S. R.

MINISTÉRIO DAS CIDADES, ORDENAMENTO DO TERRITÓRIO E AMBIENTE

INSTITUTO DA ÁGUA

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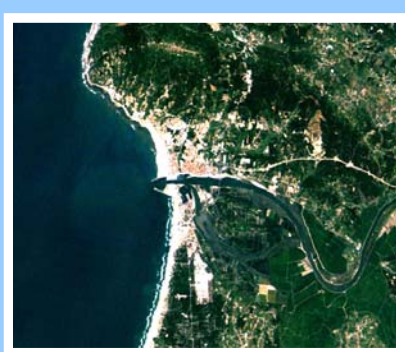
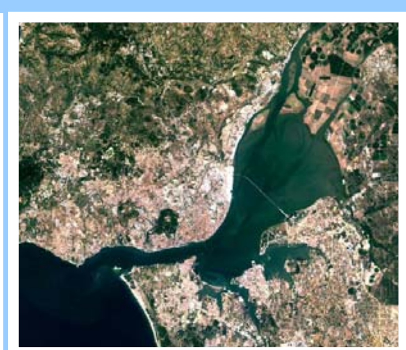
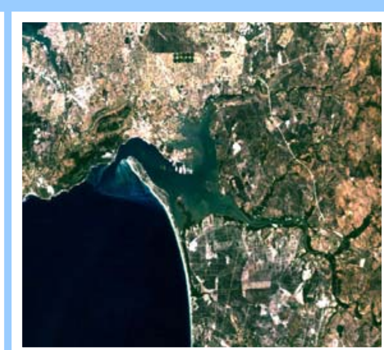
OSPAR Convention for the Protection of the Marine Environment of the North East Atlantic

Comprehensive Procedure

PORTUGAL

Mondego, Tagus and Sado Estuaries

Maretec
Marine Environment and Technology Center

Instituto Superior Técnico

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TABLE OF CONTENTS

INDEX OF TABLES

INDEX OF FIGURES

INTRODUCTION

As Contracting Parties of the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, Portuguese authorities adopted the OSPAR Strategy to Combat Eutrophication. OSPAR's objective with regard to eutrophication is "to combat eutrophication in the OSPAR maritime area, in order to achieve and maintain a healthy marine environment where eutrophication does not occur" according to the OSPAR Convention (1992) where the Contracting Parties agree to "take all possible steps to prevent and eliminate pollution and to take the necessary measures to protect the maritime area against adverse effects of human activities so as to safeguard human health and to conserve marine ecosystems and, when practicable, restore marine areas which have been adversely affected".

The defined strategy, in order to reach these ambitious objectives, consists, in a first stage, to classify the maritime areas as a problem area, potential problem area or non-problem area following the Common Procedure for the Identification of the Eutrophication Status of the Maritime Area.

The Common Procedure comprises two steps: Screening and Comprehensive Procedure. The screening procedure consists to identify obvious non-problem areas with regard to eutrophication. In the second stage, the areas not identified as non-problem areas, in the first, shall be subject to the Comprehensive Procedure which includes four categories of assessment:

Category I – Degree of Nutrient Enrichment;

Category II – Direct Effects of Nutrients Enrichment;

Category III – Indirect Effects of Nutrient Enrichment;

Category IV – Other possible effects of Nutrient Enrichment.

Each category has a set of parameters that should be analyzed in order to identify possible symptoms of eutrophic conditions. This report describes the application of the Comprehensive Procedure to the Mondego, Tagus and Sado Estuaries.

The classification of the areas with regard to eutrophication must be obtained appealing to actual and historical observations, resulting from comparison between the actual conditions and background conditions. The concept of background conditions, or reference conditions, aims to represent the conditions existing before remarkable anthropogenic inputs. In this study, the background concentrations are considered to be the oldest values measures in the study area, since no alternative definitions have been found. It's important to notice that there is a relevant lack of historic and present field data, thus becoming difficult the process of establishing a trend of trophic evolution of these systems.

To overcome this obstacle this study include results obtained with MOHID model, a three-dimensional water modelling system, which have already been used to apply the Urban Waste Water Treatment Directive and Nitrate Directive. The MOHID model allows us to fill the information gapes and, above all, give us an insight of the system itself. All systems were simulated considering fresh water discharges in the river boundary, tide in the ocean boundary and wastewater treatment plants discharges were they occur. Model results are in good agreement with field data, being able to show the most relevant trends.

The same processes and forcing conditions are considered in all estuaries, being differences systems a consequence of the relative importance of those processes. For example in the Mondego estuary the intense flow in the North branch causes a low residence time of water constituents, thus diminishing the role of primary production in water column because organisms don't have time to multiply inside the estuary. In Tagus estuary the average residence time is close to three weeks and biological processes of primary production and nutrient cycling have an enhanced relevance, being limited by light penetration.

The model produces a large amount of information regarding both temporal and spatial distributions and thus it was essential to find a way to compile this information and deliver it in a summarized form. Having this in mind, model results were time (annual) averaged providing average values of computed water properties (e.g. salinity, phytoplankton, DIN) in each domain cell. These results were divided into classes regarding the classes established after the definition of the background concentrations. This report presents, for each estuary, maps showing the areas where concentrations of Chlorophyll-a and Dissolved Inorganic Nitrogen (DIN) (defined as a sum of nitrate, nitrite and ammonia concentrations) falls under these classes. For DIN concentration classes average salinity distribution is shown. The purpose of these maps is to show that, in every estuary, there are significant concentration gradients that should be considered. For example in Tagus estuary middle class (ranging between the background value and this value plus 50%) appears in middle estuary. This means that field measurements used for defining the background concentrations are evenly distributed which is also corroborates by model results. The mean concentration increases upstream and decreases down estuary towards the ocean, as expected in systems where rivers are major sources of nutrients.

The organization of this report, for each estuary, follows the steps indicated by the Comprehensive Procedure. The analysis starts with a short description of the area in study, showing the most important factors with regard to eutrophication symptoms. The assessment criteria and their evaluation are synthesized in a table, allowing a clearly results comprehension. Extra information is providing in the last chapter, for each estuary, in order to complement the assessment in some of the considered parameters.

I. Mondego Estuary

1. Area

LATITUDE	LONGITUDE
40º 08’ 40’’ N	8º 52’ 20’’ W
40º 07’ 10’’ N	8º 47’ 40’’ W

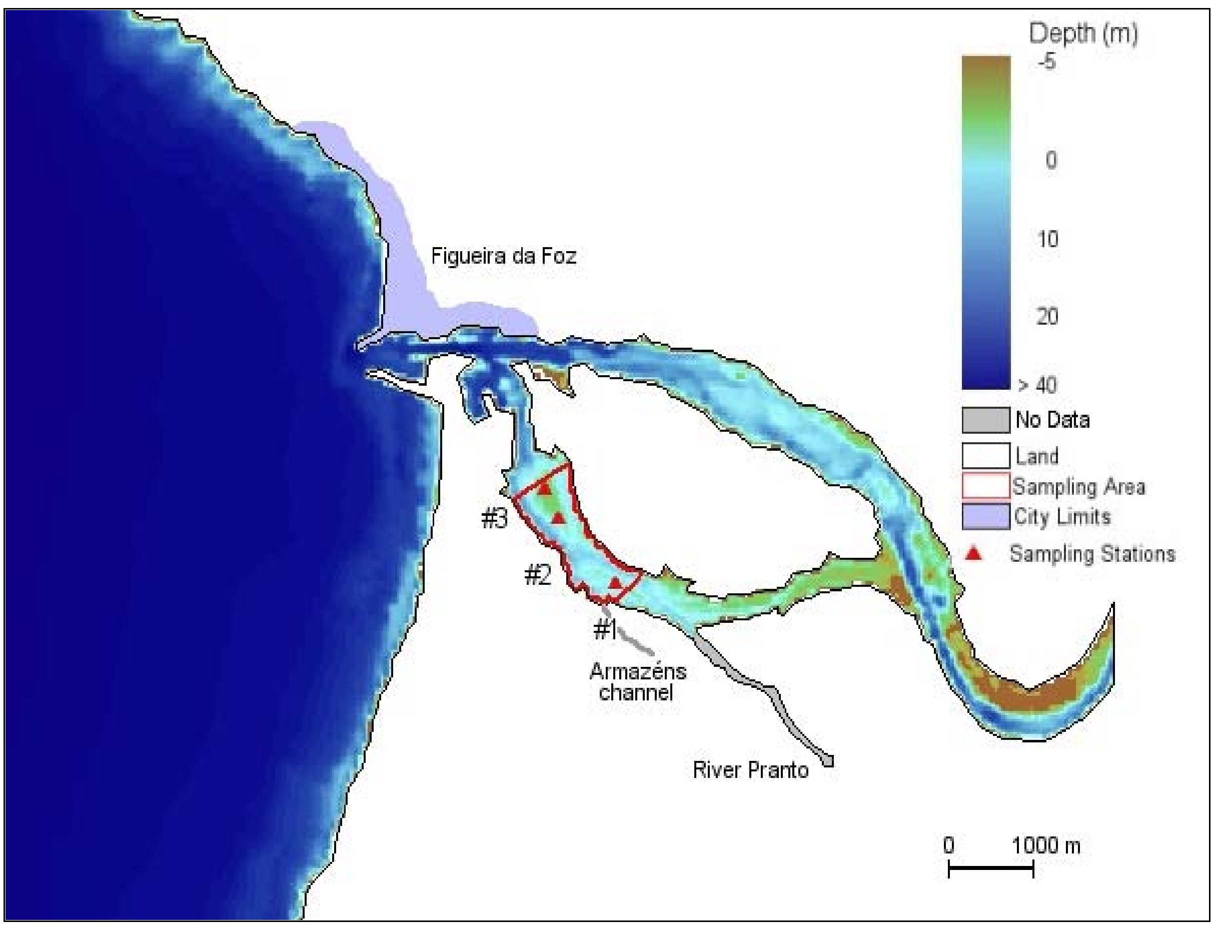


Figure 1 – Mondego estuary

2. Description of the Area

Mondego River drains a 6700 km^2 watershed and ends in a tidal estuary on west coast of Portugal at Figueira da Foz.

The estuary has a surface area of 6.4 km^2, and average spring tidal range is 3m. About 7 km from the mouth, the estuary branches into two channels (north and south) separated by an island. Northern Channel is deeper (5-10 m), while the southern is 2-4 m deep, making them hydrologically very different [3].

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

Southern channel is less affected by human activity but, due to its low depth, restricted circulation is considered to be more vulnerable to environmental stress.[3]

The next Table shows some of the main physical properties of Mondego estuary.[3]

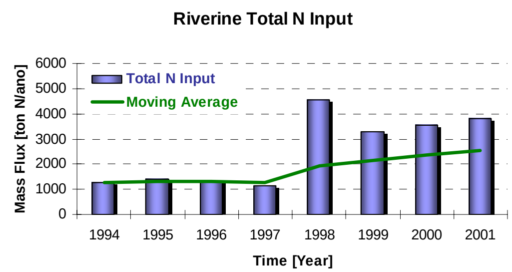
Parameter	Value
Volume	22 x 10^6 m^3
Total area	6.4 km^2
River Discharge	80 m^3 s^{-1}
Tidal range (average spring tide)	3.0 m
Neighbouring	66 000
Typical residence time	North channel: 2 days South channel: 9 days

Table 1 – Main physical properties of the Mondego Estuary

3. Assessment

<table>
<tr><th rowspan="2">MONDEGO ESTUARY</th><th colspan="7">Category I – Degree of Nutrient Enrichment</th></tr>
<tr><th colspan="2">Actual Situation</th><th colspan="2">Criteria of Classification</th><th colspan="2">Partial Classification</th><th>Notes</th></tr>
<tr><td>1. Riverine Total N and/or Total P inputs and direct discharges (RID)</td><td>4000 ton N/year
87 ton P/year</td><td>Description:

Mondego and Pranto River
3700 ton N/year
83 ton P/year

Domestic Load
311 ton N/year
4 ton P/year</td><td colspan="2">
</td><td>+</td><td rowspan="3">+</td><td></td></tr>
<tr><td>2.Winter DIN and/or DIP Concentrations</td><td>51 µmol/l
(average)

87 µmol/l
(Percentile 90)</td><td>Description:

Calculated with available data since 1991 (138 datapoints in winter and available only in the South Channel of the Mondego estuary)</td><td>Background Value

44 µmol/l</td><td>Elevated Value

66 µmol/l</td><td>-</td><td>Look for complementary information in Point nº.6</td></tr>
<tr><td>3. Increased winter N/P ratio</td><td colspan="4">Description:

