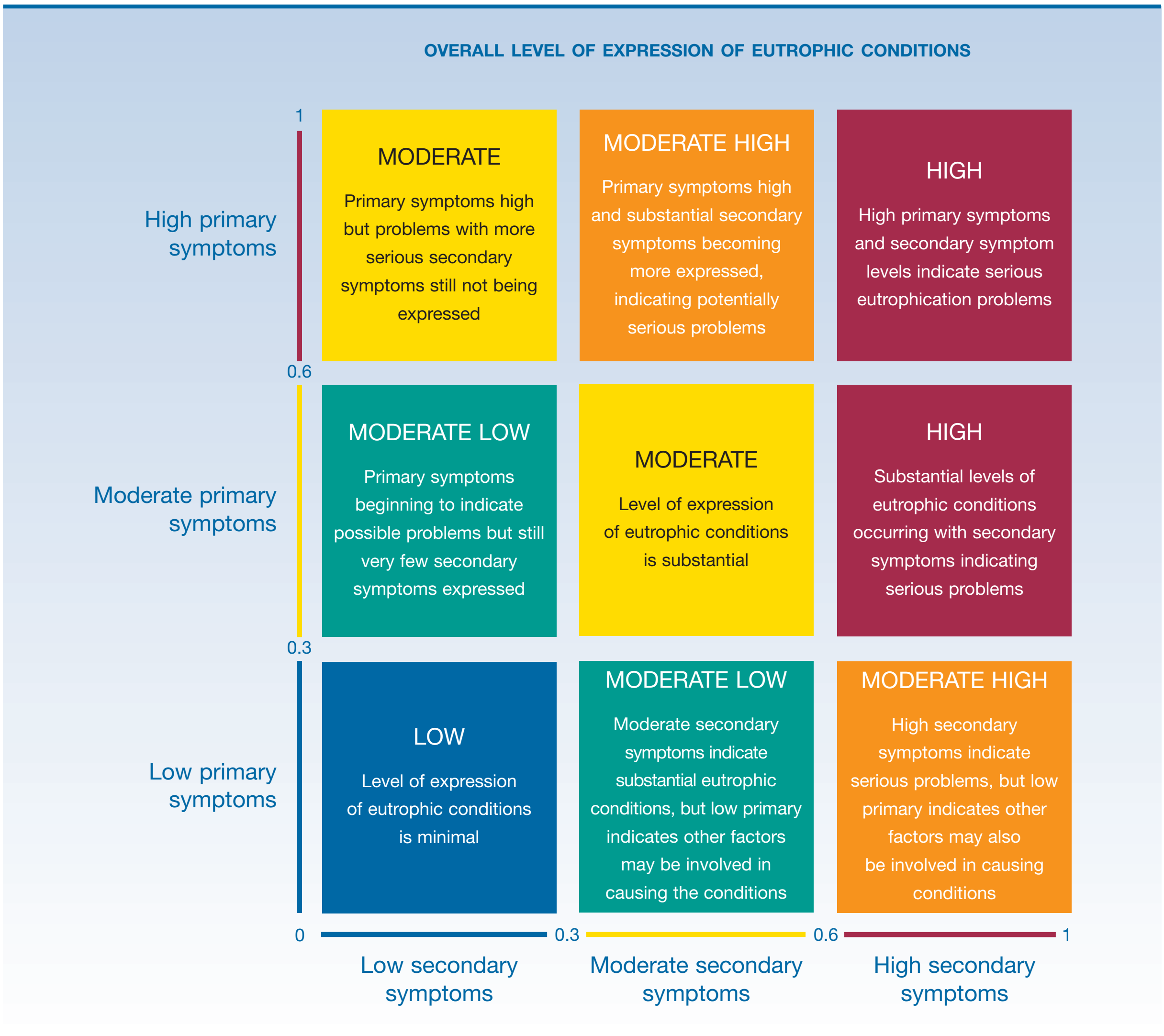


Phase 1: Primary Symptoms Method (PSM), considering algal biomass (using chlorophyll *a* as an indicator), epiphyte and macroalgal grouth.

Phase 2: Secondary Symptoms Method (SSM), considering loss of submerged aquatic vegetation (SAV), harmful algae and low dissolved oxygen.

After the division into homogeneous zones and application of DCR, followed by Phases 1 and 2 of OEC, the last stage is the determination of the Overall Level of Expression of Eutrophic Conditions (OLEC), which combines the Phase 1 (primary) symptoms on the Y-Axis with the Phase 2 (secondary) symptoms on the X-Axis to provide an OLEC matrix (Figure 6).

FIGURE 6. OVERALL LEVEL OF EXPRESSION OF EUTROPHIC CONDITIONS MATRIX.



OVERALL HUMAN INFLUENCE

Following the determination of the **Overall Eutrophic Condition** (OEC) using the approach described above, there is a similar procedure for determining the **Overall Human Influence (OHI) index**, based on another set of stepwise calculations.

Susceptibility Determining the estuarine export potential (EXP), by defining a dilution potential (DIL) and a flushing potential (FLU). Dilution is determined as a function of the system volume, weighted with a stratification term, where applicable. Flushing is a function of tidal amplitude and river flow.

Nutrient inputs based on watershed loads, determined through direct (e.g. river discharge x measured substance concentration) and indirect (e.g. estimates for fertilizer application) methods.

The **susceptibility** approach and its combination with the **nutrient inputs** are shown in Figure 7.

This approach has been extended by the development of a simple loading-susceptibility model (Figure 8), which is described below.

FIGURE 7. COMBINATION OF DILUTION AND FLUSHING FOR SUSCEPTIBILITY (TOP) AND SUSCEPTIBILITY AND NUTRIENT INPUT FOR OHI (BOTTOM) (ADAPTED FROM NEEA).

ESTUARINE EXPORT POTENTIAL & SUSCEPTIBILITY

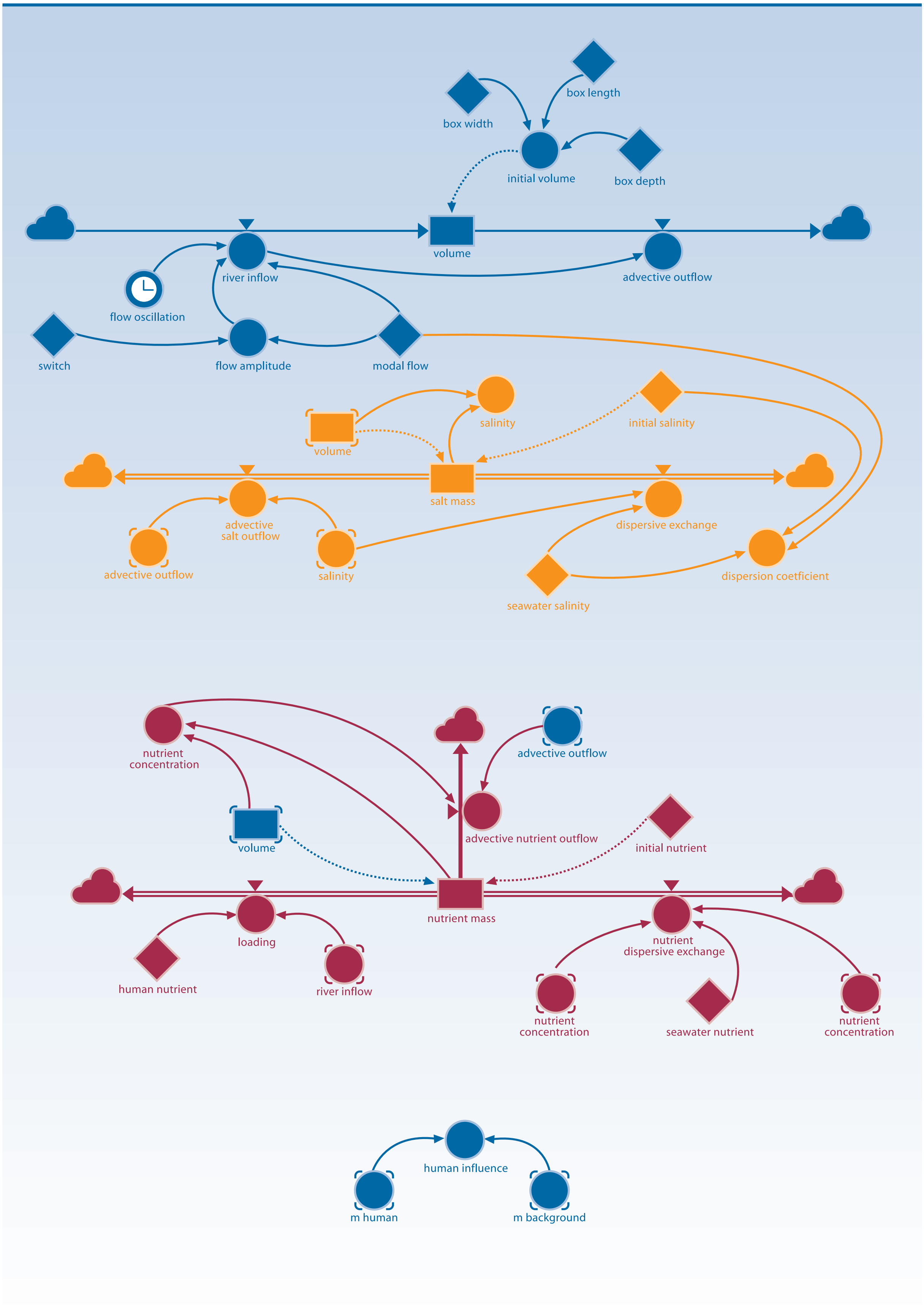
Flushing Potential \ Dilution Potential	High	Moderate	Low
High	Low Susceptibility	Low Susceptibility	Moderate Susceptibility
Moderate	Low Susceptibility	Moderate Susceptibility	High Susceptibility
Low	Moderate Susceptibility	High Susceptibility	High Susceptibility

- High Potential. The estuary has the capacity to dilute and flush nutrients
- Low Potential. The estuary does not have the capacity to dilute or flush nutrients
- Moderate Potential. The estuary has the capacity to dilute or flush nutrients

OVERALL LEVEL OF HUMAN INFLUENCE

Susceptibility \ Nutrient Input	Low	Moderate	High
High	MODERATE Even low additions may cause problems in these estuaries	MODERATE HIGH Symptoms observed are moderately to highly related to nutrient additions	HIGH Symptoms are probably closely related to nutrient additions
Moderate	MODERATE LOW Symptoms are minimally to moderately related to nutrient inputs	MODERATE Symptoms observed are moderately to related to nutrient inputs	MODERATE HIGH Symptoms observed are moderately to highly related to nutrient additions
Low	LOW Symptoms have mainly natural causes or are due to other humanfactors	LOW Symptoms have mainly natural causes or are due to other humanfactors	MODERATE LOW Symptoms may be naturally related, but high inputs may cause problems

FIGURE 8. CONCEPTUAL SCHEME FOR LOADING-SUSCEPTIBILITY MODEL.



The nutrient loading to a system may be determined by calculating the relative magnitude of the different sources. These include the boundary contributions (river and ocean), point-source discharges and diffuse loading within the estuarine perimeter. In this simple box model, the ocean loading to an estuary during the flood tide is balanced by the corresponding nutrient outflow during the ebb.

Susceptibility is partly dependent on tidal exchange, which will determine the capacity of an estuary to assimilate nutrient inputs, simulated as dispersive exchange due to the tide (Figure 9).

The model requires as input data basic estuarine physiography, salinity, nutrient concentration in adjacent ocean water, and anthropogenic loads. The latter are divided into *River load*, *Effluent load* and *Other sources.* In coastal areas (e.g. coastal lagoons) with negligible freshwater input, the nutrient input depends on effluent discharge into the watershed and on tidal exchanges. The modelling approach has been adapted to determine the natural conditions based on the nutrient concentration at the seaward boundary and the water residence time of the coastal system. The human influence is determined from the model, by considering the concentration of nutrients in the estuary if the sole origin is human input, and the component of the estuarine nutrient concentration, which is due to inputs at the ocean boundary (Figure 10). A set of categories has been defined heuristically (Figure 11) where the intervals correspond to the relative contribution of the anthropogenic load to the total input, as measured according to the *Human influence* metric.

This metric examines the relative role of natural sources and anthropogenic sources of nutrients in determining both the load and the concentration. Although the input associated with a "Low" score may not be low in absolute terms, when it is

FIGURE 9. COMPARATIVE NUTRIENT LOADS TO AN ESTUARY FROM DIFFERENT SOURCES DURING THE EBB AND FLOOD.

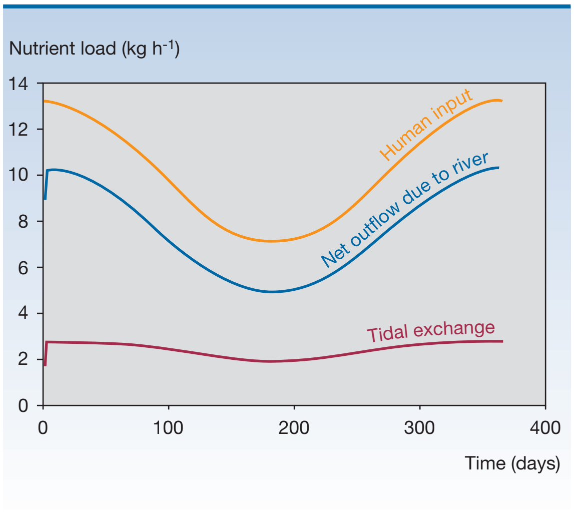


FIGURE 10. HUMAN INFLUENCE FOR A "CONCEPT" ESTUARY. THRESHOLDS ARE INDICATED WITH DOTTED LINES.

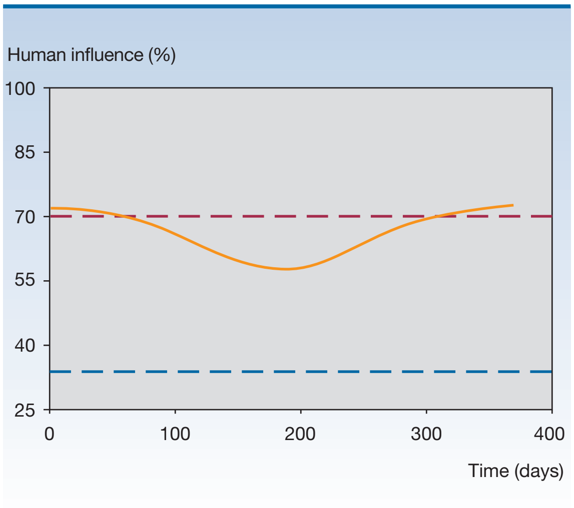


FIGURE 11. THRESHOLDS AND CATEGORIES USED TO CLASSIFY NUTRIENT INPUTS IN THE ESTUARIES.

Class	Thresholds	Category
Low	0 to < 30%	Low nutrient input
Moderate	30 to < 70%	Moderate nutrient input
High	70 to ≤ 100%	High nutrient input

examined in terms of the total load it is clear that control measures would at best reduce overall concentrations by 30%. The "Moderate" and "High" classes would potentially allow a more significant degree of control in reducing overall nutrient concentrations.

DETERMINATION OF FUTURE OUTLOOK

Finally, there is a stage for determination of future outlook (DFO), which looks at the foreseeable evolution of the system. The susceptibility component of the approach is used for both OHI and DFO, and therefore needs to be input only once. The choices to be made in this part of the decision process are heuristic.

This means that the user will be presented with a list of three choices for the nutrient pressures part of the matrix:

1. **Future nutrient pressures decrease;**
2. **Future nutrient pressures are unchanged;**
3. **Future nutrient pressures increase.**

The combined usage of the different components of the NEEA approach is a powerful tool for analysing eutrophication in estuaries and coastal lagoons. In the next ten chapters, this evaluation is carried out for the Minho, Lima, Douro, Ria de Aveiro, Mondego, Tagus, Sado, Mira and Guadiana estuaries and the Ria Formosa coastal lagoon, to address the following questions:

1. **What is the eutrophication status of each of the systems, as a whole and in sections; how does it compare with other estuaries and coastal systems, in Portugal and elsewhere?**
2. **Which systems or parts of systems should be classified as sensitive areas and/or vulnerable zones?**
3. **What are the potential management solutions, for example through effluent treatment or improvement of agricultural practices?**
4. **What will be the trends in nutrient loading to these estuaries, from urban and agricultural sources, over the next few decades?**
5. **Where are the main data gaps, and what are the recommendations for monitoring and research in each of the systems?**
6. **How can this assessment be used as the basis for a national strategy?**

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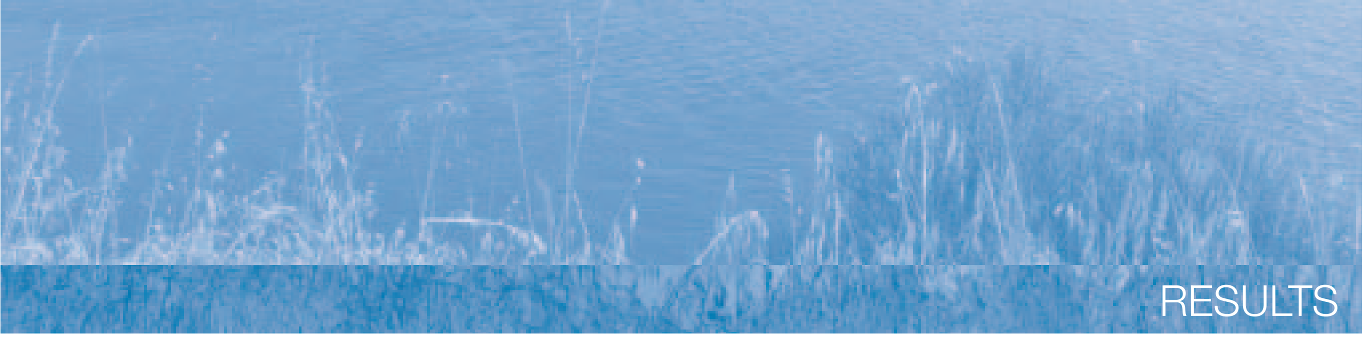


RESULTS

The results of this study are presented in ten chapters, one for each system under analysis. The information collected for each estuary was loaded into a relational database, which was subsequently used to perform calculations, extract time series and export datasets for use in geographic information systems (GIS). Figure 12 gives an overview of the information in each database.

These databases bring together in MS-Access™ format all the relevant information for the application of the NEEA index which was accessible to the study team. There are up to 25 years of sampling data stored, and whenever possible, complementary data were included, which may prove useful for other types of studies in the future.

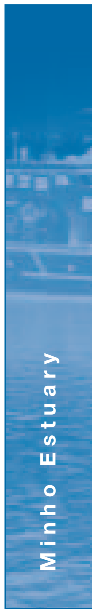
FIGURE 12. RECORDS LOADED INTO EACH SYSTEM DATABASE.

System	Records			
	Stations	Samples	Parameters	Results
Minho	17	322	34	3 538
Lima	31	603	70	8 096
Douro	39	292	42	5 006
Ria de Aveiro	84	1 441	91	13 499
Mondego	4	339	22	3 485
Tagus	40	4 821	119	60 567
Sado	273	2 833	31	17 448
Mira	8	6 354	13	29 708
Ria Formosa	67	96 665	165	135 730
Guadiana	105	35 665	32	133 783
Sub-total	*668*	*149 335*	*619*	*410 860*
Total number of records: 561 482				

The chapters on the Minho, Lima, Douro, Mondego and Mira reflect some of the limitations of available data: in the case of Minho and Lima, these are related to the number of parameters and spatial distribution. In the Mondego and Douro estuaries, the main issue is the limited spatial distribution of available data. In the case of the Mira, these are mainly related to the number of parameters.

Despite these constraints, the structure of the different chapters is whenever possible identical, in order to allow for comparisons between the different systems.

MINHO ESTUARY



GENERAL CHARACTERISTICS

The Minho river is about 300 km long. The upper part of the river is in Spain and the lower 70 km lie within Portuguese territory. Only 5% of the total catchment area (17 080 km^2) is in Portugal. The limit of salt intrusion is 35 km from the mouth (Figure 13).

The Minho is a mesotidal estuary in which vertical stratification occurs during periods of high freshwater discharge. Better vertical mixing occurs during spring tides when the tidal range reaches 4 m.

The estuary has a maximum width of about 2 km near the mouth, decreasing to about 10 m at the head. In the middle of the estuary the flow

FIGURE 13. MINHO ESTUARY: BATHYMETRY AND SAMPLING STATIONS.

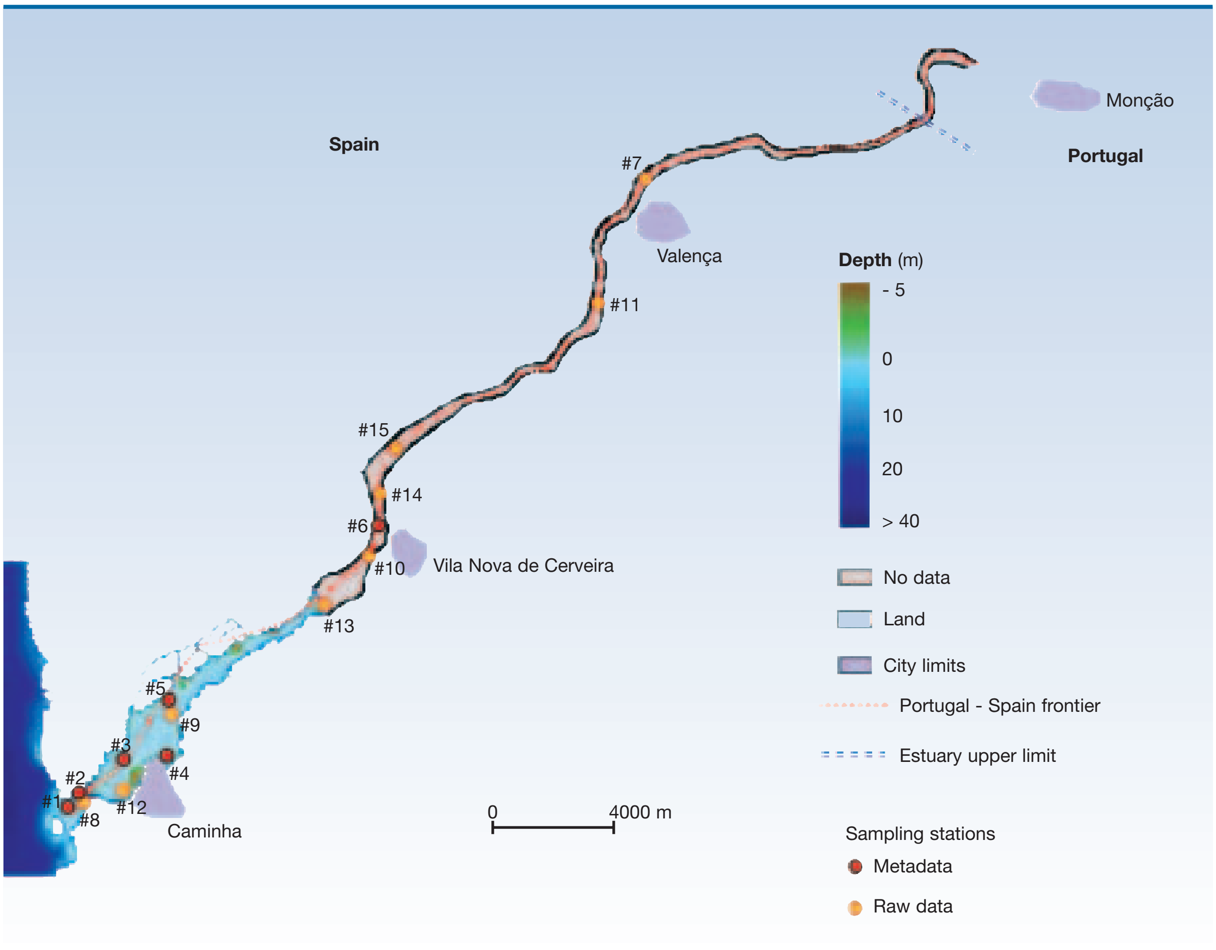


FIGURE 14. MAIN CHARACTERISTICS OF THE MINHO ESTUARY.

Parameter	Value
Volume	70 x 10^6 m^3
Area	23 km^2
Tidal prism	55 x 10^6 m^3
Tidal range	2.0 m
Population	45 000
Mean residence time	1.5 days

FIGURE 15. MEDIAN OR MEAN SALINITIES FOR EACH STATION IN THE ESTUARY.

Raw data	
Stations	**Median salinity**
# 8	11
# 12	21
Metadata data	
Stations	**Mean salinity**
#1	19
#2	28
#3	15
#4	3
#5	18

velocity decreases, allowing sedimentary deposits to accumulate and form sand banks and islands. The main physical properties of the Minho estuary are shown in Figure 14.

HOMOGENEOUS AREAS

The salinity data available (Figure 15) did not allow the determination of homogeneous salinity zones. For most of the campaigns undertaken in the Minho estuary only metadata is available, i.e. the main annual statistical parameters: average, standard deviation, minimum and maximum. The estuary was therefore analysed as a single zone.

DATA COMPLETENESS AND RELIABILITY

Descriptions of the datasets are shown in Figure 16.

The data reliability is adequate, but the data completeness for all parameters is considered to be zero. Due to lack of data the NEEA methodology could only be partly applied to some of the primary and secondary symptoms.

OVERALL EUTROPHIC CONDITION

Primary symptoms method

Chlorophyll *a* is the only parameter with information for the primary symptoms. No information was found for epiphytes and macroalgae, which were therefore classified as "Unknown".

Chlorophyll *a*

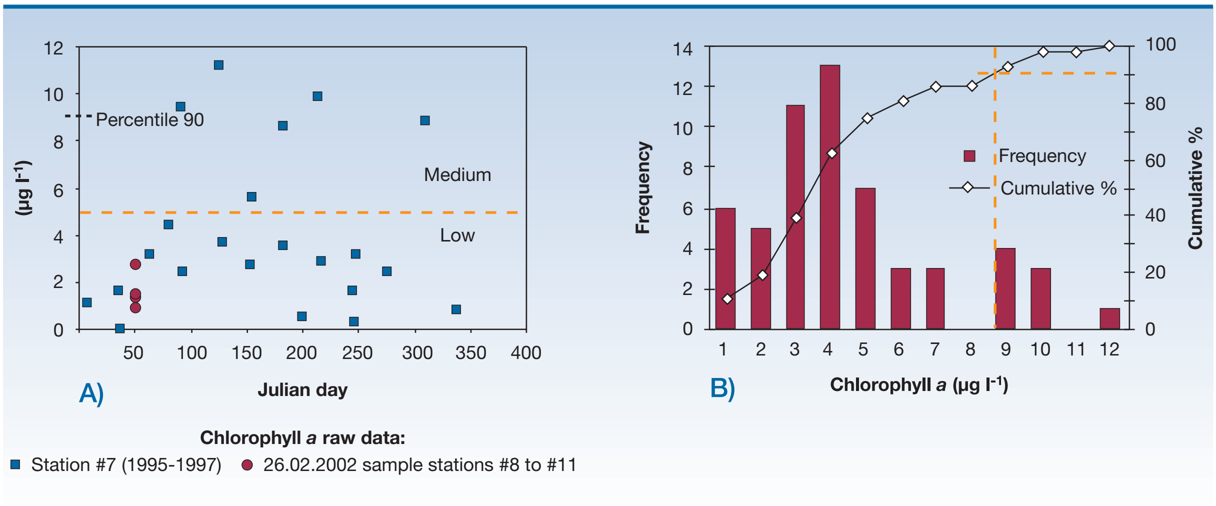
Based on the raw data and the metadata the chlorophyll *a* concentration falls in the "Medium" class (Figure 17).

FIGURE 16. DATASETS FOR THE MINHO ESTUARY.

Number of campaigns	Date	Stations	Parameters
1	26.02.2002	#8 to #11	Temperature; salinity; pH; dissolved oxygen; chlorophyll *a*, *b* and *c*; phaeopigments; ammonia; nitrate; nitrite; phosphate; silicate; suspended matter.
47	October 1993 to September 1997	#7	Temperature; salinity; pH; conductivity; dissolved oxygen; chlorophyll *a*; phaeopigments; ammonia; nitrate; nitrite; phosphate; total phosphorus; suspended matter.
12	January to December 1982	#8, #12.	Salinity.
		#8, #9, #10, #13, #14.	Suspended matter; % organic matter.
		#8, #9, #10, #12, #13, #14, 15.	Temperature; pH; dissolved oxygen.
5*	Monthly from May until September 1993	#1, #3, #4.	Temperature; salinity; pH; dissolved oxygen; chlorophyll *a*; ammonia; nitrite; nitrate; phosphate; total phosphorus.
12*	Annual cycle in the period of 1994-1997	#1, #3.	Temperature; salinity; pH; dissolved oxygen; chlorophyll *a*; ammonia; nitrite; nitrate; phosphate; total phosphorus.
12*	Monthly from November 1992 until October 1993	#1, #3, #4.	Temperature; salinity; pH; dissolved oxygen; chlorophyll *a*; phaeopigments; ammonia, nitrite, nitrate; phosphate, total phosphorus.
10*	Monthly from September 1996 until June 1997	#2, #5, #6.	Temperature; salinity; pH; chlorophyll *a*; phaeopigments; nitrate; phosphate, total phosphorus; suspended particulate matter.
9*	Monthly from October 1996 until June 1997	#2, #4, #6.	Temperature; salinity; pH.
12*	Monthly during one year	#1, #3.	Temperature; salinity; conductivity; pH; dissolved oxygen.

* For these campaigns only metadata (mean, standard deviation, minimum and maximum) were available for each station, tidal situation and sample depth.

FIGURE 17. MINHO ESTUARY: A) CHLOROPHYLL CONCENTRATIONS DURING AN ANNUAL CYCLE; B) FREQUENCY DISTRIBUTION FOR CHLOROPHYLL RAW DATA AND MAXIMUM VALUES OF METADATA (1993-2002).



These results are only indicative since:

1) Seasonal data are only available for one station;

2) Metadata do not allow the determination of percentile 90, used for classification of typical chlorophyll *a* maxima in NEEA.

Secondary symptoms method

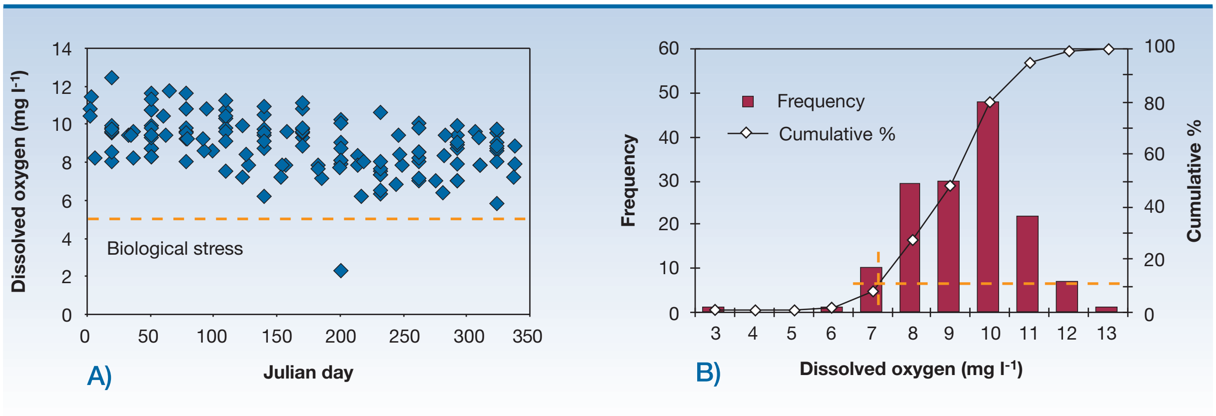
No information was reported in literature concerning submerged aquatic vegetation and nuisance and toxic blooms. Therefore these parameters are classified as “Unknown”. For dissolved oxygen, raw and metadata were analysed.

Dissolved oxygen

The percentile 10 value for dissolved oxygen is above the threshold for biological stress conditions (5 mg l^{-1}). There is only one value for the Minho estuary below the threshold. Because it is unique and has a value completely different from the universe of the sampling data it was considered an outlier. The results obtained with the raw data are confirmed by the metadata (Figure 18). There is not one sample with a minimum value below the biological stress condition.

There appear to be no problems regarding dissolved oxygen.

FIGURE 18. MINHO ESTUARY RAW DATA (1982 UNTIL 2002): A) DISSOLVED OXYGEN VALUES DURING AN ANNUAL CYCLE; B) FREQUENCY DISTRIBUTION FOR DISSOLVED OXYGEN.



OVERALL HUMAN INFLUENCE

Susceptibility

Dilution potential

The stratification of the estuary varies with freshwater discharge and tidal conditions:

- **During spring tides tidal processes are dominant - the tidal range reaches 4 meters and the estuary may be considered well-mixed;**
- **During winter the river flow reaches 1000 m^3 s^{-1}. In this situation the freshwater volume largely exceeds the tidal prism and the system is vertically stratified;**
- **During other seasons the estuary is moderately stratified.**

In order to calculate the NEEA dilution potential the intermediate conditions were considered and the estuary was classified as type B – "Moderate" category.

Flushing potential

The Minho estuary is mesotidal, with a tidal range of 3 m. Considering a mean annual freshwater inflow of 300 m^3 s^{-1} and a mean volume of 70 x 10^6 m^3 the flushing potential is estimated as "High".

Figure 19 shows the combination of dilution and flushing potential for the Minho estuary, which yields a final susceptibility result of "Low".

Nutrient inputs

The main sources of nutrients discharging into the estuary are:

1) Effluents from domestic wastewater treatment plants (WWTP);

2) Non-point sources (rainfall runoff).

The characterization of wastewater treatment for Portuguese urban areas in the Minho estuary basin is shown in Figure 20. The domestic nutrient loads were estimated based on the proportion of the population served by a sewage network and wastewater treatment plants (WWTP) (Figure 21).

Assumptions were made of a daily nutrient input per capita of 12 g N and 2.8 g P and 70% nutrient removal efficiency for the WWTP. The proportion of population that is not served by a sewage network was not considered since the wastewater discharges are not made directly into the estuary. No data were available for Spanish domestic loads, and the estimates for vulnerability and sensitivity in this work relate

FIGURE 19. OVERALL SUSCEPTIBILITY FOR THE MINHO ESTUARY.

Type	IF Vertical stratification	THEN Dilution volume		THEN Dilution potential
B	Partly mixed	$1/V_t$	10^{-8}	Moderate
	Tidal prism	**Freshwater flow/estuary volume**		**Flushing potential**
	Mesotidal	Moderate	0.37	High
	Overall susceptibility for the estuary: Low			

directly to management measures which may be taken in Portugal.

No data on nutrient inputs from industry were available for calculations. Since industry has a reduced importance in the watershed and industrial effluents represent only 5% of the mean annual domestic flow they were not considered a significant source.

Non-point sources were estimated based on the freshwater quality data and on the mean annual river inflows (Figure 22).

Calculations for the Minho river were made with water quality from a sampling station near the head of the estuary and, for the Coura river, using data from the Outeiro station. Spanish rivers were not considered due to lack of data.

FIGURE 20. POPULATION SERVED BY SEWAGE NETWORKS AND WASTEWATER TREATMENT IN THE MINHO ESTUARY.

Town	Resident population	Population served by sewage network and with WWTP	Treatment Level
Caminha	9 600	5 000	Tertiary
Paredes de Coura	10 000	2 000	Tertiary
Valença	15 300	7 700	Secondary
V.N. de Cerveira	9 100	1 800	Secondary
Total	**44 000**	**16 500**	

FIGURE 21. LOADS OF N AND P FROM DOMESTIC EFFLUENTS INTO THE MINHO ESTUARY.

	Population equivalent	Nutrient per capita (kg pop. equiv.$^{-1}$ yr^{-1})		Nutrient loads (ton yr^{-1})	
		Total N	Total P	Total N	Total P
Served by sewage network and WWTP	16 500	3	0.7	51	12
Without sewage network	27 500	-	-	-	-
Total	**44 000**	**-**	**-**	**51**	**12**

FIGURE 22. N AND P LOADS FROM FRESHWATER INFLOW OF THE MAIN AFFLUENTS TO THE MINHO ESTUARY.

River	Flow	River concentration		Annual load	
	(10^6 m^3 yr^{-1})	N (mg l^{-1})	P (mg l^{-1})	N (ton yr^{-1})	P (ton yr^{-1})
Minho	9 617	1.3	0.02	13 000	200
Coura	3 719	2.0	0.03	7 000	100
Total	-	-	-	**20 000**	**300**

The riverine nutrient inputs are considerable. The soil uses in the Portuguese catchment of the Minho river are shown in Figure 24. The main factor contributing to this appears to be cattle farming in the Spanish and Portuguese areas of the watershed (estuary and river). Additionally, some minor sources are:

- **Runoff of domestic effluents which are not linked to a sewage system;**
- **Direct discharge of domestic wastewater into the Minho river at Monção, near the upstream limit of the estuary.**

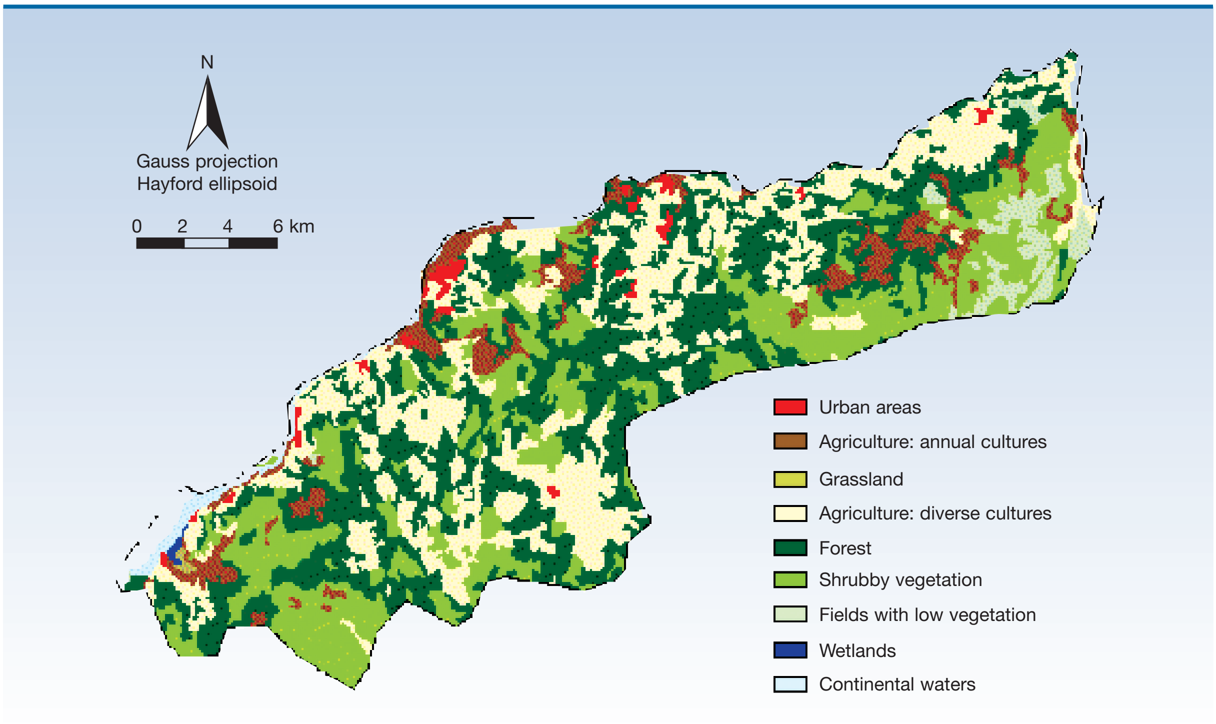
The application of the loading–susceptibility model described previously shows that the human influence is about 96%, which falls into the “High” category. The inputs to the Minho estuary are therefore considered to be high. Domestic effluents are negligible (Figure 23).

Although the freshwater nutrient loads to the estuary are rated as “High” the system susceptibility is “Low”, which leads to a final classification of “Moderate Low” for *Overall Human Influence*.

FIGURE 23. NITROGEN AND PHOSPHORUS LOADS FROM THE MAIN SOURCES OF NUTRIENTS TO THE ESTUARY.

Sources	Nitrogen (ton N y^{-1})	Phosphorus (ton P y^{-1})
Treated and untreated sources	51	12
Non-point sources (runoff)	20 000	300
Total	**20 051**	**312**

FIGURE 24. SOIL USES IN THE PORTUGUESE HYDROGRAPHIC BASIN OF THE MINHO RIVER.



All nutrient data in the Minho estuary are below the threshold for nitrate (50 mg l^{-1}) given in EU Directive 91/676/EEC (Figure 25).

DETERMINATION OF FUTURE OUTLOOK

No predictions about the evolution of domestic or industrial wastewater treatment systems are available. The land use proposals made by local authorities anticipate the increase of urban and industrial areas in the area of the Minho watershed, which would suggest an increase of nutrient loads. However, since the main input appears to be linked to cattle, the relative importance of these increases is debateable.

No predictions about nutrient input changes are available for the Spanish part of the river. Since this represents a high percentage of the total drainage basin of the river Minho the DFO is "Unknown".

SUMMARY OF THE NEEA INDEX APPLICATION

Figure 26 summarises the results obtained for the NEEA index to the Minho estuary.

FIGURE 25. NITRATE CONCENTRATIONS IN THE MINHO ESTUARY (STATIONS #7 TO #11).

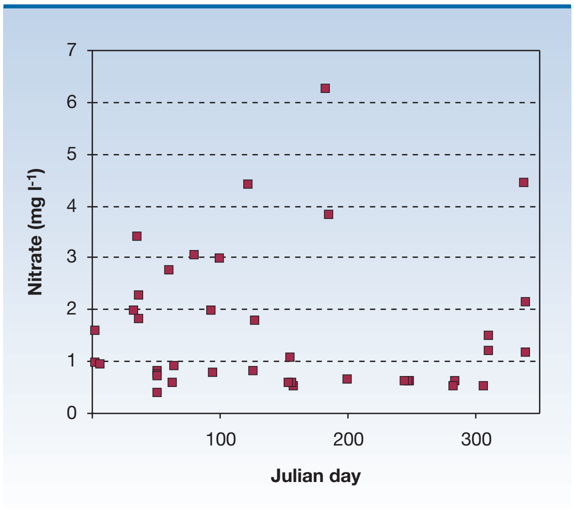


FIGURE 26. SUMMARY OF THE NEEA INDEX RESULTS OBTAINED FOR THE MINHO ESTUARY. SLE: SYMPTOM LEVEL EXPRESSION; EAR: ESTUARY AGGREGATION RULES; PSM: PRIMARY SYMPTOMS METHOD; SSM: SECONDARY SYMPTOMS METHOD.

Indices	Methods	Parameters/Values/EAR			Index category
Overall Eutrophic Condition (OEC)	PSM	Chlorophyll *a*	Medium	-	-
		Epiphytes	-		
		Macroalgae	-		
	SSM	Dissolved oxygen	Low	-	
		Submerged aquatic vegetation	-		
		Nuisance and toxic blooms	-		
Overall Human Influence (OHI)	Susceptibility	Dilution potential	Moderate	Low susceptibility	Moderate Low
		Flushing potential	High		
	Nutrient inputs	High nutrient input			
Future Outlook for future conditions (DFO)	Future nutrient pressures	-			-

CONCLUSIONS

The following conclusions can be drawn from the NEEA assessment of the Minho estuary:

- **The NEEA methodology could only be partly applied due to lack of data. In particular, data are lacking for the evaluation of the current state of the estuary, as regards primary and secondary eutrophication symptoms;**
- **Based on limited available data, a "Medium" classification was determined for chlorophyll *a*, but no spatial or temporal analysis could be carried out;**
- **The estuary does not appear to have dissolved oxygen problems;**
- **The OHI index classifies the system as "Moderate Low" although river nutrient loads are high;**
- **Solutions for reducing the nutrient runoff due to cattle farming should be considered;**
- **From the (lack of) available data it is clear that the Minho estuary needs a *Surveillance Monitoring* programme, covering the relevant parameters at a suitable spatial and temporal scale;**
- **The results of this monitoring programme are required to evaluate the eutrophic status of the estuary as regards the UWWTD and the Nitrates Directive.**

KEY REFERENCES

Fidalgo, M. L., 1998. Contribution to the ecological characterization of the river Minho estuary (northern Portugal). Verh. Internat. Verein. Limnol., 26, 1448-1451.

