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OSPAR CONVENTION FOR THE PROTECTION OF THE MARINE ENVIRONMENT OF THE NORTH EAST ATLANTIC

COMPREHENSIVE PROCEDURE **MONDEGO ESTUARY - PORTUGAL**



MARETEC

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1 Summary

The Mondego River draining a 6700 km² watershed is the main fresh water source of the estuary. The low estuary downstream of the bifurcation of the two channels has a surface of 6.4 km² and is about 7 km long. In this area the estuary is divided into two channels by the Murraceira island. The northern channel is hydrodynamically the most active, receiving most of the marine tidal water and most of the fresh water from Mondego River. As a consequence high daily salinity fluctuations are registered and the residence time is low (typically 2 days). The southern channel is saltier and has a longer residence time (9 days). It receives some fresh water from the Mondego and the water from the Pranto River which discharge is controlled by a sluice located 3 km upstream of the mouth. The anthropogenic pressure in the southern channel is lower than in the northern channel but the first one is more vulnerable to environmental problems, due to its low depth, restricted circulation and higher residence time.

The overall classification of the Mondego Estuary as a “potential problem area” regarding to eutrophication resulted by a shift of species recorded in the 90’s when opportunistic macroalgae replaced the seagrass *Zostera noltii* in a large area of the southern channel. The background concentrations required for the implementation of the comprehensive procedure were obtained using the older consistent values measured in the study area, since no alternative definition was found. The characterization of the actual situation refers to the environmental conditions observed from 2003 to 2006, as result of a monitoring programme including 25 field stations, uniformly distributed along the estuary. The assessment also includes the evaluation of total nitrogen and phosphorus riverine concentrations, winter DIN and DIP concentrations and summer DO and chlorophyll *a* concentrations in the estuary. Macrophytes, including macroalgae, were considered region specific and changes or kills in zoobenthos and algal toxins were also monitored.

The study is complemented with results obtained through a three-dimensional water modelling system (www.mohid.com), simulating the actual environmental conditions in the estuary, considering ocean tide and fresh water discharge forcing. Model results were annually averaged in each computing cell for comparing with field data (e.g. salinity, chlorophyll *a*, DIN) which is too scarce for comparing on a time basis. Model results are in good agreement with field data and were used for assessing the processes in the estuary on an instantaneous basis, putting into evidence the most relevant trends. Classes were defined for assessing the results and maps were produced showing the areas where concentrations of chlorophyll-*a* and DIN fall into those classes. The model has shown that phytoplankton production in northern channel is directly influenced by the Mondego River discharge which has a low residence time (2 days), too short to allow bloom’s development inside the channel. In terms of nutrients, the concentration is higher in the northern channel but eutrophication symptoms - green seaweeds *Ulva* spp. and *Enteromorpha* spp. growth - were detected in the southern channel. The observed shifts of long-lived macrophytes species like seagrass *Zostera noltii* into those nuisance opportunistic short-lived species were explained by the model as being mainly attributed to

morphological modification of southern channel and not a consequence of anthropogenic nutrient enrichment. The morphological modification of the southern channel – closure of the upstream communication with the main channel - modified the hydrodynamics and the salinity distribution of this channel creating better conditions for the development of macroalgae (INAG/MARETEC, 2002). Reopening the communication between the channels in May 2006 recreated the previous conditions and should result into a decrease of eutrophication symptoms (Lillebø *et al.*, 2005). The monitoring program started in 2003 is going on and data collected so far is supporting that forecast. The classification status of Mondego estuary as a “Potential Problem Area” will remain unchanged up to the confirmation of the modelling results.

Areas for improvement of the assessment are:

- a) improvement of background levels for DIN, by using a catchment river model (SWAT) to simulate “pristine” conditions;
- b) updating and improvement of the estuary background concentrations of nutrients during winter, mean and maximum chlorophyll *a* values during the growing season, using the MOHID Modelling System.
- c) maintain the monitoring programme to get more data after southern channel reopening.

2 Introduction

As Contracting Party 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.

Based on the Screening Procedure, the overall classification for the Portuguese coast is "non problem area" regarding to eutrophication. Concerning the estuaries, in 2002 after the first application of the Comprehensive Procedure, Tagus and Sado estuaries were classified as "non-problem areas", while Mondego estuary got the classification of "potential problem area". The second application of the Comprehensive Procedure concerns thus only the Mondego Estuary.