Data Not Available</td><td></td><td></td></tr>
</table>

<table>
<tr><th rowspan="2">MONDEGO ESTUARY</th><th colspan="7">Category II – Direct Effects</th></tr>
<tr><th colspan="2">Actual Situation</th><th colspan="2">Criteria of Classification</th><th colspan="2">Partial Classification</th><th>Notes</th></tr>
<tr><td>1. Maximum and Mean Chlorophyll-a Concentration</td><td>6.4 µg/l
(average)
12.4 µg/l
(percentile 90)</td><td>Description:
Summer
(145 data points)</td><td>Background Value
6 µg/l</td><td>Elevated Value
9 µg/l</td><td>-</td><td rowspan="3">+</td><td>Look for complementary information in Point nº.6</td></tr>
<tr><td>2.Region/Area Specific phytoplankton indicator species</td><td colspan="4">Description:
Data Not Available</td><td></td><td></td></tr>
<tr><td>3.Macrophytes including macroalgae (region specific)</td><td colspan="4">Description:
In Mondego estuary hard substrates extend along 60% of the total estuarine perimeter dominating the North channel and 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 algae Enteromorpha, Ulva and the red seaweed Gracillaria verrucosa – these are classified as the main ephiphytes in the system. Regular Enteromorpha blooms have been observed, especially in the inner areas of the south channel.[3]</td><td>+</td><td></td></tr>
</table>

MONDEGO ESTUARY	Category III and IV – Indirect Effects and Other possible effects					
	Actual Situation		Criteria of Classification	Partial Classification		Notes
1. Degree of oxygen deficiency	11.2 mg O_2/l (average) 6.8 mg O_2/l (percentile 10)	Description: (334 data points)	< 2 mg O_2/l => acute toxicity 2 – 6 mg O_2/l => deficiency	-		Look for complementary information in Point nº.6
2.Changes/kills in Zoobenthos and fish mortality	Description: No changes/kills in Zoobenthos and fish mortality have been reported in the literature			-	-	
3.Organic Carbon/Organic Matter	Description: Data Not Available					
4. Other Possible Effects Algal Toxins (DSP/PSP mussel infection events)	Description: No nuisance or toxic algal blooms have been reported in the literature			-		

4. Overall Classification

Area	Category I Degree of Nutrient Enrichment	Category II Direct Effects	Category III and IV Indirect Effects/Other possible effects	Initial Classification	Appraisal of all relevant information	Final Classification
MONDEGO ESTUARY	+	+	-	Problem Area	Modelling confirms that the north channel is a non-problem area, mostly because of its short residence time. Local characteristics of the south channel bring the necessity of further study. (see discussion)	Potential Problem Area

5. Discussion

In the Mondego estuary, the limiting factor of phytoplankton production is the residence time (two days), which is not long enough to allow the growing of a bloom. In this estuary the concentration of nutrients is higher in the Northern channel; however eutrophication symptoms are detected in the Southern channel (growth of macro-algae). This seems to be a consequence of the hydrodynamical properties of this channel. Artificial closing of the upper connection between the two channels has stimulated the settling characteristics of the Southern channel. So, the causes of the macroalgal blooms 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. The modification of the trophic characteristics of the Southern channel requires the reopening of the communication between the channels and cannot be achieved by a realistic reduction of nutrients discharged by the rivers.[4] Control measures should consider improved agriculture practices in the Pranto basin and propose ecotechnological solutions.

A comprehensive study of the Mondego estuary has been undertaken in order to complete the spatial description of the estuary, to shed light on key processes and to establish its appropriate classification. [3]

6.Other Information

The next figure represents a time series of the winter dissolved inorganic nitrogen (DIN) concentration measured in the Mondego estuary between 1993 and 1997. Each year is represented by the average of all field data in the winter season. The green line represents a moving average of two years. The moving average can allowing finding a trend for the field data and even with an obvious lacking of measurements it is possible to assume no significant variation on the winter DIN Concentration.

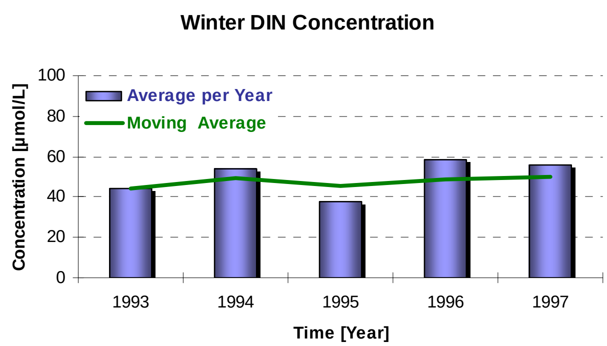


Figure 2 – Distribution of Winter DIN Concentration in the Mondego Estuary

Table 2 shows annual averages and the number of samples used in that average. The actual winter DIN Concentration, 51 µmol N/L, was computed as the total average of all data points. The table also shows the value of the percentile 90, resulting of the statistical analysis, which means that 90% of the data samples is below 87 µmol N/L.

Year	DIN Concentration [µmol N/L]	Number of Data Points
1993	44.17	31
1994	54.00	24
1995	37.58	23
1996	58.65	48
1997	55.84	12
Actual Situation (average)	**51**	**138**
Percentile 90	**87**	**138**

Table 2 – Winter DIN Concentrations in the Mondego Estuary

The assessment criteria for classification is based on the background concentration, assumed as the average value corresponding to 1993, the oldest registered data. Values of winter DIN concentration above 66 µmol N/L are considered elevated values according to OSPAR strategy, calculated as 50% above de background concentrations, Table 3.

Background Concentration	Assumed as the oldest register (1993)	44 µmol N/ L
Elevated Values	50 % above the background concentration	66 µmol N/ L

Table 3 – Criteria of Classification in the Mondego Estuary (DIN Concentration)

From the analysis of Table 2 and Table 3, it is possible to conclude that all annual averages are inferior to the elevated value so, in this assessment parameter, the Mondego estuary, as a whole, can be classify as a non-problem area, despite the percentile 90 value exceed the elevated level. However, this does not mean that the estuary do not display local symptoms of eutrophication, as is the case of macroalgae development in some points the southern channel.

The next figures represent spatial distribution of the properties computed by MOHID model for the Mondego estuary. The figures establish the areas in which DIN concentrations are below the background value, between the background and the elevated level and the areas where the concentration is above the elevated. To improve the study, it is also shown the salinity distribution in each area. The figures show clearly the existence of three different zones in the Mondego estuary: seawater zone, mixing zone and tidal fresh zone.

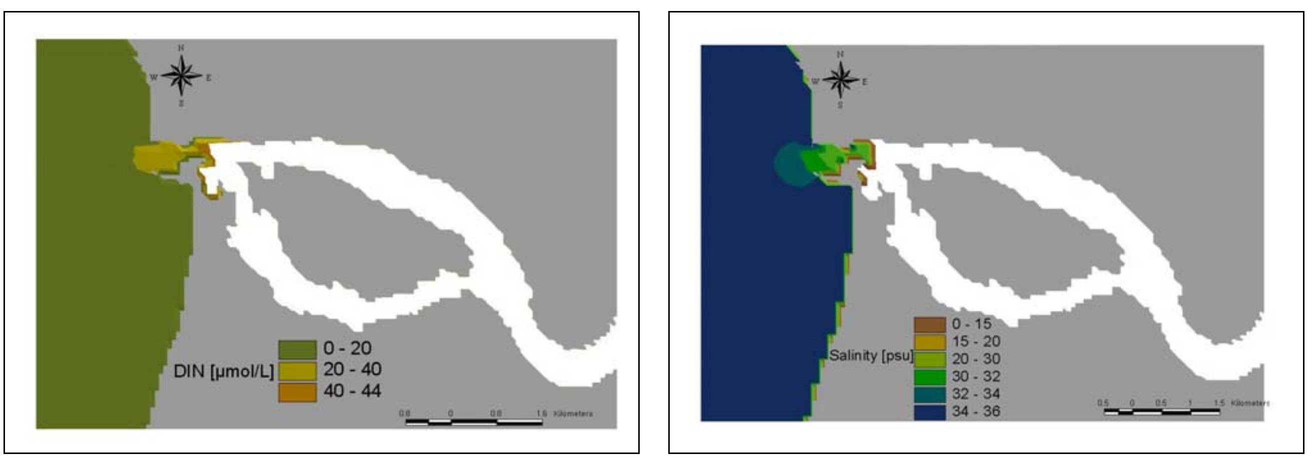


Figure 3 – Areas with DIN concentration below Background Value (0-44 µmol N/L); Spatial distribution of salinity

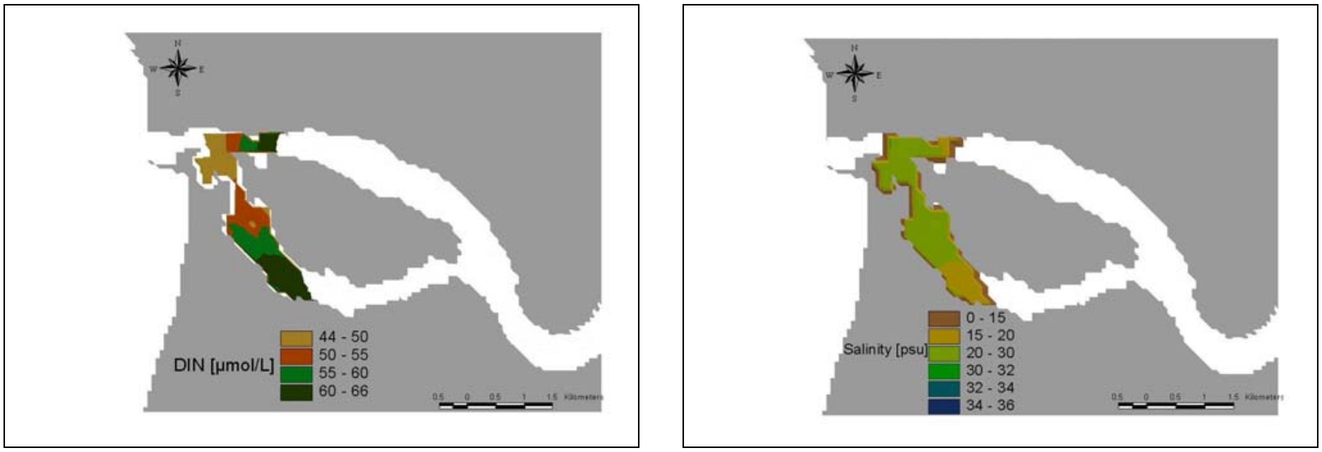


Figure 4 - Areas with DIN concentration between the Background and the Elevated Value (44-66 µmol N/L); Spatial distribution of salinity

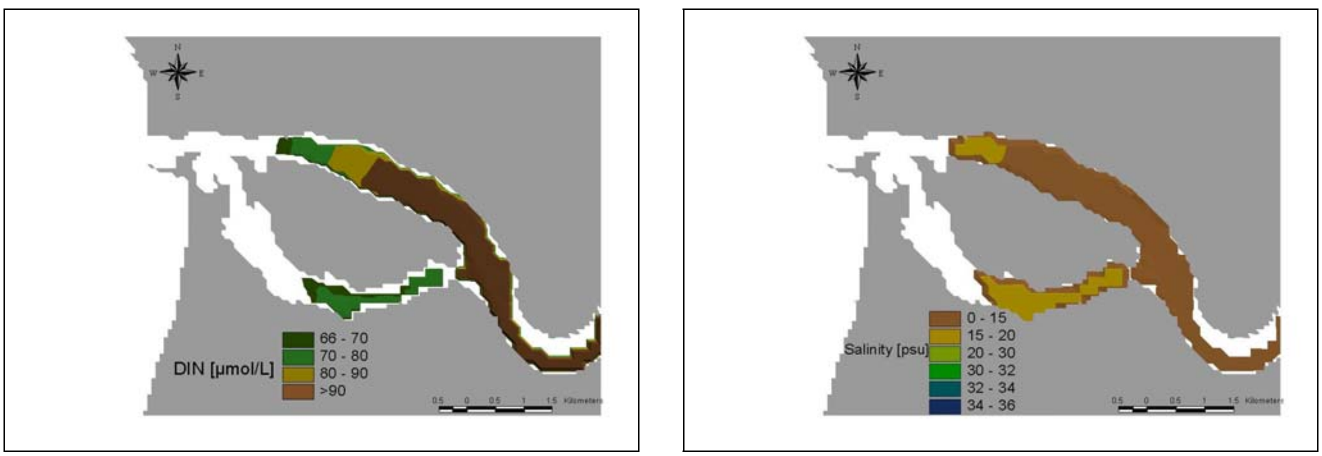


Figure 5 - Areas with DIN concentration above the Elevated Value (>66 µmol N/L); Spatial distribution of salinity

The limits of these areas for DIN and salinity distributions are identical. Generally, it is possible to say that, according to MOHID results, higher values of salinity correspond to areas of lower.