References for grey literature consulted for this chapter may be found at http://www.imar.pt/perfect/

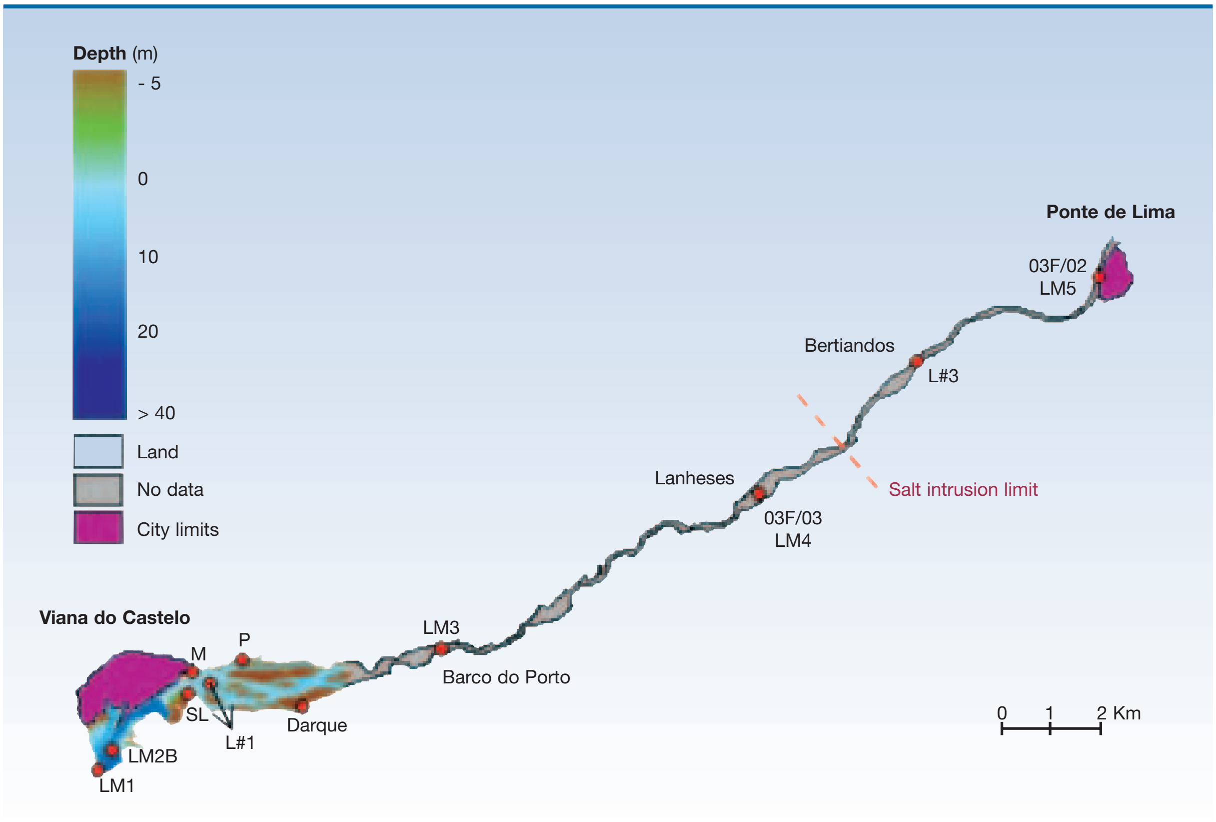
LIMA ESTUARY

GENERAL CHARACTERISTICS

The Lima river has its source in Spain and enters Portugal at Lindoso. It has a length of 108 km, 67 of which in Portugal, and reaches the ocean at Viana do Castelo.

The Lima estuary is shown in Figure 27, and has a mean depth of 2 m and a modular freshwater inflow of 54 $m^3\ s^{-1}$. Downstream, due to the development of sandy channels near Cabedelo, the estuary has a narrow, deep (> 5 m) connection to the ocean with over 5 m depth. The main physical properties of the Lima estuary are shown in Figure 28.

FIGURE 27. LIMA ESTUARY: BATHYMETRY, SAMPLING STATIONS AND SALT INTRUSION LIMIT.



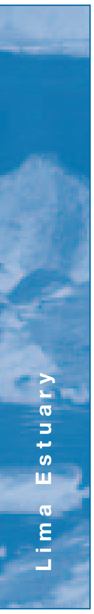


FIGURE 28. MAIN CHARACTERISTICS OF THE LIMA ESTUARY.

Parameter	Conditions	Value
Tidal range	Mean high tide	3.1 m
	Mean tide	2.0 m
	Mean low tide	0.9 m
Volume	Mean high tide	24×10^6 m^3
	Mean tide	19×10^6 m^3
	Mean low tide	15×10^6 m^3
Area	Mean high tide	5.84 km^2
	Mean tide	5.41 km^2
	Mean low tide	5.21 km^2
Tidal prism		9×10^6 m^3
Population (Viana do Castelo)		36 000
Mean residence time		1 day

FIGURE 29. MEDIAN SALINITIES FOR EACH STATION IN THE LIMA ESTUARY.

Station	Location	Median salinity
LM3	Barco do Porto	6.2
Darque	Darque channels (left bank)	3.1
P	Meadela salt pans (right bank)	27.8
M	Tide mill (right bank)	24.0
SL	S. Lourenço beach (right bank)	28.2
LM2B	Estuary mouth	31.0
LM1	Estuary mouth	35.9

HOMOGENEOUS AREAS

The median salinities calculated for each station are shown in Figure 29. Considering the salt intrusion as the upstream limit of the tidal freshwater zone, it is known that for low river flow conditions (4 m^3 s^{-1}) measured at Ponte de Lima, salt intrusion may reach Bertiandos. For average conditions, this limit was set to 2 km downstream for a 15 m^3 s^{-1} river flow (Figure 27). Since the most upstream station for which salinity data are available (station LM3) has a value falling into the mixing zone, it was not possible to determine the boundary between the tidal freshwater and mixing zones.

The boundary between the mixing and seawater zones could only be tentatively defined since it referred to salinity data from stations located on the shore or in channels running into the estuary. According to Figure 29 the transition between the mixing and seawater zones should occur between stations M and SL. Due to the lack of salinity data, only one zone was considered in the application of the NEEA indices corresponding to the area from the head to the estuary mouth.

DATA COMPLETENESS AND RELIABILITY

The Lima estuary was sampled for water quality parameters in 52 campaigns between 1984 and 1988, and 1 campaign in 2002 (Figure 30). Data were also collected in 1993 but were not available for this study. Most of the available datasets correspond to sampling sites located near the banks of the estuary or in the muddy sand channels running into the estuary (Figure 27).

Although the estuary was sampled at one station (L#1) over an annual cycle, these data are only for chlorophyll *a* and phytoplankton species composition. For the stations located at the mouth of the estuary, a dataset is available

FIGURE 30. DATASETS FOR THE LIMA ESTUARY.

Number of campaigns	Date	Area	Parameters
12	January to December 1984	North shore saltmarshes: - Tide mill (4.5 km from the mouth) - Salinas (6.5 km from the mouth)	Salinity Temperature Dissolved oxygen Oxygen saturation pH Nitrate, nitrite and ammonia Phosphate Silicate Chlorophyll *a*
16	July 1984 to October 1985	Intertidal zone in the South bank (3 km from the mouth)	
12	April 1985 to March 1986	South bank Salinas (8 km from the mouth)	
12	May 1987 to April 1988	One station in the centre of the estuary (3.8 km from the mouth)	Chlorophyll *a* Phytoplankton species Composition
1	February 2002	4 stations in the estuary	Salinity Temperature S.P.M. Dissolved oxygen pH Nitrate, nitrite and ammonia Phosphate Silicate Chlorophyll *a*, *b* and *c*

only for one sample date collected during a neap tide.

Due to the spatial and temporal data gaps, the full application of the NEEA methodology was not possible. However, all the primary and secondary symptoms were examined for the estuary as a whole.

OVERALL EUTROPHIC CONDITION

Primary symptoms method

Chlorophyll *a* is the only parameter with information for the primary symptoms. No information was found for epiphytes and macroalgae, which were therefore classified as "Unknown".

Chlorophyll *a*

Maximum chlorophyll *a* values in the Lima estuary do not exceed the threshold indicated in the NEEA for "Medium" eutrophic conditions. The percentile 90 value falls within the 4.5 µg l^{-1} class, below the threshold defined for the "Low" category (Figure 31).

Secondary symptoms method

Data for dissolved oxygen and phytoplankton species composition were analysed. No information was reported in the literature concerning submerged aquatic vegetation. Therefore this parameter is classified as "Unknown".

Dissolved oxygen

No values below the NEEA threshold for the biological stress conditions (5 mg l^{-1}) were registered for the Lima estuary.

The minimum values were obtained during the summer months (July and August) and the percentile 10 is within the 7 mg l^{-1} class indicating no problems with this parameter (Figure 32).

Nuisance and toxic blooms

Three species known to be toxic and/or harmful were identified: *Skeletonema sp.*, *Ceratium fusus* and *Ceratium furca*. These species were

FIGURE 31. LIMA ESTUARY: A) CHLOROPHYLL CONCENTRATIONS DURING AN ANNUAL CYCLE; B) FREQUENCY DISTRIBUTION FOR CHLOROPHYLL.

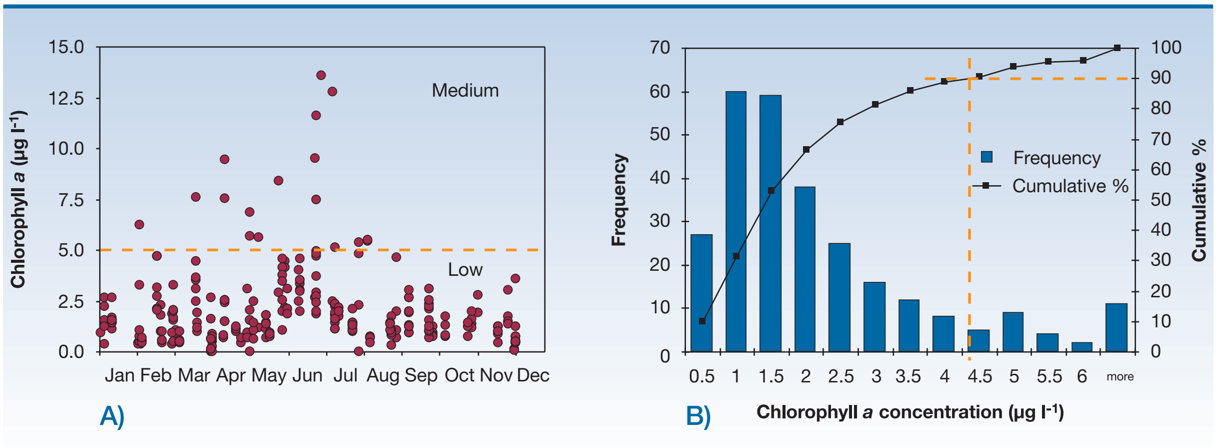
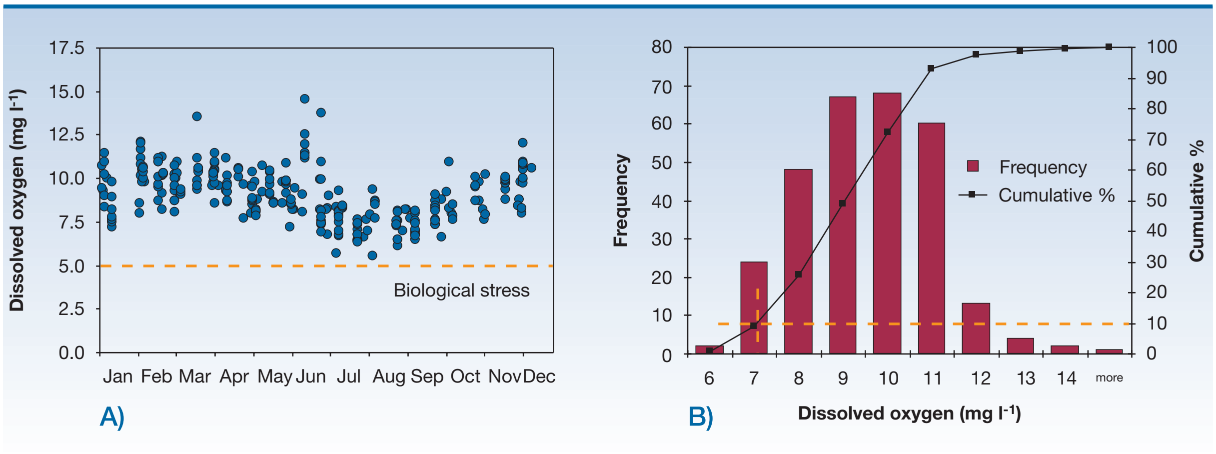


FIGURE 32. LIMA ESTUARY: A) DISSOLVED OXYGEN CONCENTRATIONS DURING AN ANNUAL CYCLE; B) FREQUENCY DISTRIBUTION FOR DISSOLVED OXYGEN.



detected in March and September but there is no reference to the occurrence of blooms. Furthermore, these data were collected synoptically with the chlorophyll *a* values presented in Figure 31, and given the low to medium concentrations obtained no problems were considered for this symptom.

OVERALL HUMAN INFLUENCE

Susceptibility

Dilution potential

No information was found in the literature for vertical stratification in the Lima estuary. However, the high freshwater inflow together with the morphological characteristics of the estuary should be enough to consider that minor vertical stratification occurs (Type B). Using the NEEA expression to calculate the estuary dilution volume for this stratification type (1 / estuary volume) the dilution potential falls into the “Low” category.

Flushing potential

The Lima estuary is a mesotidal estuary with a mean tidal range of 2 m. The ratio between the freshwater inflow and the mean estuary volume indicates that the system has a “High” capacity to flush nutrients.

In the NEEA matrix for estuarine export potential and susceptibility, the Lima estuary is classified as having the capacity to dilute and flush nutrients (“Moderate” susceptibility).

Nutrient inputs

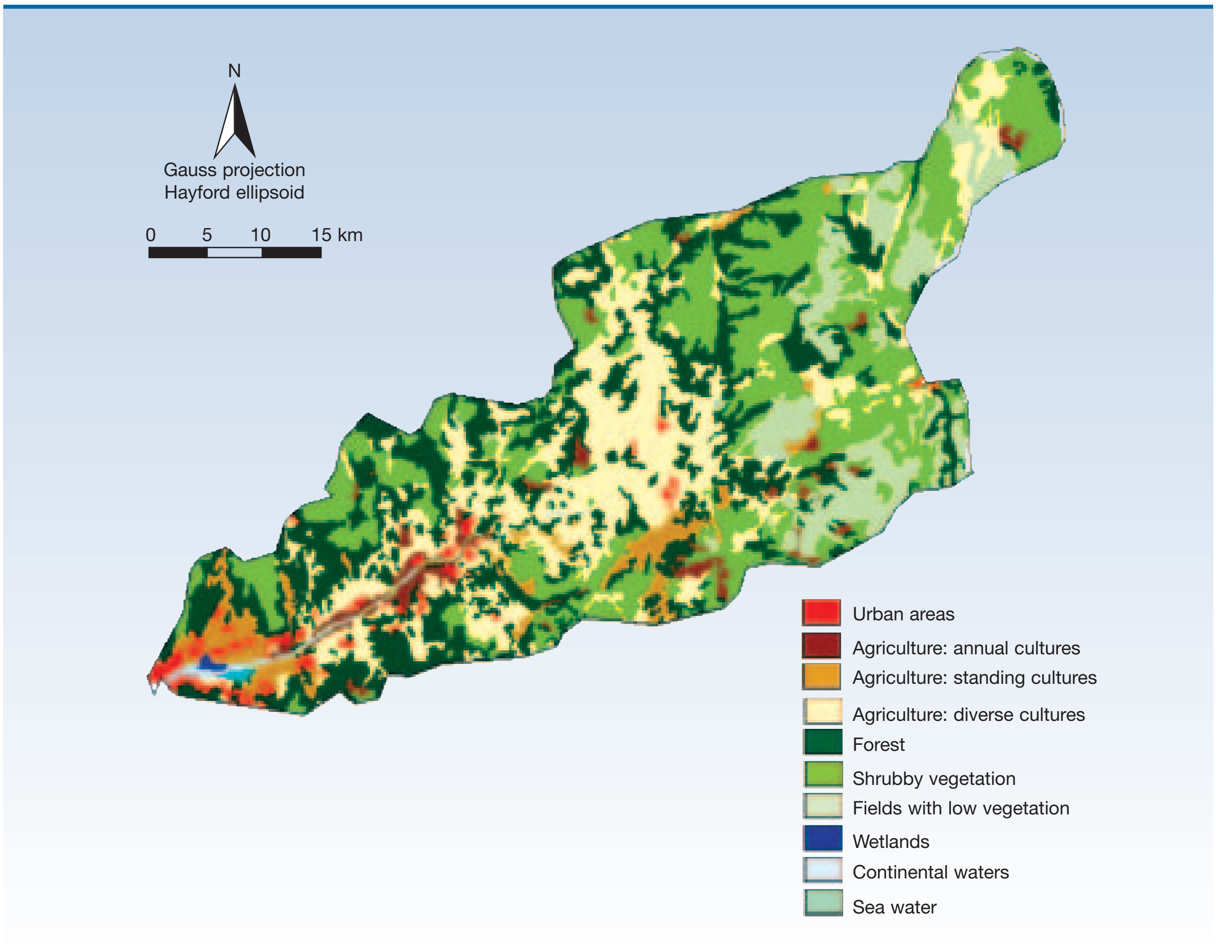
The main sources of nutrients discharging into the Lima estuary are:

1) Load from the river Lima, which includes the loads from treated and untreated urban effluents, treated and untreated industrial effluents and non-point sources upstream of Bertiandos.

Most of the nutrient inputs coming from the Viana do Castelo urban area are discharged treated or untreated directly into the sea. For this reason the main nutrient load generated on the estuary perimeter is due to non-point sources, largely agriculture (Figure 33). These sources of nutrients were quantified as 0.19 ton P y^{-1} and 0.51 ton N y^{-1} from Ponte da Barca until Viana do Castelo; these are negligible in comparison to the riverine inputs.

The nutrient sources coming from the river were

FIGURE 33. SOIL USES IN THE LIMA WATERSHED.



calculated using nitrogen and phosphorus concentrations in Lanheses (station 03F/03, Figure 28) and the modular river flow (54 $m^3 s^{-1}$). The nitrogen and phosphorus loads reaching the estuary are 1 077 ton y^{-1} and 86 ton y^{-1} respectively.

The application of the loading – susceptibility model followed the approach described for transitional waters in the methodology. The results obtained show that the human influence is about 72%, which falls into the "High" category. The final classification for the OHI in the Lima estuary is thus "Moderate High".

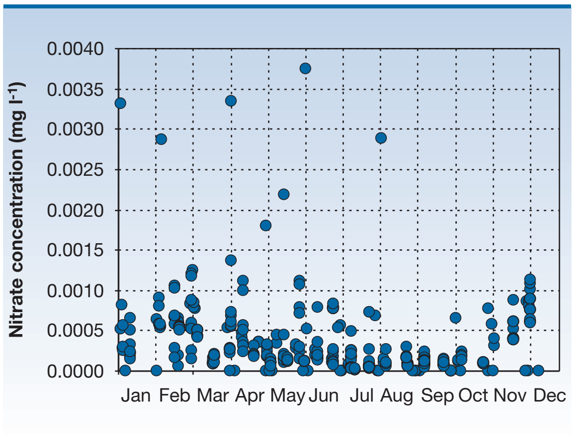
However, the data gaps identified should be borne in mind, since the median salinity of 26.8 used to run the model corresponds to sampling sites which cannot be considered as temporally and/or spatially representative of the whole system.

Taking into account the threshold (50 mg l^{-1}) in the EU Directive 91/676/EEC for the nitrate concentration, values in the Lima estuary are generally two orders of magnitude below it with a mean value of 0.6 mg l^{-1} (Figure 34).

DETERMINATION OF FUTURE OUTLOOK

The four wastewater treatment plants (WWTP) in the Lima watershed serve about 45 000 inhabitants and were planned for about 65 000 inhabitants (Figure 35). Although the Ponte da Barca WWTP has already reached its full capacity, an

FIGURE 34. NITRATE CONCENTRATIONS IN THE LIMA ESTUARY.



enlargement is planned. Considering the current level of WWTP use, which is about 70%, it can be considered that the present and future treatment of nutrients discharged into the Lima watershed is assured and no change in future nutrient pressures should occur.

SUMMARY OF THE NEEA INDEX APPLICATION

Figure 36 summarizes the results obtained for the application of the NEEA index to the Lima estuary.

FIGURE 35. CAPACITY OF THE WASTEWATER TREATMENT PLANTS IN THE LIMA WATERSHED AND FUTURE IMPROVEMENTS.

WWTP	Treatment level	Districts	Discharge basin	Resident population in 1998	Population to be served in the project
Arcos de Valdevez	Secondary	Arcos de Valdevez	River Vez (Lima affluent)	2 688	5 000
Ponte de Lima	Secondary	Ponte de Lima	Lima	3 898	6 000
Ponte da Barca	Secondary	Ponte da Barca	Lima	2 345	1 950
Viana do Castelo	Secondary	Viana do Castelo	Sea	35 650	52 400
			Total	**44 581**	**65 350**

FIGURE 36. SUMMARY OF THE NEEA INDEX RESULTS OBTAINED FOR THE LIMA ESTUARY. SLE: SYMPTOM LEVEL EXPRESSION; EAR: ESTUARY AGGREGATION RULES; PSM: PRIMARY SYMPTOMS METHOD; SSM: SECONDARY SYMPTOMS METHOD.

Indices	Methods	Parameters/Values/EAR			Index category
Overall Eutrophic Condition (OEC)	PSM	Chlorophyll *a*	Low	-	-
		Epiphytes	-		
		Macroalgae	-		
	SSM	Dissolved oxygen	Low	-	
		Submerged aquatic vegetation	-		
		Nuisance and toxic blooms	0		
Overall Human Influence (OHI)	Susceptibility	Dilution potential	Low	Moderate susceptibility	Moderate High
		Flushing potential	High		
	Nutrient inputs	High nutrient input			
Future Outlook for future conditions (DFO)	Future nutrient pressures	No change in future nutrient pressures			No change

CONCLUSIONS

The following conclusions can be drawn from the NEEA index application to the Lima estuary:

- **The available values for chlorophyll *a* and dissolved oxygen indicate no problems with eutrophication in the system;**
- **The OEC index value could not be assessed due to spatial and temporal data limitations as well as lack on information for the other primary and secondary symptoms (macroalgae, epiphytes, submerged aquatic vegetation);**
- **Although no problems with eutrophication were detected and the estuary is considered to have the capacity to flush nutrients, the inputs to the system are considered "High" and the OHI index classifies the estuary in the "Moderate High" category;**
- **The future nutrient pressure (DFO) are expected to remain unchanged;**
- **The OEC symptoms, together with the Overall Human Influence, show a clear need for a comprehensive survey programme in the Lima estuary. This *Surveillance Monitoring* should take into account the characterization of water quality, and the identification of the key processes involving the main biotic compartments related to eutrophication: phytoplankton, macroalgae and submerged aquatic vegetation. A monitoring exercise of this nature, carried out at an appropriate temporal and spatial scale, will allow a full application of NEEA and an appropriate classification under the UWWTD as regards eutrophication and Nitrates Directive.**

KEY REFERENCES

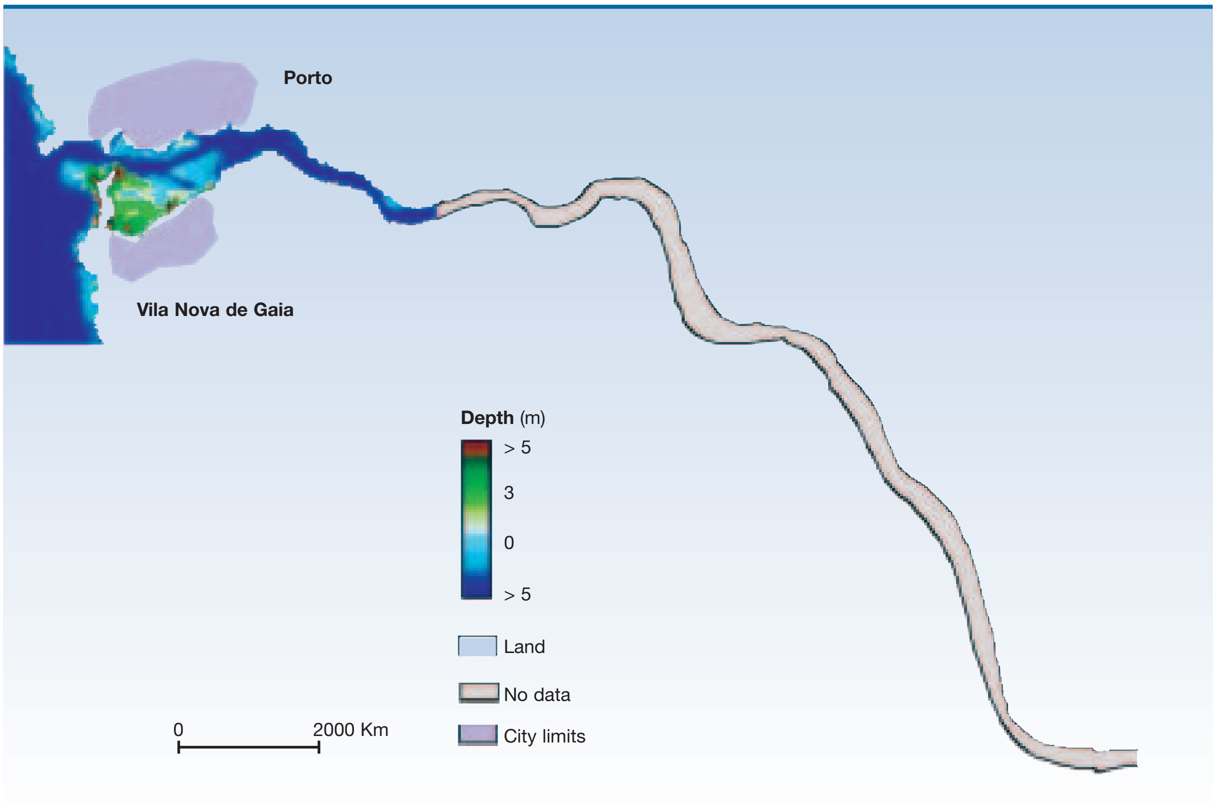
References for grey literature consulted for this chapter may be found at http://www.imar.pt/perfect/

GENERAL CHARACTERISTICS

The Douro river drains the largest watershed of the Iberian Peninsula, with about 98 000 km^2, 80% in Spain and 20% in Portugal (19 600 km^2). The source is at *Los Picos de Urbion* at an altitude of 1 700 m, and the river has a total length of 927 km. The estuary is shown in Figure 37, from the upstream limit at Crestuma-Lever dam to the mouth downstream of the city of Porto.

The Douro basin is heavily dammed, mostly for hydroelectric generation. Nevertheless, these interventions do not significantly decrease the total water and sediment discharge. The annual discharge is estimated as 17 100 hm^3, which corresponds to a modular flow of 542 m^3 s^{-1}, about 85% of the undisturbed flow.

FIGURE 37. DOURO ESTUARY BATHYMETRY, AND CITY LIMITS.



The Douro estuary (Figure 37) has its upstream limit at the Crestuma-Lever dam, about 22 km from the mouth at “Foz do Douro”. At the entrance into the Atlantic Ocean, there is a mobile sand bar, the “Restinga do Cabedelo”

and the estuary develops upstream within a narrow valley with rocky shores.

The estuary is generally divided into three zones:

- **Lower estuary, from the mouth until Arrábida Bridge;**
- **Mid estuary, until Freixo Bridge;**
- **Higher estuary, until the Crestuma-Lever Dam.**

The main characteristics of the Douro estuary are summarised in Figure 38. The estuary exhibits vertical salinity gradients, due to the important river discharge and due to its physiography.

There are no significant intertidal areas. The small salt marshes of S. Paio, Lordelo, Massarelos, Areinho and Avintes are reported as degraded and are the only remaining wetlands.

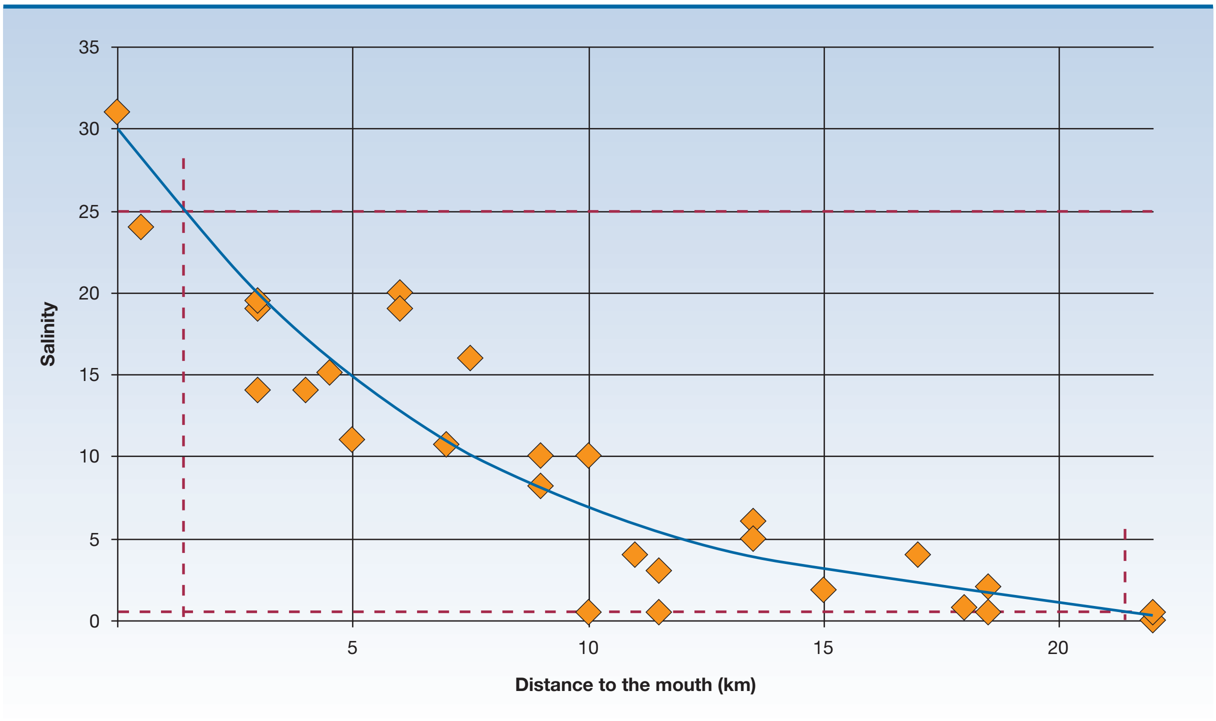
FIGURE 38. MAIN CHARACTERISTICS OF THE DOURO ESTUARY.

Parameter	Value
Volume	58.8 x 10^6 m^3
Total Area	9.8 x 10^6 m^2
River flow	542 m^3 s^{-1}
Tidal Range (max)	3.8 m
Tidal Prism	20.9 x 10^6 m^3
Population	755 000
Mean residence time	1 day (winter flow)
	9 days (summer flow)

HOMOGENEOUS AREAS

Published results on salinity are very limited, with most sources providing only statistical data. The longitudinal profile presented in Figure 39 was made with raw data covering

FIGURE 39. LONGITUDINAL PROFILE OF SALINITY AT THE DOURO ESTUARY



discrete observations in summer and winter and averaged “winter” and “summer” data representing an 18 month time series.

A polynomial trend line was fitted to the data (r = 0.95) and the limits of salinity zones taken graphically from the curve. The mixing zone is limited downstream by a section about 1.5 km from the mouth and extends until near the artificial river end member (Crestuma-Lever dam). In winter conditions tidal freshwater may be present further downstream, at about 12 km from the mouth.

The scarcity and nature of available salinity data suggest that the Douro estuary can be treated as a single homogeneous mixing zone characterized by salinity between 0.5 and 25. Expert knowledge indicates that under most hydrological conditions a seawater zone may not be identified within the estuary.

DATA COMPLETENESS AND RELIABILITY

Although there are data from 163 campaigns, most of them are from only one station in the estuary. The other data series correspond to data collected at several stations on only one sampling date (Figure 40).

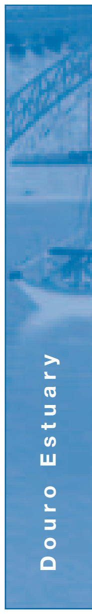


FIGURE 40. DATASETS FOR THE DOURO ESTUARY.

Number of campaigns	Date	Area	Parameters
2	July and October 1987	Ten stations downstream of the Crestuma-Lever dam	Temperature Salinity pH Dissolved oxygen
160	October 1993 to September 1997	Only one station downstream of the Crestuma-Lever dam	Temperature pH Dissolved oxygen SPM Nitrate Ammonia Phosphate BOD5 Faecal coliforms
1	February 2002	Five stations downstream of the Crestuma-Lever dam	Salinity Temperature pH Dissolved oxygen Oxygen saturation Chlorophyll *a*, *b* and *c* Phaeopigments Nitrate, nitrite, ammonia Phosphate Silicate

OVERALL EUTROPHIC CONDITION

Primary symptoms method

Chlorophyll *a*

Available chlorophyll *a* data for the Douro estuary consist in a few discrete values and graphs with average values per station and season (winter and summer) for a period of 18 months (October 2000-March 2002) (Figure 41).

These data are unsuitable for determining median values of chlorophyll *a*. Nevertheless, for indicative purposes, the cumulative frequency of this data set was calculated. The percentile 90 falls into the "Low" category (Figure 42), and the maximum value is 5 μg l^{-1}, although it should be noted that it is an average value with no associated information on range or standard deviation.

FIGURE 41. AVAILABLE DATA ON CHLOROPHYLL FOR THE DOURO ESTUARY.

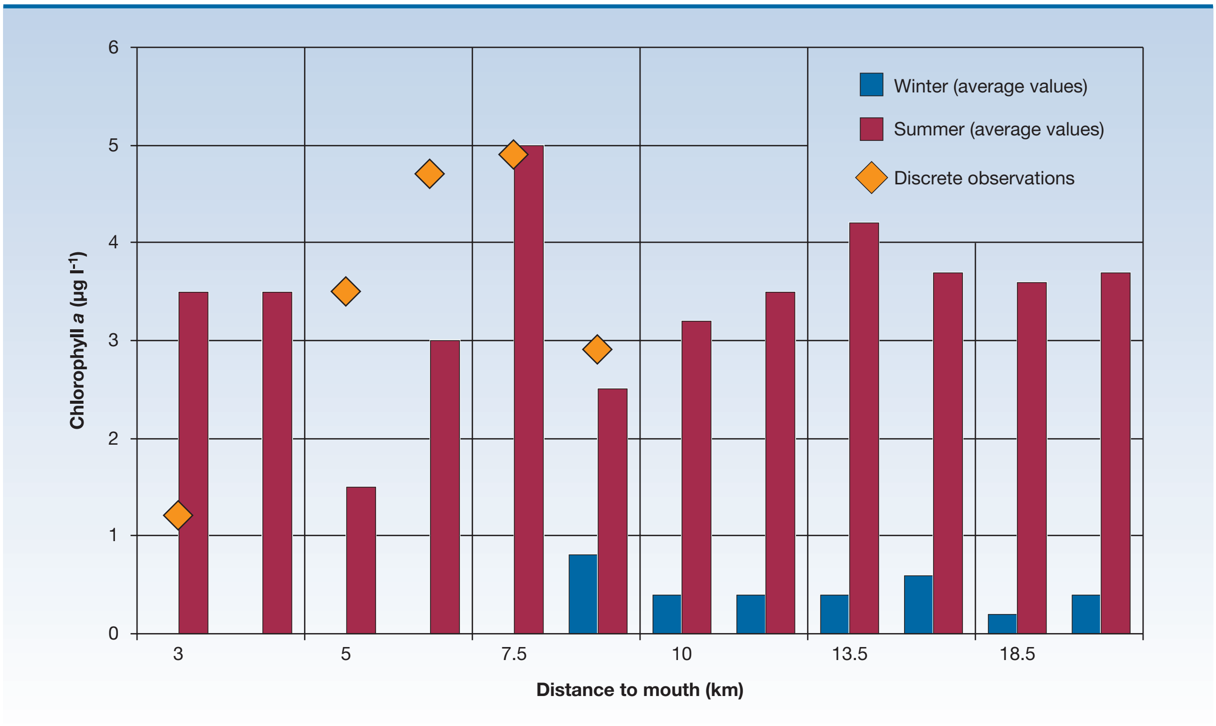
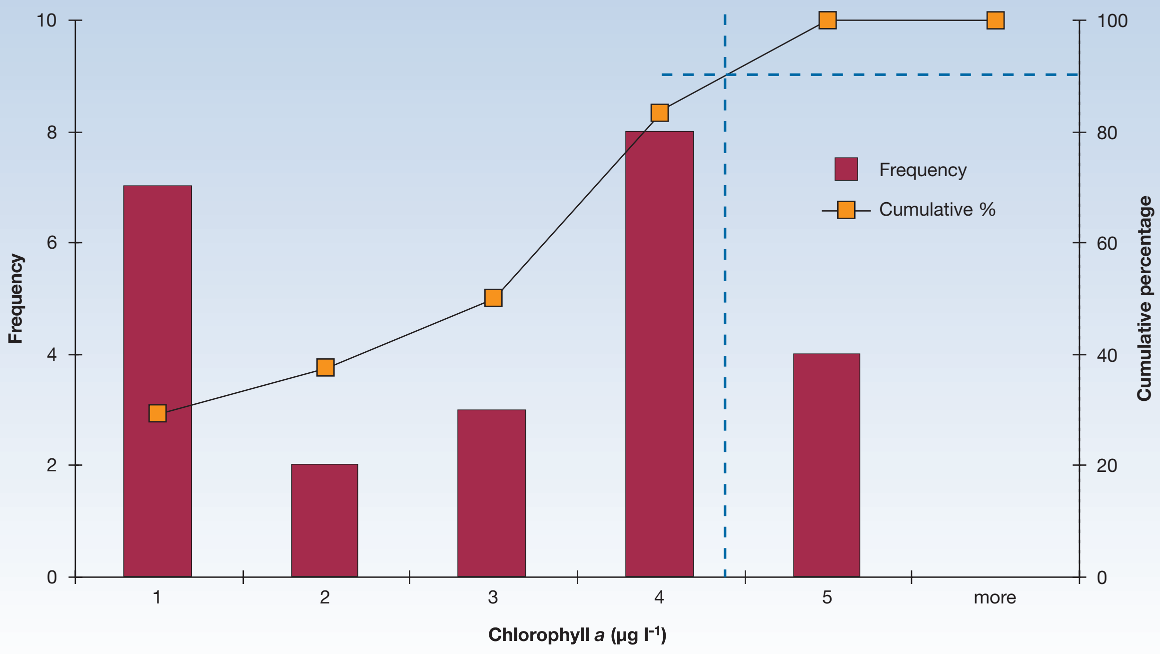


FIGURE 42. FREQUENCY DISTRIBUTION FOR CHLOROPHYLL IN THE DOURO ESTUARY.



Macroalgae and epiphytes

The coverage of macroalgae is a function of the substrate, available light and nutrients.

In the Douro estuary the most important macroalgal areas are in the lower estuary. The presence of *Fucus sp*. and *Enteromorpha* is strongly connected with brackish water at the surface. The most abundant species are shown in Figure 43.

The presence of macroalgae is mostly confined to the marginal shallow zones, as the Douro estuary is a turbid water body. This turbidity seems to be mostly due to natural causes associated with its flow and the geological nature of its catchment, although the contribution of direct loads of suspended matter from point and local diffuse sources may also be relevant. The turbidity, mostly due to detritus, may be a limiting factor of estuarine productivity. No occurrences of problems with exceptional

FIGURE 43. MOST ABUNDANT SPECIES OF MACROALGAE IN THE DOURO ESTUARY.

Green algae	*Ulva lactuca* *Enteromorpha sp.* *Codium tomentosum*
Brown algae	*Saccorhiza polyschides* *Laminaria digitata* *L. hyperborea* *Fucus sp.* *Bifucardia bifurcata* *Sargassum sp.* *Dictyota dichotoma*
Red algae	*Lithophyllum incrustans* *Corallina mediterranea* *Gigartina stellata* *Gelidium sp.* *Gracilaria sp.*

macroalgal growth have been reported in the literature or identified by experts.

Secondary symptoms method

Dissolved oxygen

Figure 44 shows a longitudinal profile of dissolved oxygen concentrations. Most values are within the range from 6 to 10 mg l^{-1} although high values corresponding to super-saturation conditions are observed in the sections about 10 km from the mouth.

Figure 45 displays the frequency distribution of the dissolved oxygen data. The percentile 10 is above 6 mg l^{-1}, showing an estuary without significant signs of oxygen depletion. Nevertheless, one data point has a value of 3 mg l^{-1}, classified as biological stress.

Submerged aquatic vegetation

Apart from the information on macroalgae, present in the littoral region of the estuary, no information is available on submerged aquatic vegetation. The high turbidity may be a natural limiting factor for benthic photosynthetic activity.

Nuisance and toxic blooms

The presence of dinoflagellates in the estuary is strongly dependent on river flow, as well as on the occurrence of blooms in the near coastal waters. At the Crestuma-Lever reservoir, in late summer, the presence of cyanophytes has been reported and these organisms may be transported into the estuary. Nevertheless, no reports on episodes of harmful algal blooms have been reported.

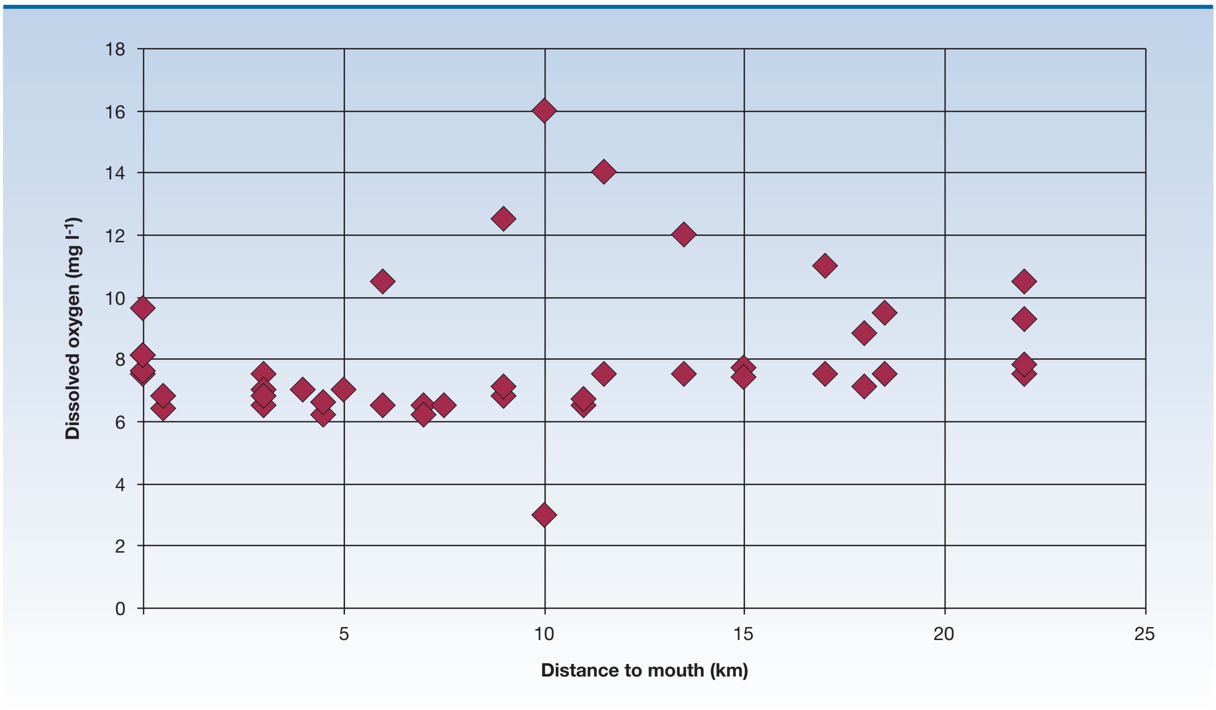
OVERALL HUMAN INFLUENCE

Susceptibility

Dilution potential

The Douro is a mesotidal estuary with a tidal range varying from 1.4 m to 3.8 m for neap and

FIGURE 44. LONGITUDINAL PROFILE OF DISSOLVED OXYGEN IN THE DOURO ESTUARY.



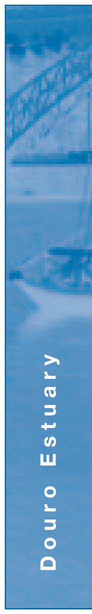
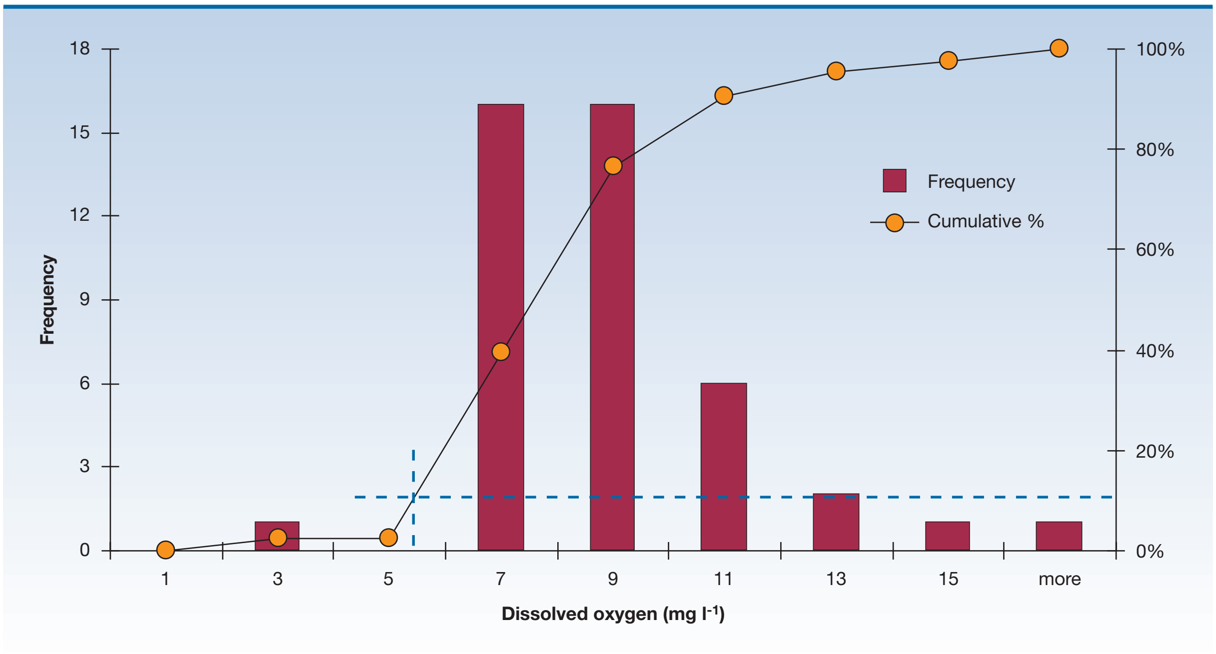


FIGURE 45. FREQUENCY DISTRIBUTION FOR DISSOLVED OXYGEN IN THE DOURO ESTUARY.



spring tides. The average tidal range is about 2.2 m. The river flow is highly variable so a stratification analysis must consider these two variables.