The values established to characterize the actual situation, 51 µmol N/L, correspond to an area in the estuary centre, the mixing area (Figure 4), with middle values of DIN and Salinity (20-30 psu). Thus, despite the average value considered to apply the assessment criteria, it is important to note that the model results evidence an important gradient of DIN concentrations in the estuary, characterize the actual situation with a large range of values, between 0 and 90 µmol N/L.

The next plot shows the DIN vs. salinity curve, based on field data registers. From the figure it is not viable to identify any clearly relation between the DIN and salinity values but it is possible to observe a higher cloud of points corresponding to high values of salinity and lower DIN concentration. In fact, the irregular distribution can be related with the existence of a sluice controlling the Pranto river discharge. As it was reported before, the characteristics of the south channel can change in a very significant way, if the sluice is closed, with salinity increases, as a consequence of hydrodynamic conditions changes. Figure 6 shows all the existing samples, since was not possible to distinguish the sluice state in the registers, which mean that include both conditions.

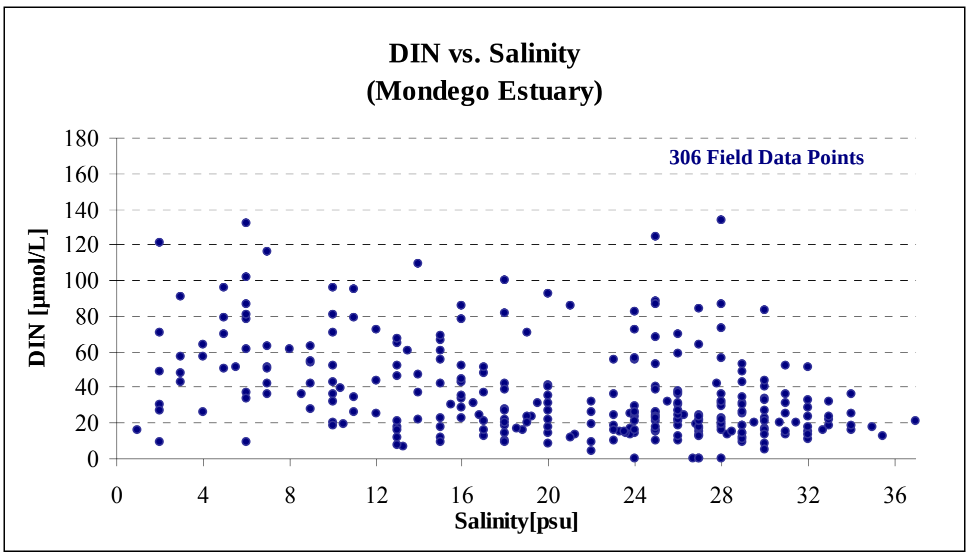


Figure 6 – DIN distribution vs. Salinity in Mondego Estuary

Chlorophyll-a field data are available for three years, between 93 and 96 on a total of 145 samples. Annual average values are shown in Table 4 and represented in Figure 7. Considering the small number of available samples, conclusions are safer if supported by model results.

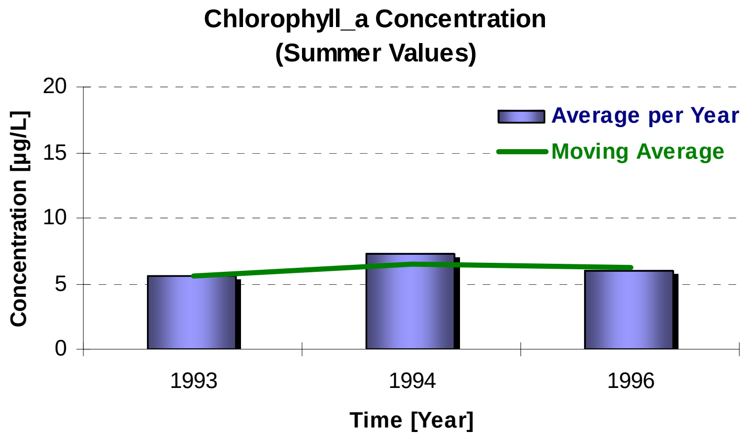


Figure 7 – Distribution of Chlorophyll-a Concentration during the summer

Year	Chlorophyll-a Concentration [µg/L]	Number of Data Points
1993	5.6	22
1994	7.3	53
1996	6.0	70
Actual Situation (average)	**6**	**145**
Percentile 90	**12.4**	**145**

Table 4 – Chlorophyll-a Concentrations during the summer

Background Concentration	Considered as an average value of the oldest registers (1993)	6 µg N/ L
Elevated Values	50 % above the background concentration	9 µg N/ L

Table 5 – Criteria of Classification in the Mondego Estuary (Chlorophyll-a Concentration)

The next collections of figures represent Chlorophyll-a spatial distribution of MOHID compute. The North Channel has concentrations below the elevated level while in the South channel, the values can reach to 14 µ g/L. The model results show clearly the differences between the two channels indicated before.

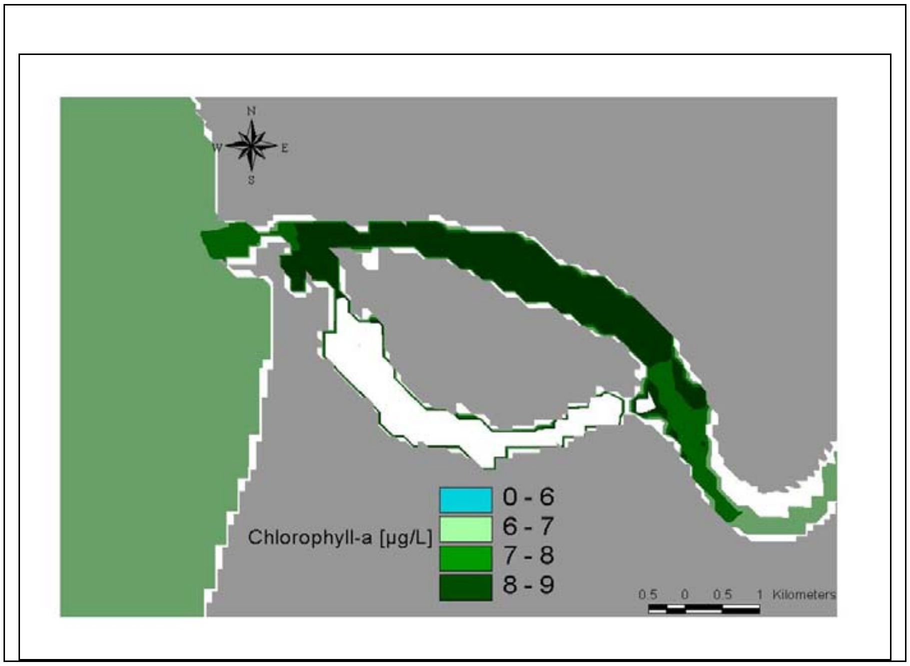


Figure 8 - Areas with Chlorophyll-a concentration below the Elevated Value (<9 µg/L)

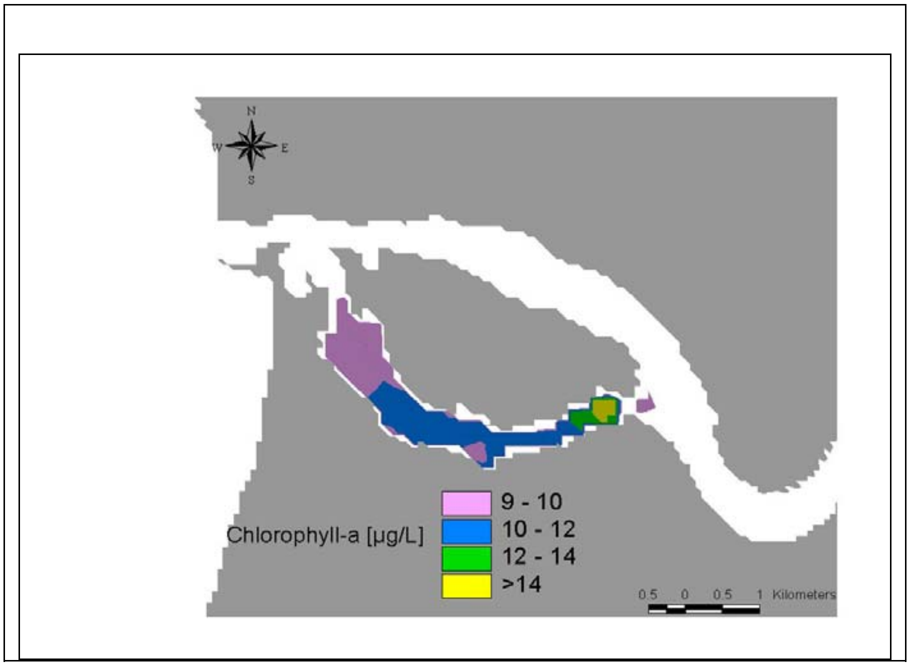


Figure 9 - Areas with Chlorophyll-a concentration above the Elevated Value (>9 µg/L)

Figure 10 represents the annual average of oxygen spatial distribution in the estuary resulting form the model simulation. Oxygen concentration between 8 and 9 mg/L are found in most estuary and higher values are found in the south channel, in concordance with higher values of Chlorophyll-a.

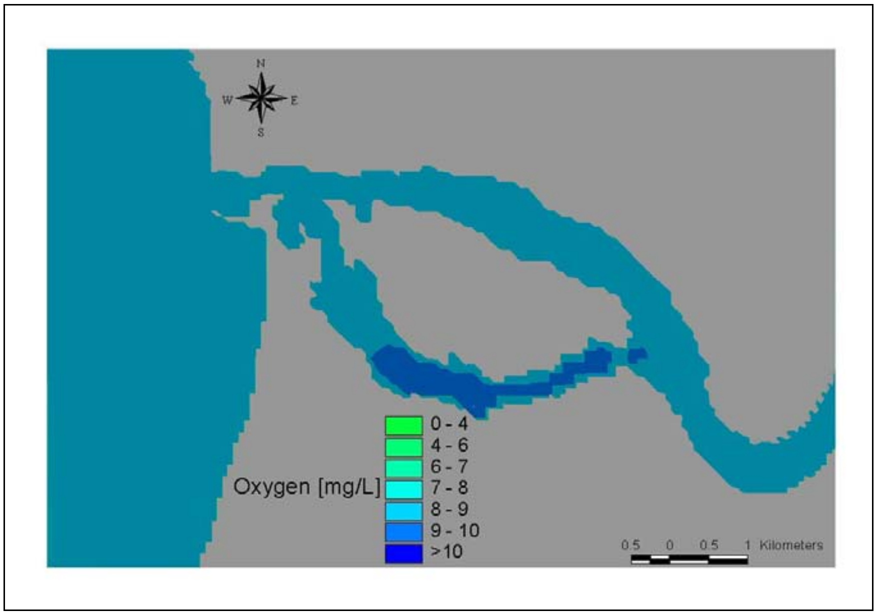


Figure 10 – Spatial distribution of Oxygen in the Mondego Estuary

II. Tagus Estuary

1.Area

LATITUDE	LONGITUDE
38º 57’ 12’’ N	8º 55’ 10’’ W
38º 36’ 40’’ N	8º 19’ 30’’ W

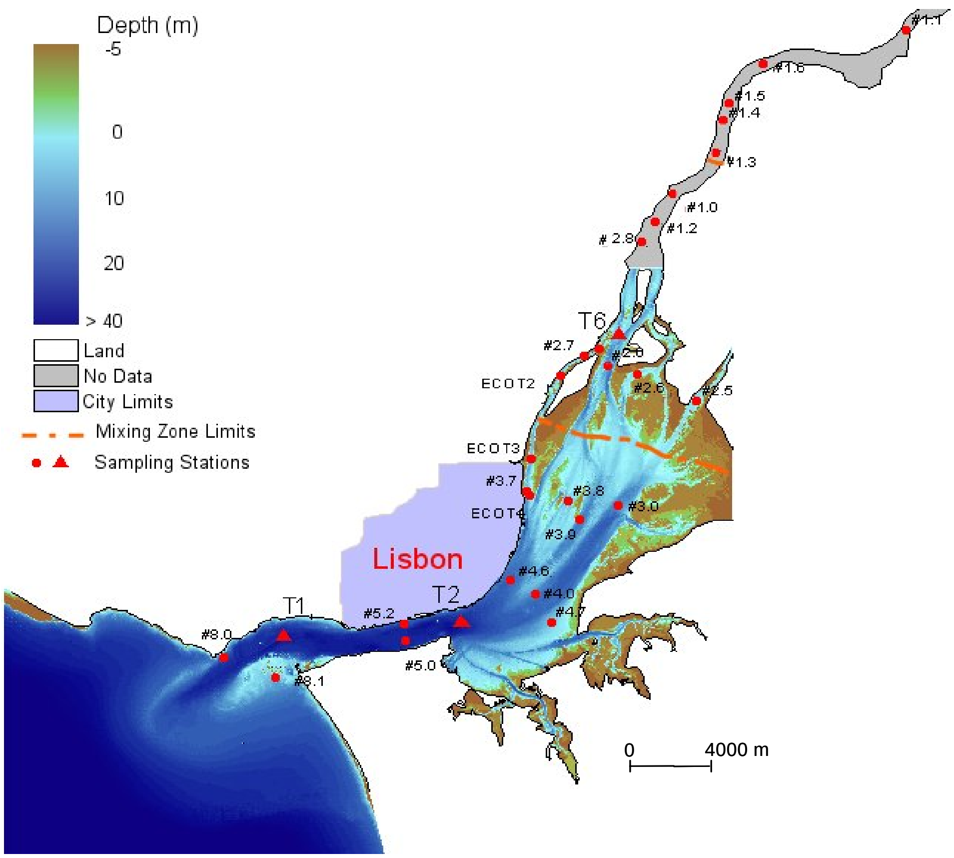


Figure 11 – Tagus estuary

2. Description of the Area

The Tagus is the largest river of Iberian Peninsula, ending in a large tidal estuary covering an area of 320 km^2. About 110 km^2 are intertidal areas; being 20 km^2 occupied by salt marsh vegetation and 80 km^2 by mudflats. Morphologically the estuary can be divided into three parts: upstream, middle and downstream sections. The upstream part, between Vila Franca de Xira and the Alcochete – Sacavém, has an average depth of 2 m and includes most mudflats. The middle part is deeper (average of 7 m), and the dowstream part reaches depths of 46 m and is the main navigation channel of the estuary.[3]

The main physical properties of the Tagus estuary can be summarized as:.