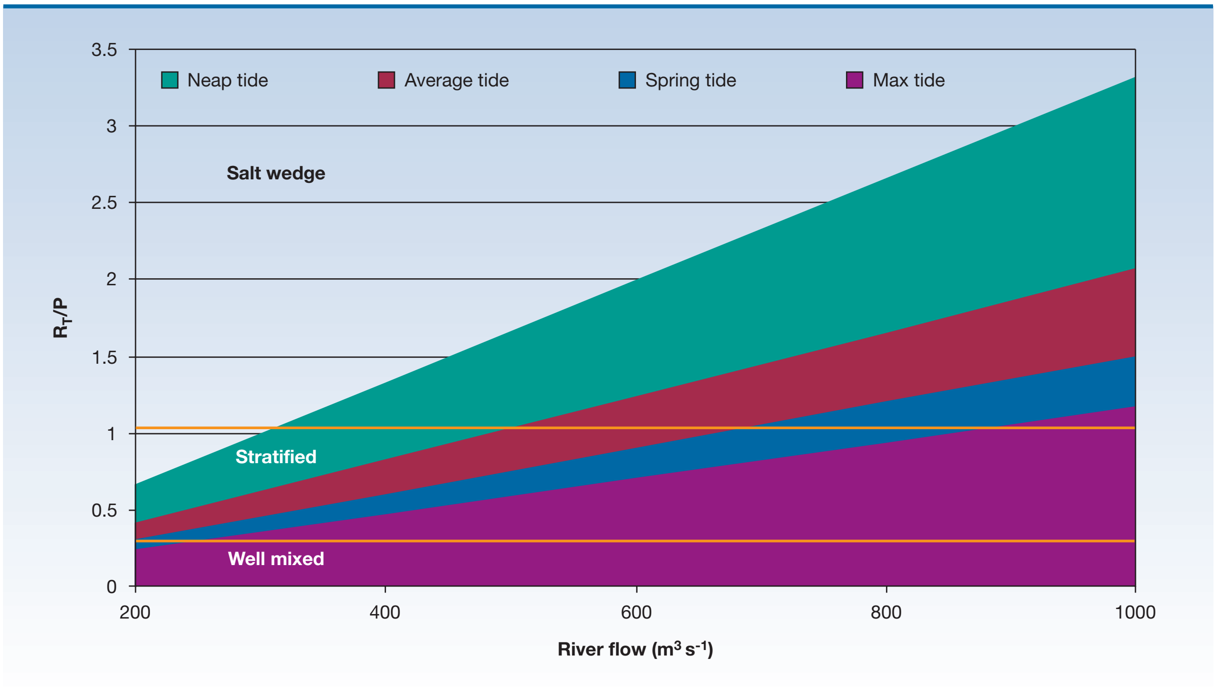
The estuary number is above 0.25 (Figure 46) in all situations and above 1.00 for flows greater than 850 $m^3\ s^{-1}$ at equinoctial spring tide. This agrees with heuristic knowledge that the Douro estuary is almost permanently stratified.

The dilution volume is calculated with the fresh water volume (V_{total} x fresh water fraction). Considering a salinity of 8 (median of values in Figure 39) the dilution volume is 2.2 x 10^{-8}. According to the NEEA criteria, the dilution potential is “Low”.

Flushing potential

The flushing potential is also a function of the relative values of the estuarine and river flows. The ratio of the modular fresh water inflow to the estuary volume is 0.8 d^{-1}, which classifies the estuary within the “High” category for the flushing potential.

FIGURE 46. VARIATION OF ESTUARY NUMBER WITH FLOW AND TIDAL RANGE.



The overall susceptibility of the Douro estuary may be classified as “Moderate”.

Nutrient inputs

The main source of nutrients in the Portuguese part of the catchment is domestic wastewater entering the Douro estuary from different origins:

- **Treated and untreated effluents from populations in the estuary catchment;**
- **Wastewater from populations in the catchments of the Douro and Sousa rivers.**

The nutrient inputs from wastewater effluents were calculated based on the population-equivalents, daily nutrient inputs per capita (10 g N d^{-1} and 3 g P d^{-1}) and treatment efficiency. The loads generated in the drainage basins of the estuary, Douro and Sousa rivers are presented in Figure 47.

As a result of the populations resident in the estuary catchment (Porto and Vila Nova de Gaia) discharging untreated sewage, the nutrient loads are similar to those from the much larger basin of the Douro river (Figure 48).

FIGURE 47. ESTIMATED NUTRIENTS IN WASTEWATER FROM BASINS DRAINING TO THE DOURO ESTUARY.

Basin	Nutrients (ton y^{-1}) Total N	Total P
River Douro	2440	737
River Sousa	177	562
Douro estuary	2134	631

FIGURE 48. WASTEWATER SOLUTIONS IN THE DOURO ESTUARY CATCHMENT.

	Inhabitants %
Served by sewage network and WWTP	16
Served by sewage network	45
Not served	39

The nutrient loads into the estuary were calculated based on direct wastewater discharges (Figure 49) and on river loads (Figure 50).

The river loads were calculated using nutrient concentration and discharge at Crestuma-Lever for the Douro river and at the mouth of the Sousa river.

FIGURE 49. WATEWATER LOADS INTO THE DOURO ESTUARY.

City	Population PEQ	Treatment efficiency % Total N	Total P	Load ($ton.y^{-1}$) Total N	Total P
Gondomar	20 400	28	28	54	16
Porto	266 200	0	0	972	292
V.N. de Gaia	59 200	0	0	216	65
Total	**345 800**	**-**	**-**	**1242**	**373**

FIGURE 50. NITROGEN AND PHOSPHORUS LOADS FROM RIVERS FEEDING INTO THE DOURO ESTUARY.

Source	Nitrogen ($ton\ y^{-1}$)	Phosphorus ($ton\ y^{-1}$)
River Sousa	488	22
River Douro	18 928	52
Total	**19 416**	**545**

The relative contribution of each nutrient source is presented in Figure 51.

A simple estimate using these values and the modular flow results in the determination of the order of magnitude of river inputs that integrate the contribution from the upstream basin to the estuarine loads. The land use pattern in the Douro basin is presented in Figure 52. Intensive agriculture with important use of fertilizers is not relevant in this basin. The Douro slopes, upstream of the estuary, are mainly occupied by vineyards with relatively low export potential of nitrogen and phosphorus.

The application of the loading – susceptibility model for transitional areas using the median salinity value of 8 taken from Figure 39, the modal flow (542 $m^3\ s^{-1}$) and the estuary volume (Figure 38) shows that the human influence is

FIGURE 51. RELATIVE CONTRIBUTION OF EACH NUTRIENT SOURCE IN THE DOURO ESTUARY.

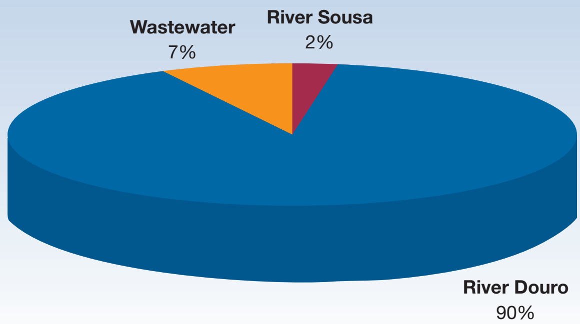
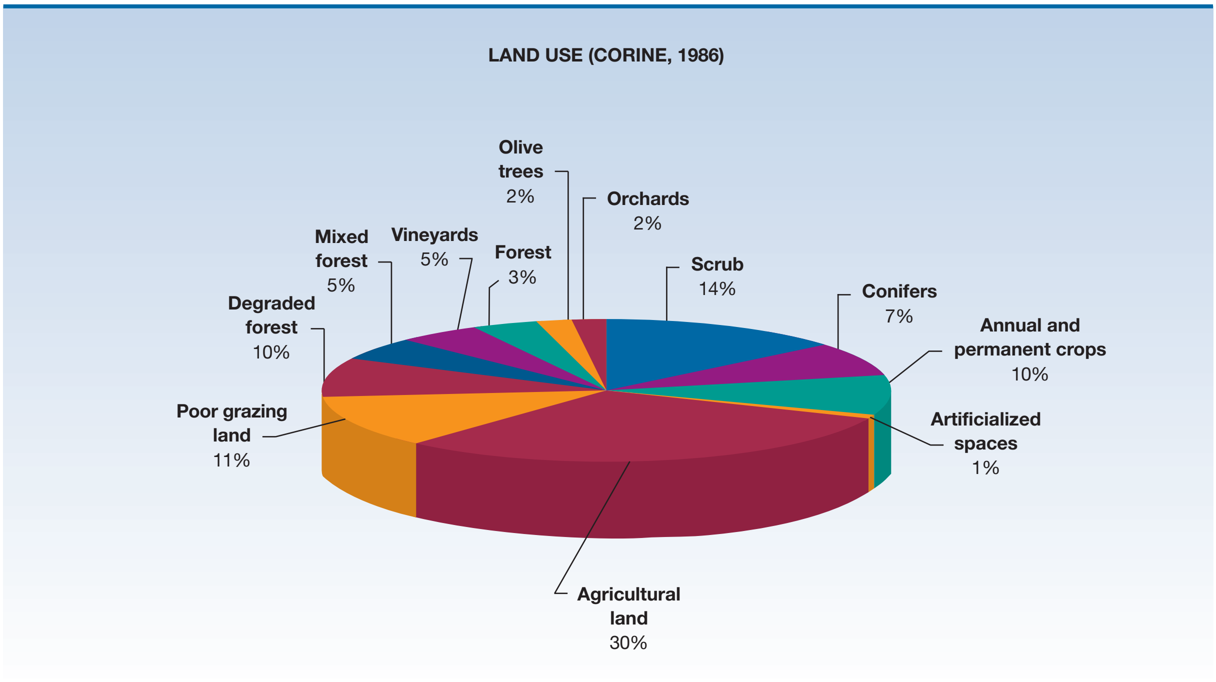


FIGURE 52. RELATIVE IMPORTANCE OF DIFFERENT LAND USES IN THE DOURO BASIN.



about 98%, which falls into the “High” category. Combining the moderate susceptibility with the high nutrient inputs, the overall classification for the Douro is terms of human influence, is “Moderate High”.

DETERMINATION OF FUTURE OUTLOOK

It is expected that the loads of nutrients from urban sources will decrease, as the wastewater treatment plants of Porto and Gaia, as well as those in the estuarine catchment, become fully operational.

SUMMARY OF THE NEEA INDEX APPLICATION

Figure 53 summarises the results of the application of the NEEA methodology. It must be stressed that this exercise was done using a rather limited dataset and in such circumstances the conclusions are mostly indicative. Nevertheless, susceptibility is determined on

FIGURE 53. SUMMARY OF THE NEEA INDEX APPLICATION TO THE DOURO ESTUARY. SLE: SYMPTOM LEVEL EXPRESSION; EAR: ESTUARY AGGREGATION RULES; PSM: PRIMARY SYMPTOMS METHOD; SSM: SECONDARY SYMPTOMS METHOD.

Indices	Methods	Parameters/Values/EAR			Index category
Overall Eutrophic Condition (OEC)	PSM	Chlorophyll *a*	Low	-	-
		Epiphytes	0		
		Macroalgae	0		
	SSM	Dissolved oxygen	Low	-	
		Submerged aquatic vegetation	-		
		Nuisance and toxic blooms	0		
Overall Human Influence (OHI)	Susceptibility	Dilution potential	Low	Moderate susceptibility	Moderate High
		Flushing potential	High		
	Nutrient inputs	High nutrient input			
Future Outlook for future conditions (DFO)	Future nutrient pressures	Reduction in future nutrient pressures			Improve Low

the basis of morphological and hydrographical data that is accurate enough for this work.

CONCLUSIONS

The following conclusions can be drawn from the NEEA index application to the Douro estuary:

- **There is a clear need for a *Surveillance Monitoring* programme to complete its characterization of water quality under different hydrographic and hydrological conditions. This survey should also take into account the identification of the key processes involving the main biotic compartments related to entrophication: phytoplankton, macroalgae and SAV;**
- **Although the OEC index value could not be assessed, the available values for chlorophyll *a* and dissolved oxygen indicate no problems with eutrophication in the system;**
- **The nutrient input to the system is "High" and susceptibility (based in the dilution and flushing potencial) is "Moderate" which results in an OHI classification of "Moderate High";**
- **The nitrate concentrations are far below the threshold indicated in the Nitrates Directive 91/676/EEC.**

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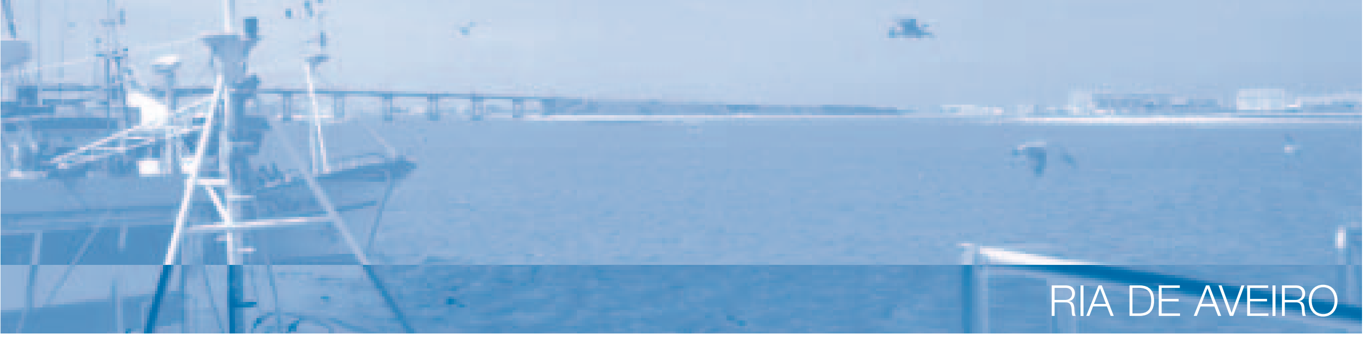


RIA DE AVEIRO

GENERAL CHARACTERISTICS

The Ria de Aveiro is a shallow lagoon system with several prolonged channels. It is separated from the Atlantic Ocean by a sand spit with an length of 45 km. About 76% of the system volume is exchanged over each tidal cycle, through an artificially fixed inlet.

In terms of hydraulic properties the Ria de Aveiro can be separated into five channels (Figure 54): the main channel (river Vouga), the Ovar channel, the Espinheiro channel, the Ílhavo channel and the Mira channel. There are several rivers or streams discharging into the channels, the main being the river Vouga, which discharges into the Espinheiro channel. Freshwater discharges to the system are seasonal and range from 4.3 m s^{-1} during summer to an extreme value of 820 m^3 s^{-1} in the winter. The freshwater inflow causes a

FIGURE 54. RIA DE AVEIRO: BATHYMETRY, CHANNELS AND SAMPLING STATIONS.

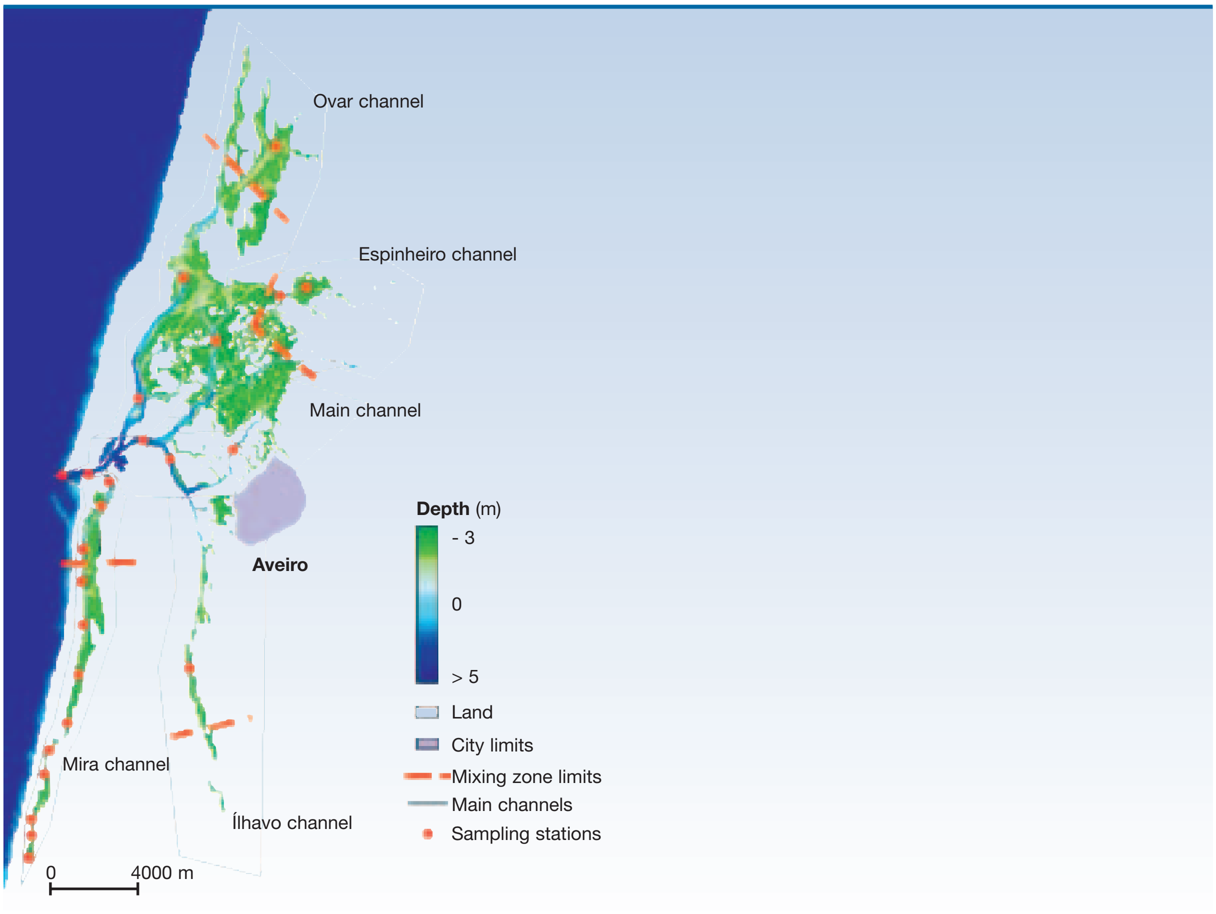
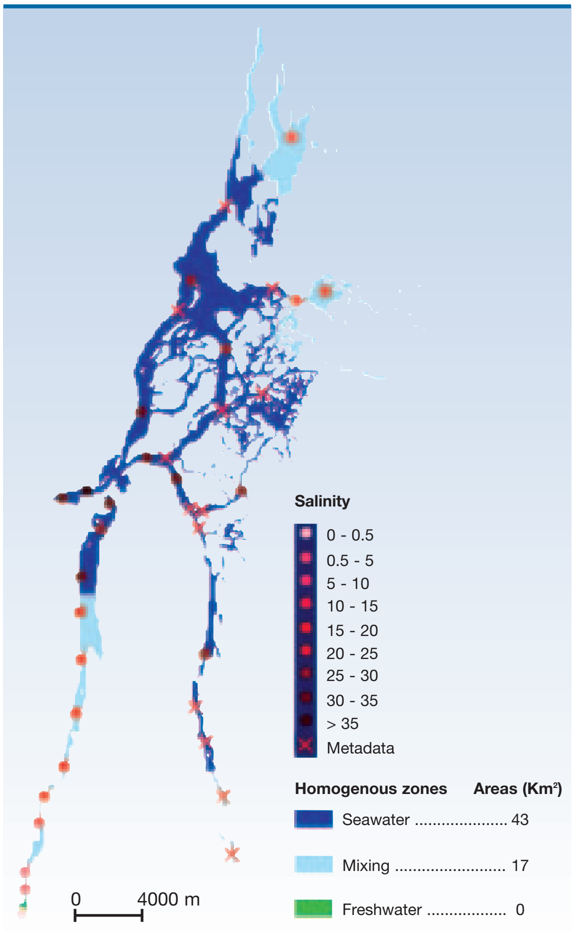


FIGURE 55. MAIN CHARACTERISTICS OF THE RIA DE AVEIRO.

Parameter	Conditions	Value
Tidal range	Mean high tide	3.0 m
	Mean tide	2.0 m
	Mean low tide	0.7 m
Volume	Mean high tide	158 x 10^6 m^3
	Mean tide	84 x 10^6 m^3
	Mean low tide	39 x 10^6 m^3
Area	Mean high tide	74 km^2
	Mean tide	60 km^2
	Mean low tide	17 km^2
Tidal prism		119 x 10^6 m^3
Population	Resident (October to May)	250 000
	Peak (June to September)	300 000
Mean residence time	-	4 days

FIGURE 56. RIA DE AVEIRO: SALINITY ZONES, SALITY STATIONS.



longitudinal salinity gradient in the channels. The main physical properties of the Ria de Aveiro are shown in Figure 55.

HOMOGENEOUS AREAS

The definition of the salinity zones in the Ria was made using only the sampling stations with available data for all seasons and tidal situations. Salinity median values for each station were defined in a geographic information system (GIS) implemented for the Ria de Aveiro. The area of influence of each station was determined by the Thiessen polygons method. For each polygon, the homogeneous zone category was assigned.

A freshwater zone was defined in the extreme of the Mira channel. Since it is a very small area (< 1 km^2) it was included in the mixing zone and only two salinity zones were considered for the application of the NEEA methodology (Figure 56).

Although a potential freshwater zone was identified for a neap tide situation in the lower limit of the river Vouga, data for other tidal situations are required in order to confirm the classification of this area as a tidal freshwater zone.

DATA COMPLETENESS AND RELIABILITY

The number of campaigns, dates and water quality parameters for the Ria de Aveiro are shown in Figure 57. The analysis of the data completeness and reliability (DCR) is presented in Figure 58. The entire Ria de Aveiro DCR value is 42%.

FIGURE 57. DATASETS FOR THE RIA DE AVEIRO.

Number of campaigns	Date	Area	Parameters
3	February, May and August 1990	Mixing	Salinity; pH; temperature.
2	July and September 1998	Seawater and mixing	Salinity; SPM; temperature; ammonia; nitrate; nitrite; phosphate; silicate; dissolved oxygen.
12	February, May, August and November 1998, 1999 and 2000	Seawater and mixing	Salinity; SPM; temperature; chlorophyll *a*, *b* and *c*; ammonia; nitrate; nitrite; phosphate; silicate; dissolved oxygen; dissolved N; dissolved P; total N; total P.
1	February 2002	Seawater and mixing	Salinity; temperature; chlorophyll *a*; phaeopigments; nitrate; nitrite; ammonia; silicate.
10	Twice monthly, from January until May 1972	Seawater	Temperature; salinity; chlorophyll *a*, *b* and *c*, carotenoids.
1	Semidiurnal tidal cycle, April of 1985	Mixing	Salinity; temperature; chlorophyll *a*; ammonia; nitrate; nitrite; phosphate; silicate; total alkalinity.
2	March and June of 1986	Seawater and mixing	Temperature; salinity; pH; % of organic matter.
12	Monthly from May 1988 until April 1989	Mixing	Temperature; salinity; pH; dissolved oxygen.
24	Monthly samples 1989 and 1990	Mixing	Temperature; salinity; pH; chlorophyll *a*; phaeopigments; suspended particulate matter; particulate organic matter; bacterial numbers; bacterial biomass.
5	Semidiurnal tidal cycle, February, April, June, August and October 1989	Mixing	
4	Semidiurnal tidal cycle, February, April, June and August 1990	Mixing	
7	April, August and October of 1992 and 1993. January 1993	Seawater	Temperature; salinity; pH; dissolved oxygen.
6	April, May and August of 1992, December and January of 1993, March of 1994	Seawater and mixing	Temperature; salinity; chlorophyll *a*.

FIGURE 58. DATA COMPLETENESS AND RELIABILITY CALCULATION FOR THE RIA DE AVEIRO.

DCR rating for each parameter							Total
Chl *a*	Epiphytes	Macroalgae	DO	SAV	Nuisance algae	Toxic algae	DCR
100%	0%	0%	100%	100%	0%	0%	43%

OVERALL EUTROPHIC CONDITION

Primary symptoms method

Chlorophyll *a*

Maximum values of chlorophyll *a* calculated with the percentile 90 were highly variable between salinity zones (Figure 59 and Figure 60). A "High" level of expression was obtained for chlorophyll *a* in the estuary.

The percentile 90 value obtained from chlorophyll *a* data in the seawater zone falls within the threshold defined for "Medium" eutrophic conditions. The level of expression for this parameter in the seawater zone falls within the "High" category since there is a high spatial coverage for the medium or high values.

The concentrations of chlorophyll *a* obtained for the mixing zone are higher than those in the seawater zone. The percentile 90 falls within the "High" category and some data largely exceed the threshold of 60 µg l^{-1} (Figure 60). The analysis of the available dataset suggests that this problem is confined to the lower end of the

FIGURE 59. RIA DE AVEIRO, SEAWATER ZONE: A) CHLOROPHYLL CONCENTRATIONS DURING AN ANNUAL CYCLE; B) FREQUENCY DISTRIBUTION FOR CHLOROPHYLL (1972 – 2000).

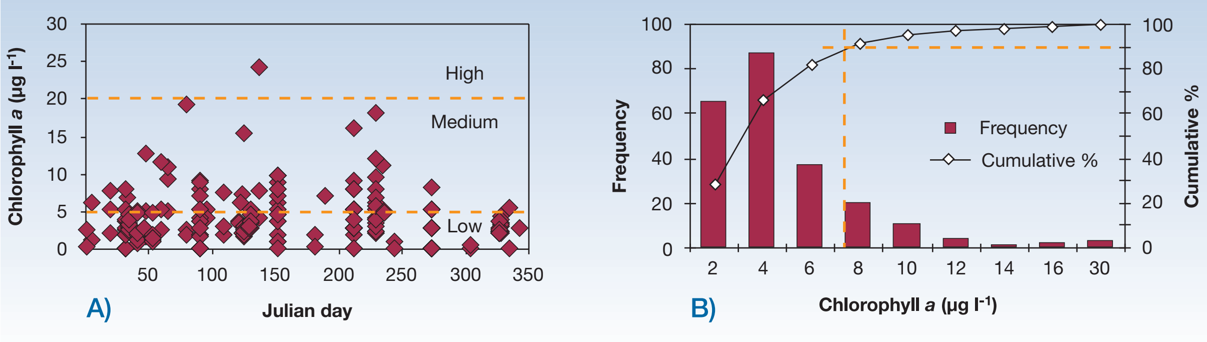


FIGURE 60. RIA DE AVEIRO, MIXING ZONE: A) CHLOROPHYLL CONCENTRATIONS DURING AN ANNUAL CYCLE; B) FREQUENCY DISTRIBUTION FOR CHLOROPHYLL A (1988 – 2000).

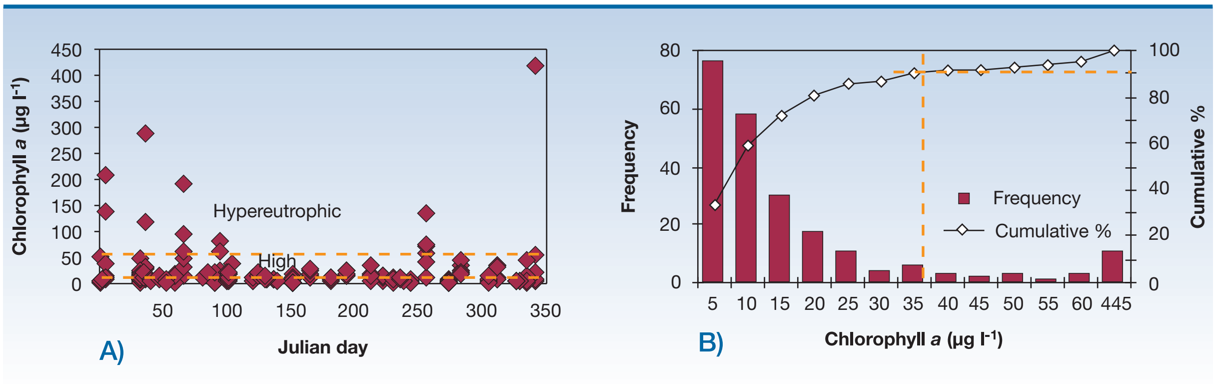
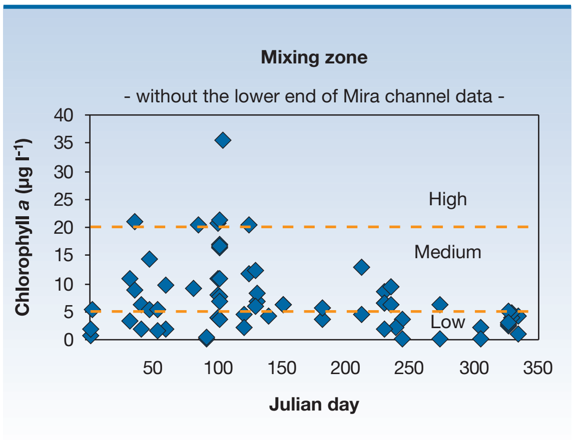


FIGURE 61. RIA DE AVEIRO, MIXING ZONE: CHLOROPHYLL CONCENTRATIONS DURING AN ANNUAL CYCLE.



Mira channel (Figure 61). This is emphasized by the chlorophyll *a* percentile 90 value (17 µg l^{-1}) for the mixing zone excluding the lower Mira channel data, which falls within the "Medium" category.

The spatial coverage was determined by calculating the percentage of affected cells within each zone (Figure 62). A station is considered affected if it has concentrations above the lower limit of the category that was determined with the chlorophyll *a* data percentile 90 values for all the stations in its salinity zone.

FIGURE 62. SPATIAL COVERAGE OF SAMPLING STATIONS.

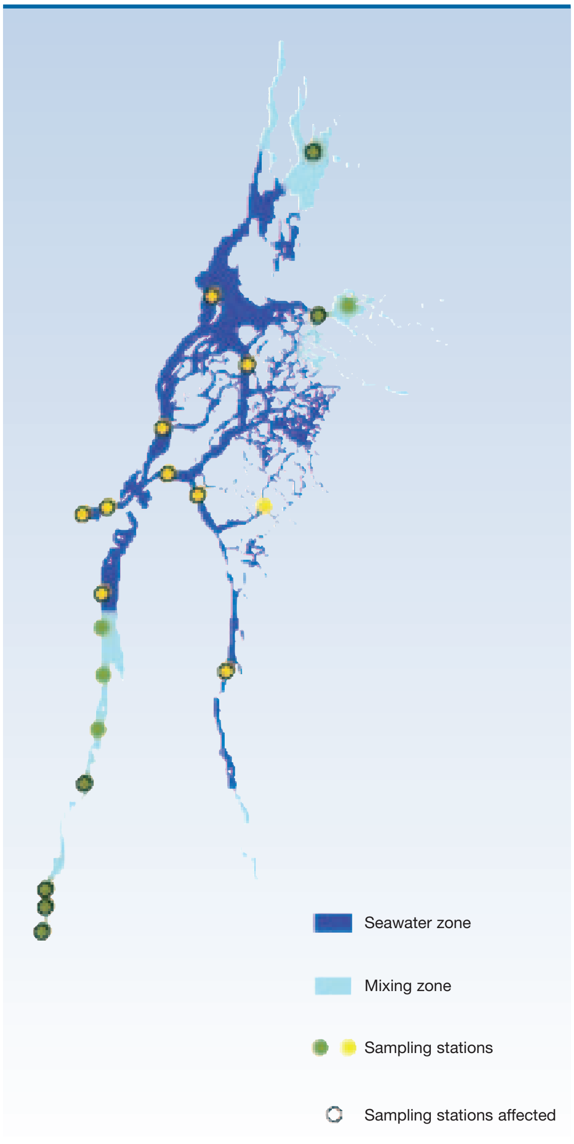


FIGURE 63. RESULTS OF THE NEEA INDEX APPLICATION FOR THE CHLOROPHYLL IN THE RIA DE AVEIRO. SLE MEANS SYMPTOM LEVEL OF EXPRESSION.

ZONE	IF Concentration	AND Spatial coverage	AND Frequency	THEN Expression	Value	Area	SLE
Seawater	Medium	High	Periodic	High	1	43	0.72
Mixing	High	High	Periodic	High	1	17	0.28
					Total	**60**	**1**

Flag A: Not enough data were available. In this case, assumptions were made based on conservative estimates that unknown spatial coverage is at least 10% of a zone.

Figure 63 summarises the results of the NEEA index application for chlorophyll *a*.

Epiphytes

In the Ria de Aveiro submerged aquatic vegetation and macroalgae (locally named *moliço*) were important economic resources at least since 1880 as a natural fertiliser. This activity began to decline in the 1960's and 1970's, with crops of 3 000 ton (wet weight) in 1979 compared with

FIGURE 64. SPECIES COMPOSITION OF MOLIÇO IN 1936 SORTED BY ABUNDANCE (1 – HIGHER, 8 – LOWER) AND IN 1979/81 WITH BIOMASS FOR HOMOGENOUS ZONES.

1936		
Order	**Species**	**Group**
1	*Zostera nana*	Submerged aquatic vegetation
2	*Potamogeton pectinatus*	Submerged aquatic vegetation
3	*Ruppia spiralis*	Submerged aquatic vegetation
4	*Ruppia rostellata*	Submerged aquatic vegetation
5	*Zostera marina*	Submerged aquatic vegetation
6	*Chara flexilis, Chara aspera*	Seaweeds
7	*Myriophyllum spicatum*	Seaweeds
8	*B. siphonacea, Ulva, Enteromorpha*	Seaweeds

1979/81			Biomass (ton dw)	
Order	**Species**		**Seawater zone**	**Mixing zone**
1	*Potamogeton pectinatus*	SAV	627	53
2	*Ruppia cirrhosa*	SAV	263	357
3	*Zostera noltii*	SAV	0	285
4	*Gracillaria verrucosa*	Seaweeds	130	206
5	*Chlorophyceae*	Seaweeds	188	93

FIGURE 65. PERCENTAGE OF BIOMASS OF *MOLIÇO* SPECIES IN 1979/81 BY HOMOGENOUS ZONE. MACROALGAE IN BOLD.

Channel distribution Homogenous zone	Ovar channel (tip) Mixing	Ovar channel (middle #1) Seawater	Ovar channel (middle #2) Seawater
Potamogeton pectinatus	52%	10%	1%
Ruppia cirrhosa	22%	62%	13%
Zostera noltii	0%	1%	53%
Gracillaria verrucosa	16%	17%	3%
Chlorophyceae	11%	10%	30%

crops of about 400 000 ton (wet weight) in 1883 and 250 000 ton (wet weight) in 1930. The decrease of cropped biomass is related to the economic competitiveness of this type of fertilizer.

The species composition of *moliço* in 1936 and in 1979-81 is presented in Figure 64, sorted by abundance. For the period of 1979-81 the biomass data are also available.

The *moliço* species can occur singly or in interspecific association. The presence of epiphytes on submerged aquatic vegetation and their distribution in the channels is documented in several studies in 1936, 1970's and 1979-81. Epiphytes are dominated by filamentous green macroalgae. In the study period there was a reduction in spatial coverage: in 1936 association of *moliço* species were observed in four channels (Ovar, Mira, Ílhavo and Main channels), this spatial distribution was limited to the Ovar channel in 1979-81.

Combining the information given in Figure 64 and Figure 65 an equilibrium between submerged aquatic vegetation and macroalgae can be suggested. There are also no indications of problematic epiphytic growth in the literature, therefore the level of expression for this primary symptom is zero.

FIGURE 66. NUMBER OF MACROALGAL SPECIES IN THE RIA DE AVEIRO.

Class	Total number
Chlorophyceae	30
Rhodophyceae	18
Unidentified	1

Macroalgae

The number of macroalgal species present in Ria de Aveiro are shown in Figure 66 by macroalgal class with a numeric predominance of green algae. Densities and biomass of macroalgae that appear in the relevant areas of *moliço* are shown in Figure 67.

In the mixing zone there is a dominance of green algae over the red alga *Gracillaria verrucosa*. In the seawater zone this relation is variable with the sampling site. Macroalgal biomass density is similar in both zones.

There are descriptions from the beginning of the XXth century of a high natural abundance of *moliço* in the Ria de Aveiro. The available data on biomass as well as the literature on this symptom give no indications on problematic

FIGURE 67. BIOMASS DENSITY AND TOTAL BIOMASS OF MACROALGAE IN THE *MOLIÇO* AREAS.

	Ovar channel (tip) Mixing		Ovar channel (middle #1) Seawater		Ovar channel (middle #2) Seawater	
	g dw m^{-2}	ton dw	g dw m^{-2}	ton dw	g dw m^{-2}	ton dw
Chlorophyceae	90	188	83	80	9	13
Gracillaria verrucosa	62	130	49	47	109	159
Total	**152**	**318**	**132**	**127**	**118**	**172**

growth occurrences. Therefore the level of expression for this symptom equals zero in all the zones.

Secondary symptoms method

Dissolved oxygen

In the two Ria de Aveiro salinity zones, the values obtained for the dissolved oxygen percentile 10 (Figure 68) are higher than the threshold adopted as indicative of biological stress. Thus, there are no problems with low dissolved oxygen concentrations and the level of expression takes a value of zero in both zones.

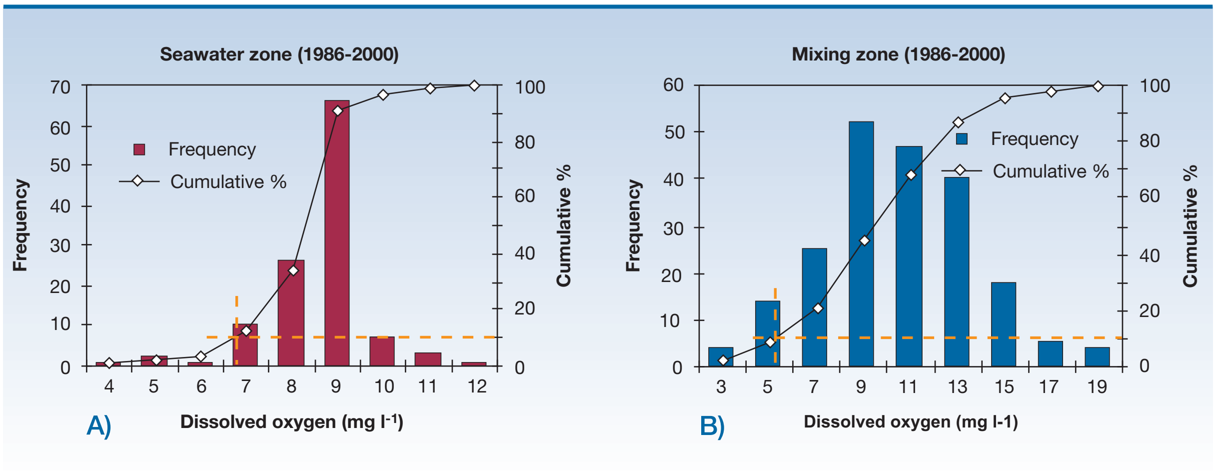
Submerged aquatic vegetation

The last (1979-81) existing biomass estimates in Ria de Aveiro (14 000 ton wet weight) indicate a value that is two orders of magnitude lower than annual crops harvested before 1960. This indicates that during the available data period there was a reduction of the submerged aquatic vegetation spatial coverage.

In 1936 *moliço* was present in almost all the Ria channels. In the 1970's the area was confined to Ovar and Mira channels and in 1979-81 only in the Ovar channel. The current estimated area of SAV in the Ria de Aveiro is about 8 km^2. The reduction in SAV in the Ria de Aveiro may be due to the following factors, singly or in combination:

- Changes in current velocity due to channel dredging and inlet consolidation, which affect sediment transport and salinity distributions;
- Alterations in management practices for harvesting SAV;

FIGURE 68. FREQUENCY DISTRIBUTION FOR DISSOLVED OXYGEN IN THE A) SEAWATER AND B) MIXING ZONES OF RIA DE AVEIRO.



- **Increased nutrient loads, leading to enhanced pelagic production and decreased light availability for benthic production due to shading.**

Since the focus of this study is on eutrophication, the last option was examined by comparing the concentration of suspended particulate matter (spm) with the fraction of phytoplankton in this material. This was carried out by converting water column chlorophyll *a* first to carbon and then to dry matter, and then determining the ratio of phytoplankton equivalent spm to total spm. The median shading component was 3% (P_{90}= 25%) which indicates that the role of pelagic algae in reducing available light energy for SAV is not significant. It would appear that the disappearance of SAV is therefore largely related to factors other than nutrient enrichment, but a precautionary classification of the SAV loss as "Moderate" was used (Figure 69).

Nuisance and toxic blooms

The occurrence of "red tides" is referenced in the literature for Ria de Aveiro and adjacent coastal waters every year between 1985 and 1993. 34 potentially toxic species were listed for this system in a 70 year survey period (1929 – 1998). Information regarding the duration, periodicity and persistence of these events, is still required for the application of the NEEA index. However, there is evidence that these blooms develop in frontal systems offshore, and are then advected into the Ria de Aveiro. This phenomenon, which is well described for the Western Iberian coast makes these events difficult to manage, except through measures such as preventive fisheries interdition.

Figure 69. Results of the NEEA index application for the submerged aquatic vegetation in the Ria de Aveiro.

ZONE	IF SAV Loss	AND Magnitude of loss	THEN Expression	Value	Area	SLE
Seawater	Observed	Moderate	Moderate	0.5	43	0.14
Mixing	Observed	Moderate	Moderate	0.5	17	0.36
				Total	**60**	**0.5**

OVERALL HUMAN INFLUENCE

Susceptibility

Dilution potential

The low depth and high tidal amplitudes make Ria de Aveiro a vertically well-mixed system, with an estuary number of 3%. The dilution potential is classified in type A, "High" category, although the dilution volume factor (10^{-8} m^3) is relatively low when compared to larger estuaries.

Flushing potential

Ria de Aveiro is a mesotidal estuary with a tidal range of 2.4 m. Considering a mean annual freshwater inflow of 73 m^3 s^{-1} and the mean volume of 84 x 10^6 m^3 the flushing potential is estimated as "Moderate".

Following the NEEA methodology the estuarine export potential and susceptibility is classified as "Low" based on dilution and flushing potential.

Nutrient inputs

The main sources of nutrients discharging into the Ria de Aveiro are:

1) Non-point sources (due to rainfall runoff).

Recently, an integrated wastewater treatment solution was implemented. The system includes a treatment plant and a sea outfall for domestic and industrial sewage from the Ria de Aveiro watershed. Since effluents are not discharged directly into the Ria they were not considered in this analysis. Domestic and industrial nutrient inputs not connected to this treatment system (about 10%) were considered as diffuse loads.

Non-point sources were estimated based on river nutrient concentrations and on the mean annual freshwater flow of the Ria de Aveiro drainage basin (Figure 70).

Figure 71 shows the land uses of the Ria de Aveiro watershed where there is a large proportion of agricultural area. Anthropogenic non-point sources and ocean exchange are the only sources considered to contribute nutrient loads into the system.

FIGURE 70. N AND P LOADS FROM FRESHWATER INFLOW OF RIA DE AVEIRO DRAINAGE BASIN.