Parameter	Value
Volume	1900×10^6 m^3
Total area	320 km^2
River Discharge	400 m^3 s^{-1}
Tidal range (average spring tide)	2.6 m
Neighbouring	2 200 000
Typical residence time	3 weeks

Table 6 - Main physical properties of Tagus Estuary

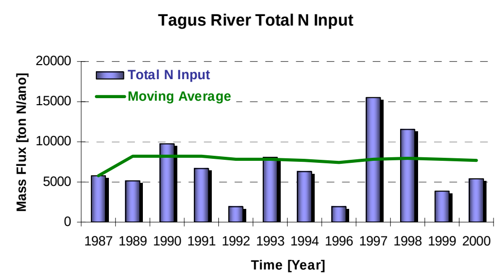
The combined effects of low average depth, strong tidal currents, and low input of river water make the Tagus a globally well-mixed estuary, with stratification being rare and occurring only in specific situations such as neap tides or after heavy rains. The Tagus estuary is meso-tidal and its circulation is mainly tidally driven. The amplitude of the tide is the controlling variable of the flowand is responsible to a large extent for the turbidity of the Tagus, which in shallow areas of upstream part of the estuary is enhanced by small high frequency wind waves. The wind is however of secondary importance for estuarine circulation.

3. Assessment

<table>
<tr><th rowspan="2">TAGUS ESTUARY</th><th colspan="6">Category I – Degree of Nutrient Enrichment</th></tr>
<tr><th colspan="2">Actual Situation</th><th colspan="2">Criteria of Classification</th><th colspan="2">Partial Classification</th><th>Notes</th></tr>
<tr><td>1. Riverine Total N and/or Total P inputs and direct discharges (RID)</td><td>≈20100 ton N/year</td><td>Description:
Tagus River 12000 ton/year

Sorraia River 2000 ton/year

Trancão River 1600 ton/year

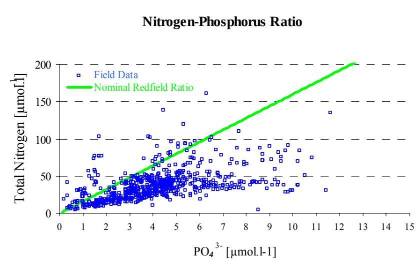
Domestic Load 4500ton/year</td><td colspan="2">
</td><td>-</td><td rowspan="3">-</td><td></td></tr>
<tr><td>2.Winter DIN and/or DIP Concentrations</td><td>37.5 µmol/l
(average)

67.3 µmol/l
(percentile 90)</td><td>Description:

Calculated with 713 data points in the winter</td><td>Background Value

34 µmol N/l</td><td>Elevated Value

51 µmol N/l</td><td>-</td><td>Look for complementary information in Point nº.6</td></tr>
<tr><td>3. Increased winter N/P ratio</td><td>10
(average)

16.3
(percentile 90)</td><td colspan="3">Description:

</td><td>-</td><td></td></tr>
</table>

<table>
<tr><th rowspan="2">TAGUS ESTUARY</th><th colspan="7">Category II – Direct Effects</th></tr>
<tr><th colspan="2">Actual Situation</th><th colspan="2">Criteria of Classification</th><th colspan="2">Partial Classification</th><th>Notes</th></tr>
<tr><td>1.Maximum and Mean Chlorophyll-a Concentration</td><td>9.1 µg/l
(average)

22.4 µg/l
(percentile 90)</td><td>Description:

Summer Values
(1603 data points)</td><td>Background Value

9 µg/l</td><td>Elevated Value

14 µg/l</td><td>-</td><td rowspan="3">-</td><td>Look for complementary information in Point nº.6</td></tr>
<tr><td>2.Region/Area Specific phytoplankton indicator species</td><td colspan="4">Description:

Diatoms are the most important phytoplankton group with indicators species such as Skeletonema costatum, Pseudonitzschia spp. and Chaetocerus subtilis.[1]</td><td>-</td><td>Not available information on phytoplankton indicator species shifts.</td></tr>
<tr><td>3.Macrophytes including macroalgae (region specific)</td><td colspan="4">Description:

The study of macrophyte algae in the estuary was carried out between 1985 and 1998. The main substrates colonized by algae in the Tagus estuary were old oyesterbeds located in the intertidal zones within the mixing and seawater salinity zones. The brown alga Fucus vesiculosus is the most abundant species while fast growing species such as Ulva lactuta 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 euthrophic systems shows that the maximum biomass for Ulva lactuta in the Tagus estuary can be considered low.[3]</td><td>-</td><td></td></tr>
</table>

<table>
<tr><th rowspan="2">TAGUS ESTUARY</th><th colspan="6">Category III and IV – Indirect Effects and Other possible effects</th></tr>
<tr><th colspan="2">Actual Situation</th><th>Criteria of Classification</th><th colspan="2">Partial Classification</th><th>Notes</th></tr>
<tr><td>1. Degree of oxygen deficiency</td><td>7 mg O_2/l
(average)
5.5 mg O_2/l
(percentile 10)</td><td>Description:
(2418 data points)</td><td>< 2 mg O_2/l => acute toxicity
2 – 6 mg O_2/l => deficiency</td><td>-</td><td rowspan="4">-</td><td>Look for complementary information in Point nº.6</td></tr>
<tr><td>2.Changes/kills in Zoobenthos and fish mortality</td><td colspan="3">Description:
No changes/kills in Zoobenthos and fish mortality have been reported in the literature</td><td>-</td><td></td></tr>
<tr><td>3. Organic Carbon/Organic Matter</td><td colspan="3">Description:
Data Not Available</td><td>-</td><td></td></tr>
<tr><td>4. Other Possible Effects Algal Toxins (DSP/PSP mussel infection events)</td><td colspan="3">Description:
No nuisance or toxic algal blooms have been reported in the literature</td><td>-</td><td></td></tr>
</table>

4. Overall Classification

Area	Category I Degree of Nutrient Enrichment	Category II Direct Effects	Category III and IV Indirect Effects/Other possible effects	Initial Classification	Appraisal of all relevant information	Final Classification
TAGUS ESTUARY	-	-	-	Non Problem Area	Modelling confirms that the Tagus is a non problem area, because it is a well-mixed estuary with a high dilution potential and production is light limited. (see discussion)	Non Problem Area

5. Discussion

In the Tagus estuary the trophic level is limited by light penetration due to the turbidity in the water column, which is associated to the resuspension of the fine sediments deposited in the intertidal areas, by tidal currents and surface waves generated by the long fetch of local wind. As a consequence, a reduction of the nutrient loads discharged by the rivers or by the Urban Waste Water Treatment Plants (UWWTP) has no consequences for the trophic activity in the estuary.[4]

In conclusion, 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.[3]

Changes in the treatment level (from secondary to tertiary) are projected for some of the UWWTP in the estuary, in order to remove nutrients (particularly phosphorus) more efficiently. Other Information

The next figure represents the annual average of Winter DIN concentration distributed along 18 years. It is possible to identify some interannual variability, but no trend. Table 7 shows the number of samples. The interannual oscillations in 96-98 can be attributed to the small number of samples.

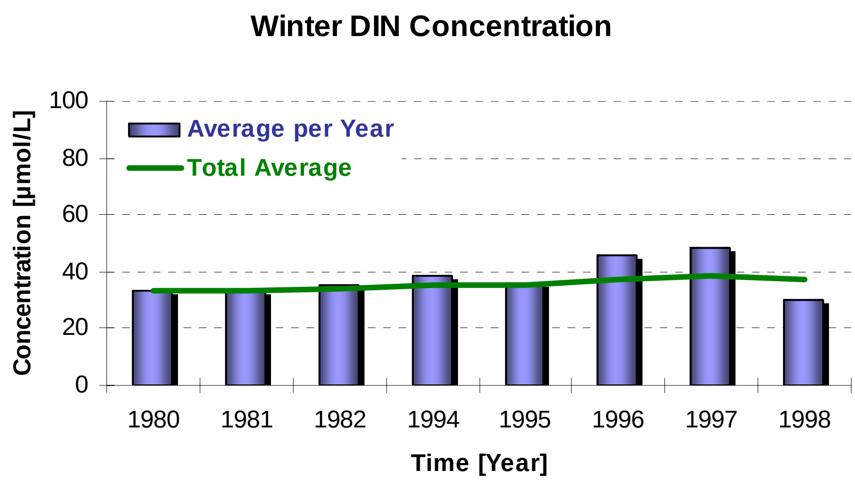


Figure 12 – Distribution of Winter DIN Concentration

The actual situation is characterized by 37.5 µmol N/L, resulting from the total average of all field data points (Table 7). Maximum value was observed in 1997 (48 µmol N/L), which is within the range defined by the elevated value indicated in Table 8.

Year	DIN Concentration [µmol N/L]	Number of Data Points
1980	33.1	258
1981	33.2	282
1982	35.2	67
1994	38.6	37
1995	36.2	41
1996	45.6	8
1997	48.0	10
1998	30.3	10
Actual Situation (average)	**37.5**	**713**
Percentile 90	**67.3**	**713**

Table 7 – Winter DIN Concentrations

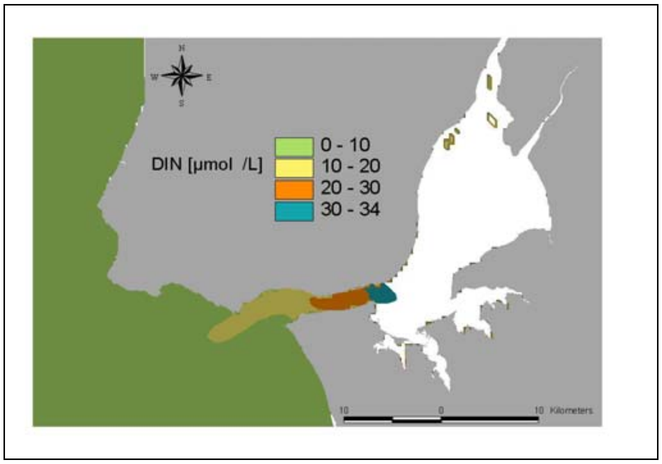
Background Concentration	Considered as an average value of the oldest registers (1980, 81 and 82)	34 µmol N/ L
Elevated Values	50 % above the background concentration	51 µmol N/ L

Table 8 – Criteria of Classification in the Tagus Estuary (DIN Concentration)

Next figures represent MOHID results for a simulation considered representative of the actual situation. Three sets of figures represent the zones where the concentration lays between background concentration and the elevated value, zones where it is below this range and zones above the range. Figures showing the salinity in the same zones are also shown.

Figures show a clear relation between salinity and nutrient concentration. The zone with concentrations between the background concentration and the elevated value are shown in Figure 14 and correspond to zones with salinity in range [15-25]. Regions with lower salinity have higher concentrations of DIN, Figure 15, and zones with lower concentrations to higher salinities, Figure 12.

The actual situation is however characterized by a large range of values distributed in the estuary, with high values of DIN where the salinity values are lower near the river boundary and low values of DIN where the salinity values are higher near the ocean boundary. This interpretation leads to the conclusion that the nutrients distribution depends essentially from the rivers contribution.



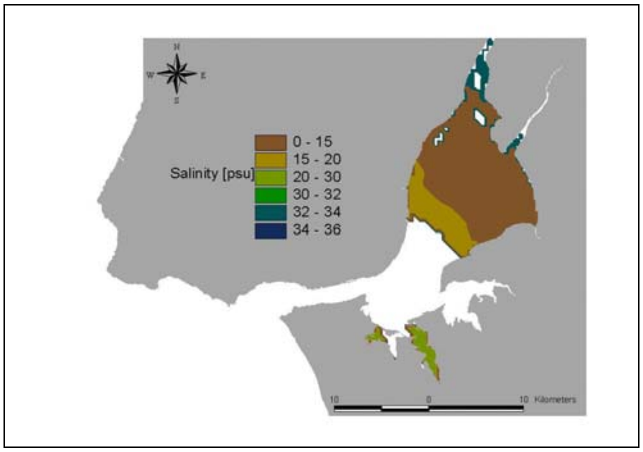


Figure 13 – Areas with DIN concentration below Background Value (0-34 µmol N/L); Spatial distribution of salinity

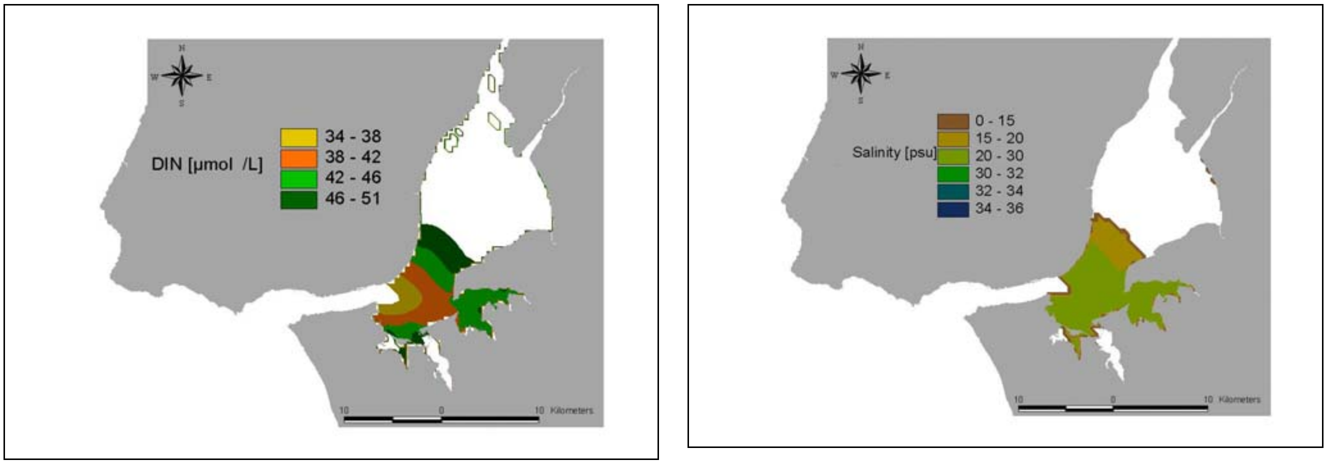


Figure 14 - Areas with DIN concentration between the Background and the Elevated Value (34-51 µmol N/L); Spatial distribution of salinity

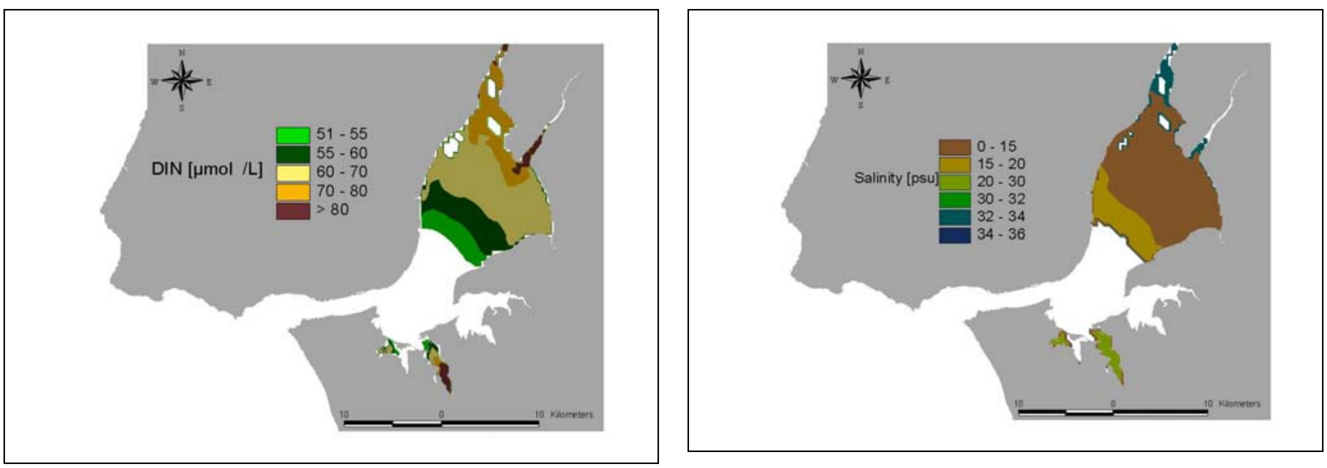


Figure 15 - Areas with DIN concentration above the Elevated Value (>51 µmol N/L); Spatial distribution of salinity

The next figure shows the DIN vs. salinity curve based on the field data points measure between 1994 and 1998. The orange hatched line represents the tendency for linear relation between the two properties which can be explained by the fact that the major DIN source (Tagus) is also the major fresh water source. The discrepancies from the major trend are associated to local DIN discharges (UWWTP and other rivers).

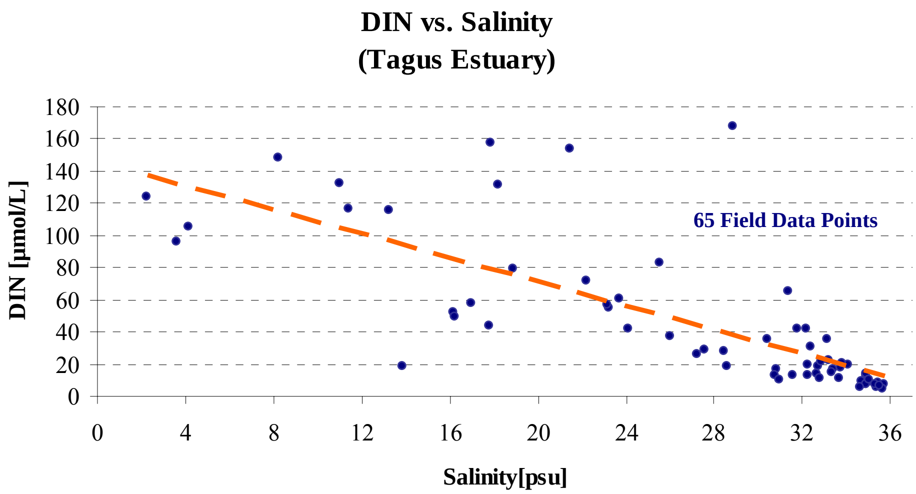


Figure 16 - DIN distribution vs. Salinity in Tagus Estuary

Figure 17, shows a time series of average Chlorophyll-a between 1980 and 1999. The figure shows a high interannual variability which can be explained by the number of samples (indicated in Table 9). The background concentration is defined as the average of the oldest years (Table 10), but it is important to notice the existence of a high variability between different years. This variability is probably related with climatologic factors affecting the river flows (Tagus river mostly) that will affect directly the nutrients offer in the estuary and indirectly the light limitation factor. Together with these effects, variability can be also due to variability of production together with tidal oscillating transport and their influence on sampling.

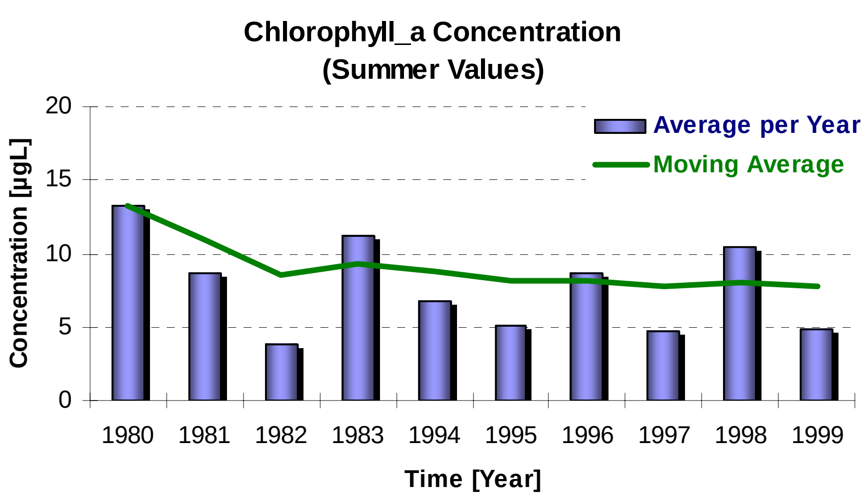


Figure 17 – Distribution of Chlorophyll-a Concentration during the summer

Year	Chlorophyll-a Concentration [µg/L]	Number of Data Points
1980	13.26	595
1981	8.69	391
1982	3.79	417
1983	11.23	105
1994	6.69	24
1995	5.04	23
1996	8.62	7
1997	4.74	12
1998	10.44	8
Actual Situation (average)	**9.1**	**1603**
Percentile 90	**22.4**	**1603**

Table 9 – Chlorophyll a Concentration during the summer

Background Concentration	Considered as an average value of the oldest registers (1980, 81, 82 and 83)	9 µg N/ L
Elevated Values	50 % above the background concentration	14 µg N/ L

Table 10 – Criteria of Classification in the Tagus Estuary (Chlorophyll-a Concentration)

According to Table 10, in present conditions of Chlorophyll-a concentration during the summer, has annual average value below the elevated value. Figure 18, Figure 19 and Figure 20 represent the Chlorophyll-a distribution in the estuary, according to the MOHID results. Figure 20 shows the most productive areas with concentrations above the elevated value, reaching 20 µg N/L. Figure 18 represents areas where Chlorophyll-a concentrations are below 9 µg N/L. The average value, 9.1 µg N/L, characterizing the actual situation is located in the middle area of the Tagus estuary (Figure 19).

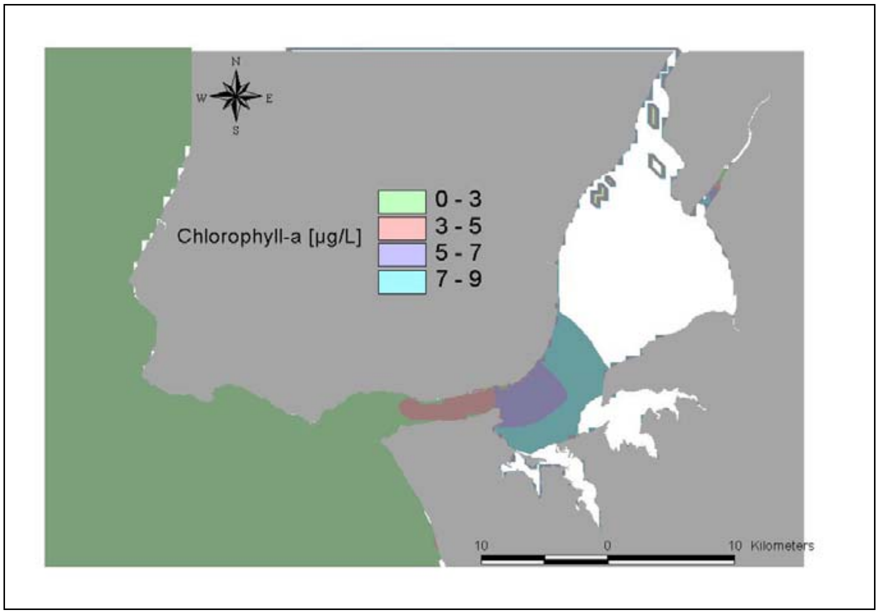


Figure 18 - Areas with Chlorophyll-a concentration below the Background Value (<9 µg/L);