Water flow (m^3 s^{-1})	River concentration		Annual load	
	N (mg l^{-1})	P (mg l^{-1})	N (ton yr^{-1})	P (ton yr^{-1})
73	1.2	0.17	2 760	390

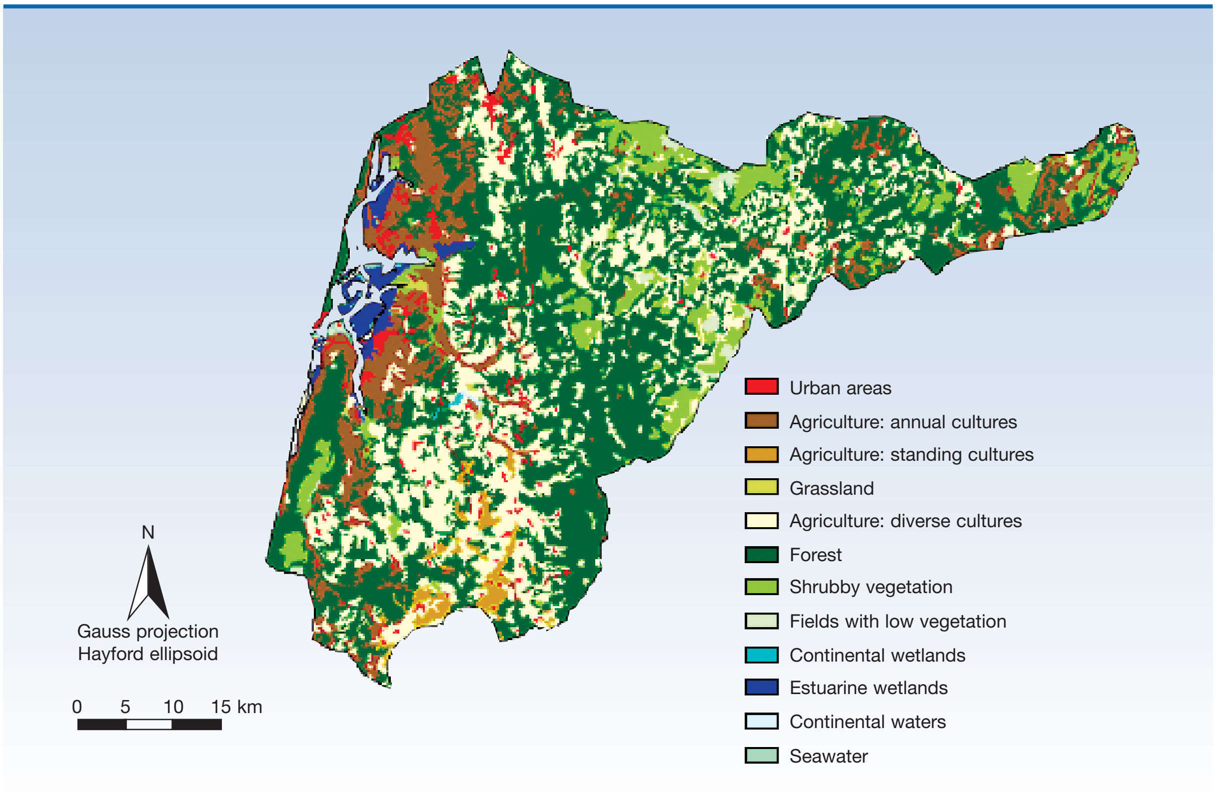
The application of the loading – susceptibility model followed the approach described in the methodology section for transitional waters. The Human Influence is calculated to be about 89%, which falls into the "High" category. The main factor contributing to this is agriculture.

Although the nutrient loads into the estuary are rated as "High" the system susceptibility is "Low", which leads to a final classification of "Moderate Low" for *Overall Human Influence*.

DETERMINATION OF FUTURE OUTLOOK

The evaluation of future outlook should be carried out considering the non-point source loading into the system, since there is practically no wastewater inflow to the system. However, there is no information on the

FIGURE 71. SOIL USES IN THE RIA DE AVEIRO HYDROGRAPHIC BASIN.



evolution of agriculture both as regards culture practices or area. No change in future nutrient pressures is assumed.

SUMMARY OF THE NEEA INDEX APPLICATION

Figure 72 summarizes the results obtained for the NEEA index application in the Ria de Aveiro.

CONCLUSIONS

The following conclusions can be drawn from the NEEA index application to the Ria Aveiro:

- Some data gaps were detected concerning the spatial coverage of chlorophyll *a*, macrophyte dynamics including epiphytes and macroalgae, and the duration and frequency of nuisance and toxic blooms, these gaps should be adressed with an adequate *Surveillance Monitoring* programme;
- The Ria de Aveiro is a well mixed system with a “High” flushing potential. The nutrient inputs to the system are limited to the river inflow and land runoff. These loads are evaluated as “High”. The OHI index classifies the impact of nutrients in the system as “Moderate Low”, accordingly to the NEEA classification this means that the symptoms observed may be natural or that the high level of nutrient additions may cause problems despite low susceptibility;
- The OEC classifies the Ria de Aveiro in the “Moderate” category. This result is mainly due to:
  - the general loss of SAV in the system, which is not clearly related to nutrient enrichment. *Investigative Monitoring* should be carried out to accurately determine the causes of SAV loss;

FIGURE 72. RESULTS OF THE NEEA INDEX APPLICATION TO THE RIA DE AVEIRO. SLE: SYMPTOM LEVEL EXPRESSION; EAR: ESTUARY AGGREGATION RULES; PSM: PRIMARY SYMPTOMS METHOD; SSM: SECONDARY SYMPTOMS METHOD.

Indices	Methods	Parameters/Values/EAR			Index category
Overall Eutrophic Condition (OEC)	PSM	Chlorophyll *a*	1	0.33 Moderate	Moderate
		Epiphytes	0		
		Macroalgae	0		
	SSM	Dissolved oxygen	0	0.5 Moderate	
		Submerged aquatic vegetation	0.5		
		Nuisance and toxic blooms	-		
Overall Human Influence (OHI)	Susceptibility	Dilution potential	High	Low susceptibility	Moderate low
		Flushing potential	Moderate		
	Nutrient inputs	High nutrient input			
Future Outlook for future conditions (DFO)	Future nutrient pressures	No change in future nutrient pressures			No change

– elevated chlorophyll *a* concentrations observed in the lower tip of the Mira channel (corresponding to an area of 0.3 km^2, 0.5 % of the Ria de Aveiro). Since 0.3 available data do not allow a cause-effect relation to be established, *Investigative Monitoring* is required to provide appropriate scientific insights;

• The nitrate concentrations are far below the threshold considered in the Nitrates Directive 91/676/EEC;

• The results obtained with the application of NEEA methodology do not show a direct relation between human nutrient inputs and the Ria de Aveiro water quality status. Furthermore, the indication that nutrient

pressures are not expected to increase (DFO) support the conclusion that neither the Ria de Aveiro nor parts of the estuary should be listed as sensitive areas (Directive 91/271/EEC) or vulnerable zones (Directive 91/676/EEC) due to eutrophication concerns.

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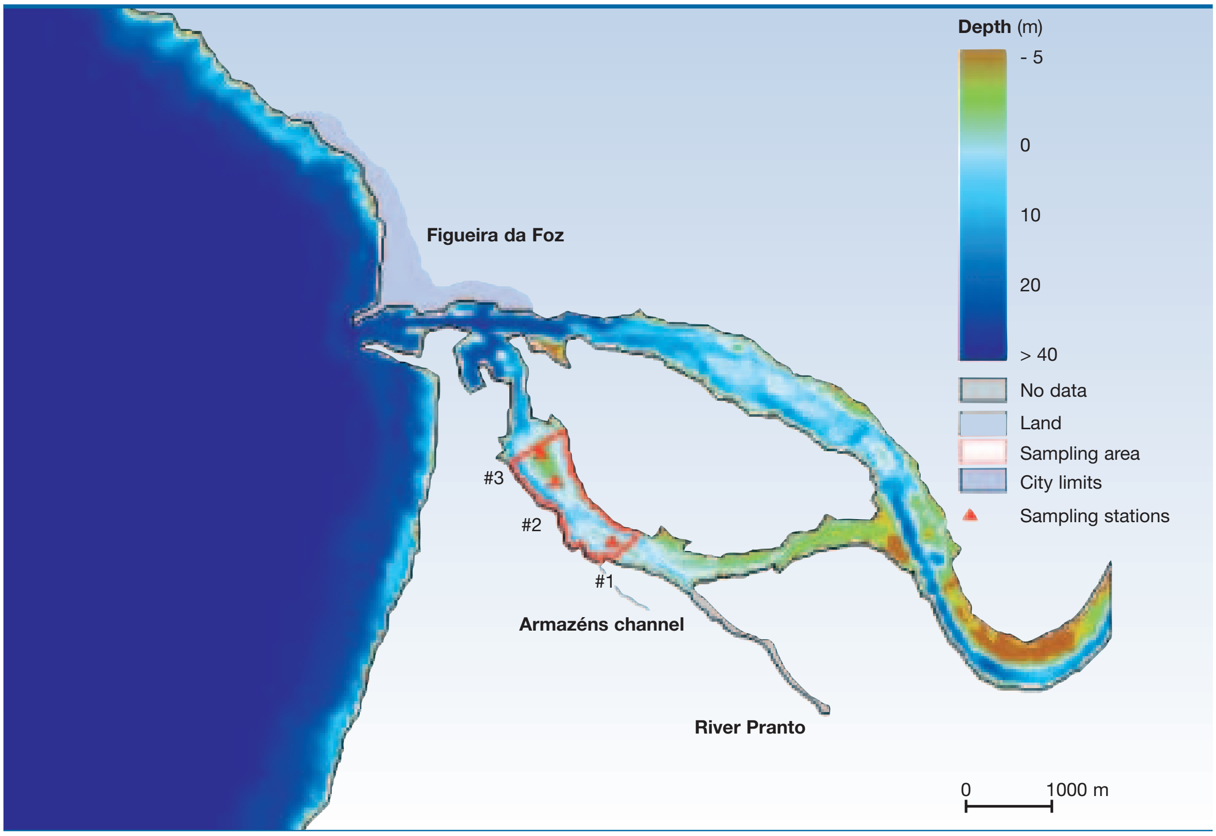
References for grey literature consulted for this chapter may be found at http://www.imar.pt/perfect/

GENERAL CHARACTERISTICS

The Mondego river drains a 6 670 km^2 watershed, and ends in a tidal estuary on the west coast of Portugal at Figueira da Foz (Figure 73).

The estuary has a surface area of 6.4 km^2, and, about 7 km from the mouth, branches into two channels (north and south) separated by an island. Hydrographically, the two channels are very different: the northern one is deeper (5-10 m during high tide, tidal range 2-3 m), while the southern one has a maximum depth of 2-4 m during high tide and is largely silted up in the upstream areas. The main freshwater discharge

FIGURE 73. MONDEGO ESTUARY: BATHYMETRY, SAMPLING STATIONS AND LIMITS OF THE SAMPLING AREA.



from the river therefore flows through the northern channel, and water circulation in the south channel is mainly tidally driven, with irregular (small) fresh water inputs from the Pranto river, which is regulated by a sluice located 3 km upstream. The tidal excursion is greater in the northern channel, which receives the main freshwater inflow, causing high daily salinity fluctuations.

The South channel of the estuary is less affected by human activity but, due to its low depth, restricted circulation and discharge of inorganic nutrients from the Pranto River, is considered to be more vulnerable to environmental stress. The main physical properties of the Mondego estuary are shown in Figure 74.

During the last decade the south channel of the Mondego estuary has been almost continuously monitored with respect to nutrient concentrations in the water column, biomass and productivity of benthic primary producers, population dynamics and production of macrofaunal key species, seasonal and interannual variation of wading birds, and impacts of macroalgal blooms on macrofaunal communities and waders.

HOMOGENEOUS AREAS

The available dataset corresponds to monthly samples collected from January 1993 to February 1997 in three stations of the South channel, covering an area of about 0.9 km^2. The median salinity at all stations in this area falls within the mixing zone thresholds. For this reason, the division of the estuary into salinity zones, and the complete application of the NEEA methodology, could not be applied, since these data only cover 26% of the total estuarine area (Figure 73). Despite these limitations, all the NEEA index parameters were examined for the South channel and suggestions for further work are discussed. The whole estuary is identified as a vulnerable zone in the ERM report, but expert consultations show that eutrophication problems are confined to the South channel. In any case, the North channel could not be considered due to lack of data: there is a clear need for further surveys on the whole estuary, from the head at Montemor-O-Velho to the mouth at Figueira da Foz.

FIGURE 74. MAIN CHARACTERISTICS OF THE MONDEGO ESTUARY.

Parameters	Values
Volume	22 x10^6 m^3
Total area	6.4 km^2
River flow	80 m^3 s^{-1}
Tidal range	3.0 m
Population	66 000
Mean residence time	North channel: 2 days South channel: 9 days

OVERALL EUTROPHIC CONDITION

Primary symptoms method

Chlorophyll *a*

The percentile 90 for maximum chlorophyll *a* values in the South channel falls within the “Medium” category (Figure 75). The annual distribution of the monthly medians is around 5 µg l^{-1}, with slight peaks in spring and summer (Figure 76).

Macroalgae and epiphytes

In the Mondego estuary the colonization and succession of macroalgal species is related to the type of substrate. Hard substrates extending along 60% of the total estuarine perimeter dominate the North channel of the estuary, while most of the intertidal zone in the South channel consists of sandy and muddy substrates. Hard substrates are primarily covered by the genera *Enteromorpha*, *Fucus* and *Ulva*. Soft substrates, which in the past were predominantly covered by the seagrass *Zostera noltii* and the saltmarsh species *Spartina maritima*, are being gradually replaced by the opportunistic green algal *Enteromorpha*, *Ulva* and the red seaweed *Gracillaria verrucosa* - these are classified as the main epiphytes in the system. Regular *Enteromorpha* blooms have been observed, especially in the inner areas of the South channel. The growth dynamics of the most abundant green seaweeds (*Enteromorpha intestinalis* and *Enteromorpha compressa)* was studied in a biomass gradient transect in the South channel of the estuary. The sampling stations are shown in Figure 73 and biomasses decrease downstream. Although plants are

FIGURE 75. FREQUENCY DISTRIBUTION FOR CHLOROPHYLL IN THE NORTH CHANNEL OF THE MONDEGO ESTUARY.

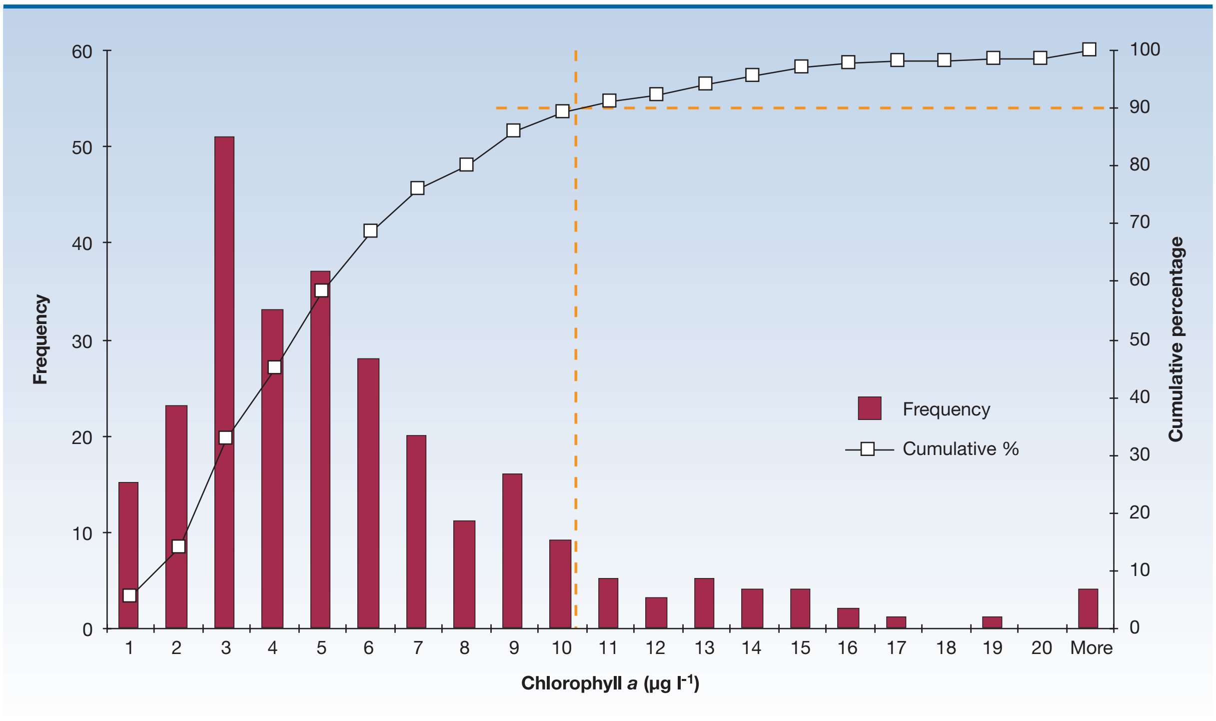
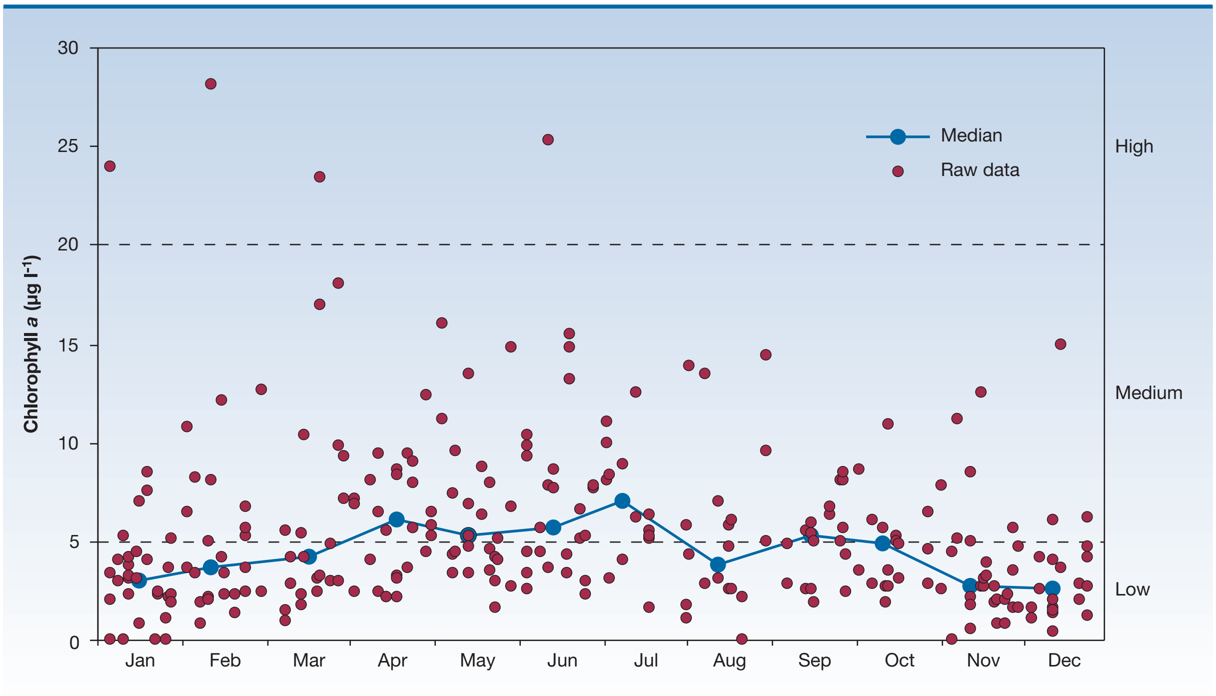


FIGURE 76. MEDIAN VALUES FOR CHLOROPHYLL IN THE SOUTH CHANNEL OF THE MONDEGO ESTUARY. DATA COLLECTED AT LOW TIDE.



present throughout the year at all sampling stations, at the most abundant station (#1), blooms occur in spring and early autumn. At the other two stations, the seaweed growing season starts in late winter and maximal biomass usually occurs in spring, with a second peak in mid-summer (Figure 77).

The reported macroalgal blooms in the South channel of the estuary are mainly controlled by three factors:

1) Changes in salinity;

2) Hydrodynamics;

3) Presence of excessive nutrient concentrations, particularly ammonia.

The optimum salinity range for these seaweeds is 17 to 22. *Enteromorpha* blooms are directly related to a rise of salinity values in the South channel. This occurs in months of low rainfall, when the Pranto sluice is closed to maintain the water level in the paddy fields. In this situation, the water circulation depends on the tides. When the sluice is opened, fresh water is discharged into the South channel, and freefloating materials are exported to the ocean. Advective transport is a significant mechanism controlling macroalgal biomass, particularly for free-floating species such as *Ulva*. Although *Enteromorpha* is attached to the bottom, the shear stress due to the current

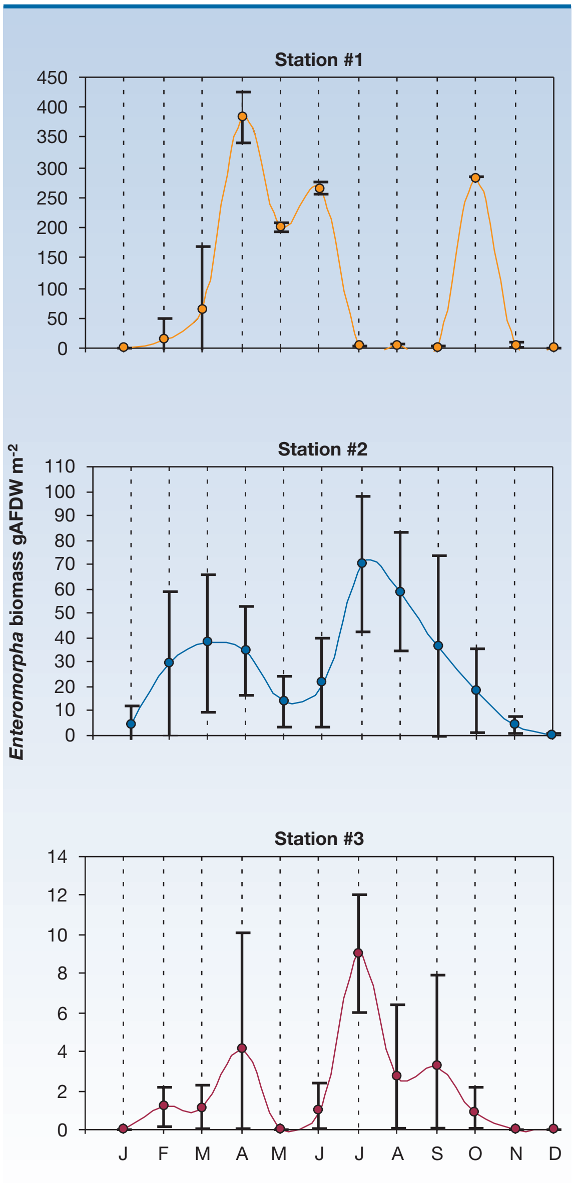


FIGURE 77. MONTHLY MEANS OF *ENTEROMORPHA* BIOMASS IN THE SOUTH CHANNEL OF THE MONDEGO ESTUARY.

(1.4 m s^{-1}) is sufficient to cause export to the ocean. The agricultural practices in the Pranto watershed, coupled to the freshwater discharge regime appear to be the main factors for the dissolved nitrogen and organic matter enrichment of the South channel of the estuary. Organic matter accumulates in the sediment and decomposes, releasing ammonia into the water, which is a primary driver of seaweed blooms (Figure 78).

FIGURE 78. VARIATION OF THE MAIN FACTORS CONTROLLING SEAWEED BLOOMS IN THE SOUTH CHANNEL OF THE MONDEGO ESTUARY. THE VARIATION DEPENDS ON PRECIPITATION AND RIVER MANAGEMENT PRACTICES, DETERMINED BY WATER REQUIREMENTS FOR RICE CULTURE.

	Dry winter and/or spring	Rainy winter and spring
Sluice gates	Closed	Open
Salinity	High	Low
Dissolved inorganic nitrogen	Low	High
N:P ratio	Near 16	High
Current velocity	Low	High
Seaweed blooms	High	Low

FIGURE 79. CUMULATIVE FREQUENCY DISTRIBUTION FOR DISSOLVED OXYGEN IN THE SOUTH CHANNEL OF THE MONDEGO ESTUARY.

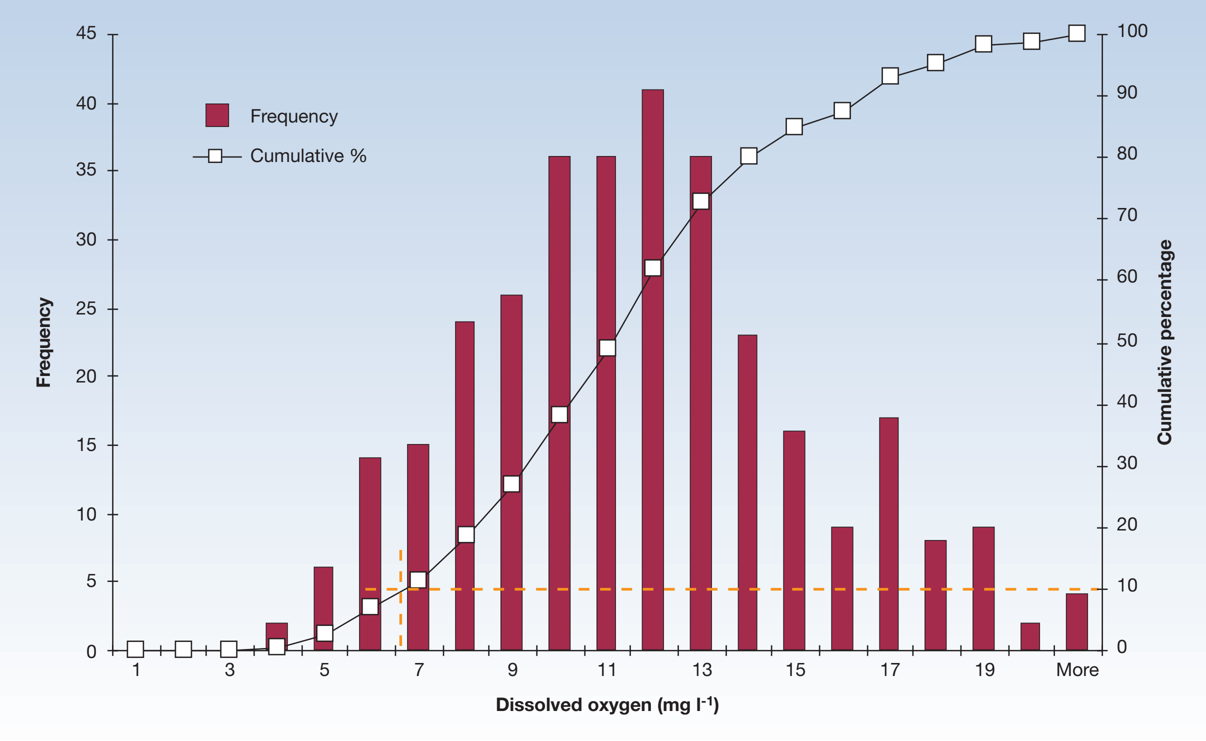
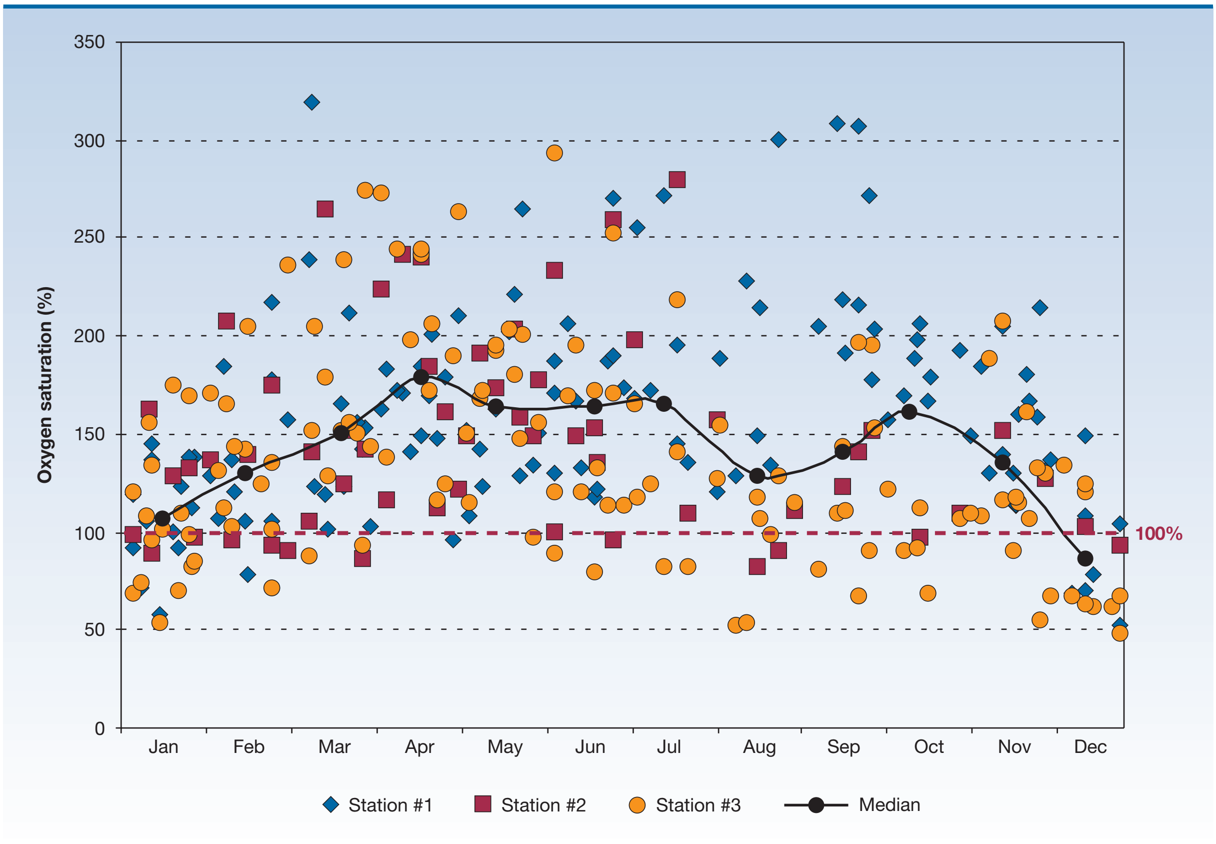


FIGURE 80. OXYGEN SATURATION IN THE SOUTH CHANNEL OF THE MONDEGO ESTUARY.



Secondary symptoms method

Dissolved oxygen

Most data for dissolved oxygen in the South channel are above the threshold for the biological stress. Only 5% of the values fall within this category (Figure 79). These values were all obtained in station #3, mainly in winter.

Although most of the oxygen saturation values are above 100%, all stations present some values below this threshold, particularly stations #1 and #3 (Figure 80).

Generally the lowest values are obtained during the winter and the highest in spring and summer during the macroalgal bloom period.

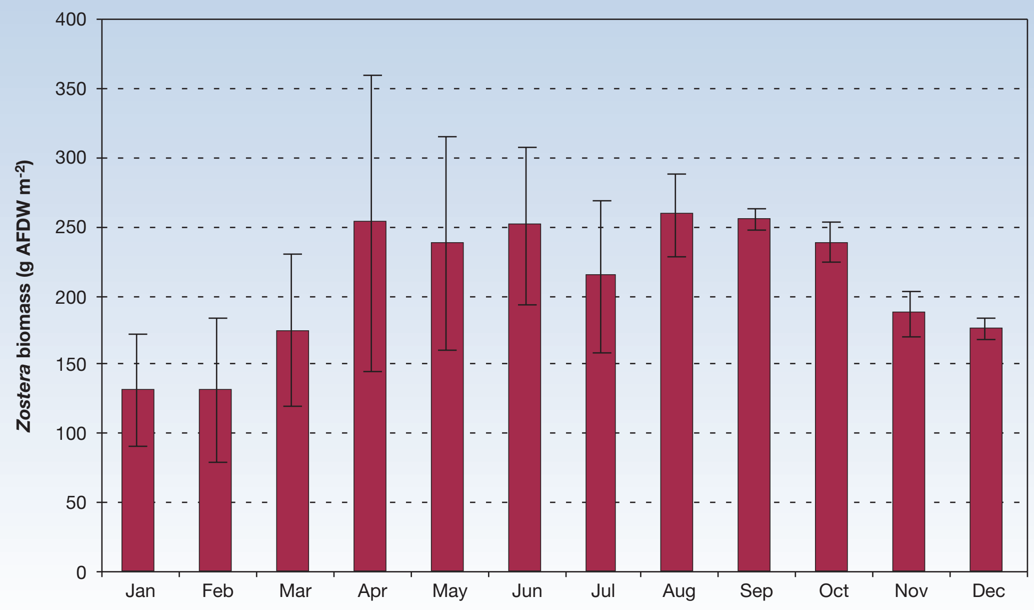
Submerged aquatic vegetation

Zostera noltii is the main species of submerged aquatic vegetation (SAV) in the Mondego estuary. Although there has been a decrease in the area occupied by this species since the early 1980's, no data on the percentage loss are available. However, it is known that the *Zostera noltii* meadows, which in the past occupied most of the subtidal estuarine area, are presently restricted to the downstream section of the South channel. The overgrowth of green algae is the main cause of SAV losses due to reduced light availability and smothering. In the downstream part of the South channel, the annual peaks of *Zostera noltii* biomass can be observed during the growing season in spring and summer. The lowest biomass values are in late winter (Figure 81).

Nuisance and toxic blooms

No nuisance or toxic algal blooms have been reported in the literature, and the experts consulted for this estuary do not consider this to be a problem area.

FIGURE 81. MEAN ZOSTERA BIOMASS IN THE SOUTH CHANNEL OF THE MONDEGO ESTUARY (STATION #3).



OVERALL HUMAN INFLUENCE

Susceptibility

Due to the reduced water circulation in the system, which is mainly driven by tides, the dilution potential in the South channel can be considered low. For the flushing potential analysis, it was assumed that the only freshwater input to the South channel comes from the Pranto river, during periods when the sluice is opened. Considering that the sluice is opened from October to March, the flushing potential is high only during half of the year and low during summer and spring, since it depends solely on the tide. The classification of the South channel as a “Moderate” or “High” system as regards susceptibility to nutrient loads depends on agricultural management practices in the Pranto watershed.

Nutrient inputs

The potential nutrient inputs in the Mondego estuary have the following sources:

1) Treated or untreated domestic effluents;

2) Treated or untreated industrial effluents;

3) Agricultural point and diffuse sources;

4) Load from the river Mondego, integrating the main agricultural, domestic and industrial sources upstream of the estuary;

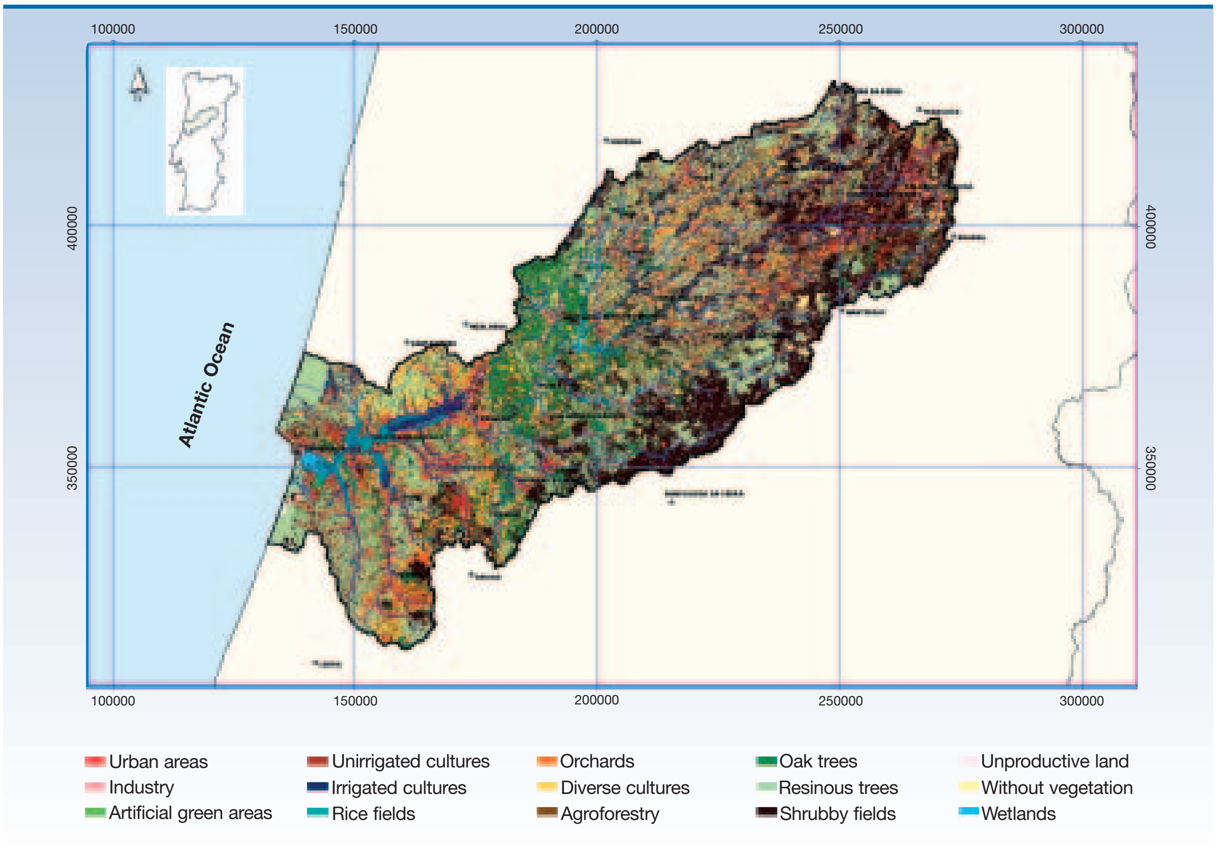
5) Load from the Pranto river.

The nutrient load from domestic sources to the estuary is mainly due to the population of Figueira da Foz and to the Mondego river discharge. The sewage of about 90% of the population is discharged to the system without treatment. Six wastewater treatment plants (WWTP) presently serve about 10% of the population (Figure 82).

FIGURE 82. WASTEWATER PLANTS AND POPULATION SERVED IN THE WATERSHED OF THE MONDEGO ESTUARY.

WWTP	Population served with WWTP	Type of treatment	Population without WWTP	Total Population
Brenha	750	Secondary	60 000 (90%)	65 700 (100%)
Maiorca	1 500	Secondary		
Paião	1 000	Secondary		
Praia de Quiaios	500	Tertiary		
Quiaios	2 000	Secondary		

FIGURE 83. SOIL USES IN THE WATERSHED OF THE MONDEGO ESTUARY.



No data on nutrient inputs from industry and agriculture in the banks of the estuary were available for calculations. Nutrient inputs from the Mondego river were calculated using discharge data and concentrations of nitrogen and phosphorus measured in the river. The annual loads into the North channel are about 92 tonnes of N and 4 tonnes of P.

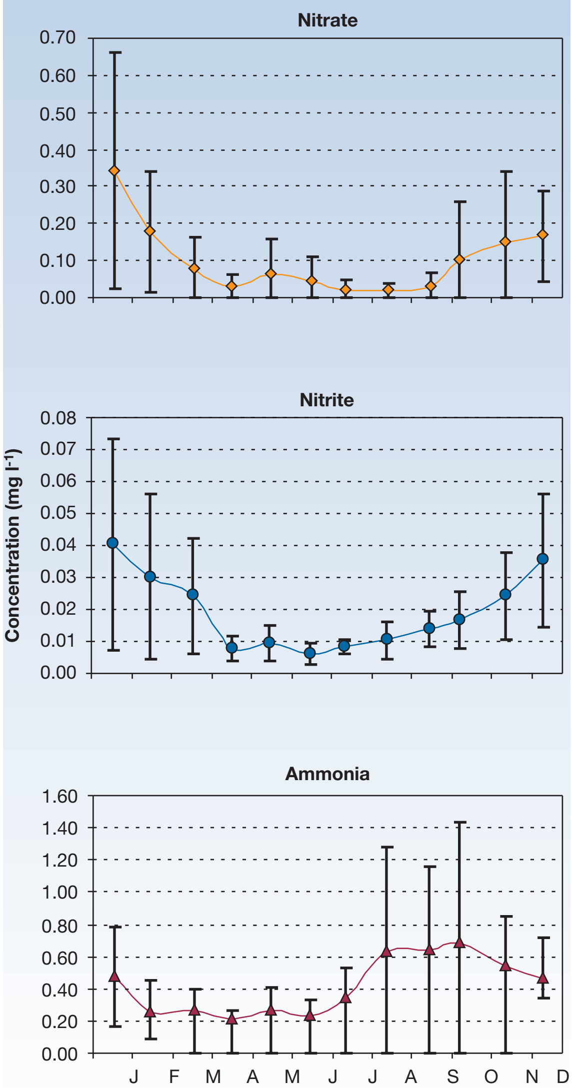
Since the eutrophication problems are identified in the South channel, it is important to consider all the potential nutrient contributions to this area. During the ebb, some of the load flowing out through the North channel may affect the South channel, although since there is water flowing downstream in both channels, this is unlikely. The Pranto river is considered the main anthropogenic source of nutrients (agricultural and domestic) to the South channel. Agricultural practices upstream in the Pranto are based on rice and maize cultures. In the lower part of the Mondego river (from Coimbra until Figueira da Foz) these cultures cover 45% and 51%, respectively, of the soil used for agricultural purposes (Figure 83).

In the Pranto river basin, between 50 and 80% of the population has a sewage system linked to wastewater treatment plants. Considering secondary treatment in most of the WWTP, with 70% efficiency on nitrogen removal, and a mean value of 70% of the population served by WWTP, the annual domestic load into the South channel was calculated at 51 tonnes of N and 23 tonnes of P. The “Armazéns” channel is also a nutrient source (of industrial origin) to the South channel, as yet unquantified.

Nitrate and total nitrogen concentrations in the South channel of the Mondego estuary are far below the threshold of 50 mg l^{-1} stipulated in the Nitrates Directive (Figure 84).

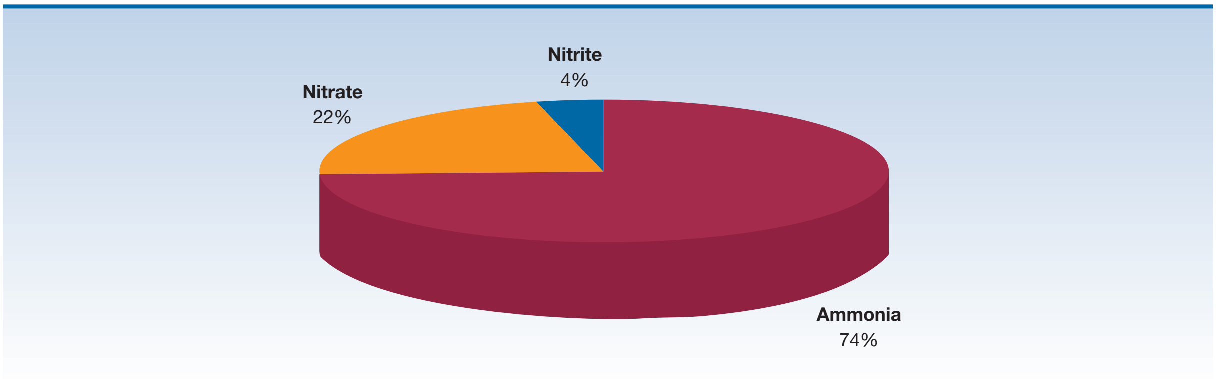
Ammonia is the major contributor to dissolved inorganic nitrogen in the South channel

FIGURE 84. AVERAGE MONTHLY VALUES OF NITRATE AND DISSOLVED INORGANIC NITROGEN IN THE SOUTH CHANNEL OF THE MONDEGO ESTUARY.



Mondego Estuary

FIGURE 85. RELATIVE CONTRIBUTION OF DISSOLVED NITROGEN SPECIES TO THE SOUTH CHANNEL OF THE MONDEGO RIVER.



(Figure 85). Decomposition of organic matter in the sediment, bivalve (cockle) excretion and industrial release of reduced nitrogen compounds are the main factors responsible for the high ammonia concentrations in the water.

CONCLUSIONS

The main conclusions are as follows:

- Eutrophic areas have been documented only in the South channel of the Mondego estuary;
- Periodic green seaweed blooms and submerged aquatic vegetation loss are the main primary and secondary symptoms of eutrophication in the South channel of the Mondego estuary;
- The causes of the macroalgal blooms are complex, and are apparently linked to the management of the Pranto sluice. When the sluice is opened, high concentrations of nutrients are discharged to the South channel, leading to organic enrichment in the sediment. When the sluice is subsequently closed, the salinity increase, associated to nutrient availability, is a trigger for seaweed blooms;
- Control measures should consider improved agricultural practices in the Pranto basin, and propose ecotechnological solutions:

a. Optimisation of the management of the Pranto discharge;

b. Construction of artificial wetlands between the upstream farmland and the Pranto sluice connection to the Mondego Southern channel. This type of artificial wetlands, with appropriate vegetation (e.g. *Typha*), can remove a substantial proportion of nitrogen from the water. Macrophyte cropping may

allow for recycling and solutions must be defined for periods of flooding. The wetland area required may be estimated through the use of models.