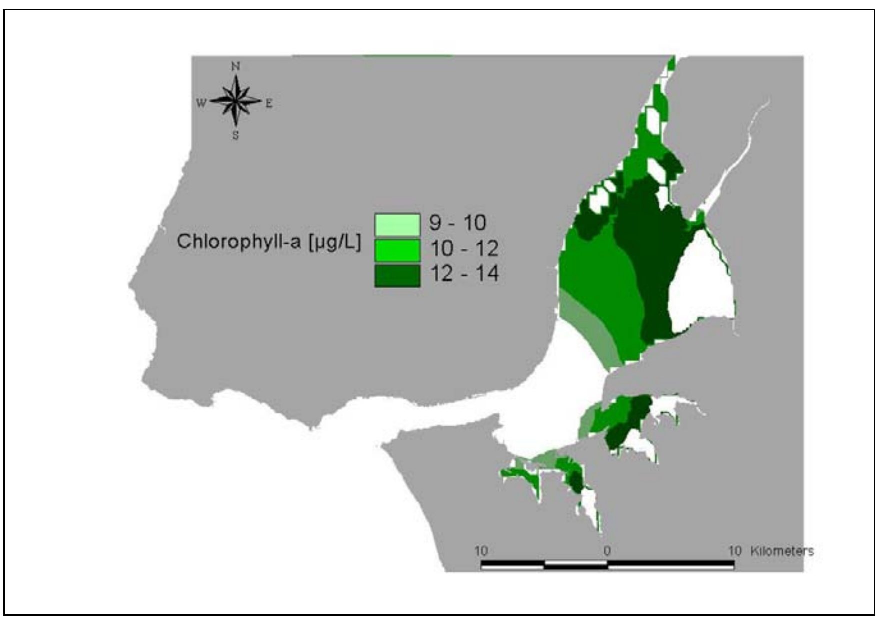


Figure 19 - Areas with Chlorophyll-a concentration between the Background and the Elevated Value (9-14 µg/L)

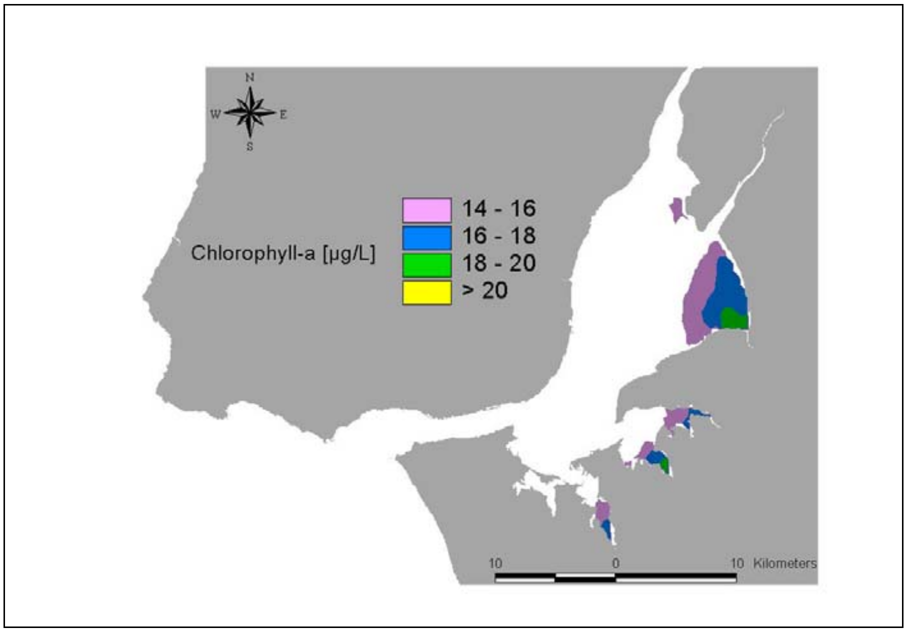


Figure 20 - Areas with Chlorophyll-a concentration above the Elevated Value (>14 µg/L)

Figure 21, represents the average distribution of Oxygen in the Tagus estuary, showing concentrations above the limit for deficient conditions, 6 mg/L.

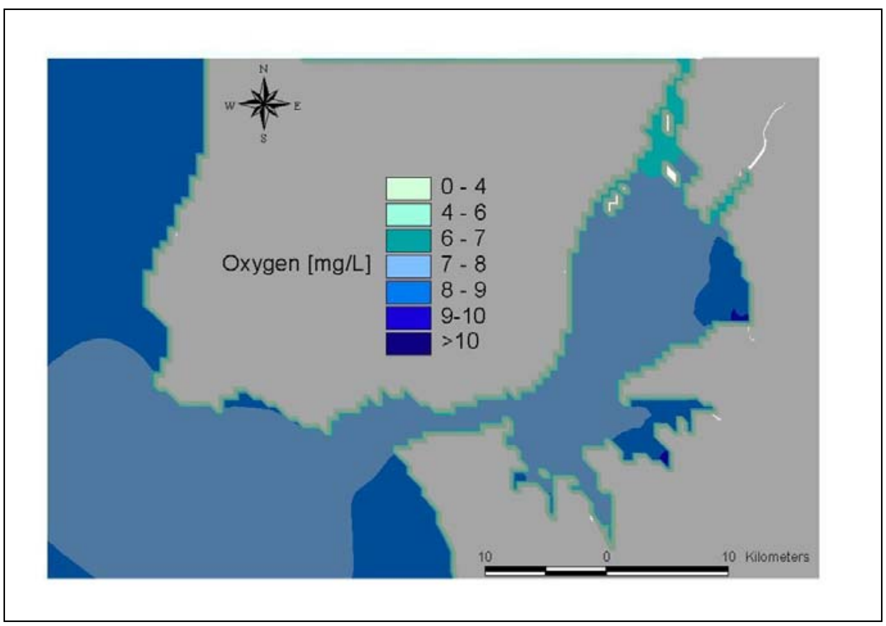


Figure 21 – Spatial distribution of Oxygen in the Tagus Estuary

III. Sado Estuary

1.Area

LATITUDE	LONGITUDE
38º 57’ 12’’ N	8º 55’ 10’’ W
38º 36’ 40’’ N	8º 19’ 30’’ W

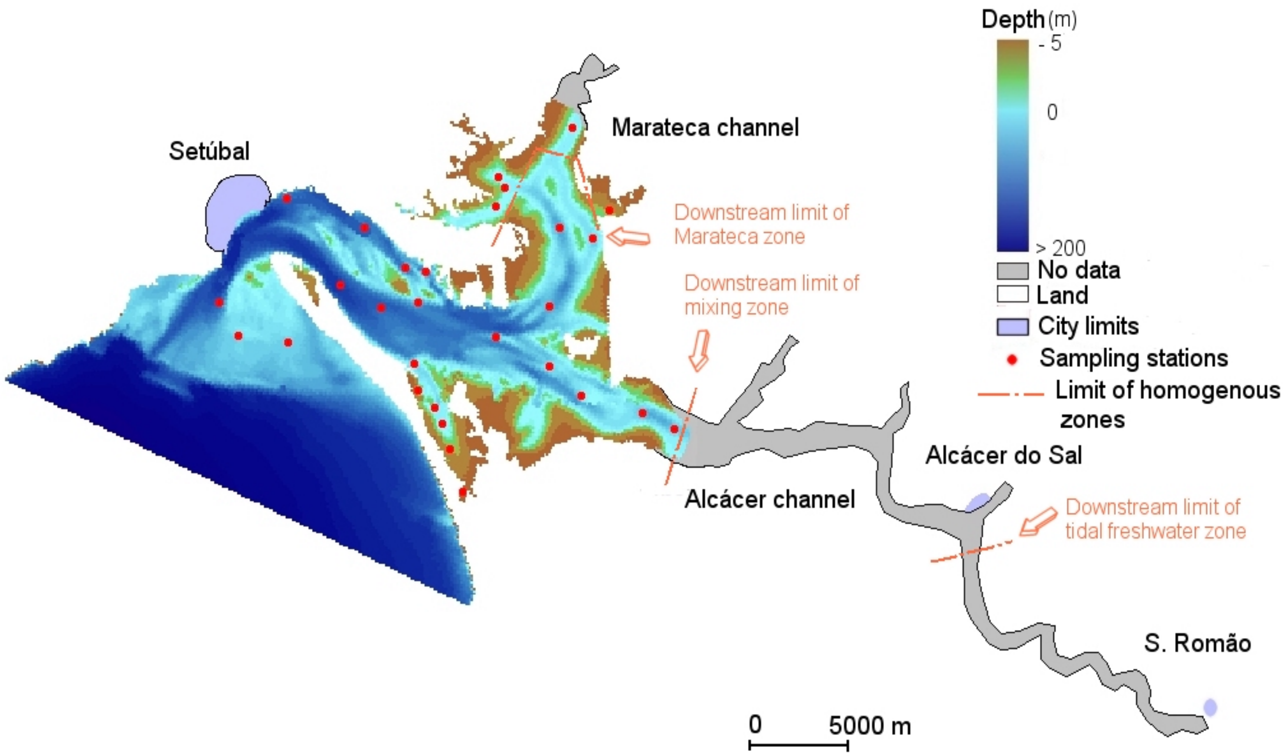


Figure 22 – Sado Estuary

2. Description of the Area

The Sado River drains an area of 6700 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.

The upper estuary has two channels: the Alcácer channel, Sado river, (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.

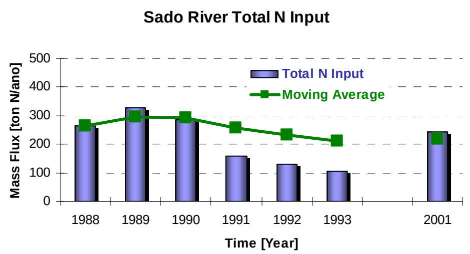
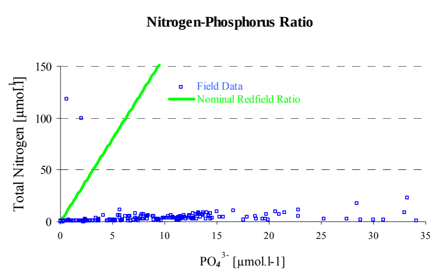
The low average depth, strong tidal currents and low freshwater discharge make the Sado a well-mixed estuary, which is stratified only rarely in specific situations such as high river discharges [3]. The Sado estuary is a mesotidal estuary with an average spring tidal range of 2.7 m.

The next table shows some of the main physical properties of the Sado estuary.[3]

Parameter	Value
Volume	500 x 10^6 m^3
Total area	180 km^2
River Discharge	40 m^3 s^{-1}
Tidal range (average spring tide)	2.7 m
Neighbouring	990 000
Typical residence time	1 month

Table 11 - Main physical properties of Sado Estuary

3. Assessment

<table>
<tr><th rowspan="2">SADO ESTUARY</th><th colspan="7">Category I – Degree of Nutrient Enrichment</th></tr>
<tr><th colspan="2">Actual Situation</th><th colspan="2">Criteria of Classification</th><th colspan="2">Partial Classification</th><th>Notes</th></tr>
<tr><td>1. Riverine Total N and/or Total P inputs and direct discharges (RID)</td><td>≈3800 ton N/year</td><td>Description:
Sado River and Marateca Channel 2300 ton/year
Domestic Load 200 ton/year
Industrial Effluents
1300ton/year</td><td colspan="2">
</td><td>-</td><td rowspan="3">-</td><td></td></tr>
<tr><td>2.Winter DIN and/or DIP Concentrations</td><td>24 µmol/l
(average)
52 µmol/l
(percentile 90)</td><td>Description:
Calculated with available data since 1978 (206 data points in the winter)</td><td>Background Value
21 µmol/l</td><td>Elevated Value
32 µmol/l</td><td>-</td><td>Look for complementary information in Point nº.6</td></tr>
<tr><td>3. Increased winter N/P ratio</td><td>5
(average)
6
(percentile 90)</td><td colspan="3">Description:

</td><td>-</td><td></td></tr>
</table>

<table>
<tr><th rowspan="2">SADO ESTUARY</th><th colspan="7">Category II – Direct Effects</th></tr>
<tr><th colspan="2">Actual Situation</th><th colspan="2">Criteria of Classification</th><th colspan="2">Partial Classification</th><th>Notes</th></tr>
<tr><td>1.Maximum and Mean Chlorophyll-a Concentration</td><td>5 µg/l
(average)

7.1 µg/l
(percentile 90)</td><td>Description:

Summer season
(228 data points)</td><td>Background Value

6 µg/l</td><td>Elevated Value

9 µg/l</td><td>-</td><td rowspan="3">-</td><td>Look for complementary information in Point nº.6</td></tr>
<tr><td>2.Region/Area Specific phytoplankton indicator species</td><td colspan="4">Description:

Diatoms are the most important phytoplankton group with indicators species such as Skeletonema costatum, Thalassiosira excentrica, Pleurosigma angulatum, Odontella mobiliensis and Chaetocerus subtilis.[1][6]</td><td>-</td><td>No shifts were observed in phytoplankton indicator species until 2000 [6]</td></tr>
<tr><td>3.Macrophytes including macroalgae (region specific)</td><td colspan="4">Description:

Submerged aquatic vegetation (SAV) occurs in the Sado, essenciatially around the Tróia peninsula (seawater zone). [3]</td><td>-</td><td></td></tr>
</table>

SADO ESTUARY	Category III and IV – Indirect Effects and Other possible effects					
	Actual Situation		**Criteria of Classification**	**Partial Classification**		**Notes**
1. Degree of oxygen deficiency	7.6 mg O_2/l (average) 5.4 mg O_2/l (percentile 10)	Description: 275 data points	< 2 mg O_2/l => acute toxicity 2 – 6 mg O_2/l => deficiency	-	-	Look for complementary information in Point nº.6
2.Changes/kills in Zoobenthos and fish mortality	Description: No changes/kills in Zoobenthos and fish mortality have been reported in the literature.			-		
3. Organic Carbon/Organic Matter	Description: Not Available Data			-		
4. Other Possible Effects Algal Toxins (DSP/PSP mussel infection events)	Description: No nuisance or toxic algal blooms have been reported in the literature.			-		

4. Overall Classification

Area	**Category I** Degree of Nutrient Enrichment	**Category II** Direct Effects	**Category III and IV** Indirect Effects/Other possible effects	**Initial Classification**	**Appraisal of all relevant information**	**Final Classification**
SADO ESTUARY	-	-	-	Non Problem Area	Modelling confirms that the Sado is a non problem area, because it is a well-mixed estuary with a high dilution potential and a moderate flushing potential. Production is nutrient limited. (see discussion)	Non Problem Area

5.Discussion

Sado estuary is a well-mixed estuary with interannual high mixing and a moderate flushing potential, behaving at low flows almost like a coastal lagoon. Nutrient inputs to the estuary are low, with a tendency to be lower in the future.

In Sado estuary, the primary production is limited by nutrients and by the interaction between the phytoplankton and zooplankton. The residence time of the water, inside each part of the estuary, is of the order of one week, resulting into strong mixing between zones of the estuary, with deposition and mineralization of the particulate organic matter in the shallow intertidal areas [4].

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 development is expected. Consequently, due to decreased future nutrient pressures, an improvement in eutrophic conditions and nutrient related symptoms in the Sado estuary is expected. [3]

6. Other Information

Figure 23 represents the evolution of winter DIN Concentration measure in the Sado estuary in different years. Table 12 shows the number of data points considered to calculate de average concentration for each year. The low frequency number establishes the relative soundness of this analysis and must be the main reason for interannual variability. The tendency of the moving average suggests an increase of DIN concentration during 1982, 83 and 84 but, in fact, in these years the number of data points is low. The average value of the gathered data is 24.3 µmol N/L which, according to Table 13, is below the elevated value considered for this estuary.

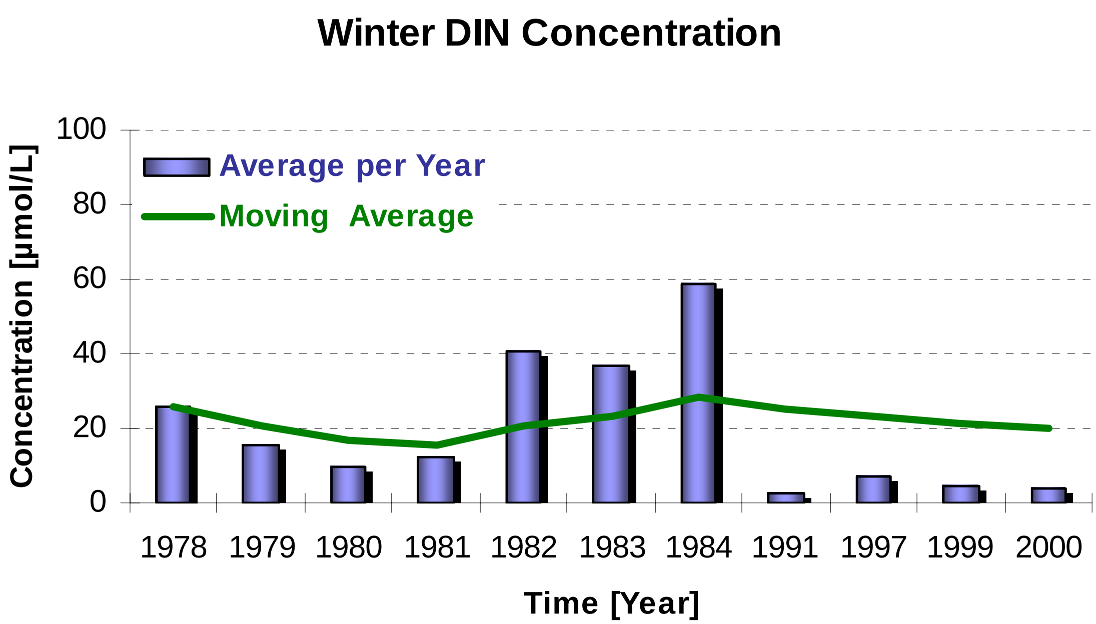


Figure 23 – Distribution of Winter DIN Concentration in the Sado Estuary

Year	DIN Concentration [µmol N/L]	Number of Data Points
1978	26.0	26
1979	15.3	70
1980	9.9	30
1981	12.0	20
1982	40.8	3
1983	37.0	19
1984	58.7	13
1991	2.3	8
1997	6.9	7
1999	4.6	1
2000	3.8	5
Actual Situation (average)	**24.3**	**206**
Percentile 90	**52.2**	**206**

Table 12 – Winter DIN Concentration in the Sado Estuary

Background Concentration	Assumed as an average of the oldest registers (1978 and 1979)	21 µmol N/ L
Elevated Values	50 % above the background concentration	32 µmol N/ L

Table 13 – Criteria of Classification in the Sado Estuary (DIN Concentration)

Similarly to the other estuaries, the value representing percentile 90 concentrations, resulting from the statistical analysis, is above the elevated value which can be justified by the MOHID results. Figure 26 represents the areas where DIN concentration values are above the elevated. As expected, these areas are found in Sado river channel (Alcácer Channel), pointing it as the main source of nutrients. Since primary production is nutrient limited, phytoplankton concentrations are higher in this channel. Due to consumption and especially to intense mixture with poor ocean waters, DIN concentration decreases strongly downstream[1]. It is important to note that most estuary is characterized by DIN concentrations below the background value, 21 µmol N/L (Figure 24). Figure 25 shows the small area were model results are between the background and elevated values.

[1] Consumption terms are responsible for the deviation between the computed curve and a pure mixing straight

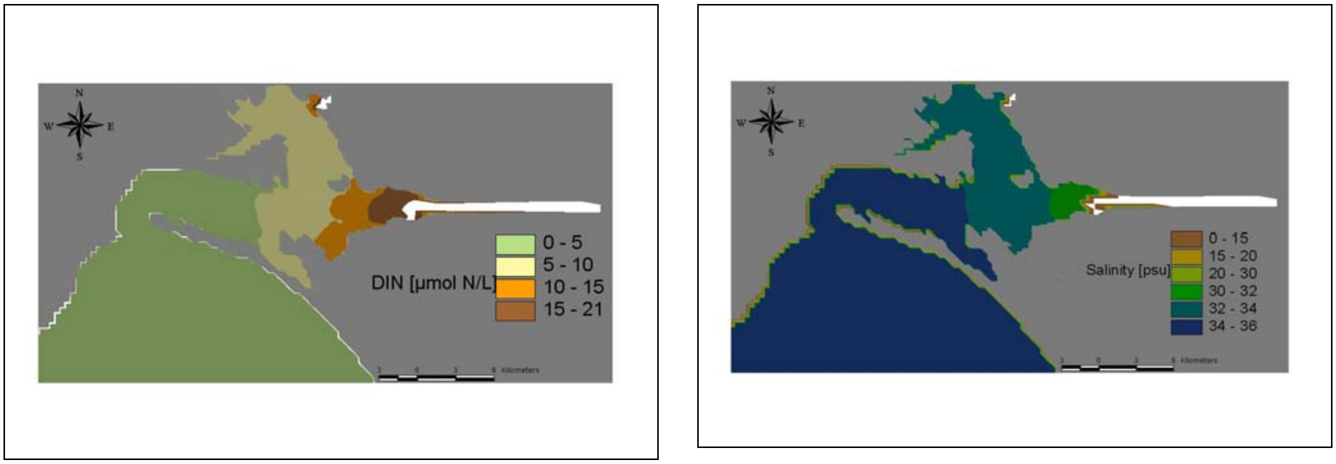


Figure 24 – Areas with DIN concentration below Background Value (0-21 µmol N/L); Spatial distribution of salinity

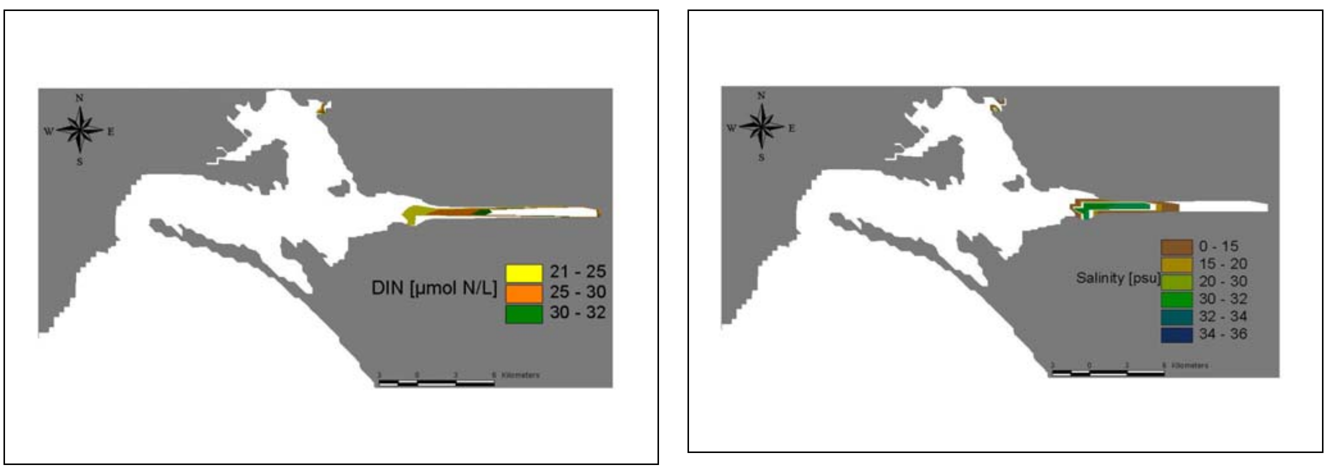
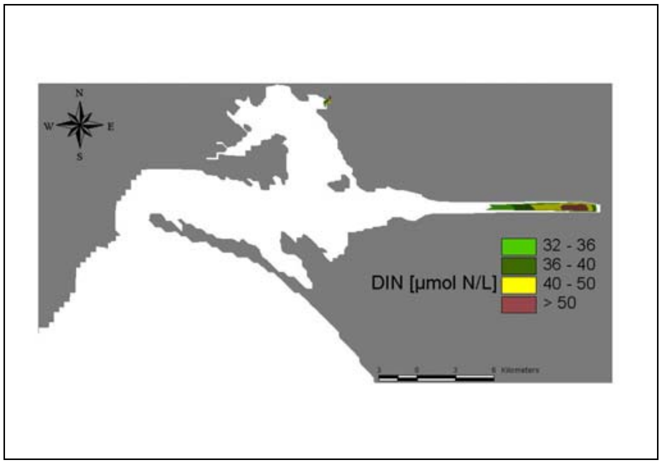


Figure 25 - Areas with DIN concentration between the Background and the Elevated Value (21-32 µmol N/L); Spatial distribution of salinity



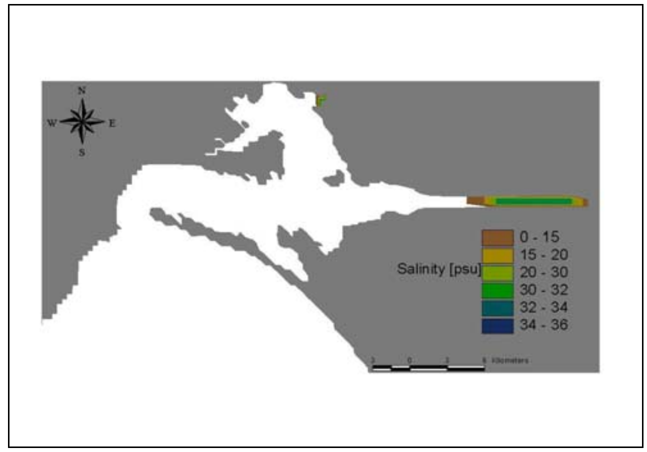


Figure 26 - Areas with DIN concentration above the Elevated Value (>32 µmol N/L); Spatial distribution of salinity

The next plot shows the DIN vs. salinity curve. In the Sado estuary the linear relation between the DIN and Salinity values are not so clearly as in the Tagus estuary. For the high salinity ranges it’s possible to observe a wide range of DIN concentrations that are probably associated with local anthropogenic inputs. These DIN inputs have cessed gradually with the implementation of treatment facilities, so this plot shows an historic situation that presently doesn’t occur. From figure analysis it is also possible to conclude some irregularity distribution in samples, since most part of the points are localized in areas with salinity above 34 psu.