- **There is a clear need for an *Investigative Monitoring* programme for the Mondego estuary, in order to complete the spatial description of the estuary, to shed light on key processes, and to establish the appropriate classification with regard to the Nitrate Directive and UWWTD due to eutrophication concerns.**

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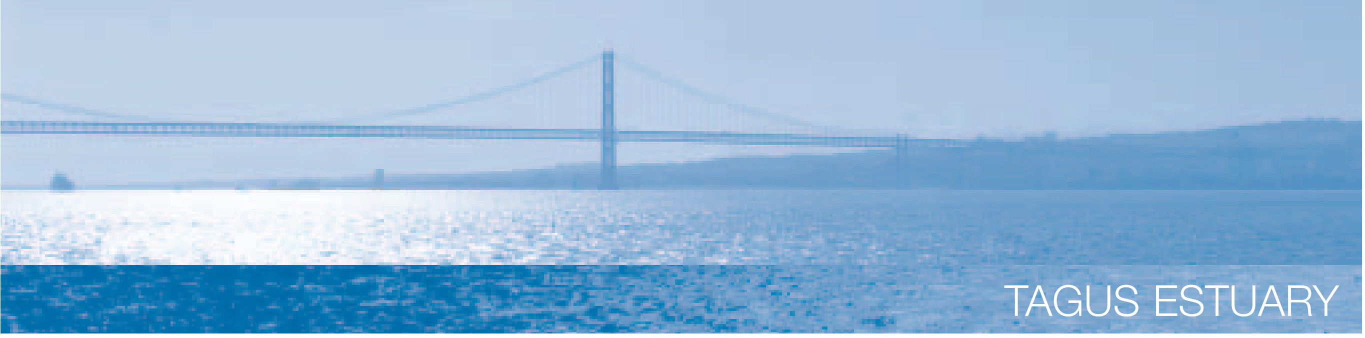
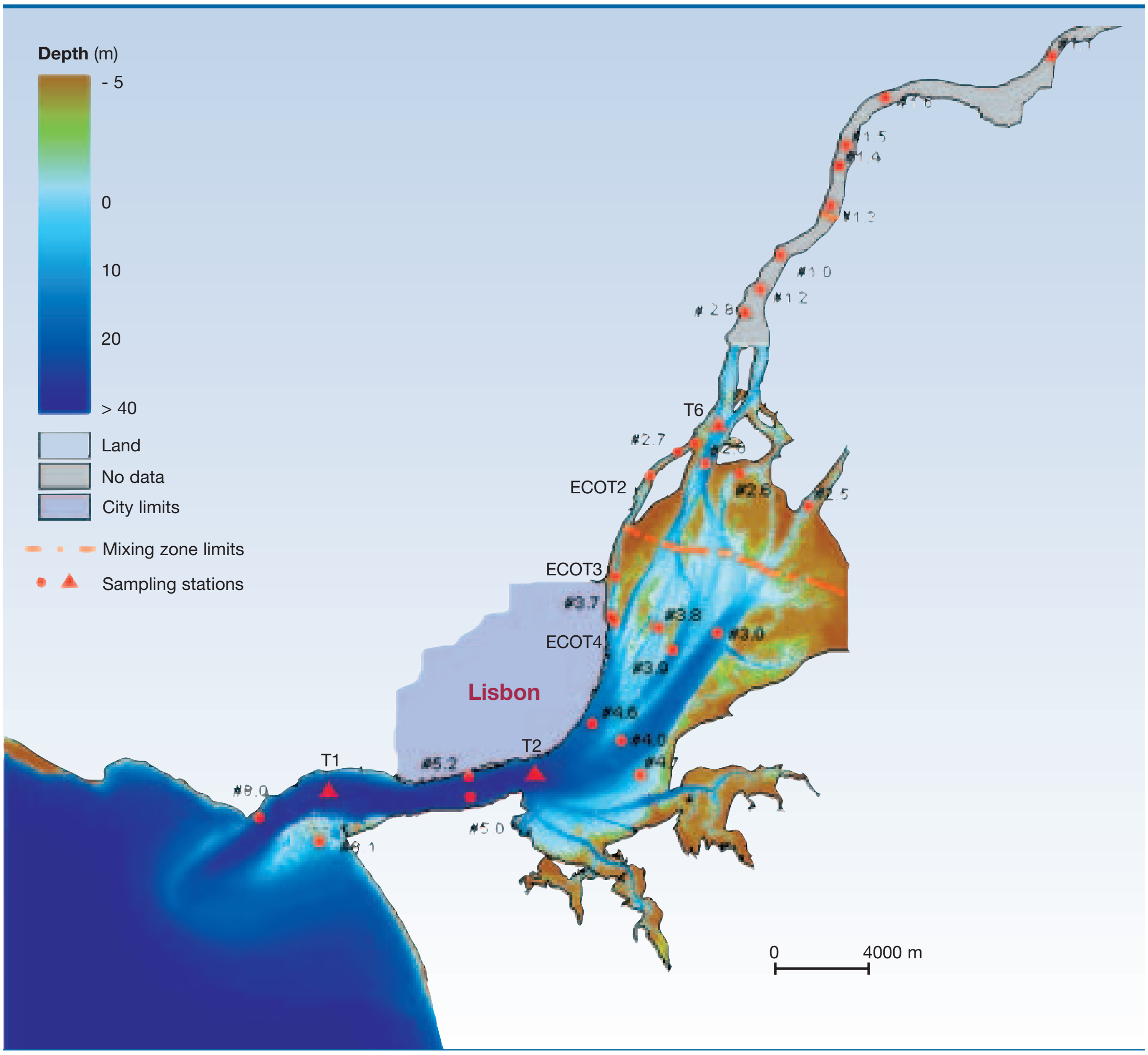


GENERAL CHARACTERISTICS

The Tagus River is the largest of the Iberian Peninsula, ending in a large tidal estuary covering an area of 320 km². Forty percent, or 138 km², corresponds to intertidal zones, of which 19 km² are occupied by salt marsh vegetation, and 81 km² are mudflats. Morphologically the estuary is divided into upstream, middle and downstream sections. The upstream section is located between Vila Franca de Xira and the

FIGURE 86. TAGUS ESTUARY: BATHYMETRY, SAMPLING STATIONS AND LIMITS OF HOMOGENEOUS ZONES.



Alcochete – Sacavém section, has an average depth of 2 m and includes most of the mudflats. The middle part is deeper (average of 7 m), and the terminal part reaches depths of 46 m and is the main navigation channel of the estuary (Figure 86).

The combined factors of low average depth, strong tidal currents, and low input of river water make this a well-mixed estuary, with stratification occurring only in specific situations such as neap tides or after heavy rains. The main characteristics of the estuary are shown in Figure 87.

FIGURE 87. MAIN CHARACTERISTICS OF THE TAGUS ESTUARY.

Parameter	Value
Volume	1900 x10^6 m^3
Total area	320 km^2
River flow	400 m^3 s^{-1}
Tidal range	2.6 m
Population	2 000 000
Mean residence time	19 days

HOMOGENEOUS AREAS

The physical classification of the estuarine area into homogeneous zones was made using the thresholds defined in the NEEA and the median salinity values of sampling stations, which have values for all tidal situations (Figure 88).

The areas of the homogeneous zones were calculated using a GIS.

The estuary upstream limit was defined on the basis of geographical, physical and chemical criteria.

Although the most upstream station #0.0 has a median salinity of 0.02, it is located outside the

FIGURE 88. DATA AND THRESHOLDS USED TO DIVIDE THE TAGUS ESTUARINE AREA INTO SALINITY ZONES.

Zone name	Thresholds	Stations	Median salinity
Tidal freshwater	0 to 0.5	#1.1	0.18
		#1.6	0.28
		#1.5	0.28
		#1.4	0.34
		#1.0	0.34
		#1.3	0.72
Mixing	0.5 to 25	#1.2	7.13
		ECOT1	8.00
		#2.8	9.32
		#2.0	21.38
		#2.5	21.67
		#2.6	21.99
		ECOT2	22.00
		#2.7	24.26
Seawater	> 25	ECOT3	26.50
		ECOT4	28.00
		#3.0	29.62
		#3.9	29.76
		#3.8	30.48
		#3.7	31.59
		#4.7	32.31
		#4.0	32.32
		#4.6	32.70
		#5.2	33.57
		#5.0	33.97
		#8.0	35.02
		#8.1	35.73

estuary physical boundaries. For this reason the upstream limit of the tidal freshwater zone was set at station #1.1.

DATA COMPLETENESS AND RELIABILITY

Data used in this study were taken from the BarcaWin2000™ database which groups the results of all the campaigns made in the Tagus estuary. The number of campaigns, dates and the water quality parameters sampled are shown in Figure 89.

The calculated data completeness and reliability (DCR) for all the three salinity zones was 100% for chlorophyll, dissolved oxygen and macrophytes since all the estuarine area was sampled. Values of 0% were attributed for epiphytes and nuisance and toxic blooms since no problems have been documented for these elements in the estuarine area. The main aquatic vegetation present in the Tagus estuary are seaweeds and saltmarsh species; there is no colonization of submerged aquatic vegetation species (seagrasses).

FIGURE 89. DATASETS FOR THE TAGUS ESTUARY.

<table>
<tr><th>Number of campaigns</th><th>Date</th><th>Site</th><th>Parameters</th></tr>
<tr><td>27</td><td>From February 1980 until March 1982
From May 1982 until June 1982</td><td rowspan="3">All estuary</td><td rowspan="4">Salinity
Temperature
Oxygen (dissolved and % saturation)
Nitrogen (NO3, NO2, NH4; particulate)
Phosphorus (PO4)
Silicate
Dissolved metals
Chlorophyll a
Phytoplankton species
Zooplankton species
Suspended particulate matter
Particulate organic carbon</td></tr>
<tr><td>20</td><td>From April 1982 until December 1983</td></tr>
<tr><td>16</td><td>From April 1982 until April 1983</td></tr>
<tr><td>1</td><td>From June 1994 until June 1995</td><td>Cala do Norte</td></tr>
<tr><td>1</td><td>September 1999</td><td>Mixing and Seawater zones</td><td rowspan="2">Salinity
Temperature
Oxygen (dissolved and % saturation)
Nitrogen (NO3, NO2, NH4; particulate)
Phosphorus (PO4)
Silicate
Chlorophyll a
Phaeopigments
Inorganic carbon
Particulate organic carbon
Suspended particulate matter</td></tr>
<tr><td>5</td><td>February 1994 until November 1998</td><td>Mixing and Seawater zones</td></tr>
</table>

OVERALL EUTROPHIC CONDITION

Primary symptoms method

Chlorophyll *a*

The percentile 90 used to calculate the maximum chlorophyll *a* values for all three zones is presented in Figure 90. According to the NEEA thresholds, the maximum values obtained for the tidal freshwater and mixing zone, fall within the "High" category. The seawater zone presents a lower maximum, which classifies the zone in the "Medium" category.

The annual cycle of chlorophyll *a* in the estuary is shown in Figure 91, for the three salinity zones. Three main peaks can be observed during the year for chlorophyll *a* in the tidal freshwater zone: the first in the early spring (end of March), the second in the middle of the summer (July) and the third in the autumn (October). The first two peaks are also observed in the mixing and seawater zones but with lower values and slightly displaced in time.

FIGURE 90. FREQUENCY DISTRIBUTION FOR CHLOROPHYLL IN THE THREE SALINITY ZONES OF THE TAGUS ESTUARY.

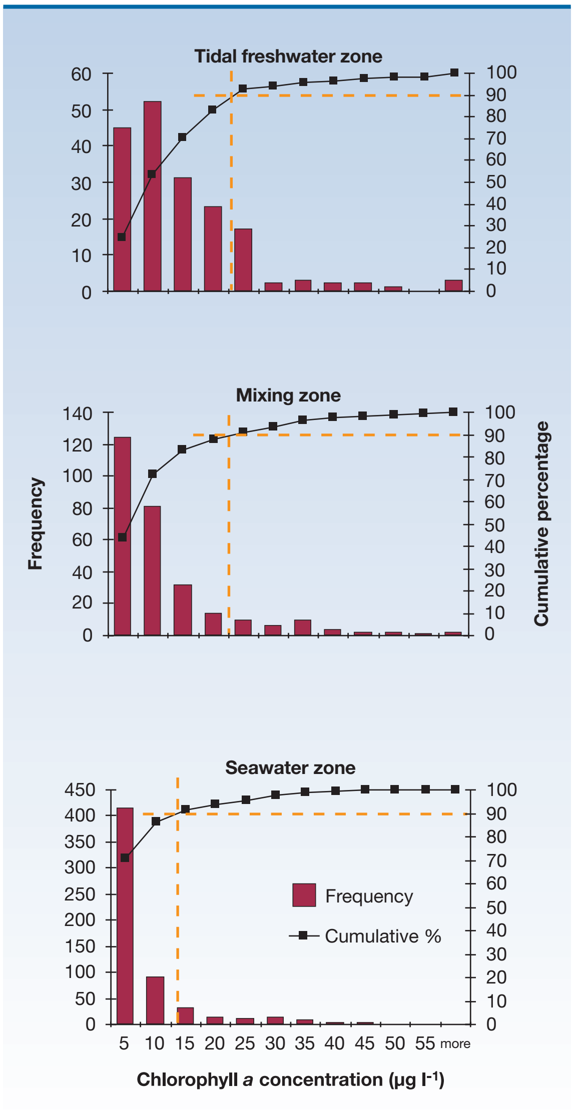
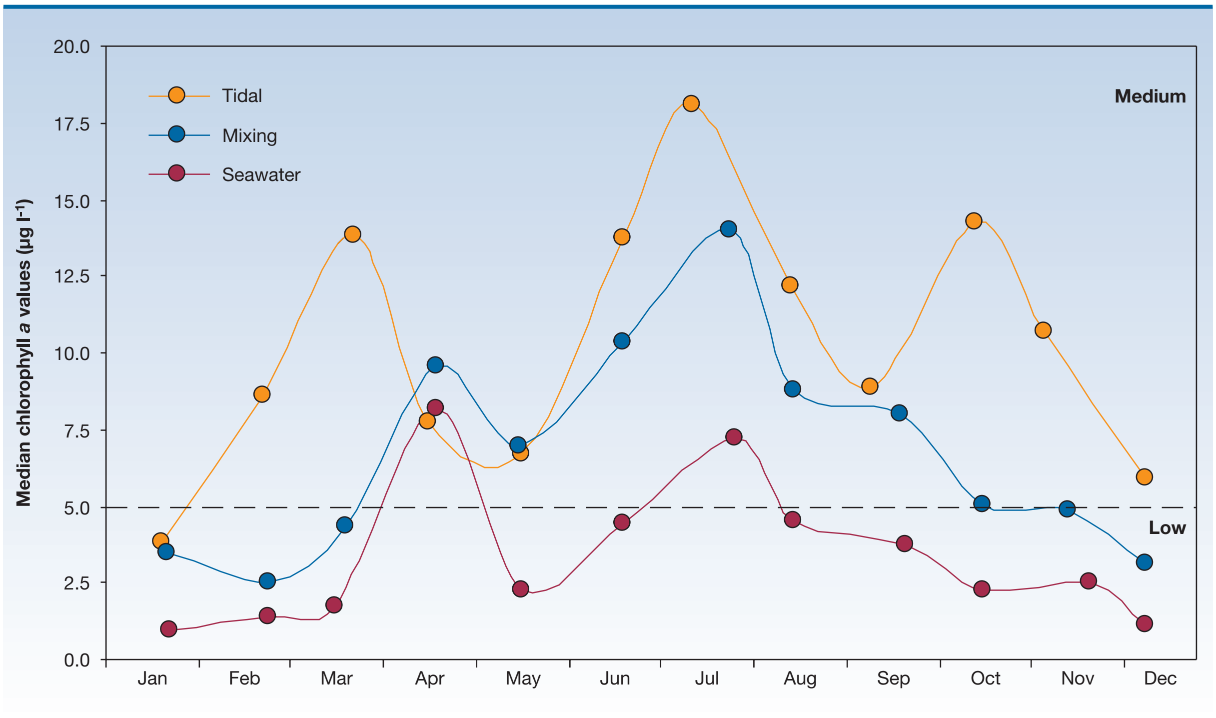


FIGURE 91. ANNUAL CYCLE FOR THE THREE ZONES IN THE TAGUS ESTUARY.



Also, the total dataset available for this parameter suggests a decrease of maximum values from hypereutrophic to medium levels in all zones (Figure 92). This could be due to the nutrient load decrease, as a consequence of improvements in the sewage treatment of the main cities and industrial plants located on the banks of the estuary. In this way, the classification of the tidal freshwater and mixing zones in the high category is influenced by the values obtained in the early 1980's when chlorophyll values reached 80 µg l^{-1} in these two salinity zones.

The Thiessen polygon method was used to calculate the spatial weight of each station within its salinity zone (Figure 93). The spatial coverage of percentile 90 values in each salinity zone was then calculated through the sum of spatial weights where maximum values were observed. Information on the sampling date of the maximum values was used to evaluate the

FIGURE 92. SURFACE CHLOROPHYLL IN THE TAGUS ESTUARY.

FIGURE 93. ZONES OF INFLUENCE CALCULATED WITH THE THIESSEN POLYGONS METHOD.

frequency of occurrence within the salinity zone. The summary of the results obtained for the NEEA index application in each salinity zone is presented in Figure 94.

Epiphytes

Expert consultations on this subject show that no problems with epiphytes have been observed within the estuarine area. The value used for epiphytes in each zone equals zero.

Macroalgae

The study of macrophyte algae in the estuary was carried out between 1985 and 1987. The main substrates colonised by algae in the Tagus

FIGURE 94. RESULTS OF THE NEEA INDEX APPLICATION FOR THE CHLOROPHYLL IN THE TAGUS ESTUARY. SLE MEANS SYMPTOM LEVEL OF EXPRESSION.

ZONE	IF Concentration	AND Spatial coverage	AND Frequency	THEN Expression	Value	Area	SLE
Tidal fresh	High	Very low	Persistent	Moderate	0.5	13.9	0.023
Mixing	High	High	Periodic	High	1	77.6	0.252
Seawater	Medium	High	Periodic	High	1	216.3	0.703
					Total	**307.8**	**0.977**

estuary were old oyster-beds located in the intertidal zones within the mixing and seawater salinity zones. Figure 95 shows the values obtained for the biomass of the main species in the estuary. The brown alga *Fucus vesiculosus* is the most abundant species, while fast growing species such as *Ulva lactuca* reached maximum values two times lower than the *Fucus* maximum. A comparison of maximum algal biomass for fast growing species in the Tagus estuary with that obtained in typical eutrophic systems (Figure 96) shows that the maximum biomass for *Ulva lactuca* in the Tagus estuary (200 g dw m^{-2}; Figure 95) can be considered low.

Furthermore, expert consultation shows that macroalgal growth in the Tagus estuary is linked to intertidal substrates, where seaweeds have a competitive advantage as regards light availability, compared to pelagic primary producers in the channels, due to the natural turbidity of the water column. No problems with decreasing light availability or oxygen depletion in the water column due to the excessive growth of algae have been observed. For these reasons, this parameter takes a value of zero in each zone for the index calculation. Since there are only 2 years of available data for this indicator, no discussion can be made about the trend of algal biomass in the estuary.

FIGURE 95. ANNUAL CYCLE OF MACROPHYTE ALGAL BIOMASS IN THE DIFFERENT INTERTIDAL ZONES OF THE TAGUS ESTUARY.

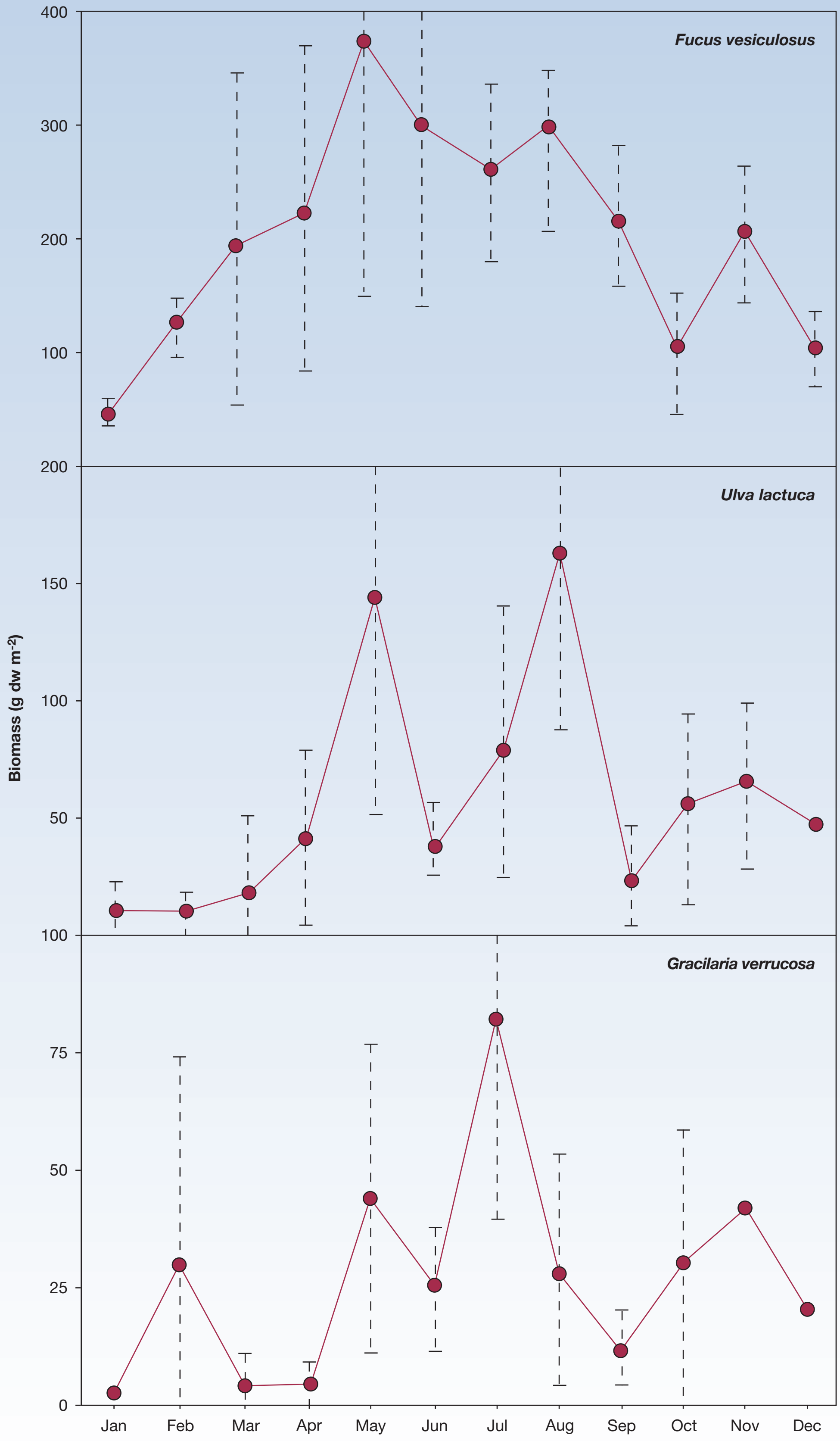


FIGURE 96. VALUES OF ALGAL BIOMASS IN SOME EUTROPHIC SYSTEMS.

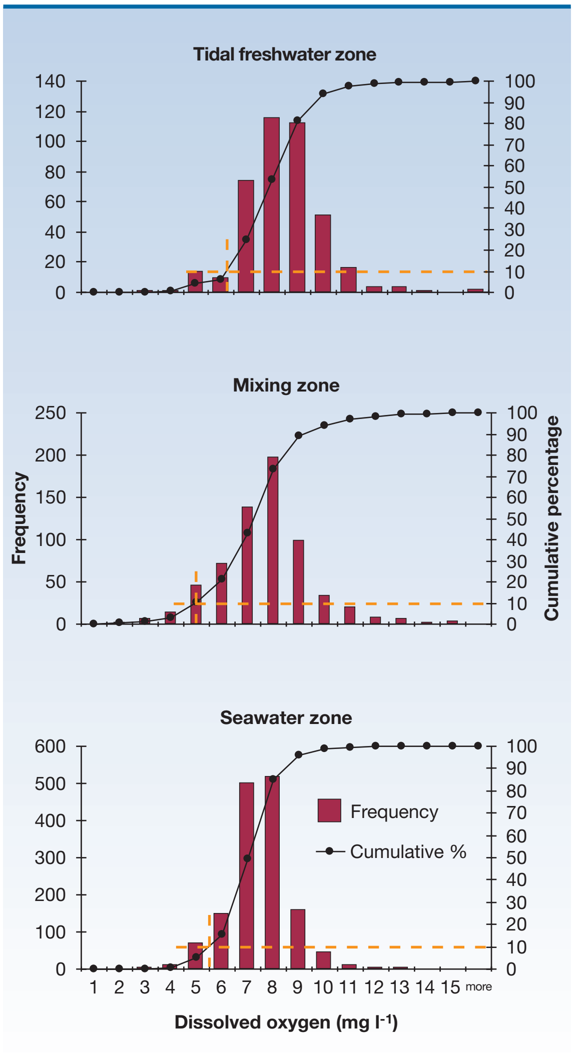
Site	Species	Maximum biomass (g dw m^{-2})
Palmones estuary (Spain)	*Ulva rotundata* *Ulva curvata*	375
Po estuary (Italy)	*Ulva rigida*	1 000
Venice Lagoon (Italy)	*Ulva rigida*	1 300
Red sea (Egyptian coast)	*Cystoseira myrica*	491
Waquoit Bay (Massachusetts – USA)	*Cladophora vagabunda*	>1 000

The aggregation of the information for the primary symptoms method and the determination of the level of expression for the Tagus estuary are shown in Figure 97.

FIGURE 97. NEEA INDEX APPLICATION FOR THE PRIMARY SYMPTOMS IN THE TAGUS ESTUARY.

Zone	Salinity	Area (km^2) (A_z)	Value (v_{ij})			A_z/A_t x v_{ij}		
			Chlorophyll *a*	Macroalgae	Epiphytes	Chlorophyll *a*	Macroalgae	Epiphytes
Seawater	> 25	13.9	0.5	0	0	0.023	0	0
Mixing	0.5 – 25	77.6	1.0	0	0	0.252	0	0
Tidal fresh	< 0.5	216.3	1.0	0	0	0.703	0	0
Sum		307.8	-	-	-	0.977	0	0
Primary symptoms level of expression value for the estuary: 0.33 Moderate								

FIGURE 98. FREQUENCY DISTRIBUTION FOR DISSOLVED OXYGEN VALUES IN THE THREE SALINITY ZONES OF THE TAGUS ESTUARY.



Secondary symptoms method

Dissolved oxygen

According to the thresholds used in the NEEA approach, the minimum values of dissolved oxygen obtained for the percentile 10 for the tidal freshwater and seawater zones (Figure 98) are above the concentration considered to indicate biological stress (5 mg l^{-1}): 6 mg l^{-1} for both the tidal freshwater and the seawater zones. In the mixing zone the value for the percentile 10 falls within the 5 mg l^{-1} interval indicating biological stress conditions. However, these values are classified as episodic with a high spatial coverage (about 66% of the total mixing zone area).

For the index calculations dissolved oxygen takes a value of zero in the tidal freshwater and seawater zones and a value of 0.5 in the mixing zone. The summary of the results obtained for the NEEA index application in each salinity zone is presented in Figure 99.

Submerged aquatic vegetation

The main aquatic vegetation present in the Tagus estuary is that typical of saltmarsh areas, there is no colonization of submerged aquatic

FIGURE 99. RESULTS OF THE NEEA INDEX APPLICATION FOR THE DISSOLVED OXYGEN IN THE TAGUS ESTUARY. SLE MEANS SYMPTOM LEVEL OF EXPRESSION.

ZONE	IF Oxygen demand	AND Spatial coverage	AND Frequency	THEN Expression	Value	Area	SLE
Tidal fresh	Not observed	-	-	-	-	13.9	0
Mixing	Biological stress	High	Episodic	Moderate	0.25	77.6	0.12
Seawater	Not observed	-	-	-	-	216.3	0
					Total	**307.8**	**0.12**

vegetation species. This parameter was not included in the index calculation.

Nuisance and toxic blooms

Expert consultations on this subject as well as literature data show that no problems with nuisance and toxic blooms have been observed in the estuary, over an extended period of time (20 years). This parameter equals zero for each salinity zone.

Figure 100 presents the aggregation of the results for the secondary symptoms method as well as the value and level of expression for all the estuarine area.

OVERALL HUMAN INFLUENCE

Susceptibility

Dilution potential

The low average depth, strong tidal currents, and low input of river water make the Tagus a well-mixed estuary, with stratification being rare and occurring in specific situations such as neap tides or in periods of high river flow. Considering the NEEA category for estuary dilution potential, the vertically homogeneous conditions of the water column, during all year and throughout all the estuarine area classifies the Tagus estuary in the Type A, "High" category.

Flushing potential

The Tagus estuary is a mesotidal estuary with a tidal range of 2.6 m. The results obtained for the flushing potential (freshwater inflow per day divided by the estuary volume) fall within the "Moderate" category.

Considering the categories for the dilution and flushing potential in the NEEA matrix for the estuarine export potential and susceptibility, the Tagus estuary is classified as having a "Low" susceptibility to dilute and flush nutrients.

Nutrient inputs

The main sources of nutrients discharging into the estuary are:

1) Effluents from domestic treatment plants;
2) Effluents from industrial treatment plants;
3) Domestic effluents without wastewater treatment;
4) Load from the river Tagus, which integrates diffuse and point sources upstream of the estuary;
5) Load from the tributaries (Sorraia and Trancão).

Information on the demography in the estuarine watershed, population equivalents for the main industrial activities and data on the efficiency of the domestic wastewater treatment plants

FIGURE 100. NEEA INDEX APPLICATION FOR THE SECONDARY SYMPTOMS IN THE TAGUS ESTUARY.

Zone	Salinity	Area (km²) (A_z)	Value (v_{ij}) Dissolved O_2	SAV	Blooms	A_z/A_t x v_{ij} Dissolved O_2	SAV	Blooms
Seawater	> 25	13.9	0	0	0	0	0	0
Mixing	0.5 – 25	77.6	0.25	0	0	0.12	0	0
Tidal fresh	< 0.5	216.3	0	0	0	0	0	0
Sum		307.8	-	-	-	0.12	0	0
Secondary symptoms level of expression value for the estuary: 0.12 Low								

FIGURE 101. WASTEWATER TREATMENT PLANTS AND POPULATION SERVED BY WASTEWATER TREATMENT IN THE TAGUS ESTUARY WATERSHED.

Area	Wastewater treatment plants (WWTP)	Population served by the WWTP	Population without WWTP	Total resident population
North shore (Greater Lisbon)	Alcântara	556 000	154 200 (10%)	1 547 600 (100%)
	Beirolas	160 000		
	Chelas	178 000		
	Frielas	329 900		
	S. João da Talha	165 000		
South shore (Setúbal Peninsula)	Fonte da Prata	4 500	489 967 (69%)	707 224 (100%)
	Alcochete	8 100		
	Quinta da Bomba	120 000		
	Seixalinho	30 000		
	Aires	2 533		
	APIC	3 000		
	Barracheia	764		
	Lagoinha	20 500		
	Palmela/Auto-Europa	12 500		
	Poceirão	360		
	Salgueirinha	15 000		
	Total	**1 606 157 (71%)**	**648 669 (29%)**	**2 254 826 (100%)**

discharging to the estuary was used to calculate the nutrient loads. At present, 17 wastewater treatment plants (WWTP) in the estuary have secondary treatment, with a mean efficiency of about 70% removal of nitrogen compounds. On the North shore, the sewage treatment plants serve most of the population. On the South shore, about 70% of the residents are not served by a WWTP (Figure 101).

No data on the composition and concentrations of the main industrial effluents to the estuary was available to calculate the nutrient input from this source. However, the main industrial activities in the estuarine area (chemical and smelting) are not associated with nutrient pollution. Nutrient inputs from other industrial activities discharging into the river (paper manufacturing, textile industry and pig farming) were accounted for in the calculation of the nutrient loading from the river Tagus and tributaries.

Considering the daily N (12 g) and P (2.8 g) load per inhabitant, the data in Figure 101 and population equivalents for the main industrial activities, the nutrient load to the estuary introduced by treated effluents is about 5.78 ton of N and 4.5 ton of P per day. The high phosphorus load is mainly due to the secondary treatment used in most of the WWTP, which does not remove phosphorus compounds from the effluents. The nutrient load due to untreated sewage (29% of the population) contributes about 7.78 ton of N and 1.82 ton of P per day (Figure 102).

Nutrient input from the river Tagus is mainly due to agricultural activities in the watershed above the head of the estuary (Figure 103). Since

FIGURE 102. NITROGEN AND PHOSPHORUS LOADS FROM THE MAIN SOURCES OF NUTRIENTS TO THE ESTUARY.

Sources	Nitrogen (ton N d^{-1})	Phosphorus (ton P d^{-1})
Effluents from the WWTP	5.78	4.50
Untreated effluents	7.78	1.82
River Tagus	25.29	5.36
River Sorraia	0.23	0.03
River Trancão	0.04	0.02
Total	**39.12**	**11.73**

FIGURE 103. SOIL USES IN THE HYDROGRAPHIC BASIN OF THE TAGUS ESTUARY.

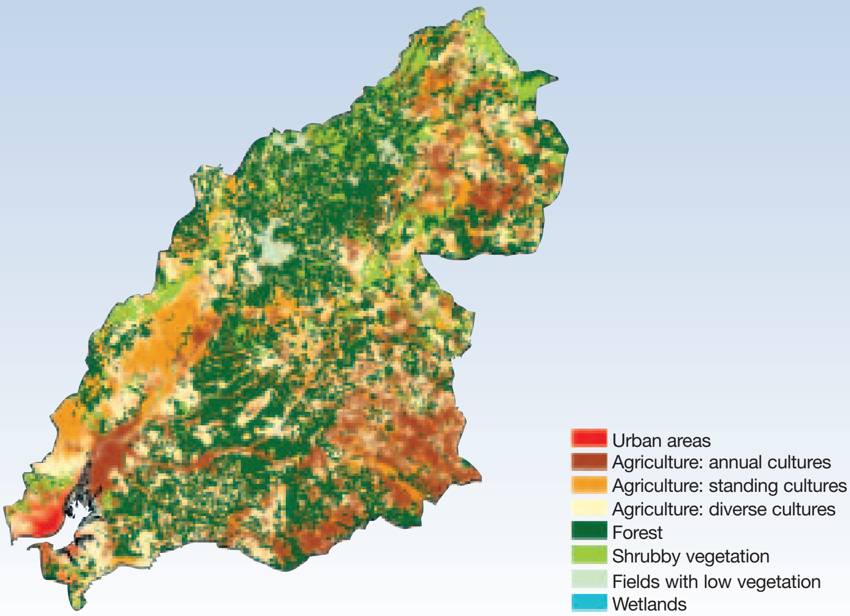
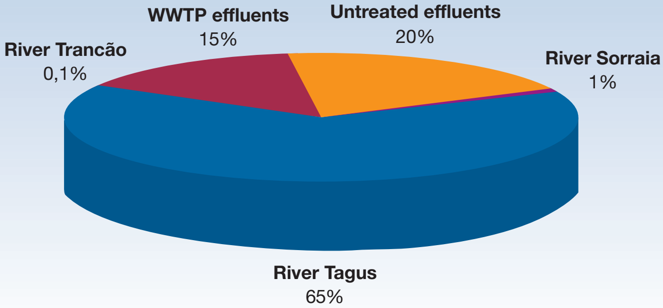
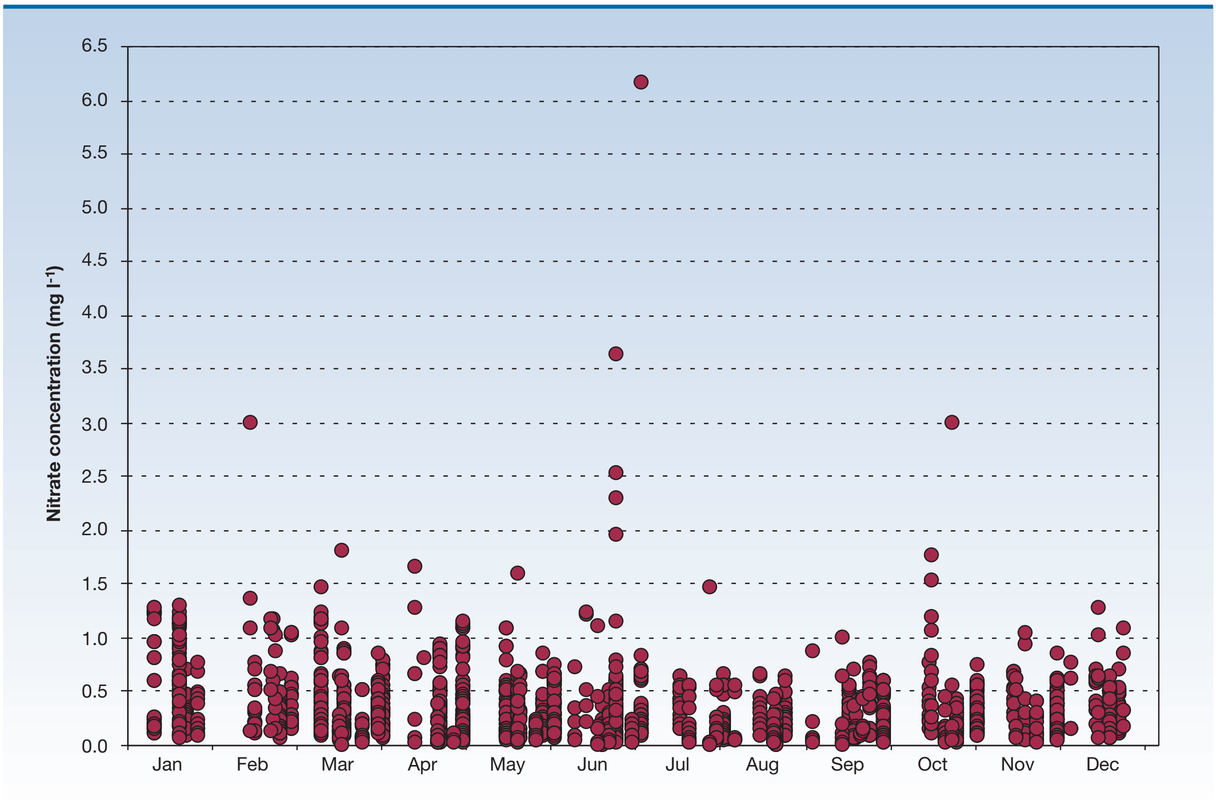


FIGURE 104. RELATIVE CONTRIBUTION OF EACH NUTRIENT SOURCE IN THE TAGUS ESTUARY.



no thresholds are considered in the NEEA methodology, to classify the nutrient inputs to the Tagus estuary a heuristic set of ranges was considered, based on the total load of nutrients into the estuary and the relative contribution of anthropogenic sources (Figure 11). In order to determine the relative contribution of anthropogenic sources and ocean exchanges to the overall dissolved nitrogen concentration, the loading-susceptibility model described previously was applied. The Human Influence determined by the model is about 61%, which falls into the Moderate category. The nutrient inputs in the Tagus estuary are therefore considered to be moderate. Figure 104 shows the relative contribution of each nutrient source into the estuary.

FIGURE 105. NITRATE CONCENTRATION IN THE TAGUS ESTUARY.



Taking into account the ERM report which classifies the North part of the Tagus estuary as a vulnerable zone, Figure 105 shows the values obtained for the nitrate concentration in the entire estuary. All values are an order of magnitude below the threshold (50 mg l^{-1}) defined in Directive 91/676/EEC.

DETERMINATION OF FUTURE OUTLOOK

Changes in the treatment level (from secondary to tertiary) are projected for some of the WWTP in estuary, in order to remove nutrients (particularly phosphorus) more efficiently. In the South shore, within the next 15 years the population will be served with five new WWTP, which will be able to treat the sewage of about 412 000 population equivalents. Also, existing WWTP are able to treat more sewage than at present, since these plants are not working at maximum capacity. Thus, it is considered that future nutrient loading to the estuary will be significantly reduced, particularly from the South shore.

SUMMARY OF THE NEEA INDEX APPLICATION

Figure 106 summarises the results obtained for the NEEA index application in the Tagus estuary.

CONCLUSIONS

The following conclusions can be drawn from the NEEA index application to the Tagus estuary:

FIGURE 106. RESULTS OF THE NEEA INDEX APPLICATION TO THE TAGUS ESTUARY. SLE: SYMPTOM LEVEL EXPRESSION; EAR: ESTUARY AGGREGATION RULES; PSM: PRIMARY SYMPTOMS METHOD; SSM: SECONDARY SYMPTOMS METHOD.

Indices	Methods	Parameters/Value/EAR			Index category
Overall Eutrophic Condition (OEC)	PSM	Chlorophyll *a*	0.997	0.33 Moderate	Moderate Low
		Epiphytes	0		
		Macroalgae	0		
	SSM	Dissolved oxygen	0.12 Low	0.12 Low	
		Submerged aquatic vegetation	-		
		Nuisance and toxic blooms	0		
Overall Human Influence (OHI)	Susceptibility	Dilution potential	High	Low susceptibility	Low
		Flushing potential	Moderate		
	Nutrient inputs	Moderate nutrient input			
Future Outlook for future conditions (DFO)	Future nutrient pressures	Future nutrient pressures decrease			Improve Low

- The Tagus is a well-studied system, which has been continuously monitored since 1980;
- The OEC index classifies the estuary in the "Moderate Low" category. This result is strongly influenced by the "High" level of expression obtained for chlorophyll *a* in the mixing and seawater zones. Despite this classification, the monthly median values of chlorophyll *a* do not exceed the threshold defined for the OEC "Medium" category. Furthermore, the high values obtained in the early 1980's are not currently detected. The other primary and secondary symptoms (dissolved oxygen) are not observed or have a low level of expression in the estuary;
- The Tagus estuary is a well-mixed estuary with a "High" dilution potential and a "Moderate" freshwater inflow. Nutrient inputs to the estuary are considered "Low" with a tendency to be even lower in the future. The OHI index classifies the impact of the nutrient inputs in the estuary as "Low";
- The nitrate concentration in the water is far below the limit considered in the Directive 91/676/EEC;
- The future nutrient pressure decrease (DFO) and the values obtained for the other indices used support the conclusion that neither the Tagus estuary nor parts of the estuary should be listed as sensitive areas as regards entrophication (Directive 91/271/EEC) or vulnerable zones (Directive 91/676/EEC).

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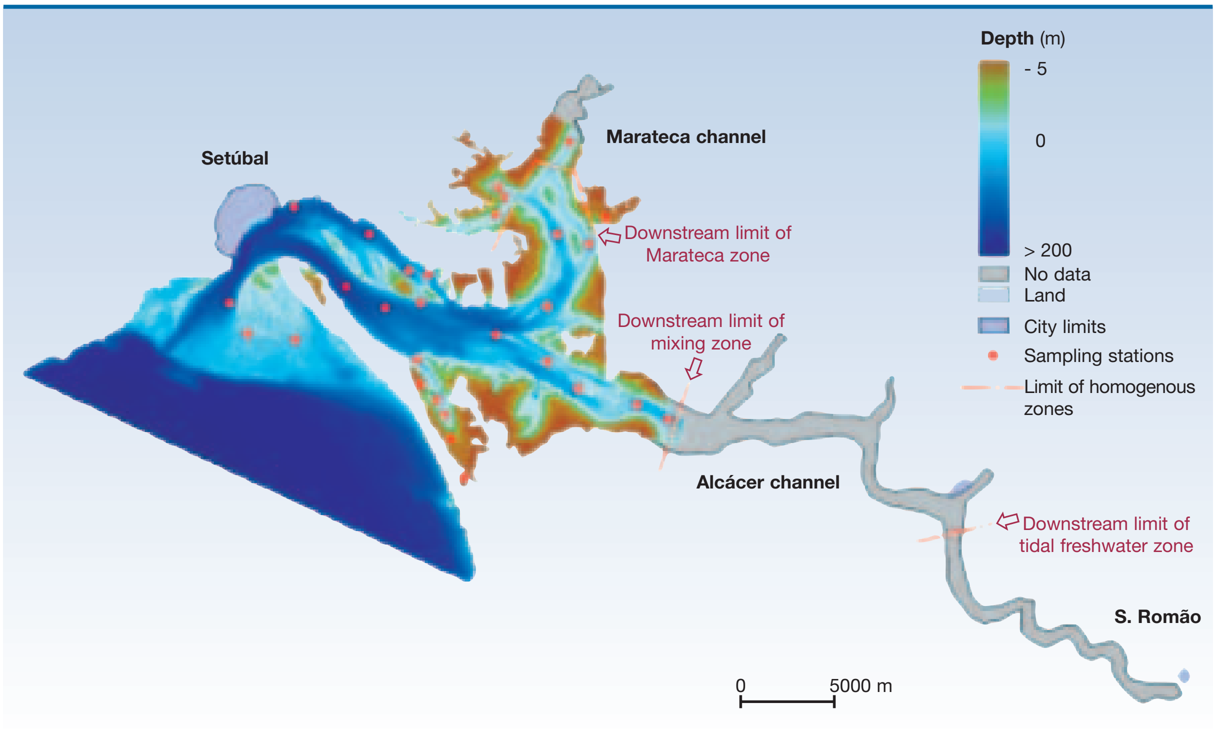
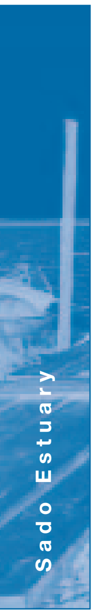
SADO ESTUARY

GENERAL CHARACTERISTICS

The Sado River drains an area of 6 700 km^2. The river flow is very irregular, varying from 1 $m^3\ s^1$ in summer to 60 $m^3\ s^{-1}$ in winter, and exhibiting large interannual fluctuations. The Sado river ends in a tidal estuary which has an area of 180 km^2 and a complex morphology (Figure 107). The upper estuary has two channels: The Sado channel (35 km long and 700 m wide, average depth 5 m, about 80% of the total freshwater inflow), and the Marateca channel on the north side (about 10% of the total freshwater inflow). The middle estuary (5 km wide, 20 km long, 10 m depth) is a wide embayment with a large salt marsh on the southern side. The connection to the ocean is made through a deep narrow channel. The Sado estuary is well mixed for normal river flow conditions, although high discharge in some winter months may cause moderate stratification in parts of the estuary (Figure 108).

FIGURE 107. SADO ESTUARY: BATHYMETRY, SAMPLING STATIONS AND LIMITS OF THE HOMOGENEOUS ZONES.





HOMOGENEOUS AREAS

The physical classification of the estuary into homogeneous zones was made using all available salinity values. However, the complex morphology of the estuary justifies the extension of the three-zone NEEA classification, through the definition of a further zone. The surface areas of the homogeneous zones were determined by GIS where digital bathymetry was available, and by planimetry for the upper regions of the estuary, using 1:25 000 and 1:50 000 scale maps.

Four homogeneous zones (Figure 109) were therefore defined, the fourth in the Marateca channel, a high salinity area (>36 occasionally) where hydrodynamic properties, nutrient dynamics and primary productivity patterns are very different from those in the adjacent areas.

FIGURE 108. MAIN CHARACTERISTICS OF THE SADO ESTUARY.