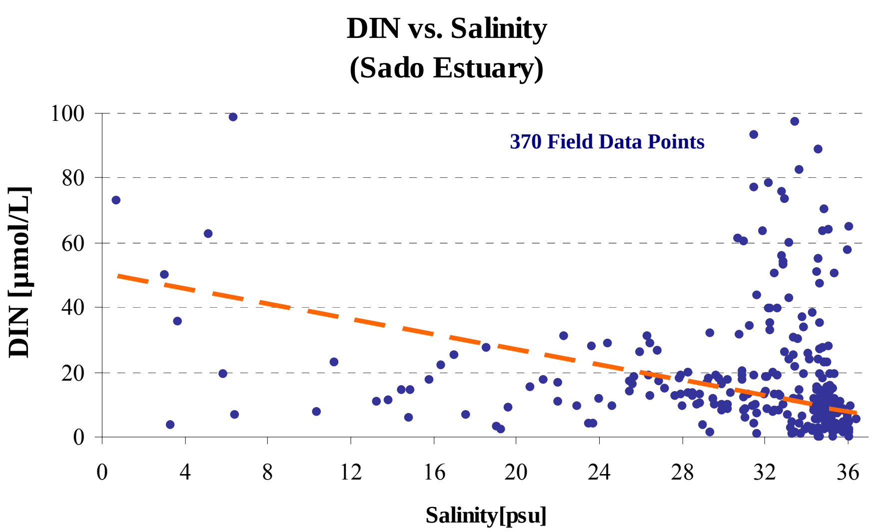


Figure 27 – DIN distribution vs. Salinity in Sado Estuary

Figure 28 shows a time series of Chlorophyll-a Concentration. The time doesn't show any explicit tendency for Chlorophyll-a evolution. Table 14 shows the number of data points used in the annual average calculation, showing that the number of samples is always below 30. This fact, together with the natural variability, explains the essence of trend. Comparisons of these values with the model results show that they are representative of the average concentrations in the estuary.

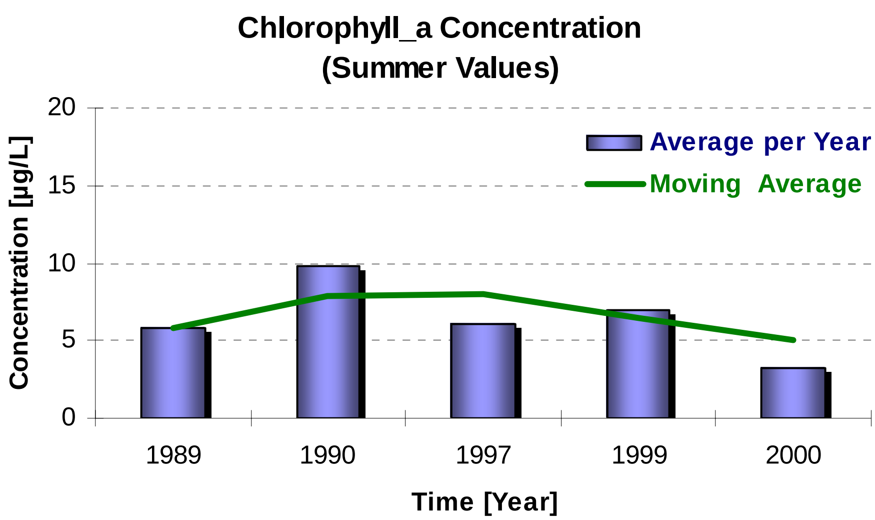


Figure 28 – Distribution of Chlorophyll-a Concentration during the summer

Year	Chlorophyll-a Concentration [µg/L]	Number of Data Points
1989	5.9	21
1990	9.8	39
1997	6.1	22
1999	6.9	12
2000	3.2	5
Actual Situation (average)	**5**	**228**
Percentile 90	**7.1**	**228**

Table 14 – Chlorophyll-a Concentration during the summer

Background Concentration	Considered as an average value of the oldest registers (1989)	6 µg N/ L
Elevated Values	50 % above the background concentration	9 µg N/ L

Table 15 – Criteria of Classification in the Sado Estuary (Chlorophyll-a Concentration)

The average value for actual situation (5 µg/L) is less then the background value, which means that there are no indications of eutrophication. In fact, according to Table 14, 90% of the data field register are below the elevated value.

The next collection of figures represents the spatial distribution of Chlorophyll-a according to MOHID model.

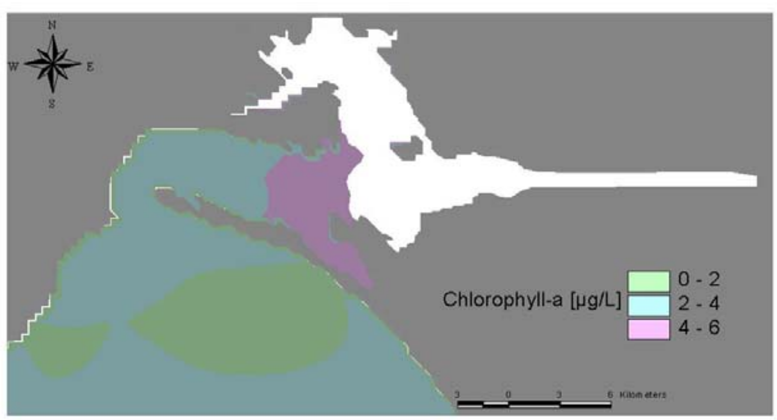


Figure 29 - Areas with Chlorophyll-a concentration below the Background Value (<6 µg/L)

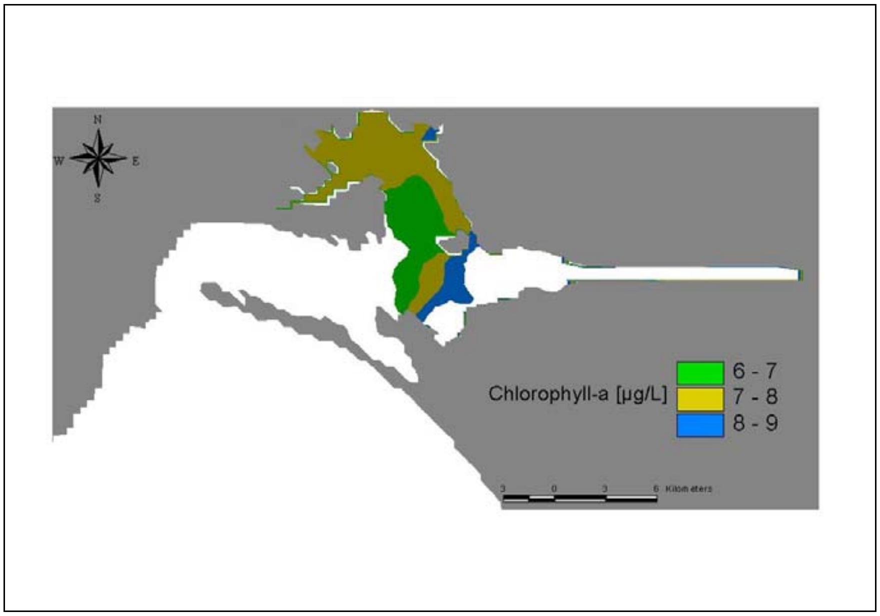


Figure 30 - Areas with Chlorophyll-a concentration between the Background and the Elevated Value (6-9 µg/L)

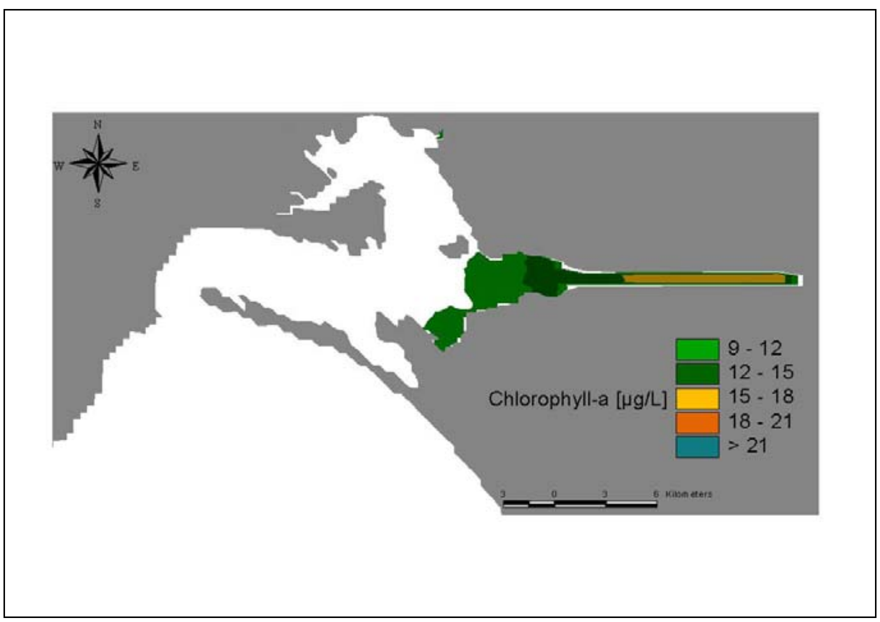


Figure 31 - Areas with Chlorophyll-a concentration above the Elevated Value (>9 µg/L)

The highest values of Chlorophyll-a concentration are found in the upstream zone, Alcácer Channel (Figure 31), where nutrient availability is higher. Downstream, next to the boundary, the concentrations are below the background concentration, essentially as a consequence of nutrients limitation. Areas where Chlorophyll-a is between background and elevated value are localized in central zone of the estuary, Figure 30. Like in Tejo and Mondego estuaries, the model results for Sado indicate a wide range of Chlorophyll-a values (between 2 and 17 µg/L).

Figure 32 represents annual average of oxygen spatial distribution, in the Sado estuary as a result of MOHID model simulation.

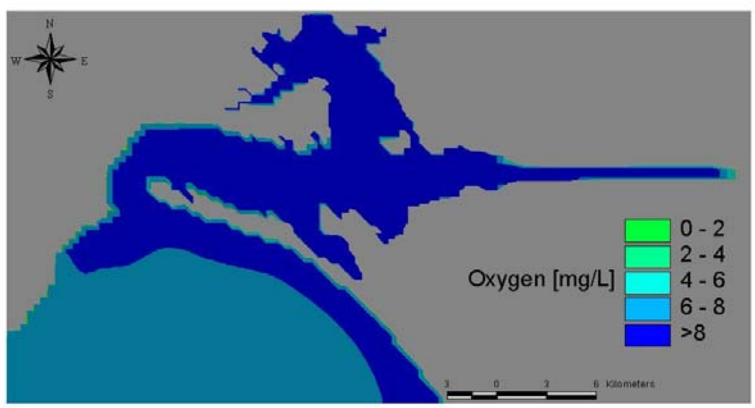


Figure 32 – Spatial distribution of Oxygen in the Sado Estuary

The concentrations in the interior of the estuary are always superior to the threshold value for deficient in oxygen (6 mg/L), which means that in terms of oxygen the Sado estuary do not show any symptom of eutrophication.

CONCLUSION

This report achieved the objective for classifying the Mondego, Tagus and Sado estuaries, accordingly to the Comprehensive Procedure defined in Common Procedure for the Identification of the Eutrophication Status of the Maritime Area. The Sado and Tagus estuaries were classified as non-problem areas, following to the steps of the Comprehensive Procedure, based on field data. This conclusion was also explained using a primary production model results. The Mondego estuary was classified as potential problem area mainly because of lack of information. Modelling proved to be a useful tool to overcome the difficulties associated with the lack of information and to its uneven distribution in space and time. Model results were also very useful for assessing the representative ness of data for explaining the ecological functioning of the estuaries and the spatial meaning of the average values defined for each estuary.

REFERENCES

[1]Cabeçadas, G., M. J. Brogueira, L. Cabeçadas, 2000 – Southern Portugal: The Tagus and Sado Estuaries, Seas at the Millennium: An Environmental Evaluation. Elsevier Science Ltd.

[2]Costa, M.J., J. Lino, L. Chaves, P. Oliveira, A. Rego, B. Quintela, S. Rodrigues, 2001 – Bases Metodológicas para a Análise da Qualidade Ecológica em Rios e Estuários Portugueses (Quere).

[3]Ferreira, J. G. ,T. Simas, K. Schifferegger, J. Lencart-Silva, 2002. Identification of Sensitive Areas and Vulnerable Zones in Four Portuguese Estuaries, INAG/IMAR.

[4]INAG/MARETEC, 2002. Water Quality in Portuguese Estuaries: Mondego, Tejo and Sado.

[5]INAG/IST, 2001. Limites de Jusante dos Estuários Portugueses.

[6]Oliveira, R.M., M.T.P. Coutinho, 1992 – Estado Trófico e Dinâmico das Zonas Superior, Média e Inferior do Estuário do Sado. Relatórios Técnicos e Científicos, Nº59, INIP, 33pp.