Parameter	Value
Volume	500 x10^6 m^3
Total area	180 km^2
River flow	40 m^3 s^{-1}
Tidal range	2.7 m
Population	128 000
Mean residence time	21 days

FIGURE 109. HOMOGENEOUS AREAS OF THE SADO ESTUARY.

Zone	Salinity	Section	Area (km^2)
Seawater	> 25	Mouth – Monte Novo do Sul	138.0
Mixing zone	0.5 – 25	Monte Novo do Sul – Porto das Lezírias	13.5
Tidal fresh	< 0.5	Porto das Lezírias – S. Romão	2.6
Marateca	-	Small channel system and upper region of Marateca channel + upper limit of Comporta channel	25.6
		Total	**179.7**

DATA COMPLETENESS AND RELIABILITY

Data used in this study were taken from the BarcaWin2000™ database, which groups the results of all the campaigns made in the Sado estuary. The number of campaigns, dates, sites and water quality parameters are shown in Figure 110. The calculated data completeness and reliability (DCR) for chlorophyll *a* and dissolved oxygen is 100% in the salt water zone, but is 0% in the other zones, due to the low sampling frequency, although spatial coverage of available data is high. The average DCR of the estuary for these parameters is 76.8%.

Values of 0% were attributed for epiphytes and macrophytes since no occurrence or problems have been documented for these elements in the Sado estuarine area.

As regards nuisance or toxic algal blooms, primary productivity studies have been carried out, with identification of phytoplankton species, and there is a regular Harmful Algal Bloom (HAB) monitoring programme.

FIGURE 110. DATASET FOR THE SADO ESTUARY.

Number of campaigns	Date	Site	Parameters
36	July 1978 December 1978 April 1979	Seawater Mixing Marateca	Chlorophyll *a* Current speed/direction Nitrogen (NH_4, NO_2+NO_3) Dissolved oxygen pH Phaeopigments Phosphate Salinity Silicate Suspended matter Temperature Turbidity
16	May 1980 to August 1981 (monthly)	Seawater	Cell counts Chlorophyll *a* Diatoms Nitrogen (NH_4, NO_2+NO_3) Dissolved oxygen pH Phosphate Phytoflagellates Primary productivity Salinity Silicate Temperature Transparency
24	December 1982 to December 1984 (monthly)	Seawater	Nitrogen (NH_4, NO_2+NO_3) Dissolved oxygen pH Phosphate Salinity Sulphate Suspended matter Temperature Turbidity
12	May and September 1989 May 1990 January 1991 March 1991 February 1992	All estuary	Chlorophyll *a* Nitrogen (NH_4, NO_2+NO_3, Total) Organic matter pH Phaeopigments Phosphorus (PO_4, Total) Salinity Silicate SPM Temperature Turbidity

The studies shown in Figure 111 cover the seawater and mixing zone, with high frequency and spatial coverage, but for the tidal fresh and Marateca zones the dataset is less complete.

Consequently, the DCR value for this parameter is 76.8% for the whole estuary.

Submerged Aquatic Vegetation (SAV) is reported only for the area around the Tróia peninsula, at the seaward limit of the estuary; the lack of reported occurrence of SAV in the estuary led to the attribution of a DCR value of 0%.

FIGURE 111. PHYTOPLANKTON SURVEYS IN THE SADO ESTUARY.

Campaign dates	Zone	Focus
Seasonally in 1990	Seawater Mixing Marateca	Trophic status and phytoplankton dynamics in the Sado estuary
Monthly 7/1986-12/1987	Seawater	Assessment of phytoplanktonic communities

OVERALL EUTROPHIC CONDITION

Primary symptoms method

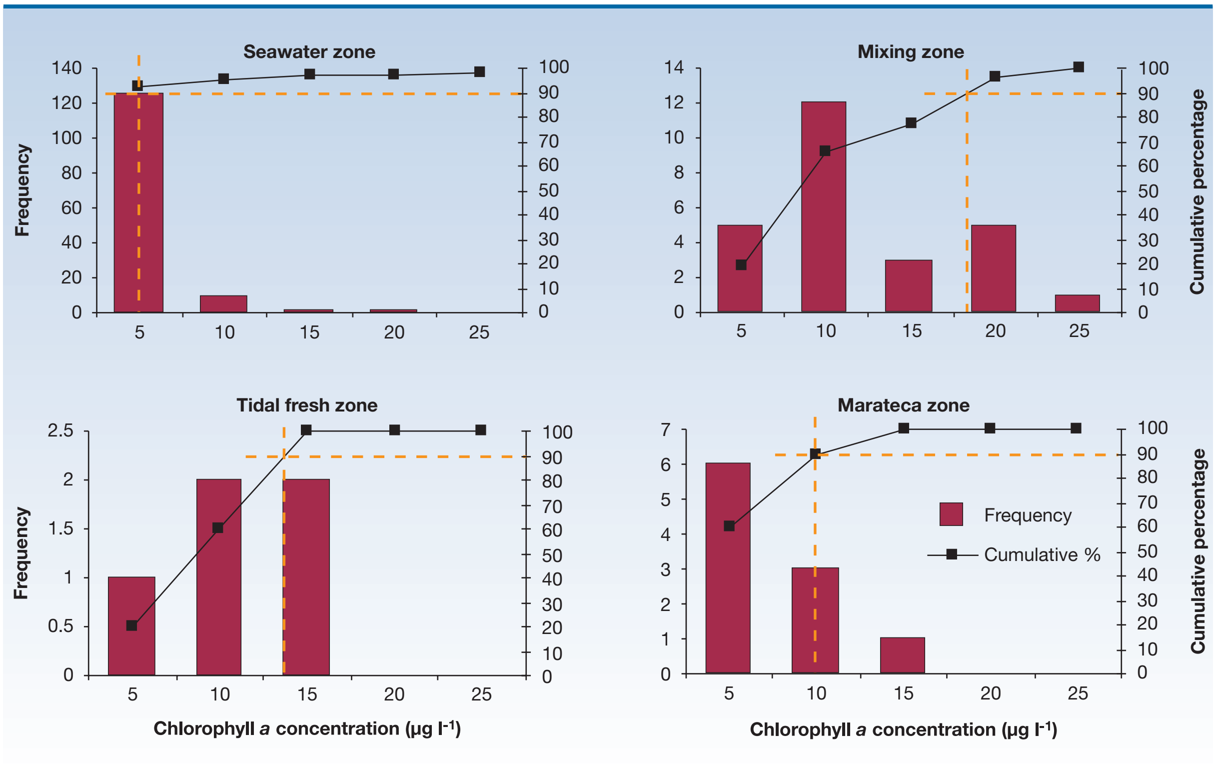
Chlorophyll *a*

The percentile 90 values used to calculate maximum chlorophyll *a* for all three zones are presented in Figure 112. According to the thresholds defined by the NEEA methodology, maximum values obtained for the seawater zone fall within the “Low” category, while the mixing, tidal freshwater, and Marateca zones are classified as “Medium”.

The NEEA approach focuses on the characteristic maxima for the system, which excludes highly unusual one-time events. Measurements for stations in the upstream area of the mixing zone for one day in February 2000 gave unusually high chlorophyll *a* values (an order of magnitude higher than typical maxima). No explanation for this event has emerged, and no species data are available. Speculatively, such high values may have been due to the release of eutrophied water retained for irrigation, where the bloom had developed. Precautionary monitoring for the area in question is therefore recommended.

The annual cycle of chlorophyll *a* in the estuary is shown in Figure 113, for the four homogeneous zones. In the seawater zone, the occurrence of two peaks is observed, the first in early spring (February/March) and a second one in midsummer (July). Values oscillate between these peaks, decreasing only in early autumn (September); in winter, chlorophyll *a* concentrations

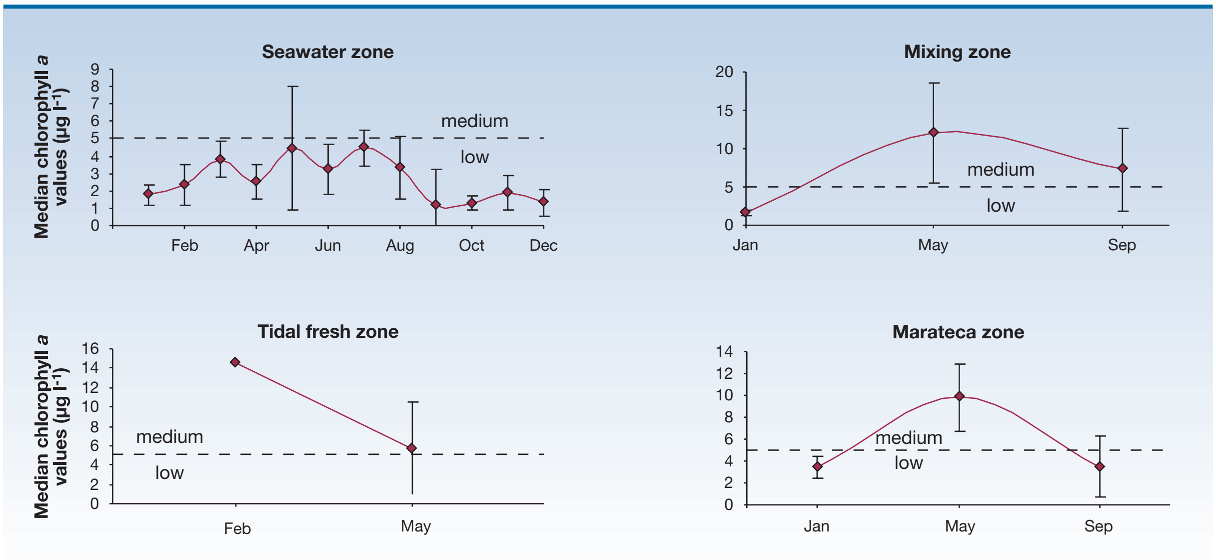
FIGURE 112. FREQUENCY DISTRIBUTION FOR CHLOROPHYLL IN THE FOUR ZONES OF THE SADO ESTUARY.



are "Low". Although the available dataset for the other zones is limited, the annual cycle appears to be similar.

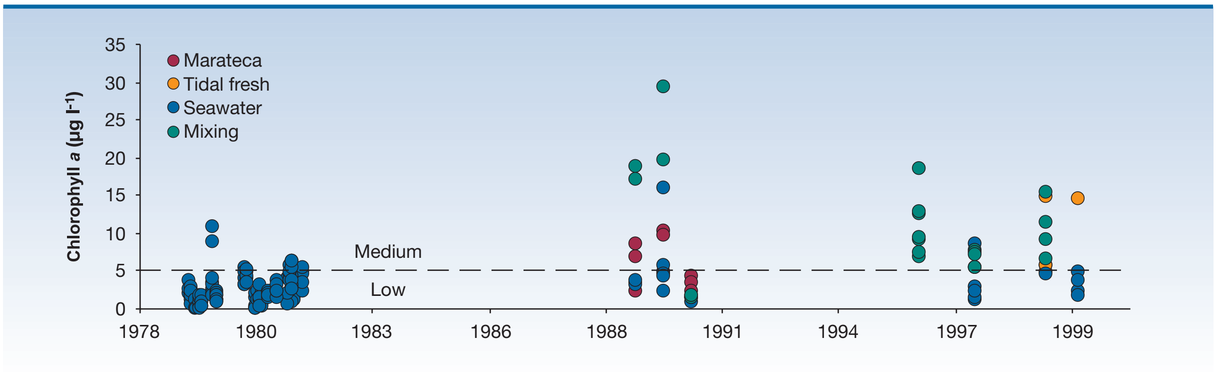
To examine the multi-annual changes in chlorophyll *a*, a trend analysis was performed (Figure 114). In the seawater zone, the values

FIGURE 113. ANNUAL CYCLE OF CHLOROPHYLL IN THE SADO ESTUARY.



from 1978 to 1999 are very similar. Consequently, despite higher concentrations in the early 1990's, values remain "Low". In the mixing zone, where concentrations are higher, a decreasing trend between 1989 and 1997 can be observed. In Marateca, the last of the three sampling years exhibits lowest concentrations. However, due to the limited dataset, no trends can be identified for the Marateca or tidal freshwater zone.

FIGURE 114. SURFACE CHLOROPHYLL IN THE SADO ESTUARY.



The summary of the results obtained for the NEEA index application in each salinity zone is presented in Figure 115.

Epiphytes

There is no available literature on epiphytes in the Sado, and expert consultations indicate that no problems with epiphytes have been observed within the estuary. The value used for epiphytes in each zone was therefore considered to be zero.

Macroalgae

No occurrence of problems with exceptional macroalgal growth has been reported in the literature or identified by experts. The value used for this symptom in each zone equals zero.

The aggregation of this information and the determination of the primary symptom level of expression value for the Sado estuary are shown in Figure 116.

FIGURE 115. NEEA INDEX APPLICATION FOR THE CHLOROPHYLL PARAMETER IN THE SADO ESTUARY.

ZONE	IF Concentration	AND Spatial coverage	AND Occurrence	THEN Expression	Value
Seawater	Low	Any	Any	Low	0.25
Mixing	Medium	High	Periodic	High	1
Tidal fresh	Medium	High	Unknown	Flag A	0.5
Marateca	Medium	Very low	Periodic	Low	0.25

FIGURE 116. NEEA INDEX APPLICATION FOR THE PRIMARY SYMPTOMS IN THE SADO ESTUARY.

Zone	Salinity	Area (km^2) (A_Z)	Value (v_{ij})			$A_Z/A_t \times v_{ij}$		
			Chlorophyll *a*	Macroalgae	Epiphytes	Chlorophyll *a*	Macroalgae	Epiphytes
Seawater	> 25	138.0	0.25	0	0	0.19	0	0
Mixing	0.5 – 25	13.5	1.00	0	0	0.07	0	0
Tidal fresh	< 0.5	2.6	0.50	0	0	0.01	0	0
Marateca	-	25.6	0.25	0	0	0.03	0	0
Sum		179.7	-	-	-	0.31	0	0
Primary symptoms level of expression value for the estuary: 0.10 Low								

Secondary symptoms method

Dissolved oxygen

Figure 118 presents the frequency distribution for dissolved oxygen.

The tenth percentile value obtained for the seawater zone is higher than the concentration considered to indicate biological stress (5 mg l^{-1}).

In the mixing zone, minimum values are below 5 mg l^{-1} (mostly in the upper region). For the tidal freshwater and Marateca zone, all existing dissolved oxygen concentration values are higher than the threshold for biological stress. The information about the dissolved oxygen levels in the different zones is shown in Figure 117. These values suggest that, apart from the mixing zone, no problems with low oxygen levels occur in the estuary, leading to the classification shown in Figure 119.

Submerged aquatic vegetation

Submerged aquatic vegetation (SAV) occurs in the Sado estuary, essentially around the Tróia peninsula (seawater zone). However, no information about this element could be found in the literature. Due to the absence of any reference to the occurrence of problems with SAV losses, and considering that the Sado estuary is a well known system, the expression of this parameter was considered to be "Unknown" in the seawater zone, where SAV exists, and zero in the other zones.

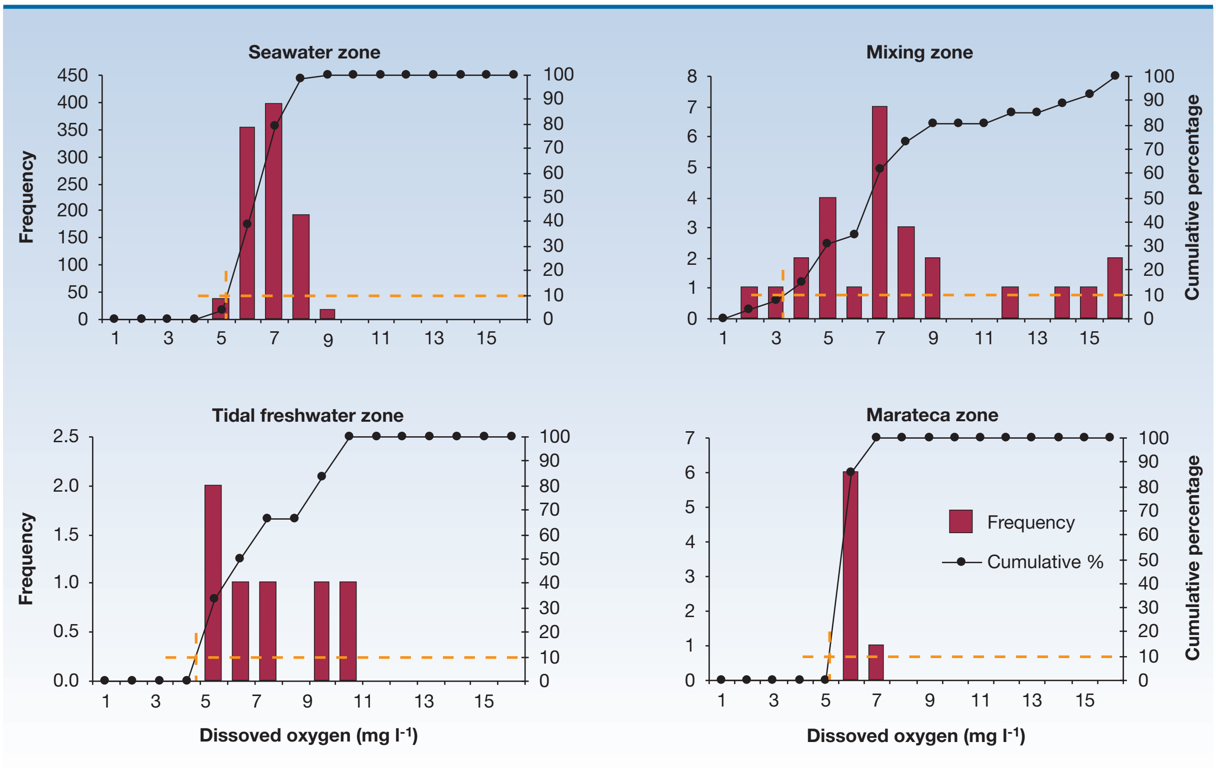
FIGURE 117. ANALYSIS OF THE AVAILABLE DATASET FOR DISSOLVED OXYGEN (DO)*.

Zone	Minimum DO	Maximum DO	Median DO
Seawater	4.8	11.6	7.2
Mixing	2.8	18.7**	7.6
Tidal fresh	5.3	10.5	6.6
Marateca	6.3	7.5	6.5

* All values in mg l^{-1}

** Maximum due to a one-time event in February 2000

FIGURE 118. FREQUENCY DISTRIBUTION FOR DISSOLVED OXYGEN IN THE DIFFERENT ZONES OF THE SADO ESTUARY.



Nuisance and toxic blooms

In the seawater zone, the presence of low concentrations of the potentially toxic, *Nitzschia pungens*, was detected, with a density of 160 – 5800 cells l^{-1}, as well as *Dinophysis acuminata* and *D. rotundata*, with 200 cells l^{-1}. In the mixing zone, the same species occurred, but at lower concentrations. In both cases, these low cellular concentrations cannot be considered blooms. The only short-lived toxic algal bloom (*Phaeocystis pouchettii* with 52x10^{6} cells l^{-1}) was observed in a very restricted area in the seawater zone (close to a sewage outfall). The origins of this bloom are probably related to the local conditions of the sampling point and do not reflect a problem which affects the whole zone. For the other zones, no references about the occurrence of nuisance or toxic algal blooms could be found in the literature. Experts confirm that these problems were never

FIGURE 119. RESULTS OF THE NEEA INDEX APPLICATION FOR THE DISSOLVED OXYGEN PARAMETER IN THE SADO ESTUARY.

ZONE	IF Oxygen demand	AND Spatial coverage	AND Frequency	THEN Expression	Value
Seawater	Not observed	-	-	-	0
Mixing	Biological stress	Very low	Episodic	Low	0.25
Tidal fresh	Not observed	-	-	-	0
Marateca	Not observed	-	-	-	0

FIGURE 120. RESULTS OF THE NEEA INDEX APPLICATION FOR THE SECONDARY SYMPTOMS IN THE SADO ESTUARY.

Zone	Salinity	Area (km²) (A_Z)	Value (v_{ij}) Dissolved O_2	SAV	Blooms	$A_Z/A_t \times v_{ij}$ Dissolved O_2	SAV	Blooms
Seawater	> 25	138.0	0	0.25	0	0	0.19	0
Mixing	0.5 – 25	13.5	0.25	0	0	0.02	0	0
Tidal fresh	< 0.5	2.6	0	0	0	0	0	0
Marateca	-	25.6	0	0	0	0	0	0
Sum		179.7	-	-	-	0.02	0.19	0
Secondary symptoms level of expression value for the estuary: 0.19 Low								

observed in all monitoring which took place between 1989 and 2000.

Consequently, the expression of this parameter was considered zero for the whole estuary.

The aggregation of all this information and the determination of the secondary symptom level of expression value for the Sado estuary are shown in Figure 120.

OVERALL HUMAN INFLUENCE

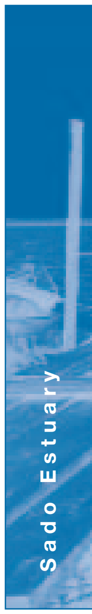
Susceptibility

Dilution potential

The low average depth, strong tidal currents, and low freshwater discharge make the Sado a well-mixed estuary, which is stratified only rarely in specific situations such as high river discharges. The vertically well-mixed water column, during all year and throughout all the estuarine area, classifies the Sado estuary in the NEEA Type A, "High" category, despite the fact that the dilution volume factor (10^{-8} m^{-3}) is relatively low, when compared to larger estuaries.

Flushing potential

The Sado estuary is a mesotidal estuary with a tidal range of 2.7 m. Since the freshwater input to the estuary by the river and tributaries is considered small compared to the estuarine volume, the results obtained for the flushing potential fall within the "Moderate" category.



Nutrient inputs

The main nutrient sources to the estuary are:

1) Domestic effluents (from sewage treatment plants or direct discharges);

2) Industrial effluents (from industrial treatment plants or direct discharges);

3) Load from the Sado River, which aggregates the main agricultural, domestic and industrial sources from the river basin;

4) Load from the tributaries (Marateca and Comporta channels).

The nutrient inputs into the Sado estuary correspond to the sum of the loads generated in the sub-watersheds that drain directly into the estuary, and to the inputs by the Sado River. Figure 122 shows the soil uses in the Sado watershed.

To estimate the direct loads into the estuary, urban and industrial point pollution sources were quantified. Urban pollution sources also included industrial sources, which discharge wastewater into the urban sewage network. Domestic inputs were estimated based on population-equivalents weighted by the treatment level of the discharge. For the industrial inputs included in this group, the specific daily or annual load of the activity and its working period were considered.

FIGURE 121. NUTRIENT INPUTS FROM POINT SOURCES (DOMESTIC AND INDUSTRIAL). ALL VALUES IN TON Y^{-1}.

Source	N input	P input
Domestic effluents	191	41
Industrial effluents	1 262	355

Setúbal, with about 114 000 inhabitants, and Alcácer do Sal, with 14 000 inhabitants, are responsible for 65% of the total domestic input.

Direct industrial sources are located mainly in the seawater zone, around Setúbal (Mitrena peninsula). The main industrial activities which discharge nutrients located around the estuary are:

FIGURE 122. SOIL USES IN THE SADO WATERSHED.

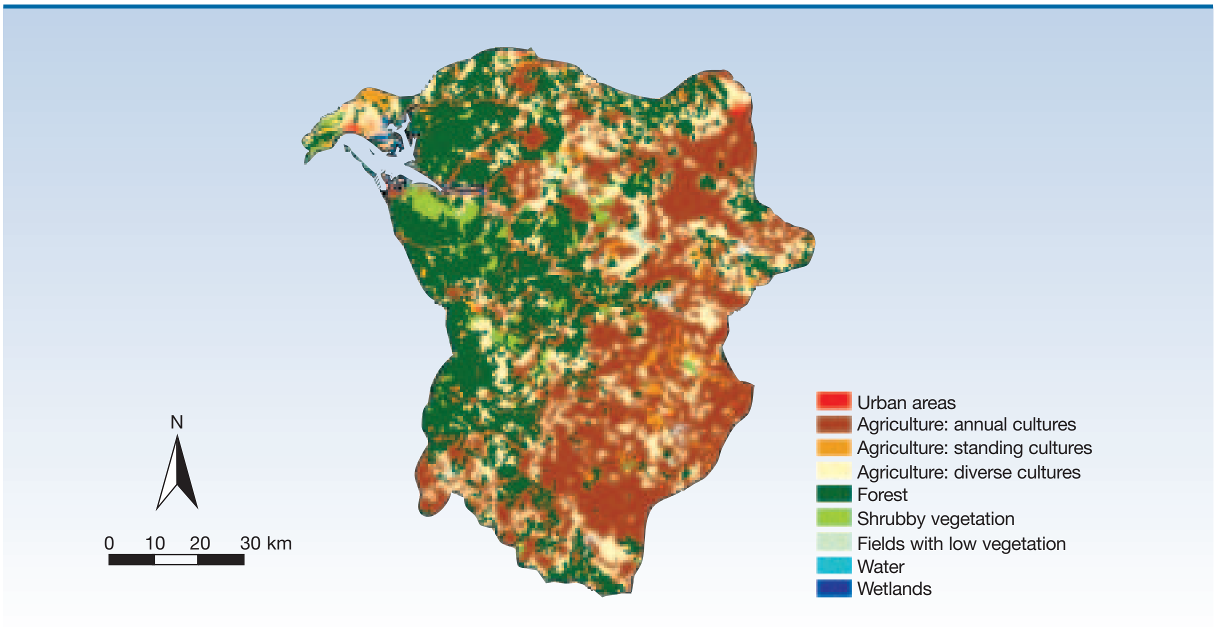


FIGURE 123. NUTRIENT INPUTS FROM THE MAIN FRESHWATER SOURCES.

Nutrient	Sado River		Marateca channel	
	Winter	Summer	Winter	Summer
P input (ton month^{-1})	70	8	7	0
N input (ton month^{-1})	300 – 500	5	60	0

- **Paper and paper pulp;**
- **Fertilizers;**
- **Food industry (tomato paste and olive oil production);**
- **Pig farms.**

The results obtained for domestic and industrial inputs for the direct sources described above are shown in Figure 121.

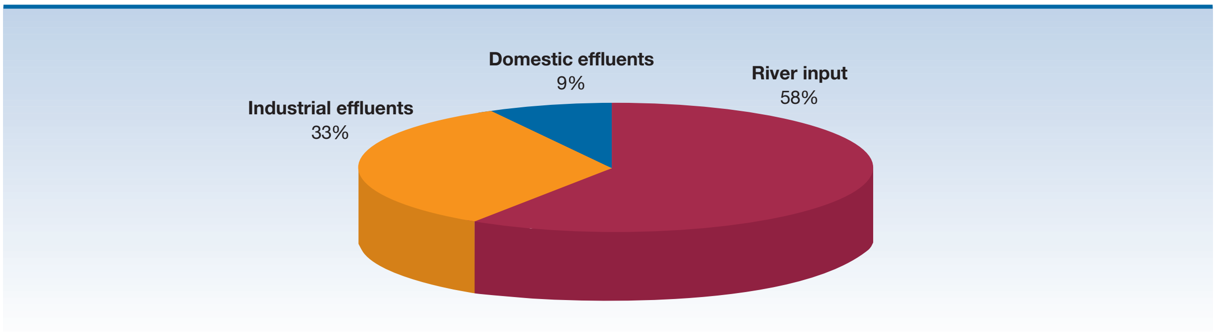
Diffuse sources, such as agricultural activities, contribute to the total estuarine nutrient input.

These sources are difficult to quantify, however, their contribution is probably reduced, compared to direct inputs. The most important contributors to this type of pollution are located either above the head of the estuary or in the upper reaches, so the bulk of the load from non-point sources is included in the estimation of inputs from the Sado River. Tomato and rice are the largest crops, with the greatest impact probably associated to paddy fields, which cover an area of approximately 10 000 ha in the Sado watershed, and produce 5 000 to 6 500 kg ha^{-1}.

The input from the Sado River and Marateca channel (the most important tributary) was calculated by multiplying the mean nutrient concentrations by the freshwater flow, using mean monthly values for winter and summer months. The values are shown in Figure 123. Considering that freshwater flow is high from October to February and low from March to September, an annual input of 2 335 ton of nitrogen and 441 ton of phosphorus is obtained.

Since no thresholds are considered in the NEEA methodology, to classify the nutrient inputs to the Sado estuary a heuristic set of ranges was considered, based on the total load of nutrients into the estuary and the relative contribution of anthropogenic sources (Figure 11). In order to determine the relative contribution of anthropogenic sources and ocean exchanges to the overall dissolved nitrogen concentration, the

FIGURE 124. RELATIVE CONTRIBUTION OF EACH NITROGEN SOURCE TO THE SADO ESTUARY.



loading-susceptibility model described previously was applied. The Human Influence determined by the model is about 45%, which falls into the “Moderate” category. The nutrient inputs to the Sado estuary are therefore considered moderate. The contribution of each nitrogen source into the estuary is shown in Figure 124.

DETERMINATION OF FUTURE OUTLOOK

The increase of percentage of treated wastewater in the estuarine area, mainly in Setúbal, will decrease nutrient inputs from these sources. Since no significant population and industrial

FIGURE 125. RESULTS OF THE NEEA INDEX APPLICATION TO THE SADO ESTUARY. SLE: SYMPTOM LEVEL EXPRESSION; EAR: ESTUARY AGGREGATION RULES; PSM: PRIMARY SYMPTOMS METHOD; SSM: SECONDARY SYMPTOMS METHOD.

Indices	Methods	Parameters/Value/EAR			Index value
Overall Eutrophic Condition (OEC)	PSM	Chlorophyll *a*	0.31	0.10 Low	Low
		Epiphytes	0		
		Macroalgae	0		
	SSM	Dissolved oxygen	0.02	0.19 Low	
		Submerged aquatic vegetation	0.19		
		Nuisance and toxic blooms	0		
Overall Human Influence (OHI)	Susceptibility	Dilution potential	High	Low susceptibility	Low
		Flushing potential	Moderate		
	Nutrient inputs	Moderate nutrient input			
Future Outlook for future conditions (DFO)	Future nutrient pressures	Future nutrient pressures marked decrease			Improve High

development is expected, nutrient inputs will be reduced significantly. Consequently, due to decreased future nutrient pressures, an improvement in eutrophic conditions and nutrient related symptoms in the Sado estuary is expected.

SUMMARY OF THE NEEA INDEX APPLICATION

Figure 125 shows the results obtained for the NEEA application.

CONCLUSIONS

The following conclusions can be drawn from the NEEA index application to the Sado estuary:

- **The Sado is a well-studied system, which has been continuously monitored since 1978, but the research effort has not been balanced throughout the system. A *Surveillance Monitoring* programme is required on the upper reaches and in the Marateca channel;**
- **The OEC index classifies the estuary in the "Low" category;**
- **The Sado estuary is a well-mixed estuary with a "High" dilution potential and a "Moderate" flushing potential, behaving at low flows almost like a coastal lagoon. Nutrient inputs to the estuary are considered "Moderate", with a tendency to be lower in the future. The OHI index classifies the impact of the nutrient inputs in the estuary as "Moderate";**
- **The nitrate concentration in the water is far below the limit considered in the Directive 91/676/EEC;**
- **The future nutrient pressure decrease (DFO) and the values obtained for the other indices used support the conclusion that neither the Sado estuary nor parts of the estuary should be listed as sensitive areas as regards eutrophication (Directive 91/271/EEC) or vulnerable zones (Directive 91/676/EEC).**

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References for grey literature consulted for this chapter may be found at http://www.imar.pt/perfect/

MIRA ESTUARY

GENERAL CHARACTERISTICS

The Mira river is 145 km long, drains an area of 1 576 km^2, and is the largest river on the Portuguese southwest coast. It ends in a narrow entrenched estuary (Figure 126) about 30 km long, 150 m wide in the lower part and 100 m in the upper part. The mean depth is about 6 m, reaching a maximum of 13 m (Figure 127). The bottom geometry is similar to the bed of the Mira river itself, with deeper areas often associated with local curvature.

FIGURE 126. MIRA ESTUARY: BATHYMETRY, SAMPLING STATIONS AND LIMITS OF HOMOGENEOUS ZONES.

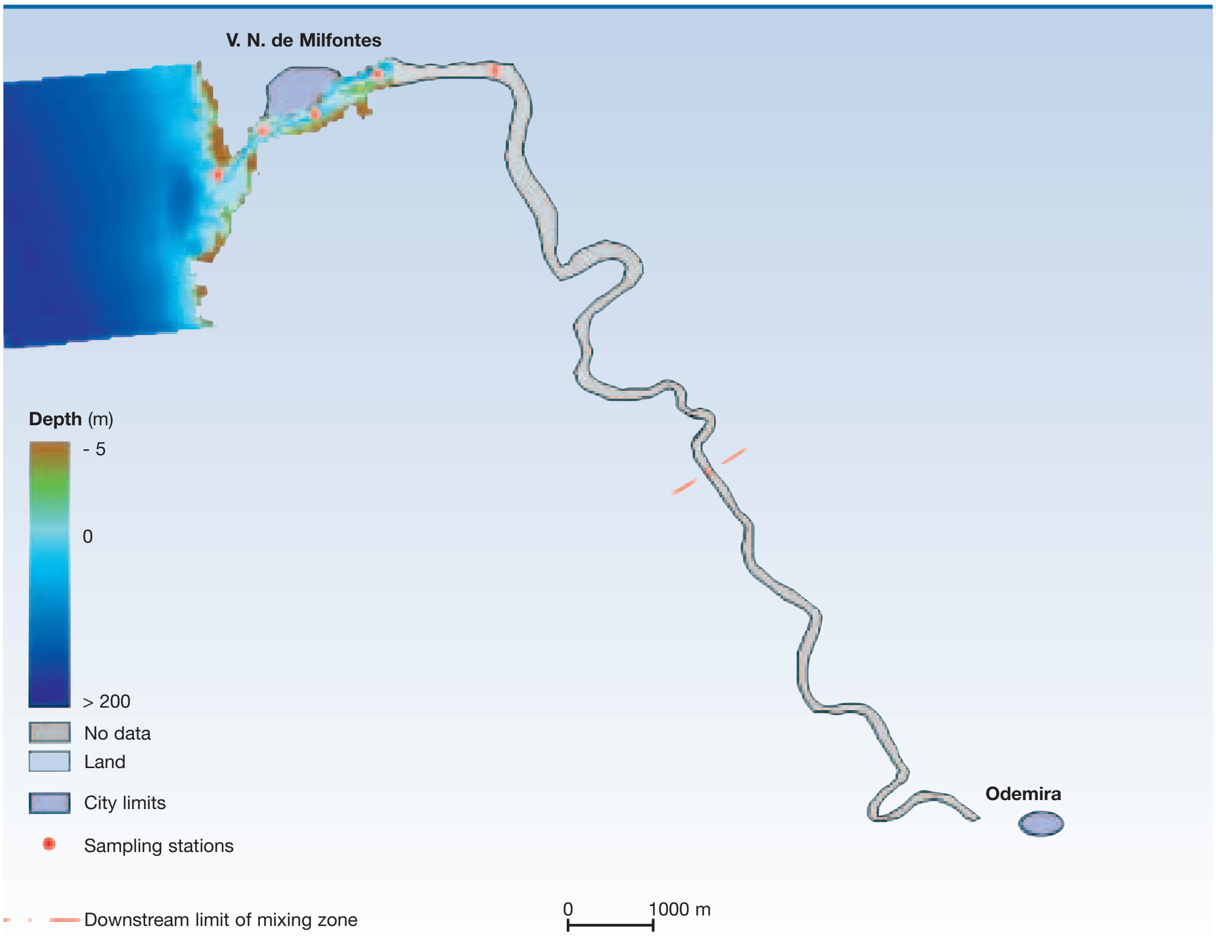


FIGURE 127. MAIN CHARACTERISTICS OF THE MIRA ESTUARY.

Parameter	Value
Volume	27x10^6 m^3
Total area	4.5 km^2
River flow	10 m^3 s^{-1}
Tidal range	3.4 m
Population	<10 000

The freshwater flow from the Mira river is very low and occurs essentially in winter months. In consequence, the estuarine hydrodynamics is strongly influenced by tidal conditions:

the penetration of saltwater is significant in months with low river flow, mostly in spring tide conditions, and is less extensive in months with high flows.

The estuary is vertically well-mixed, although stratification is observed in the deeper areas, during high freshwater flow events.

HOMOGENEOUS AREAS

The physical classification of the estuary into homogeneous zones was made using all available salinity values from fixed-station campaigns, where salinity values were measured every 625 m, from head to mouth (Figure 128).

As the median salinity measured at Odemira was higher than 0.5, and since this point is usually considered the upper estuarine limit, only two salinity zones for the application of the NEEA methodology were considered (Figure 129).

FIGURE 128. MEDIAN SALINITY VALUES AGAINST DISTANCE TO THE MOUTH IN THE MIRA ESTUARY.

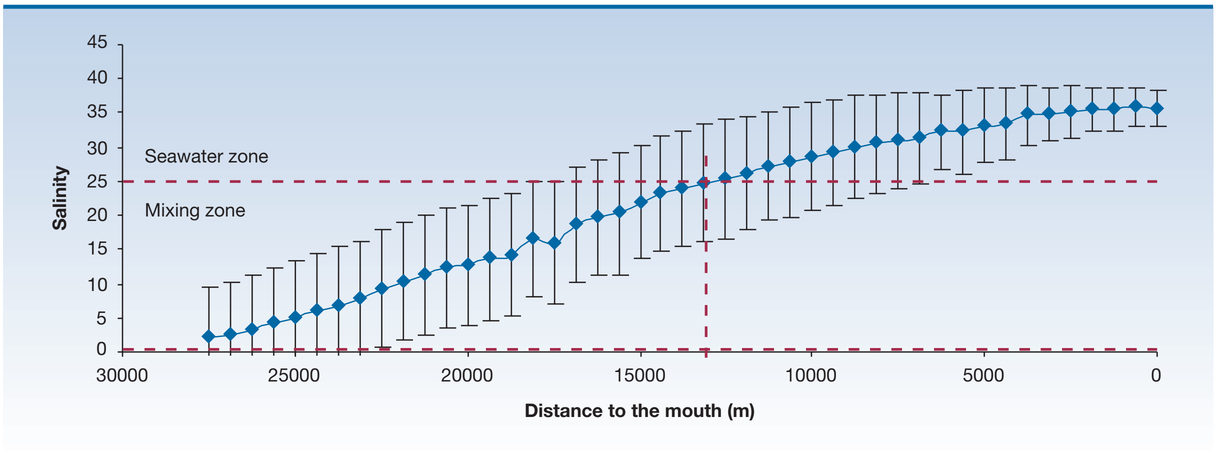


FIGURE 129. HOMOGENEOUS AREAS OF THE MIRA ESTUARY.

Zone	Salinity	Section	Area (km^2)
Seawater	> 25	0 – 12.6 km	1.9
Mixing zone	0.5 – 25	12.6 – 30 km	1.7
		Total	**3.6**

DATA COMPLETENESS AND RELIABILITY

The number of campaigns, dates and water quality parameters are shown in Figure 130. Chlorophyll *a* data exist for the entire estuary over an annual cycle, but the calculated DCR for chlorophyll *a* is 0%, because numerical listings were unavailable, and no statistical analysis could be performed.

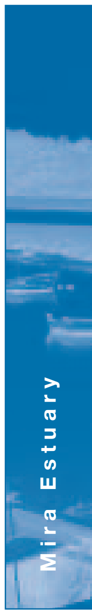
The DCR for dissolved oxygen is 100% in the two zones, due to the high spatial data coverage and reasonable sampling frequency.

The DCR value for macrophytes and epiphytes is 100% in the seawater zone, since a representative area was sampled over an annual cycle, but 0% for macrophytes in the mixing zone, because this area was not sampled (no epiphytic algae occur in the mixing zone, so this parameter was not considered in this case). The average DCR of the estuary for these parameters is 50%. Values of 0% were obtained for nuisance and toxic algal blooms and SAV loss, since no problems have been identified in the literature or by expert consultation.

FIGURE 130. DATASETS FOR THE MIRA ESTUARY.

Number of campaigns	Date	Site	Parameters
37 (Lagrangian campaigns, covering spring and neap tides, in ebb and flood conditions)	April, May and October 1983, January, February, April, July, August, October and November 1984	Seawater and mixing zones	Salinity Temperature Current velocity Turbidity
20 (Eulerian campaigns, covering spring and neap tides, in ebb and flood conditions)	April and May 1985, October 1986, January 1986	Seawater and mixing zones	Salinity Temperature Turbidity Dissolved oxygen
1	December 1990 to October 1992 (monthly sampling)	Seawater zone (0.05 km^2 salt marsh area)	Nitrite Nitrate Ammonium DIP DIN Dissolved organic nitrogen Particulate organic nitrogen Dissolved Kjeldahl nitrogen Total Kjeldahl nitrogen
1*	February to October 1989	Whole estuary	Temperature Salinity Chlorophyll *a* Zooplankton
1*	1990	Seawater zone	Salt marsh vegetation

* Only graphical data available



OVERALL EUTROPHIC CONDITION

Primary symptoms method

Chlorophyll *a*

For the classification of the estuary in terms of chlorophyll *a* concentrations, average monthly values for seven stations in the mixing and seawater zones, in low and high tide conditions were available (Figure 131). These values show an annual productivity cycle with the occurrence of two peaks, one in spring (April/May) and another in midsummer (July). Chlorophyll *a* values observed in the mixing zone are higher than in the seawater zone, and the average monthly values are always lower than the NEEA threshold of 5 µg l^{-1}. In fact, the average annual chlorophyll *a* concentration observed in the entire estuary never exceeds 3 µg l^{-1}. Despite the fact that only graphical information is available, the data for the whole estuary are unquestionably in the "Low" category.

Epiphytes

Epiphytic algal mats (mainly *Enteromorpha* sp. and *Bostrichia* sp.) growing on salt marsh vascular plants, mainly *Spartina maritima*, are documented for the Mira estuary. These epiphytes form a complex matrix capable of retaining fine sediments in suspension in the water column. The distribution of epiphytes according to sea-level elevation was analysed in four categories (Sector I: 0.95m, Sector II: 1.25m, Sector III: 1.10m and Sector IV: 1.00m). Seasonal variation of epiphyte dry weight on *Spartina maritima* is shown in Figure 132.

FIGURE 131. ANNUAL CHLOROPHYLL CYCLE IN THE MIRA ESTUARY.

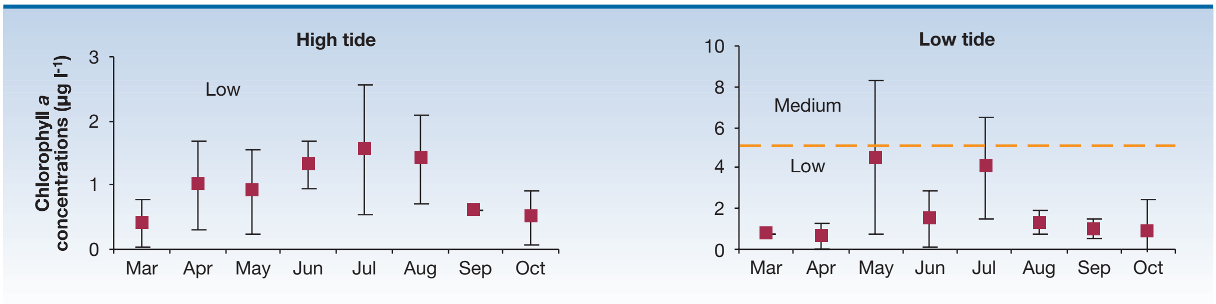
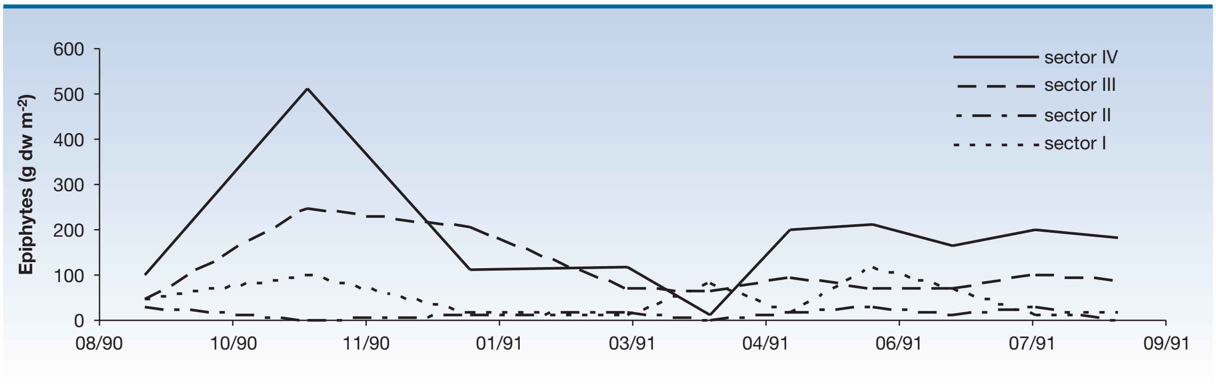


FIGURE 132. ANNUAL BIOMASS CYCLE OF SALTMARSH EPIPHYTES IN THE MIRA ESTUARY.



Epiphytes are an important element of salt marshes in the Mira estuary, which are in ecological equilibrium with other primary producers, and do not show excessive growth or adverse effects. Therefore the value used for epiphytes equals zero at all zones.

Macroalgae

No occurrence of problems with exceptional macroalgal growth has been reported in the literature or identified by experts.

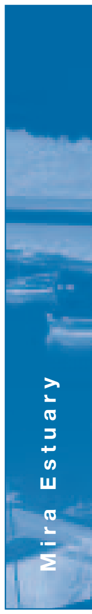
There is no evidence for a progressive increase in filamentous seaweeds (*Enteromorpha*) associated to a reduction of *Zostera* beds.

A comparative study carried out in the early 1990's at Dutch, English, French and Portuguese salt marsh sites concluded that algal mats were a significant productivity factor in the Mira estuary, as in English salt marshes (Tollesbury, Essex). Observed productivity patterns were similar, with low seasonal differences, due to the different climatic conditions. In the Mira, no excessive algal growth was identified. This is explained by the reduced nutrient load, which is reflected in low concentrations in the estuary. The value used for this symptom in each zone equals zero.

The aggregation of this information and the determination of the primary symptom level of expression value for the Mira estuary are shown in Figure 133.

FIGURE 133. NEEA INDEX APPLICATION FOR THE PRIMARY SYMPTOMS IN THE MIRA ESTUARY.

Zone	Salinity	Area (km²) (A_Z)	Value (v_{ij}) Chlorophyll *a*	Macroalgae	Epiphytes	A_Z/A_t x v_{ij} Chlorophyll *a*	Macroalgae	Epiphytes
Seawater	> 25	1.9	0	0	0	0	0	0
Mixing	0.5 – 25	1.7	0	0	0	0	0	0
Sum		3.6	-	-	-	0	0	0
Primary symptoms level of expression value for the estuary: 0 Low								



Secondary symptoms method

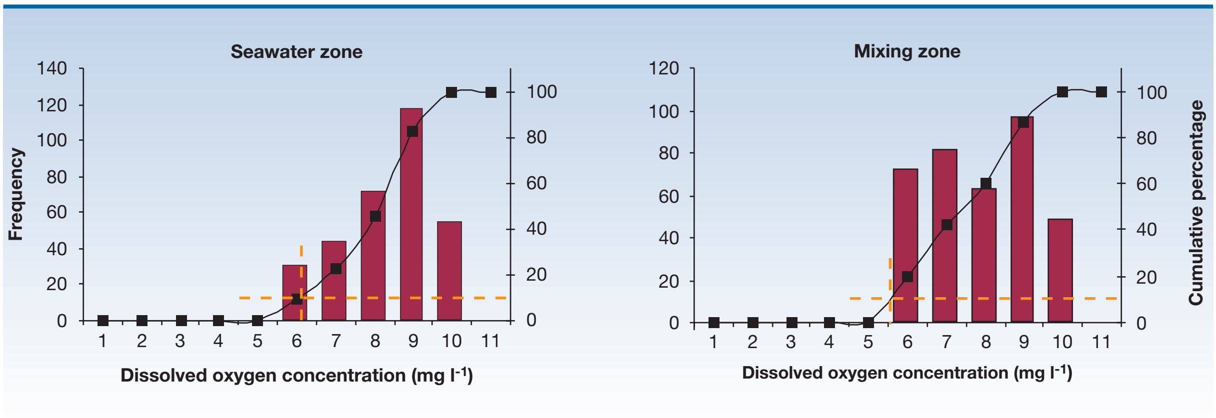
Dissolved oxygen

Figure 134 presents the frequency distribution for dissolved oxygen. The percentile 10 for dissolved oxygen is 6.5 mg l^{-1}, and all dissolved oxygen concentrations exceed the threshold adapted as indicative of biological stress. Consequently, the value used for this symptom in each zone equals zero.

Submerged aquatic vegetation

Submerged aquatic vegetation (SAV) occurs in the lower Mira estuary, from 3.5 km to the mouth. The shoreline in this part of the estuary is colonized by salt marshes. Dense mats of *Zostera marina* dominate deeper areas, while *Zostera nolti* populations are present in the upper estuary. These seagrass beds play an important role as a nursery for fish species.

FIGURE 134. FREQUENCY DISTRIBUTION FOR DISSOLVED OXYGEN IN THE DIFFERENT ZONES OF THE MIRA ESTUARY.



Several surveys have been carried out on macrobenthic communities associated to seagrasses, highlighting their ecological role in the Mira. There is no evidence for the reduction of SAV, and consequently, the value used for this symptom in the seawater zone equals zero. This symptom is not applicable to the mixing zone, since no SAV occurs.

Nuisance and toxic blooms

There is no reference to nuisance or toxic algal blooms in the literature, and expert consultations show that no problems with this symptom have been observed within the estuarine area. Consequently, the expression of this parameter was considered zero for the whole estuary.

The aggregation of all this information and the determination of the secondary symptom level of expression value for the Mira estuary are shown in Figure 135.

FIGURE 135. NEEA INDEX APPLICATION FOR THE SECONDARY SYMPTOMS IN THE MIRA ESTUARY.

Zone	Salinity	Area (km²) (A_Z)	Value (v_{ij}) Dissolved O_2	SAV	Blooms	$A_Z/A_t \times v_{ij}$ Dissolved O_2	SAV	Blooms
Seawater	> 25	1.9	0	0	0	0	0	0
Mixing	0.5 – 25	1.7	0	0	0	0	0	0
Sum		3.6	-	-	-	0	0	0
Secondary symptoms level of expression value for the estuary: 0 Low								

OVERALL HUMAN INFLUENCE

Susceptibility

Dilution potential

The NEEA dilution potential depends on the vertical stratification of the estuary and its dilution volume. The existence of stratification can be calculated by determining the estuary number, i.e. the percentage ratio of freshwater inflow (Q) to tidal prism (Tp). If Q/Tp > 100%, the estuary is stratified, if Q/Tp < 10%, the estuary is well mixed, and intermediate values correspond to partially mixed systems. The Mira estuary is classified as well mixed, considering an average annual freshwater flow of 5 m^3 s^{-1} and a tidal prism of 8.8 x 10^6 m^3. Considering that due to the reduced estuarine volume the dilution volume is low, a "Moderate" dilution potential is obtained.

Flushing potential

The Mira estuary is a mesotidal estuary with a tidal range of 3.4 m. Since the freshwater input to the estuary by the Mira (5 m^3 s^{-1}) is moderate compared to the estuarine volume (27x10^6 m^3), the results obtained for the flushing potential fall within the "High" category.

Nutrient inputs

The land cover in the Mira watershed is mainly rural, reflecting the very low population density in the Alentejo region. Towns are small and very little industrial activity exists. Consequently, the most important nutrient loads to the estuary are the diffuse sources from agricultural activities and small urban areas.

The main estuarine area is adjacent to Odemira, where the population density is 14 inhabitants km^{-2}. The only sizeable towns located in the banks of the estuary are Vila Nova de Milfontes

FIGURE 136. DOMESTIC NUTRIENT LOADS TO THE MIRA ESTUARY.

Treatment	Population	Nutrient export coefficient (kg pop eq^{-1}y^{-1})		Nutrient load (ton y^{-1})	
		N	P	N	P
Linked to the sewage network	8 000	3.3	0.4	26.4	3.2
Linked to network with WWTP	4 000	1.7	0.2	2.3	0.8
Not linked to the sewage network	1 400	-	-	0.0	0.0
Total	**23 400**	**-**	**-**	**28.7**	**4.0**

and Odemira (2 000 inhabitants). Vila Nova de Milfontes shows high population fluctuations due to tourism, reaching a summer population of 35 000. A wastewater treatment plant (WWTP) treats wastewater since 1988, and effluents are discharged directly into the Atlantic Ocean.

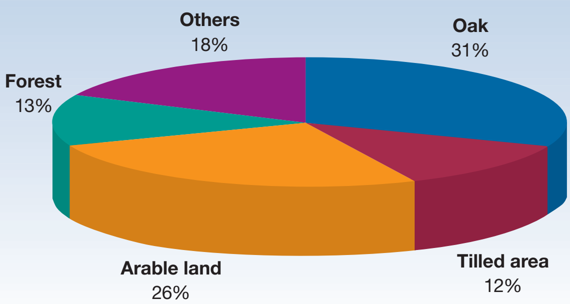
To cover the total input from domestic effluents, the whole population (26 000) from Odemira council was considered. Of these, 12 000 are served by a sewage network, 8 000 of which with a WWTP. Nutrient loads were calculated based on population equivalents (Figure 136).

The main sources of diffuse pollution are agricultural activities and pig farming. Inputs from these sources are difficult to estimate, but considering the land cover in the watershed (Figure 137) they are expected to be low. Only 12% of the area is occupied by tilled land, the rest is forested or traditional cultures, which are not irrigated or fertilized, such as cork oak.

The nutrient load from the Mira river is also difficult to estimate, since water quality data only exists for the Santa Clara reservoir upstream of the estuarine limit. The load was calculated by multiplying the average nitrogen and phosphorus concentrations by the average river flow. The values obtained (Figure 138) are only indicative, since the water quality and river flow dataset is very limited.

Since no water quality data for the ocean adjacent to the estuary are available, the human

FIGURE 137. LAND COVER IN THE MIRA WATERSHED.



contribution to total nutrient supply to the estuary could not be calculated.

However, comparing the total nutrient loads from urban sources and the Mira river (155.4 ton of N per year and 9.8 ton of P per year) to the values obtained for other estuaries, and considering that industrial loads are non-existent and diffuse pollution is insignificant, the nutrient input falls within the "Low" category.

DETERMINATION OF FUTURE OUTLOOK

Tourism had shown an increase in the past years and this trend is likely to continue. However, the pressure associated to this development appears to be stabilized, since wastewater treatment will be increased (for example, a submarine outfall is planned for wastewater discharged from the WWTP at Vila Nova de Milfontes). Agricultural activity in the region had decreased, and this trend is expected to continue, causing a reduction in diffuse loading. Consequently, no negative changes of trophic conditions in the Mira estuary appear likely.

FIGURE 138. NUTRIENT LOADING FROM THE MIRA RIVER.

Average annual river flow (hm^3)	Average nutrient concentrations ($mg\ l^{-1}$)		Nutrient load (ton $year^{-1}$)	
	N	P	N	P
180	0.71	0.03	126.7	5.8

SUMMARY OF THE NEEA INDEX APPLICATION

Figure 139 shows the results obtained for the NEEA application.

FIGURE 139. RESULTS OF THE NEEA INDEX APPLICATION TO THE MIRA ESTUARY. SLE: SYMPTOM LEVEL EXPRESSION; EAR: ESTUARY AGGREGATION RULES; PSM: PRIMARY SYMPTOMS METHOD; SSM: SECONDARY SYMPTOMS METHOD.

Indices	Methods	Parameters/Value/EAR			Index value
Overall Eutrophic Condition (OEC)	PSM	Chlorophyll *a*	0.25	Low	Low
		Epiphytes	0		
		Macroalgae	0		
	SSM	Dissolved oxygen	0	Low	
		Submerged aquatic vegetation	0		
		Nuisance and toxic blooms	0		
Overall Human Influence (OHI)	Susceptibility	Dilution potential	Moderate	Low susceptibility	Low
		Flushing potential	High		
	Nutrient inputs	Low nutrient input			
Future Outlook for future conditions (DFO)	Future nutrient pressures	Future nutrient pressures no change			No Change

CONCLUSIONS

The following conclusions can be drawn from the NEEA index application to the Mira estuary:

- The Mira needs further study in order to perform a complete application of the NEEA index: a *Surveillance Monitoring* programme should be carried out;
- Within the limitations identified in this text, the OEC index classifies the estuary in the "Low" category;
- The Mira estuary is a well-mixed system with a "Moderate" dilution potential and a "High" flushing potential. Nutrient inputs to the estuary are considered very low. The OHI index classifies the impact of the nutrient inputs in the estuary as minimal;
- The nitrate concentration in the water is far below the limit considered in the Directive 91/676/EEC;
- The future nutrient pressure decrease (DFO) and the values obtained for the other indices used support the conclusion that neither the Mira estuary nor parts of the estuary should be listed as sensitive areas (Directive 91/271/EEC) as regards eutrophication or vulnerable zones (Directive 91/676/EEC).

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References for grey literature consulted for this chapter may be found at http://www.imar.pt/perfect/

GENERAL CHARACTERISTICS

The Ria Formosa is a shallow mesotidal coastal lagoon separated from the Atlantic Ocean by several barrier islands (Barreta or Deserta, Culatra, Armona, Tavira and Cabanas) and peninsulas (Ancão and Cacela) (Figure 140). Water is exchanged with the Atlantic through six inlets, five natural (Faro-Olhão, Armona, Fuzeta, Cacela and Tavira) and one artificial.

At spring tide between 50 to 70% of the water is renewed. Freshwater input is negligible and salinity remains close to 36 except during sporadic periods of heavy winter rainfall. The lagoon has several channels with a mean depth of 2 m and an extensive intertidal area covered by sand, muddy sand flats and saltmarshes. The main characteristics of the Ria Formosa are presented in Figure 141.

FIGURE 140. RIA FORMOSA LAGOON: BATHYMETRY, SAMPLING STATIONS AND LIMITS OF HOMOGENEOUS ZONES.

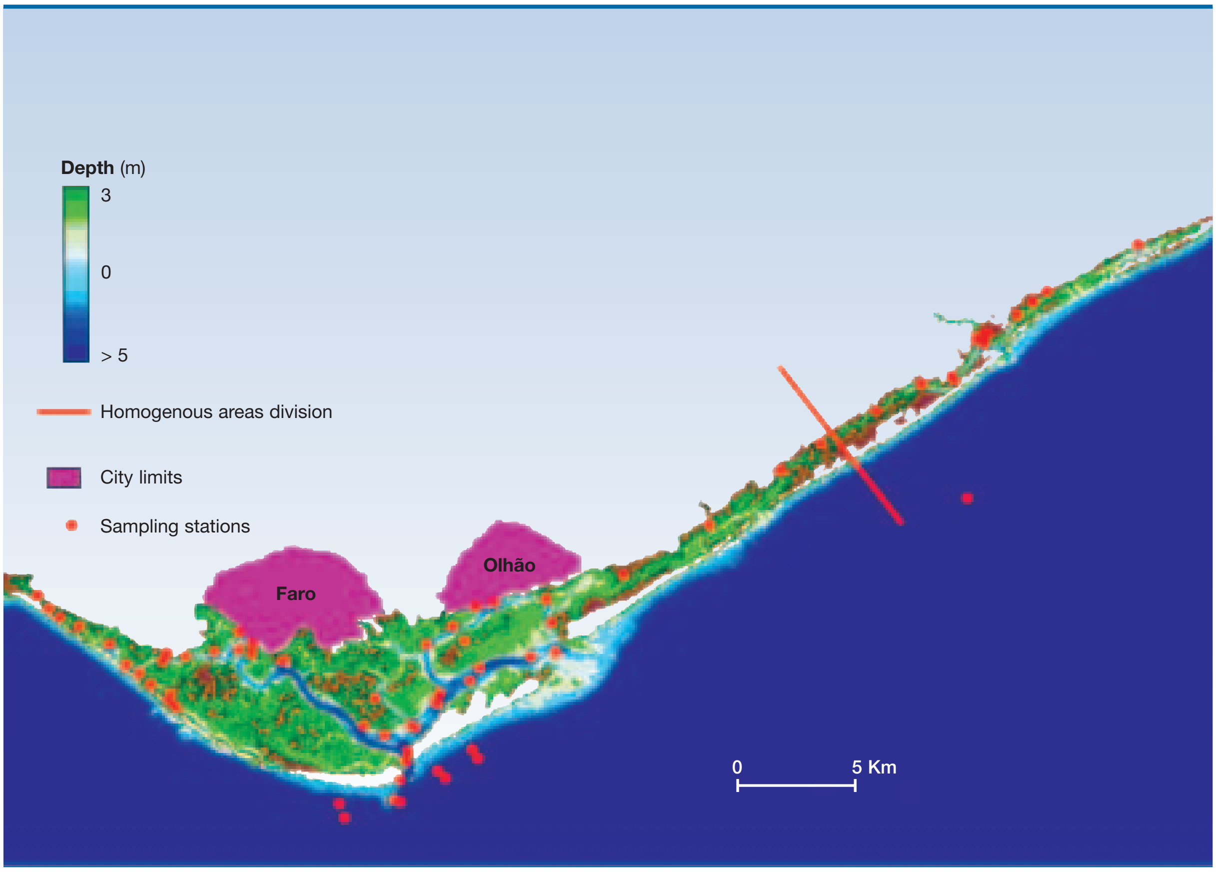


FIGURE 141. MAIN CHARACTERISTICS OF RIA FORMOSA.

Parameter	Conditions	Value
Volume	Extreme high tide	210 x 10^6 m^3
	Mean tide	92 x 10^6 m^3
	Extreme low tide	45 x 10^6 m^3
Area	Extreme high tide	91 km^2
	Mean tide	49 km^2
	Extreme low tide	18 km^2
Tidal prism	Spring tide	150 x 10^6 m^3
	Mean tide	115 x 10^6 m^3
	Neap tide	80 x 10^6 m^3
Tidal range	Mean high tide	3.0 m
	Mean	2.0 m
	Mean low tide	0.9 m
Population	Residents	124 000
	Low season (October to May)	167 000
	High season (June to September)	211 000
Mean residence time	Spring tide Neap tide	0.5 – 2 days

HOMOGENEOUS AREAS

In all the sampling stations where salinity values were available, medians are never below 35 (Figure 142), thus all system should be classified as a seawater zone. However, considering the water circulation patterns in the system two main zones can be distinguished: Faro-Olhão zone and Tavira zone, linked to each other by a narrow channel near the Fuzeta inlet (Figure 140). These two areas were considered independent homogeneous zones with areas of 45.3 and 4.2 km^2 for the Faro – Olhão and Tavira, respectively.

DATA COMPLETENESS AND RELIABILITY

This study was made using the BarcaWin2000™

FIGURE 142. MEDIAN SALINITIES FOR EACH STATION IN THE TWO HOMOGENEOUS AREAS.

Faro-Olhão	
Stations	**Median salinity**
0	36.6
1	35.6
2	35.3
3	35.8
4	35.3
5	35.3
6	35.4
7	35.3
9	35.6
10	35.5
12	35.3
14	35.3
16	35.8
18	34.6
A3	36.4
B3	36.4
Artificial	36.0
Ramalhete	36.2
IH2	36.1
IH3	36.0
IH17	36.1
IH24	36.1
Tavira	
Stations	**Median salinity**
Oyster	36.1
20	33.7
22	35.8
C3	36.2
Tavira inlet	35.9
E3	35.5
D3	36.2

FIGURE 143. DATASETS FOR THE RIA FORMOSA.

Number of campaigns	Date	Area	Parameters
10	From August 1984 until January 1985	Tavira	Salinity; pH; temperature; nitrate; nitrite; phosphate; silicate.
10	February 1985 From April until December 1985	Tavira	Salinity; temperature; chlorophyll *a*; phaeopigments; nitrate; nitrite; ammonia; silicate.
5	January and February 1986 From April until June 1986	Tavira	Salinity; temperature; chlorophyll *a*; phaeopigments; nitrate; nitrite; ammonia; silicate.
22	From September 1985 until September 1986	Faro-Olhão and Tavira	Salinity; temperature; pH; dissolved oxygen; suspended particulate matter; chlorophyll *a*; phaeopigments; nitrate; nitrite; silicate; primary production; photosynthetic efficiency.
12	From June 1987 until May 1988	Faro – Olhão and Tavira	Temperature; salinity; nitrate; nitrite; phosphate; silicate; ammonia; dissolved oxygen; DIN.
3	From January until March 1988	Tavira saltmarsh	Temperature; pH; dissolved oxygen; alcalinity; nitrate; phosphate; silicate.
43	From January until December 1989 (Four campaigns per month)	Only one station (bridge at Faro beach)	Temperature; salinity; dissolved oxygen; nitrate; nitrite; ammonia; phosphate; silicate; DIN.
2	September 1989 (Automatic sampling 30 to 30 minutes)	Only one station (bridge at Faro beach)	
5	February, April, July, August and November 1992	Faro-Olhão	Temperature; total organic nitrogen; total organic phosphorus; nitrate+ nitrite; ammonia; silicate; phosphate.
1	27 of June until 26 of July 2001 (Automatic sampling 10 to 10 minutes)	Faro-Olhão	Atmospheric pressure; water height; dynamic depth; wind speed; wind direction; air temperature; water temperature; dew temperature; omnidirectional speed.
4	January, April, July and November 1998	Faro-Olhão and one station in Tavira	Salinity; SPM; temperature; chlorophyll *a*, *b* and *c*; ammonia; nitrate; nitrite; phosphate; silicate; dissolved oxygen; oxygen saturation; dissolved N; dissolved P; total N; total P.
4	March, May, July and November 1999		
4	January, April, July and October 2000		
1	September 2000 (Automatic sampling 30 to 30 minutes)	Only one station (bridge)	Radiation; salinity; temperature.
9	December 2000 March, June, September and December 2001 April, July and September 2002	Faro-Olhão	Salinity; temperature; chlorophyll *a*; phaeopigments; nitrate; nitrite; ammonia; silicate.
1	Automatic sampling from April 2000 until July 2002	Only one station (bridge)	Temperature.
15	1986	Tavira	Salinity; temperature; chlorophyll *a*; phaeopigments; nitrate; nitrite; ammonia; silicate.
1	February 2002	Faro-Olhão	Salinity; temperature; chlorophyll *a*; phaeopigments; nitrate; nitrite; ammonia; silicate.

database which groups the data of most of the campaigns made in the Ria Formosa to study water quality. This database has about 120 000 records, loaded for 50 stations covering all the system. Figure 143 summarises the number of campaigns, dates and water quality parameters studied.

The calculated data completeness and reliability (DCR) for the two zones in the Ria Formosa was 100% for chlorophyll *a* and dissolved oxygen since all zones were sampled, 92% for epiphytes and macroalgae and 0% for nuisance and toxic blooms since no problems have been documented. For submerged aquatic vegetation, studies on the direction of change have been made. Since no information about the magnitude of loss is available, this symptom takes a value of 0%.

OVERALL EUTROPHIC CONDITION

Primary symptoms method

Chlorophyll *a*

In the area of Faro-Olhão, the maximum values of chlorophyll *a* concentrations occurred in summer reaching values in the "Medium" eutrophic class (> 5 to ≤ 20 µg l^{-1}). However, the value obtained for the percentile 90 is 2.5 µg l^{-1} (Figure 144).

In the Tavira area, the maximum values obtained for chlorophyll *a* also occurred in summer but

FIGURE 144. RIA FORMOSA, FARO-OLHÃO AREA: A) CHLOROPHYLL CONCENTRATIONS DURING AN ANNUAL CYCLE; B) FREQUENCY DISTRIBUTION FOR CHLOROPHYLL.

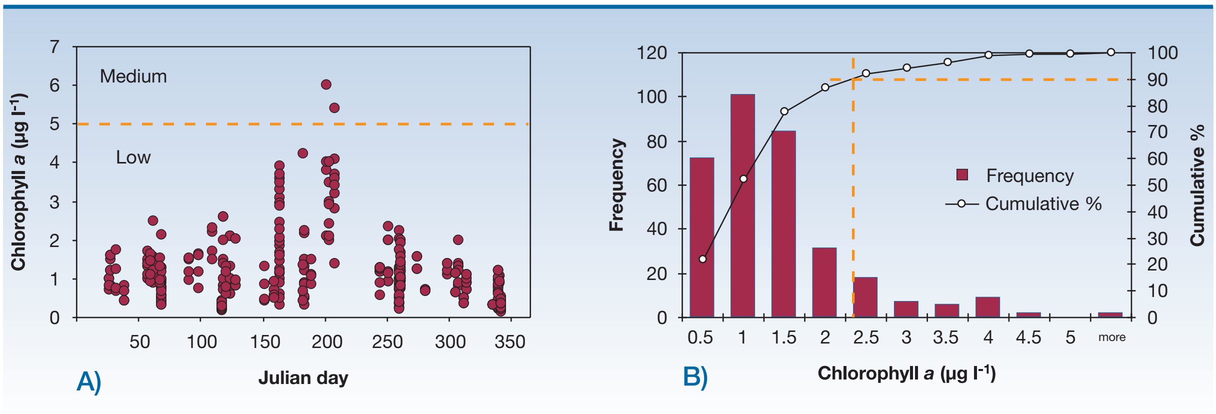
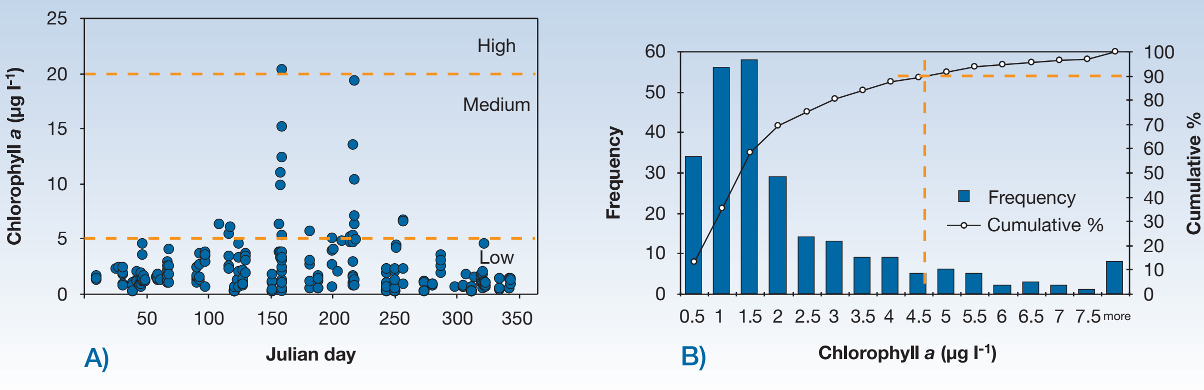


FIGURE 145. RIA FORMOSA, TAVIRA AREA: A) CHLOROPHYLL CONCENTRATIONS DURING AN ANNUAL CYCLE; B) FREQUENCY DISTRIBUTION FOR CHLOROPHYLL.



were higher than in the Faro-Olhão area, reaching values between "Medium" and "High". The percentile 90 value is 4.5 µg l^{-1} (Figure 145). According to the NEEA thresholds, both areas are classified in the "Low" category for eutrophic conditions.

The "Low" chlorophyll *a* concentrations over the whole Ria may be due to the intensive water exchange over each tide cycle (from 50% to 70%). In these conditions phytoplankton blooms are not observed in the Ria and this symptom gets an expression level of "Low" for whole system (Figure 146).

Macroalgae

The main macroalgal species present in both NEEA zones are shown in Figure 147. Species

FIGURE 146. RESULTS OF THE NEEA INDEX APPLICATION FOR CHLOROPHYLL IN THE RIA FORMOSA. SLE MEANS SYMPTOM LEVEL OF EXPRESSION.

ZONE	IF Concentration	AND Spatial coverage	AND Frequency	THEN Expression	Value	Area	SLE
Faro-Olhão	Low	Any	Any	Low	0.25	45.3	0.23
Tavira	Low	Any	Any	Low	0.25	4.2	0.02
					Total	**49.5**	**0.25**

diversity is lower in the Faro-Olhão area where green algae are dominated by the genera *Enteromorpha sp.* and *Ulva sp*. Periodic blooms of these green algae have been observed during winter. The blooms start in early autumn, after the first rainfalls, and disappear gradually during the following spring. Biomass minima are registered in the summer, when high temperatures promote plant desiccation.

The species *Enteromorpha compressa*, *Enteromorpha ramulosa* and *Ulva lactuca* are considered ubiquitous throughout this area and

FIGURE 147. MAIN MACROALGAE SPECIES IN EACH HOMOGENOUS AREA OF RIA FORMOSA. SPECIES IN BLUE OCCUR IN BOTH AREAS.

Algae	Faro-Olhão	Tavira	Both
Green algae	-	*Enteromorpha clathrata* *Cloroficia filamentosa* *Codium tomentosum*	*Ulva lactuca* *Ulva rigida* *Enteromorpha ramulosa* *Enteromorpha compressa* *Enteromorpha intestinalis*
Brown algae	*Fucus spirallis* *Colpomenia sinuosa*	*Dictyota dichotoma*	-
Red algae	*Bostrychia scorpioides*	*Gigartina acicularis* *Hildenbrandia sp* *Coralinacea incrustante* *Chondria sp* *Ceramium sp* *Gelidium sp* *Porphyra umbilicalis* *Ceramium rubrum* *Ceramium flabelligerum* *Polisiphonia sp*	*Gracilaria verrucosa* *Gracilaria folifera* *Gigartina teedii*

total biomass maximum reach about 2 kg m^{-2} (Figure 148). There is no reference to macroalgae blooms in the literature for the Tavira area. The final classification for this symptom in both areas of Ria Formosa is presented in Figure 149.

FIGURE 148. BIOMASS MAXIMUM (G DW M^{-2}) OF MACROALGAE IN THE FARO-OLHÃO AREA. NOTE: VALUES TAKEN FROM GRAPHICAL DATA.

Species	March 1993	June/July 1993
Ulva lactuca	1 350	100
Enteromorpha ramulosa	700	200
Gracilaria verrucosa	140	18
Fucus spiralis	335	75
Total macroalgal biomass	**2 250**	**520**

Epiphytes

The presence of epiphytes on the seagrass populations of Ria Formosa has been documented in several studies. In the area of Faro-Olhão the epiphytes *Ceramium sp.*, *Ectocarpales*, *Ulva sp.* and *Enteromorpha sp.* are, in this order, the most abundant species. The epiphytes preferentially colonise the subtidal beds of *Cymodocea nodosa* and *Zostera marina* (see below). On the intertidal beds of *Zostera noltii*, low abundances of epiphytes are present (Figure 150).

Although the level of abundance of each species or group was characterized (Figure 150) no data are available about the biomass values and the temporal distribution of the epiphytic

FIGURE 149. RESULTS OF THE NEEA INDEX APPLICATION FOR MACROALGAE IN THE RIA FORMOSA. SLE MEANS SYMPTOM LEVEL OF EXPRESSION.

ZONE	IF Macroalgae problems	AND Frequency	THEN Expression	Value	Area	SLE
Faro-Olhão	Observed	Periodic	High	1	45.3	0.92
Tavira	Unknown	Unknown	Unknown	0.5	4.2	0.04
				Total	**49.5**	**0.96**

FIGURE 150. ABUNDANCE OF EPIPHYTES IN EACH SEAGRASS SPECIE IN THE FARO-OLHÃO AREA.

Seagrass specie	Absent	Low abundance	Medium abundance	High abundance
Zostera noltii	38%	49%	13%	0%
Cymodocea nodosa	19%	6%	53%	23%
Zostera marina	33%	8%	50%	8%

flora in this area. Thus, the frequency of this symptom for the Faro-Olhão zone was classified as “Unknown” in the expression level table (Figure 151).

No information about the epiphytic flora was found in the literature for the Tavira area. The determination of the level of expression for this symptom in the Ria Formosa is presented in Figure 151.

Secondary symptoms method

Dissolved oxygen

The percentile 10 values for dissolved oxygen in Ria Formosa are above the biological stress threshold (Figure 153). The value obtained in both areas, was 6 mg l^{-1}. This symptom takes a value of zero in the level of expression for the whole system.

Submerged aquatic vegetation

In general, three main species of seagrasses colonize the subtidal and intertidal zones of the

FIGURE 151. RESULTS OF THE NEEA INDEX APPLICATION FOR THE EPIPHYTES IN THE RIA FORMOSA. SLE MEANS SYMPTOM LEVEL OF EXPRESSION.

ZONE	IF Epiphytes problems	AND Frequency	THEN Expression	Value	Area	SLE
Faro-Olhão	Observed	Unknown	Flag b	0.5	45.3	0.46
Tavira	Unknown	Unknown	Flag b	0.5	4.2	0.04
				Total	**49.5**	**0.50**

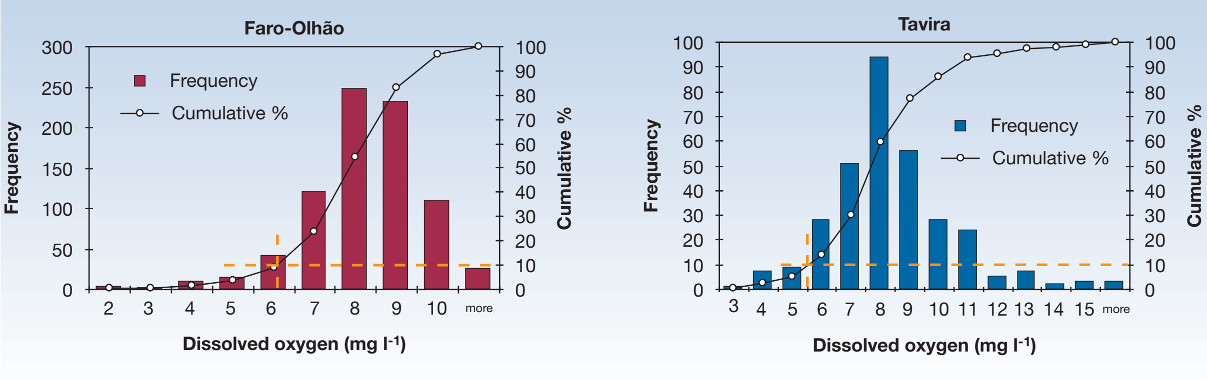
FIGURE 152. NEEA INDEX APPLICATION FOR THE PRIMARY SYMPTOMS IN THE RIA FORMOSA LAGOON.

Zone	Salinity	Area (km²) (A_z)	Value (v_{ij}) Chlorophyll *a*	Macroalgae	Epiphytes	$A_z/A_t \times v_{ij}$ Chlorophyll *a*	Macroalgae	Epiphytes
Faro-Olhão	35	45.3	0.25	1	0.5	0.23	0.92	0.46
Tavira	35	4.20	0.25	0.5	0.5	0.02	0.04	0.04
Sum		49.5	-	-	-	0.25	0.96	0.50
Primary symptoms level of expression value for the estuary: 0.57 Moderate								

Ria Formosa channels. *Cymodocea nodosa* and *zoystera marina* colonise the subtidal areas, according to sediment type, while *Zostera noltii* is typical of the intertidal areas. Studies made in the western part of the Faro-Olhão zone indicate the decline of a considerable area occupied by these populations. The high mortality rates measured for *Cymodocea nodosa* and *Zostera marina* are due to changes in the sediment dynamics, probably because of the recent inlet artificially opened in the Ancão peninsula. Although the area of seagrass loss has not been quantified it is probably a short term effect.

There is no clear indication that, in this areas the seagrass losses are linked to eutrophic

FIGURE 153. FREQUENCY DISTRIBUTION FOR DISSOLVED OXYGEN IN THE TWO AREAS OF RIA FORMOSA.



conditions and for the Tavira area, there are no references to seagrass losses. The final classification for this symptom in both zones is therefore "Low" (Figure 154).

Nuisance and toxic blooms

Expert consultations on this subject show that no problems with nuisance and toxic blooms have been observed in the system, over an extended period of time (20 years). This parameter equals zero for both homogenous areas.

The application of the NEEA criteria for secondary symptoms is presented in Figure 155.

FIGURE 154. RESULTS OF THE NEEA INDEX APPLICATION FOR SUBMERGED AQUATIC VEGETATION IN THE RIA FORMOSA. SLE MEANS SYMPTOM LEVEL OF EXPRESSION.

ZONE	IF SAV Loss	AND Magnitude of loss	THEN Expression	Value	Area	SLE
Faro-Olhão	Observed	Unknown	Flag D	0.25	45.3	0.23
Tavira	Unknown	Unknown	Flag D	0.25	4.2	0.02
				Total	**49.5**	**0.25**

Flag D: Not enough data was available. In this case, assumptions were made based on conservative estimates that unknown magnitude of loss is at least 10% of a zone.

OVERALL HUMAN INFLUENCE

Susceptibility

Dilution potential

The low mean depth, the strong tidal currents and the high water renewal make the Ria Formosa a well mixed system, with stratification being rare and occurring in specific situations such as after heavy rains in the Tavira area at the mouth of the Gilão river. Therefore, the NEEA classification for the dilution potential indicates Ria Formosa as a Type A system, "High" category.

Nutrient inputs

The main sources of nutrients discharging into the Ria Formosa:

1) **Effluents from domestic and industrial wastewater treatment plants (WWTP);**

2) **Domestic effluents without wastewater treatment;**

3) **Non-point sources (rainfall runoff).**

FIGURE 155. NEEA INDEX APPLICATION FOR THE SECONDARY SYMPTOMS IN THE RIA FORMOSA.

Zone	Salinity	Area (km²) (A_z)	Value (v_{ij}) Dissolved O_2	Value (v_{ij}) SAV	Value (v_{ij}) Blooms	$A_z/A_t \times v_{ij}$ Dissolved O_2	$A_z/A_t \times v_{ij}$ SAV	$A_z/A_t \times v_{ij}$ Blooms
Faro-Olhão	35	45.3	0	0.25	0	0	0.23	0
Tavira	35	4.2	0	0.25	0	0	0.02	0
Sum		49.5	-	-	-	0	0.25	0
Secondary symptoms level of expression value for the estuary: 0.25 Low								

FIGURE 156. LOADS OF N AND P FROM TREATED AND UNTREATED EFFLUENTS INTO THE RIA FORMOSA. LOW SEASON (LS): (FROM JANUARY TO MAY AND FROM OCTOBER UNTIL DECEMBER). HIGH SEASON (HS): (JUNE, JULY, AUGUST AND SEPTEMBER).

Districts	Nutrient loads from WWTP					
	Total N (ton N y^{-1})			Total P (ton P y^{-1})		
	LS	HS	Total	LS	HS	Total
Faro	103.5	62.4	165.9	9.4	5.7	15.1
Olhão	30.5	23.6	54.1	10.3	7.7	18.0
Tavira	36.1	25.6	61.7	7.4	5.4	12.8
Loulé	34	25.9	59.9	9.3	7.1	16.4
S. Brás de Alportel	10.1	5.3	15.4	0.9	0.5	1.4
Total (ton y^{-1})	**214.2**	**142.8**	**357**	**37.3**	**26.4**	**63.7**
Districts	**Domestic effluents without wastewater treatment**					
	Total N (ton N y^{-1})			**Total P (ton P y^{-1})**		
	LS	**HS**	**Total**	**LS**	**HS**	**Total**
Faro	7.43	4.11	11.54	2.23	1.23	3.46
Olhão	1.90	5.03	6.93	0.57	1.51	2.08
Tavira	6.85	17.10	23.95	2.05	5.13	7.18
Loulé	10.01	7.55	17.56	3.00	2.26	5.27
Vila Real de Sto. António	2.87	1.51	4.38	0.86	0.45	1.31
Total (ton y^{-1})	**29.06**	**35.30**	**64.36**	**8.72**	**10.59**	**19.31**
Total nutrient inputs	**421 ton y^{-1}**			**83 ton y^{-1}**		

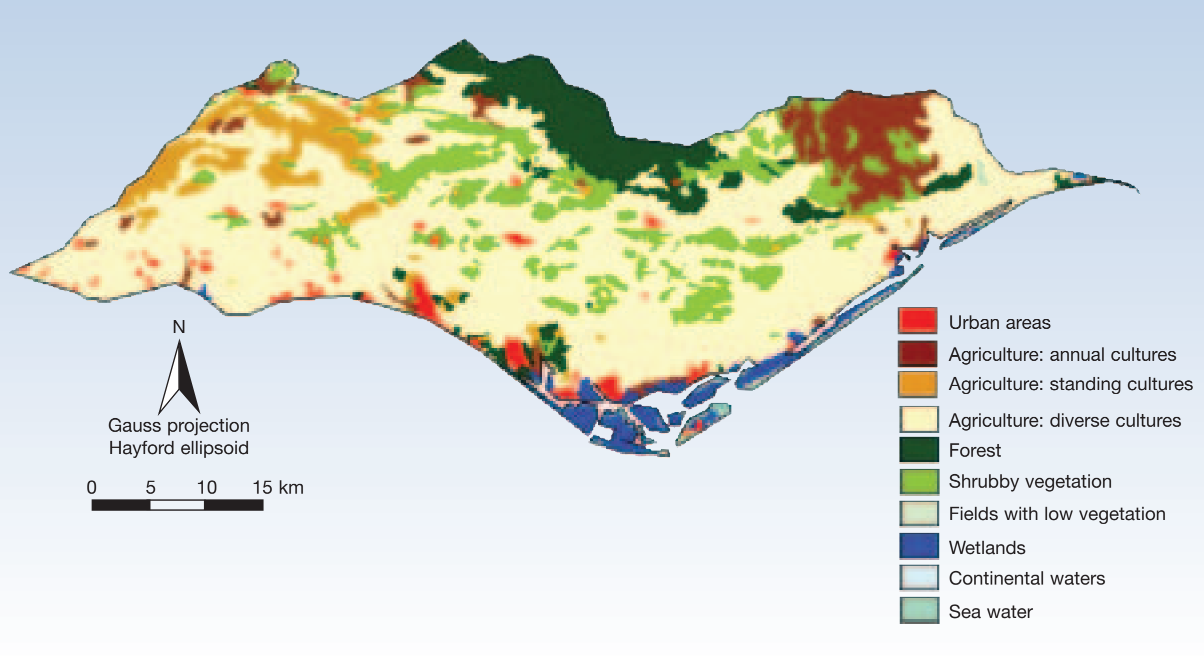
The total nutrient inputs to Ria Formosa are presented in Figure 156. Information on the demography of the catchement, population equivalents for the main industrial activities and data on the efficiency of the domestic wastewater treatment from WWTP discharging into the Ria were used to calculate the nutrient loads.

At present, 28 WWTP serve the population and industries in the watershed, with removal efficiencies averaging 36 and 53% for total nitrogen and phosphorus, respectively. Since the main economic activity is tourism, population

FIGURE 157. NITROGEN AND PHOSPHORUS LOADS FROM THE MAIN SOURCES OF NUTRIENTS TO THE ESTUARY.

Source	Relative contribution	Nitrogen (ton N y^{-1})	Phosphorus (ton P y^{-1})
Treated and untreated sources	42%	421	83
Non-point sources (rainfall runoff)	58%	607	81
Total	**100%**	**1 028**	**164**

FIGURE 158. SOIL USES IN THE HYDROGRAPHIC BASIN OF THE RIA FORMOSA.



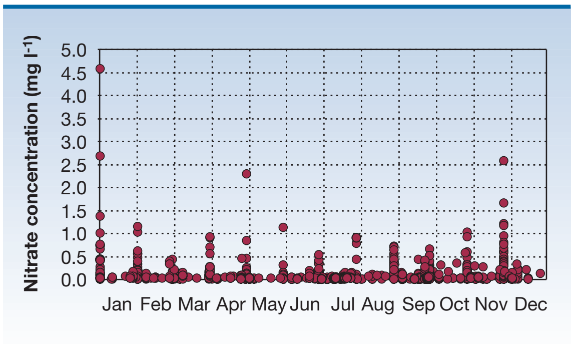
numbers as well as nutrient inputs fluctuate widely between seasons, being higher in the summer months (June, July, August, and September). In the low and high seasons about 28 and 26%, respectively, of the total population is not served with wastewater treatment.

In winter, rainfall runoff is also an important source of nutrients into the Ria (Figure 157), which is mainly due to the agricultural activities in the watershed (Figure 158).

The application of the loading – susceptibility model followed the approach described in the methodology section for coastal waters. The results obtained show that the Human Influence is about 43%, which falls into the "Moderate" category. The inputs in the Ria Formosa are therefore considered to be "Moderate". Figure 157 shows the relative contribution of each nutrient source into the lagoon.

All values in the Ria Formosa are three orders of magnitude below the EU Directive 91/676/EEC threshold (50 mg l^{-1}) for nitrates, (Figure 159).

FIGURE 159. NITRATE CONCENTRATIONS IN THE RIA FORMOSA. DATASET FROM AUGUST 1984 TO JULY 2002.



DETERMINATION OF FUTURE OUTLOOK

Several changes in the treatment level and capacity are projected for some of the existing WWTP. Furthermore, the construction of 10 new WWTP is foreseen for the next 10 years, 6 of which will be developed for the barrier islands where the tourism pressures are higher. Thus, it is considered that future nutrient loading into the Ria Formosa will be significantly reduced,

particularly those linked to the main economic activities (tourism).

SUMMARY OF THE NEEA INDEX APPLICATION

Figure 160 shows the results obtained for the NEEA index application in the Ria Formosa.

CONCLUSIONS

The following conclusions can be drawn from the NEEA index application to the Ria Formosa:

- **Some data gaps were detected for Ria Formosa, particularly in what concerns the dynamic of macrophytes, including macroalgae, seagrasses and epiphytes;**

FIGURE 160. RESULTS OF THE NEEA INDEX APPLICATION TO THE RIA FORMOSA. SLE: SYMPTOM LEVEL EXPRESSION; EAR: ESTUARY AGGREGATION RULES; PSM: PRIMARY SYMPTOMS METHOD; SSM: SECONDARY SYMPTOMS METHOD.

Indices	Methods	Parameters/Value/EAR			Index value
Overall Eutrophic Condition (OEC)	PSM	Chlorophyll *a*	0.25	0.57 Moderate	Moderate Low
		Epiphytes	0.50		
		Macroalgae	0.96		
	SSM	Dissolved oxygen	0	0.25 Low	
		Submerged aquatic vegetation	0.25		
		Nuisance and toxic blooms	0		
Overall Human Influence (OHI)	Susceptibility	Dilution potential	High	Moderate susceptibility	Moderate
		Flushing potential	Low		
	Nutrient inputs	Moderate nutrient input			
Future Outlook for future conditions (DFO)	Future nutrient pressures	Future nutrient pressures decrease			Improve Low

- **The OEC index classifies the system in the "Moderate Low" category. This result is strongly influenced by the periodic blooms of macroalgae detected in the Faro-Olhão channels. However there is a clear need for an *Investigative Monitoring* programme to determine the origin, spatial coverage and frequency of these blooms;**
- **The Ria Formosa is a well mixed system with a "High" dilution potential and a "Low" freshwater inflow with a "Moderate" input of nutrients into the system. The OHI index classifies the impact of the nutrient in the system as "Moderate", which means that the symptoms observed in the system are moderately related to nutrient inputs.**
- **The nitrate concentration in the water is far below the limit considered in the Directive 91/676/EEC;**
- **The future nutrient pressure decrease (DFO) and the values obtained for the other indices used support the conclusion that neither the Ria Formosa nor parts of it should be listed as sensitive areas (Directive 91/271/EEC) or vulnerable zones (Directive 91/676/EEC) due to eutrophication concerns.**

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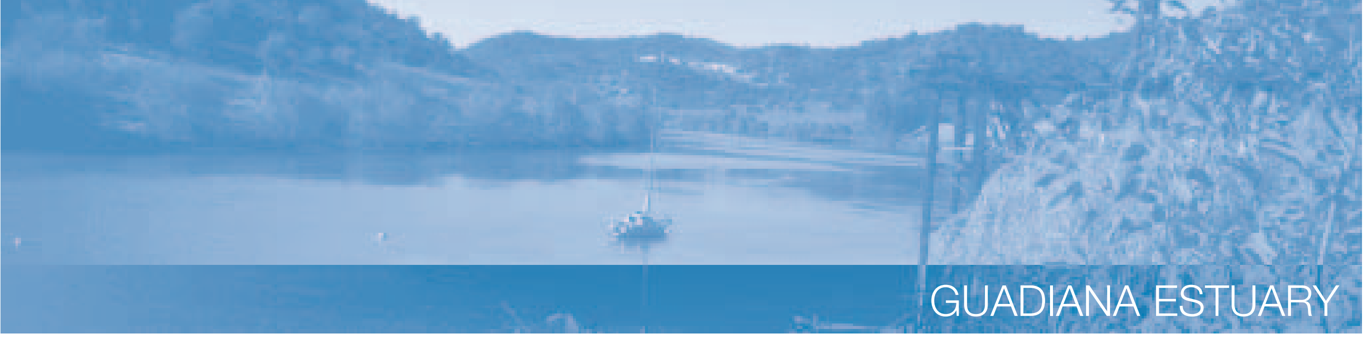
References for grey literature consulted for this chapter may be found at http://www.imar.pt/perfect/



GUADIANA ESTUARY

GENERAL CHARACTERISTICS

The Guadiana River has it source at the *Lagos Ruidera* in Spain, at an altitude of 1 700 m, and enters Portugal after a stretch of 550 km. The Portuguese reach is about 150 km long, has a general North-South orientation, and flows into the Atlantic Ocean at the south-eastern coast of Algarve, forming a border between Portugal and Spain. The Guadiana basin has a total area of 66 960 km^2, 11 700 km^2 of which in Portugal. There are a number of dams on the Spanish side, and the new Alqueva - Pedrógão system in Portugal. These dams significantly affect the total river discharge and freshwater supply to the estuary. The mean annual discharge estimated for the situation prior to Alqueva is 2 586 hm^3 (corresponding to a modular flow of 82 m^3 s^{-1}). This flow regime will be changed when the new dam is fully operational, with a flow reduction under average conditions but an increase in drought situations. The estuary is

FIGURE 161. GUADIANA ESTUARY: BATHYMETRY, SAMPLING STATIONS AND LIMITS OF HOMOGENEOUS ZONES.

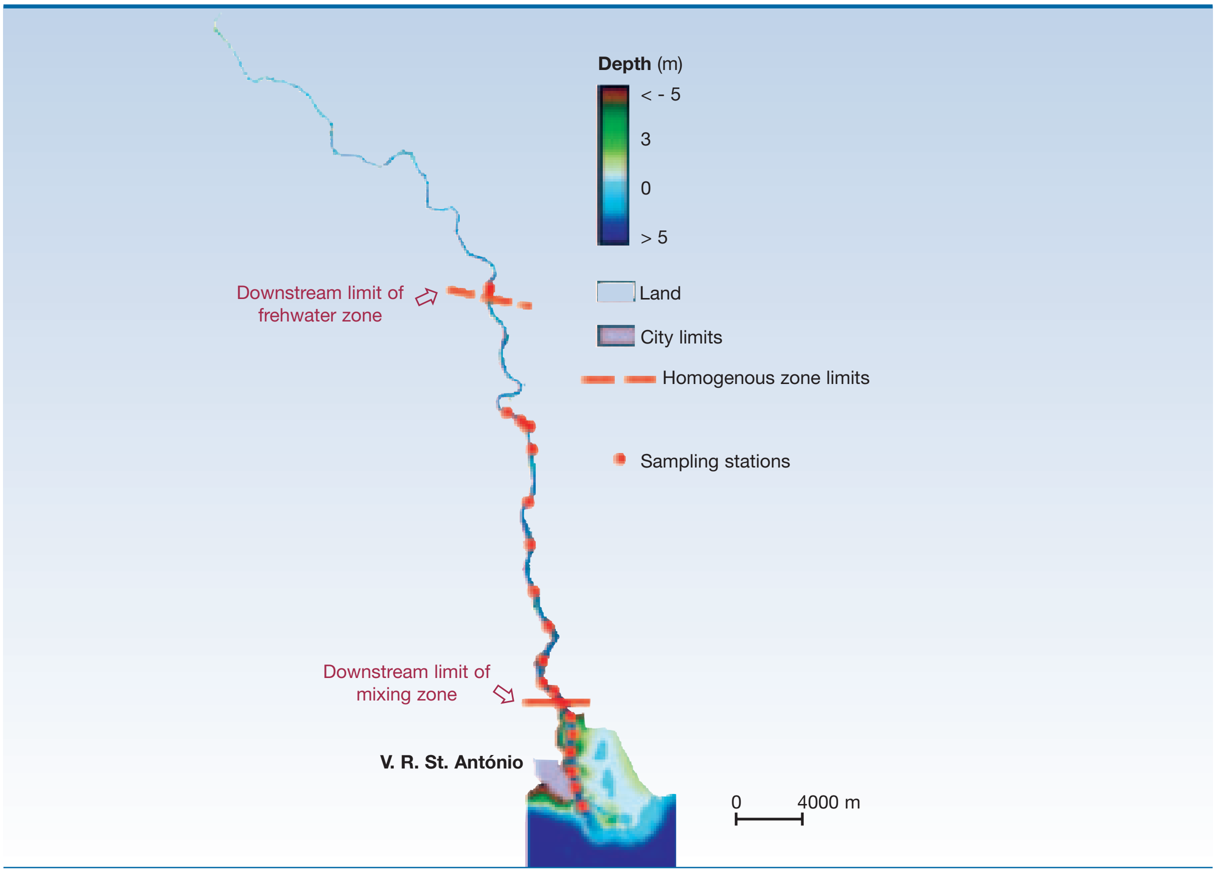


FIGURE 162. MAIN CHARACTERISTICS OF THE GUADIANA ESTUARY

Parameter	Value
Volume	100 x $10^6 m^3$
Total Area	19.5 km^2
River flow	85 $m^3 s^{-1}$
Tidal Range (max)	3.43 m (mouth) 3.13 m (Pomarão)
Tidal Prism	60 x 10^6 m^3
Mean residence time	12 days
Population: Low season (Oct. to May)	31 000
Population: High season (Jun. to Sep.)	40 000

about 70 km long, from the mouth until Mértola (Figure 161). It is a tubular estuary, with a sand bar at the mouth, and a maximum width of about 1 km near the mouth, decreasing to about 200 m at the head.

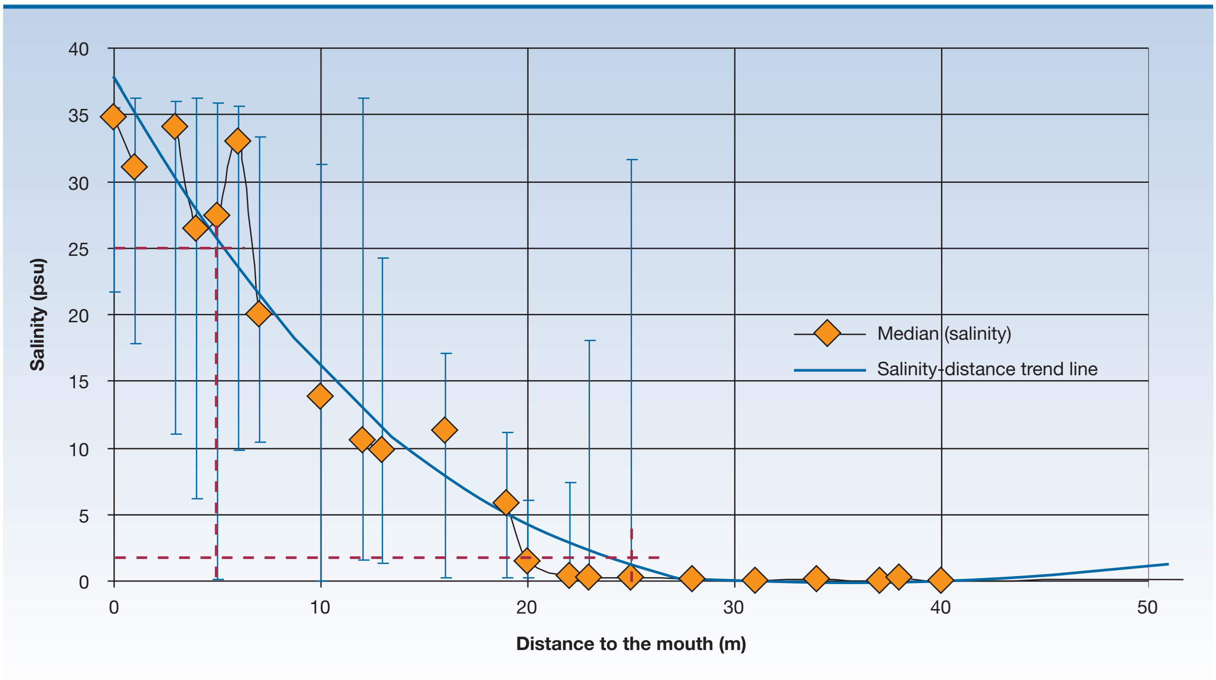
The main characteristics of the Guadiana estuary are summarised in Figure 162.

HOMOGENEOUS AREAS

The physical delimitation of the estuarine area into homogeneous zones was made using the thresholds recommended by the NEEA methodology. Data stored in the BarcaWin2000™ database, covering observations from 1977 until 2001, were processed in order to determine the median of salinity for every station sampled at different tidal and flow situations. These values were plotted as a function of the distance to the mouth (Figure 163).

A polynomial trend line was fitted to the data (r = 0.95) and the salinity zones were delimited graphically. The mixing zone covers a reach extending from 5-25 km upstream of the

FIGURE 163. LONGITUDINAL PROFILE OF SALINITY OF THE GUADIANA ESTUARY



mouth. The areas of the three homogeneous zones are shown in Figure 164.

FIGURE 164. AREAS OF HOMOGENEOUS SALINITY ZONES OF THE GUADIANA ESTUARY

Zone	Distance to mouth (km)	Area (km²)
Seawater (> 25)	0-5	4.4
Mixing (0.5 to 25)	5-25	7.6
Freshwater (< 0.5)	25-70	7.5
Total	**-**	**19.5**

The salinity distribution in the Guadiana estuary varies strongly with hydrographic conditions: under persistent conditions of low flow, brackish water is observed at the zone of Alcoutim, about 30 km from the mouth. Conversely, observations suggest that the estuary may be stratified when the river flow exceeds 100 $m^3\ s^{-1}$.

DATA COMPLETENESS AND RELIABILITY

The BarcaWin2000™ database, used to store the data from the Guadiana estuary, has about 60 000 records, loaded for 114 stations covering

FIGURE 165. DATASETS FOR THE GUADIANA ESTUARY.

<table>
<tr><th>Number of campaigns</th><th>Date</th><th>Area</th><th>Parameters</th></tr>
<tr><td>4</td><td>April, 1977</td><td>Stations in all estuary until Alcoutim</td><td>Salinity
Temperature
Suspended particulate matter
Dissolved oxygen</td></tr>
<tr><td>9</td><td>April, 1979</td><td>Stations at the estuary mouth and near coast</td><td>Salinity
Temperature
Dissolved oxygen
Nitrate, nitrite, ammonia
Phosphate
Silicate
Particulate carbon</td></tr>
<tr><td>1</td><td>July, 1990</td><td>3 stations at the estuary mouth</td><td rowspan="4">Salinity
Temperature
pH
Suspended particulate matter
Dissolved oxygen
Chlorophyll a
Nitrate, nitrite, ammonia
Phosphate
Silicate
Heavy metals</td></tr>
<tr><td>2</td><td>September and October 1998</td><td>58 stations from the mouth until Pomarão</td></tr>
<tr><td>9</td><td>February, May, September, October, 2001</td><td>8 stations from the mouth until Mértola</td></tr>
<tr><td>1</td><td>February 2002</td><td>Five stations from the mouth until Pomarão</td></tr>
</table>

all the system. Figure 165 summarises the number of campaigns, dates and water quality parameters studied.

OVERALL EUTROPHIC CONDITION

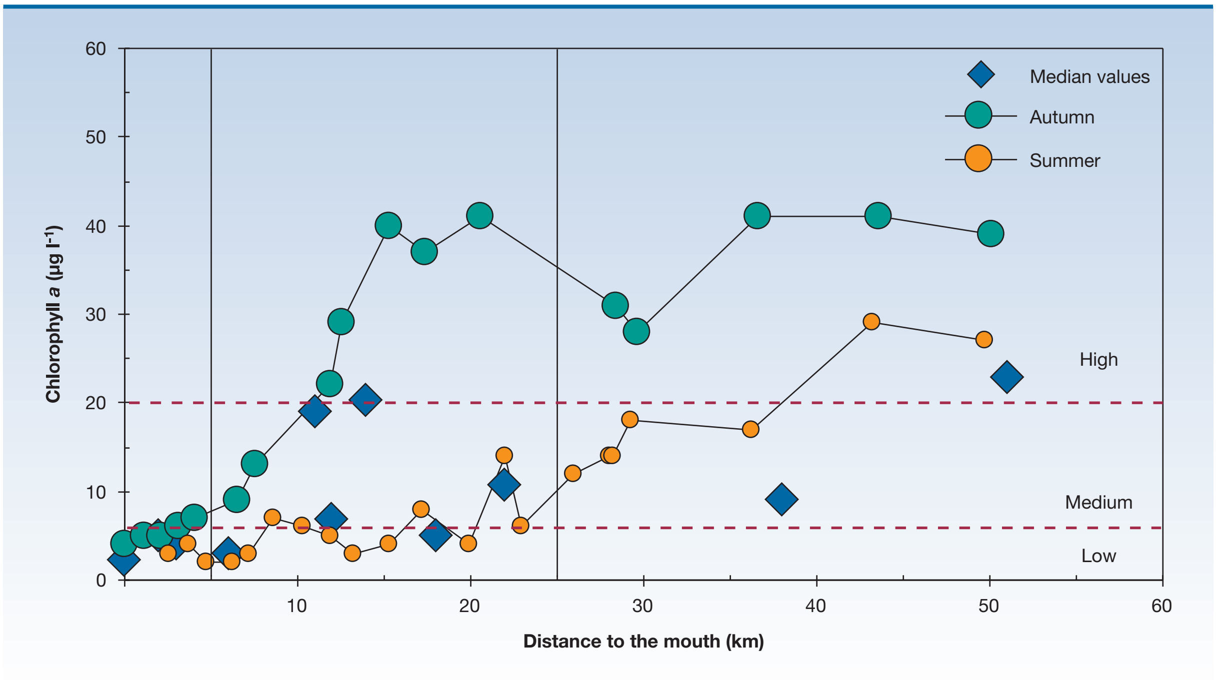
Primary symptoms method

Chlorophyll *a*

The data used for the application of primary symptoms criteria cover observations from 1996 until 2001. The temporal and spatial coverage of these data are very variable ranging from monthly observations in the seawater and mixing zones to occasional samples in limited periods of the year.

The most complete datasets are for 1996-1998 covering the mixing and the three seawater zones and for 2001 covering the homogenous zones. In Figure 166 is presented the longitudinal profile of chlorophyll *a* in the Guadiana estuary.

FIGURE 166. LONGITUDINAL PROFILE OF CHLOROPHYLL IN THE GUADIANA ESTUARY.



The results presented below may therefore in some cases be biased due to irregular sampling distribution. All the data were processed and the percentile 90 value was determined for each zone. The Guadiana is rated as "High" for the tidal freshwater and mixing zones and "Medium" for the seawater zone (Figure 167).

The available dataset does not give a clear picture of the seasonal and interannual variability and the real significance of the higher values observed could not be fully assessed. For chlorophyll *a* concentration, the NEEA index takes the values presented in Figure 168.

Macroalgae and epiphytes

No references were identified mentioning problems for these primary symptoms in the Guadiana estuary and there is no additional information on occurrence. On the assumption that any relevant problems would be indicated in the literature, a zero level of expression was attributed to these symptoms for all zones. The overall assessment for primary symptoms is summarised in Figure 169.

Secondary symptoms method

Dissolved Oxygen

Figure 170 shows a longitudinal profile of the available data on dissolved oxygen concentrations. All values are within the range of 5 to 10 mg l^{-1}.

FIGURE 167. FREQUENCY DISTRIBUTION FOR CHLOROPHYLL IN THE THREE SALINITY ZONES OF THE GUADIANA ESTUARY

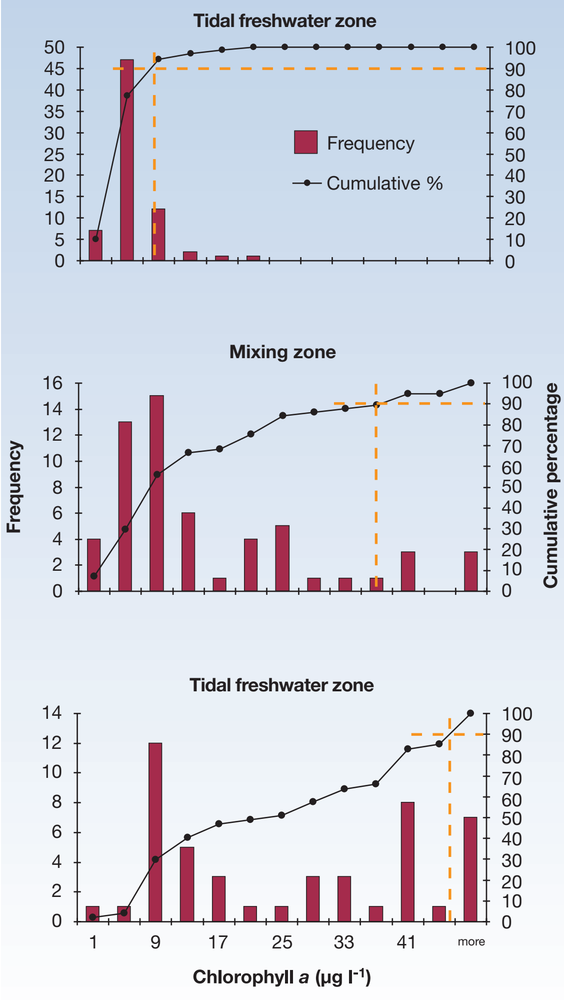


Figure 171 depicts the frequency distribution of the dissolved oxygen data. The percentile 10 is above 5 mg l^{-1}, showing an estuary without

FIGURE 168. NEEA INDEX APPLICATION FOR CHLOROPHYLL IN THE GUADIANA ESTUARY.

ZONE	IF Concentration	AND Spatial coverage	AND Occurrence	THEN Expression	Value
Seawater	Medium	Low	Periodic	Low	0.25
Mixing	High	High	Periodic	High	1.00
Tidal fresh	High	Medium	Periodic	High	0.50

FIGURE 169. NEEA INDEX APPLICATION FOR THE PRIMARY SYMPTOMS IN THE GUADIANA ESTUARY.

Zone	Salinity	Area (km²) (A_z)	Value (v_{ij}) Chlorophyll *a*	Macroalgae	Epiphytes	$A_z/A_t \times v_{ij}$ Chlorophyll *a*	Macroalgae	Epiphytes
Seawater	> 25	4.4	0.25	0	0	0.06	0	0
Mixing	0.5 – 25	7.6	1.00	0	0	0.39	0	0
Tidal fresh	< 0.5	7.5	1.00	0	0	0.38	0	0
Sum		19.5	-	-	-	0.83	0	0
Primary symptoms level of expression value for the estuary: 0.28 Low								

signs of oxygen depletion. The temporal scope of the data includes:

- Long time series with continuous observations from 1998 and from 2001;
- Historical data from the late 1970s.

Spatial coverage is not as detailed, although it seems adequate for an estuary with these characteristics, where the system pressures have been identified and the water body has been adequately monitored.

The application of NEEA criteria for dissolved oxygen concentration gives a level of expression of zero as neither biological stress nor hypoxia was observed.

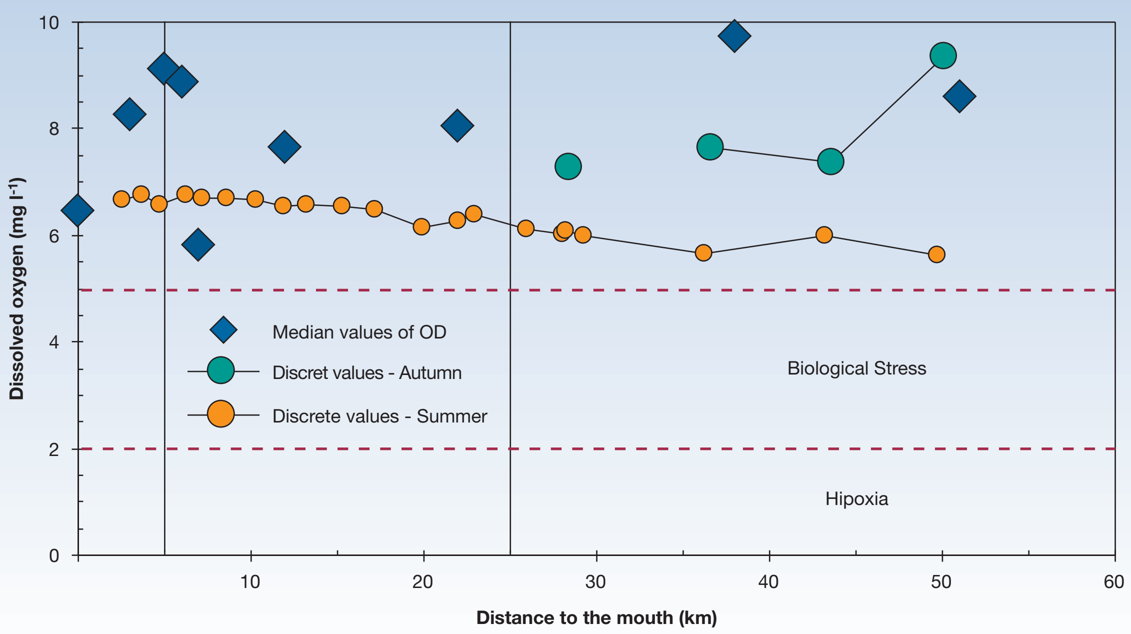
Submerged aquatic vegetation

No information was identified in the literature on the occurrence of problems with submerged aquatic vegetation. The corresponding level of expression value for this symptom is zero.

Nuisance and toxic blooms

The occurrence of high densities of harmful

FIGURE 170. LONGITUDINAL PROFILE OF DISSOLVED OXYGEN IN THE GUADIANA ESTUARY.



Guadiana Estuary

algae is described for the Guadiana river, as well as for some of the reservoirs in the watershed. Most of the studies make no reference to regions downstream of Mértola, which is considered to be the upper limit of the estuary. Despite this fact, the Guadiana estuary has previously been interdicted for shellfish harvesting in 1999 due to the presence of biotoxins.

A study carried out on the presence of cyanophytes in the Guadiana River, which also included two stations in the estuary – Alcoutim and Mértola, both in the tidal fresh water zone - states that cyanophytes are the main source of biotoxins. Species belonging to the genera *Microcystis*, *Aphanizomenon*, *Anabaena, Pseudanabaena* and *Oscillatoria* were identified, and linked to a reported episode of undesirable aesthetic conditions observed in the region of Mértola, associated to a fish kill. Blooms of cyanophytes seem to occur regularly in summer in the region of Mértola and also episodically near Alcoutim.

The duration of these blooms appears to be related to the magnitude and patterns of river discharge. Summer algal blooms in periods of

FIGURE 171. FREQUENCY DISTRIBUTION FOR DISSOLVED OXYGEN IN THE GUADIANA ESTUARY.

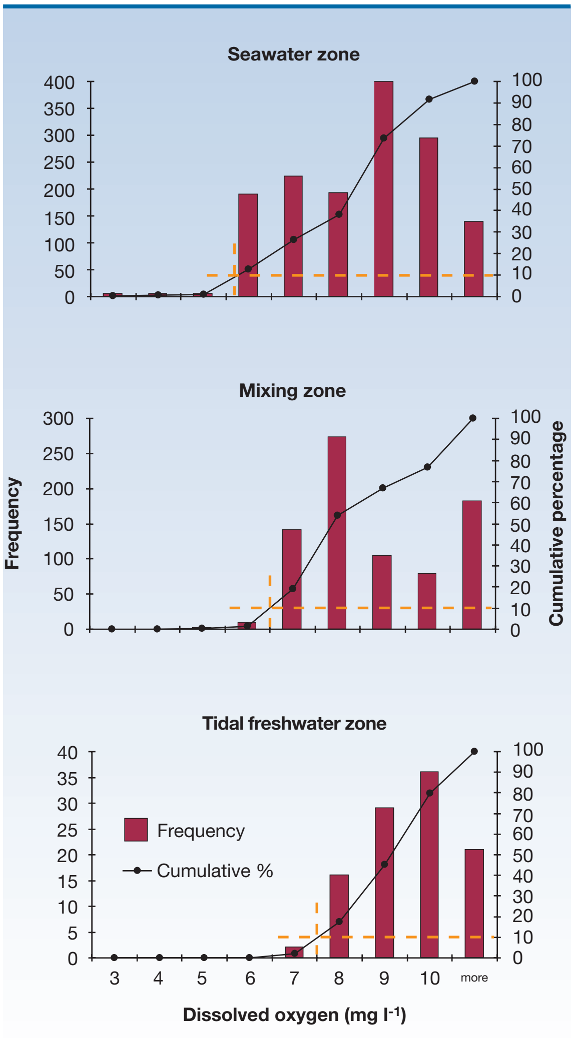


FIGURE 172. NEEA INDEX FOR NUISANCE AND TOXIC BLOOMS.

ZONE	IF Blooms	AND Duration	AND Frequency	THEN Expression	Value
Seawater	None	None	None	-	0
Mixing	None	None	None	-	0
Tidal fresh	Problem	Monthly to seasonal	Periodic	High	1

reduced river flows are confined to the tidal fresh water zone of the estuary. The application of the NEEA criteria for this secondary symptom is shown in Figure 172.

OVERALL HUMAN INFLUENCE

Susceptibility

Dilution potential

The Guadiana is a mesotidal estuary with a tidal range of 3.4 m for equinoctial spring tides and a mean tidal range of about 2.2 m. The Guadiana river is the only relevant fresh water input, and exhibits a strong seasonal and interannual variability. The operation of the new Alqueva-Pedrógão dam will cause a reduction of total inflow but also a decrease in variability. The flux ratio between the river flow *Rt* and the tidal prism *P* was calculated for the Guadiana estuary. On the basis of its variation with tidal situation and river flow, changes in vertical salinity structure may be observed.

Some observations suggest that stratification may be more important than this simplified analysis suggests. Nevertheless, as most of the hydrological conditions are at present and will be in the future characterized by flows below 100 m^3 s^{-1}, for the purpose of the present study the estuary as a whole is considered as at least *partly* mixed. On this basis, the Guadiana dilution potential is classified in type B, "Moderate" category, despite that the dilution volume factor (10^{-8} m^3) is relatively low when compared to larger estuaries.

Flushing potential

The flushing potential is also a function of the relative values of estuarine morphological

FIGURE 173. NEEA INDEX APPLICATION FOR THE SECONDARY SYMPTOMS IN THE GUADIANA ESTUARY.

Zone	Salinity	Area (km^2) (A_z)	Value (v_{ij}) Dissolved O_2	Value (v_{ij}) SAV	Value (v_{ij}) Blooms	A_z/A_t x v_{ij} Dissolved O_2	A_z/A_t x v_{ij} SAV	A_z/A_t x v_{ij} Blooms
Seawater	> 25	4.4	0	0	0	0	0	0.00
Mixing	0.5 – 25	7.6	0	0	0	0	0	0.00
Tidal fresh	< 0.5	7.5	0	0	1	0	0	0.38
Sum		19.5	-	-	-	0	0	0.38
Secondary symptoms level of expression value for the estuary: 0.38 Moderate								

FIGURE 174. DETERMINATION OF OVERALL SUSCEPTIBILITY.

Type	IF Vertical stratification	THEN Dilution volume		THEN Dilution potential
B	Partly mixed	$1/V_t$	10^{-8}	Moderate
	Tidal prism	**Freshwater flow/estuary volume**		None
	Mesotidal	Moderate	7×10^{-2}	Moderate
	Overall susceptibility for the estuary: Moderate			

characteristics and river flow. The ratio of the modular fresh water inflow to the total estuarine volume is of the order of 7×10^{-2}, leading to a classification of "Moderate" flushing potential.

In Figure 174 the determination of the overall susceptibility of the Guadiana estuary is presented, leading to a final classification of "Moderate".

Nutrient inputs

The main sources of nutrients from human activities discharging into the estuary are:

1) **Nutrients from urban and industrial waste waters, treated and untreated;**

2) **River inputs from the Guadiana basin, integrating point and diffuse sources upstream the section considered as reference;**

3) **Nutrient inputs from diffuse sources draining directly to the estuary.**

The estimation of diffuse loads used export coefficients for different classes of land use. A simplified classification was adopted, using three rural classes permanent cultures and fruit trees; annual crops, irrigated and non-irrigated; forest areas and scrub, urban, industrial and other non classified areas. Figure 175 presents the relative importance of these classes in the basin draining directly to the Guadiana estuary.

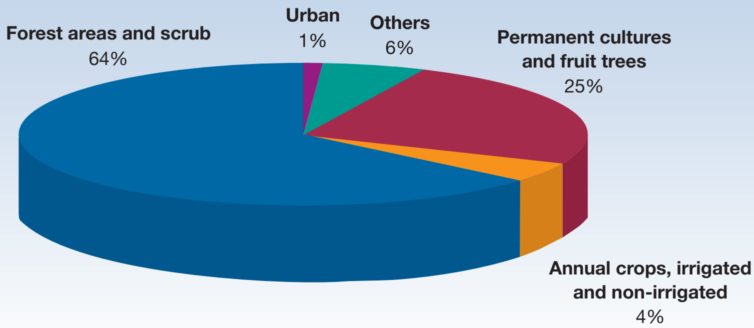
Point sources were estimated considering the loads transported by the Guadiana River and from urban and industrial wastewaters. The river inputs were estimated based on a reference river section near the upstream limit of the estuary. A positive relation between nitrogen loading and river flow was observed.

The calculation of loads from domestic wastewater used *per capita* coefficients (3.3 kg PEQ^{-1} y^{-1} for N and 0.4 kg PEQ^{-1} y^{-1} for P). Industrial

Vertical stratification

- Well mixed for $Q \simeq 170$ m^3 s^{-1};
- Partly mixed with $R_t/P \simeq 0.2$-0.45 for $Q \simeq 400$ m^3 s^{-1};
- Stratified except for spring tides, for $Q \geq 1000$ m^3 s^{-1}.

FIGURE 175. DISTRIBUTION BY LAND USE CLASSES.



wastewater discharges are of reduced relevance, but an estimate using available information was nevertheless carried out. Figure 176 presents a summary of the total estimates of the land-based inputs.

The application of the loading-susceptibility model to the Guadiana estuary followed the approach described in the methodology section for transitional waters. To run the model a salinity median of 26.8, a modular river flow of 85 m^3 s^{-1}, the estuary volume (Figure 162) and the nitrogen loads presented in Figure 176 were used. A value of 83.8% was determined which falls in the "High" category.

FIGURE 176. NITROGEN AND PHOSPHATE LOADS TO THE GUADIANA ESTUARY.

Sources	River	Diffuse	Industrial	Domestic
Total nitrogen (ton y^{-1})	3 400	259	8	70
Total phosphorus (ton y^{-1})	600	29	3	8

Combining susceptibility with nutrient inputs, the overall classification for the Guadiana estuary in terms of human influence is “Moderate High”, which means that the symptoms observed in the estuary are moderately to highly related to nutrient additions, particularly in the tidal freshwater and mixing zones.

DETERMINATION OF FUTURE OUTLOOK

Although the future outlook in the estuary is classified as unchanged, it is dependent on the potential changes in land use promoted by the Alqueva reservoir. The effective implementation of good agricultural practices according to the agro environmental EU rules is essential to prevent environmental quality degradation as regards eutrophication;

SUMMARY OF THE NEEA INDEX APPLICATION

The expression of primary and secondary symptoms to the Guadiana estuary was estimated as “Low” and “Moderate”, respectively. According to the NEEA aggregation rules this leads to an overall classification of “Moderate Low”.

Figure 177 summarises the overall results of the application of the NEEA methodology, which indicate that the estuary is considered “Moderate” as regards overall eutrophic conditions and “Moderate Low” for overall human influence. The future nutrient pressures are conditionally classified as unchanged.

CONCLUSIONS

The following conclusions can be drawn from the

FIGURE 177. RESULTS OF THE NEEA INDEX APPLICATION TO THE GUADIANA ESTUARY.

Indices	Methods	Parameters/Value/EAR			Index value
Overall Eutrophic Condition (OEC)	PSM	Chlorophyll *a*	0.84	0.28 Low	Moderate Low
		Epiphytes	0		
		Macroalgae	0		
	SSM	Dissolved oxygen	0	0.38 Moderate	
		Submerged aquatic vegetation	0		
		Nuisance and toxic blooms	0.38		
Overall Human Influence (OHI)	Susceptibility	Dilution potential	Moderate	Moderate susceptibility	Moderate High
		Flushing potential	Moderate		
	Nutrient inputs	High nutrient inputs			
Future Outlook for future conditions (DFO)	Future nutrient pressures	Future nutrient pressures no significant change			No change

NEEA index application to the Guadiana estuary:

- Although an extensive database for salinity and dissolved oxygen is available for the Guadiana estuary, the information on other biogeochemical parameters is much more limited. The analysis for chlorophyll *a* is the most obvious case, where an uneven distribution of observations in space and time may bias the data. A comprehensive and carefully designed *Surveillance Monitoring* programme (sensu WFD) is recommended, to help to fill the gaps in the dataset. This is in any case required for monitoring the early stages of the operation of the Alqueva-Pedrógão dam, in Portugal, and the Andévalo-Chanza dam, in Spain;
- The OEC index classifies the estuary in the "Moderate Low" category. This results is mainly due to the "Medium" to "High" concentrations of chlorophyll *a* as well as the occurrence of toxic blooms in the tidal freshwater and mixing zones;
- The OHI index falls into the "Moderate High" category. This value is strongly influenced by the nutrient inputs introduced by the river, due to agricultural practices upstream and along the estuary banks;
- Although the future outlook in the estuary is classified as unchanged, it is dependent on the potential changes in land use promoted by the Alqueva reservoir. The effective implementation of good agricultural practices according to the agro environmental EU rules is essential to prevent environmental quality degradation as regards eutrophication;
- On the basis of the application of the NEEA index, there is no justification for designating sensitive areas in the estuary, as regards eutrophication, under the terms of the UWWTD Directive (91/271/EEC);
- The designation of vulnerable zones in the estuary under the terms of the Nitrate Directive (91/676/EEC) is dependent on the changes in agricultural practices promoted by the future availability of water for irrigation from the Alqueva reservoir.

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GENERAL CONCLUSIONS

This study was carried out to address the potential classification of sensitive areas and/or vulnerable zones in ten Portuguese systems, the Minho, Lima, Douro, Ria de Aveiro, Mondego, Tagus and Sado, Mira and Guadiana estuaries, and the Ria Formosa coastal lagoon. The evaluation presented in this document applies the U.S. National Estuarine Eutrophication Assessment, developed by the National Oceanic and Atmospheric Administration of the United States.

- **Sensitive areas**
  Directive on urban wastewater treatment UWWTD (91/271/EEC)
- **Vulnerable zones**
  Nitrates directive ND (91/676/EEC)

This work examines the ecological quality of the ten systems, and asks six fundamental questions:

SIX KEY QUESTIONS

1. **What is the eutrophication status of each of the ten systems, as a whole and in sections; how does it compare with other estuaries and coastal waters in Portugal and elsewhere?**
2. **Which systems or parts of systems should be classified as sensitive areas and/or vulnerable zones?**
3. **What are the potential management solutions, for example through effluent treatment or improvement of agricultural practices?**
4. **What will be the trends in nutrient loading to these systems, from urban and agricultural sources, over the next few decades?**
5. **Where are the main data gaps, and what are the recommendations for monitoring and research for the ten systems studied?**
6. **How can this assessment be used as the basis for a national strategy?**

The results obtained for the ten systems are presented below.

EUTROPHICATION STATUS

Figure 178 shows the results of the NEEA assessment of the ten systems. No eutrophication problems are identified in the Minho, Lima, Douro, Ria de Aveiro, Tagus, Sado and Mira estuaries. In the Mondego, existing data for the South channel suggest the occurrence of

FIGURE 178. EUTROPHICATION STATUS OF THE PORTUGUESE SYSTEMS.

	Overall Eutrophic Condition (OEC)	Overall Human Influence (OHI)	Definition of Future Outlook (DFO)
Minho	There is insufficient information to fully apply the NEEA index in this estuary, but the analysis of available data shows that there are no problems with eutrophication symptoms		
Lima	There is insufficient information to fully apply the NEEA index in this estuary, but the analysis of available data shows that there are no problems with eutrophication symptoms		
Douro	There is insufficient information to fully apply the NEEA index in this estuary, but the analysis of available data shows that there are no problems with eutrophication symptoms		
Ria de Aveiro	Moderate low ✓	Low ✓	No change ✓
Mondego	There is insufficient information to apply the NEEA index in this estuary, but a partial analysis shows that there are problems in the south arm of the system		
Tagus	Moderate low ✓	Low ✓	Slight improvement ✓
Sado	Low ✓	Low ✓	Substantial improvement ✓
Mira	Low ✓	Low ✓	No change ✓
Ria Formosa	Moderate Low ✓	Moderate ✓	Substantial improvement ✓
Guadiana	Moderate ✓	Moderate low ✓	No change ✓

eutrophication symptoms associated with macroalgal (seaweed) growth. In the Ria Formosa, periodic blooms of macroalgae have been detected in the Faro-Olhão channels. In the tidal freshwater and mixing zones of the Guadiana estuary, the eutrophic symptoms are associated with medium to high chlorophyll *a* values.

The study carried out by NOAA on 138 estuaries in the United States, identified 34% with high expression of eutrophication conditions, 37% with moderate conditions and 29% with low conditions – 17 of the 138 estuaries did not have enough information available to apply the NEEA methodology. Given the level of development of the European Union, we would expect the application of NEEA to European estuaries to give similar results or perhaps even to identify a greater proportion of systems with high eutrophication conditions. Comparatively, the Portuguese systems for which adequate data exist have low eutrophic conditions when considered on an EU-wide scale.

CLASSIFICATION OF VULNERABLE ZONES AND/OR SENSITIVE AREAS

Designation of vulnerable zones

On the basis of the application of the NEEA index to the ten systems, there is no justification for designating vulnerable zones in the Minho, Lima, Douro, Ria de Aveiro, Tagus, Sado, Mira and Ria Formosa. In the Mondego estuary, available data suggest that the South channel is a problem area, and the measures required to reduce macroalgal blooms and restore the ecosystem balance should be urgently examined. The designation of vulnerable zones in the Guadiana estuary is dependent on the changes in agricultural practices promoted by the future availability of water for irrigation from the Alqueva reservoir.

Designation of sensitive areas

On the basis of the application of the NEEA index to the ten systems, there is no justification for designating sensitive areas in any of them, under the terms of the UWWTD Directive (91/271/EEC), as regards eutrophication.

MANAGEMENT RECOMMENDATIONS

Minho, Lima and Douro estuaries

Due to the lack of information for these estuaries no conclusions could be drawn on management recommendations.

Mondego estuary

Improve the agricultural practices in the Pranto river basin, and propose the application of ecotechnology solutions. A comprehensive list would include:

(i) Optimisation of the management of the Pranto discharge;

(ii) Construction of artificial wetlands between the upstream farmland and the Pranto sluice connection to the Mondego Southern channel.

Guadiana estuary

The effective implementation of good agricultural practices according to the EU agro-environmental rules is essential to prevent environmental quality degradation as regards eutrophication.

Other estuaries

The management measures currently being applied in the estuaries of the Ria de Aveiro, Tagus, Sado, Mira and Ria Formosa, with respect to effluent treatment and discharge to the receiving body, agricultural practices and soil protection, appear to be adequate for preserving and improving environmental quality as regards eutrophication.

FUTURE OUTLOOK

The future trends are positive in the case of the Douro, Tagus, Sado and Ria Formosa and neutral in the case of the Lima, Ria de Aveiro and Mira. No conclusions were drawn on possible trends for the Mondego and Minho due to lack of information. Negative future trends should be considered in the case of the Guadiana estuary if appropriate management recommendations are not implemented.

DATA GAPS AND RECOMMENDATIONS

All the systems except the Tagus exhibit data gaps, which should be filled by means of an adequate monitoring programme. These programmes should be implemented following the recommendations of the Water Framework Directive (WFD, Directive 2000/60/CE).

Minho estuary

The information on water quality parameters for the Minho estuary is very limited. Some of the parameters are only available as metadata and the spatial and temporal coverage is not sufficient to carry out an analysis of the system as a whole. A *Surveillance Monitoring* programme is recommended, following the definition set out in the Water Framework Directive.

Lima estuary

The areas near the banks of the Lima estuary, particularly the saltmarshes and saltpans, have been studied, but there is a requirement for an integrated approach to the whole system from the head of the estuary to the mouth. Due to the lack of information for this estuary, particularly in what concerns hydrology, macroalgae, epiphytes and submerged aquatic vegetation dynamics, a *Surveillance Monitoring* programme should be developed.

Douro estuary

The information for the Douro estuary is also scarce concerning water quality, macrophytes and nuisance and toxic blooms. For this estuary a *Surveillance Monitoring* programme is necessary.

Ria de Aveiro

Some data gaps were detected for Ria de Aveiro concerning spatial coverage for chlorophyll *a*, macrophyte dynamics and nuisance and toxic blooms. An adequate *Surveillance Monitoring* programme should be developed to rectify these gaps. Aditionally two investigative monitoring programs should be carried out to determine the reasons for general SAV loss and high chlorophyll concentrations in the extreme of Mira channel.

Mondego estuary

The South channel of the Mondego estuary is well studied, but there is a requirement for an integrated approach to the whole system, from the head of the estuary to the mouth, considering both the North and South channels. For this estuary, apart from the *Surveillance Monitoring* indicated in the WFD, an *Investigative Monitoring* programme has now been implemented, in order to respond to the outstanding issues.

Tagus estuary

The Tagus estuary is well characterized, and the fulfilment of national obligations with regard to WFD *Surveillance Monitoring* is sufficient.

Sado estuary

Some areas of the Sado estuary are not very well known, particularly the upper part. These knowledge gaps may be filled by an adequately designed *Surveillance Monitoring* programme. Elevated chlorophyll *a* peaks were identified on one sampling date in February 2000, which are clearly inconsistent with the overall dataset. As a precaution, *Investigative Monitoring* is suggested for the area in question.

Mira estuary

Sections of the Mira are poorly known, particularly the upstream part. There is also a need to improve the description of temporal and spatial variation of chlorophyll *a*. The monitoring programme falls clearly into the *Surveillance Monitoring* area of the WFD.

Ria Formosa

The data gaps detected for the Ria Formosa concern macrophyte dynamics, particularly seaweeds and seagrasses. Efforts should be made to obtain the necessary information by means of an *Investigative Monitoring* programme.

Guadiana estuary

Although an extensive database for salinity and dissolved oxygen is available for the Guadiana estuary, the information on other biogeochemical parameters is much more limited. The analysis for chlorophyll *a* is the most obvious case, where an uneven distribution of observations in space and time may bias the data. A comprehensive and carefully designed *Surveillance Monitoring* programme (sensu WFD) is recommended, to help to fill the gaps in the database.

DEFINITION OF A NATIONAL STRATEGY

This study brings together valuable information on the state of eutrophication of nine estuarine systems and one coastal lagoon in Portugal, and is a useful support for decision-making and management of these systems. The existence of a comparative methodology and results at an international level reinforces the utility of this approach. The general application of the NEEA index to a large number of Portuguese estuaries and coastal lagoons was shown to have the following advantages:

- Contribution to the definition of priorities and decision-support at a national level
- In estuaries with serious problems, application of management measures. In systems considered to be at risk, promotion of monitoring and preventive measures
- In estuaries where serious knowledge gaps exist, identification of the monitoring requirements for quality assessment

IDENTIFICATION OF SENSITIVE AREAS AND VULNERABLE ZONES
IN TRANSITIONAL AND COASTAL PORTUGUESE SYSTEMS

Application of the United States National Estuarine Eutrophication Assessment to the Minho, Lima, Douro, Ria de Aveiro, Mondego, Tagus, Sado, Mira, Ria Formosa and Guadiana systems

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