The first application of the Comprehensive Procedure in the Mondego Estuary revealed an important lack of information concerning the environmental properties in the system. The assessment was based on measures obtained between 1993 and 1997 in a particular area of the estuary – the south channel, which was considered not enough to characterize the whole system. A numeric model was then used to complement the assessment which results enable to conclude that eutrophication symptoms found in the southern channel might be a consequence of its particulate hydrodynamic characteristics suggesting re-opening communication as a mitigation action. The assessment conclusions included also the need of further studies and investments in field data measurements. In 2003 a monitoring programme, covering the entire estuary area with monthly samples in 25 field stations, was implemented and the amount of data obtained is now considered consistent and long enough to update and improve the application of the Comprehensive Procedure. The assessment present in this report refers to the environmental conditions observed from 2003 to 2006, when the communication between the two channels was very limited – through a section of only 1

m². This was considered as an intermediate mitigation action implemented in 1998, before the full re-establishment of the communication between the two channels in May 2006.

3 Description of the assessed area

The Mondego River draining a 6700 km² watershed is the main fresh water source of Mondego estuary located on west coast of Portugal at Figueira da Foz (Figure 1).

Latitude	Longitude
40° 08' 40'' N	8° 52' 20'' W
40° 07' 10'' N	8° 47' 40'' W

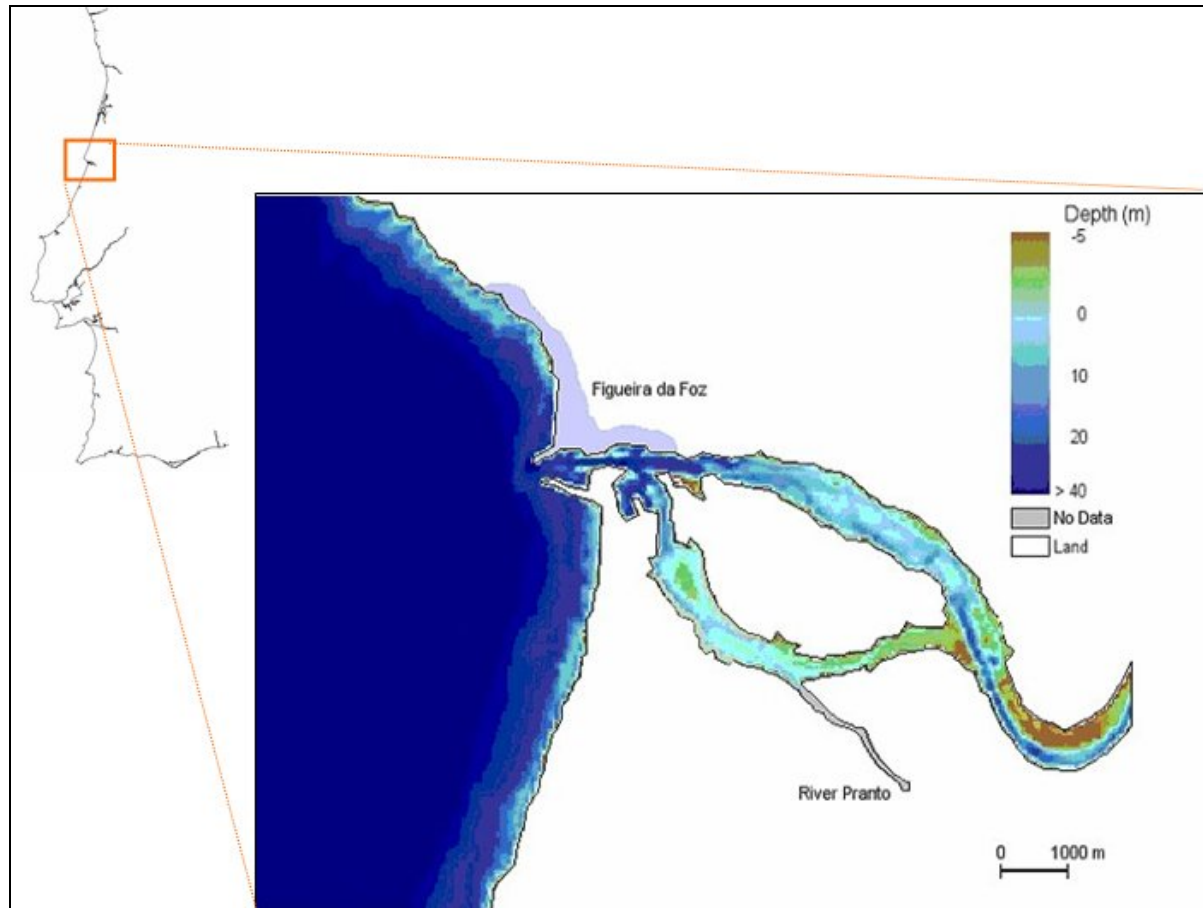


Figure 1. Mondego Estuary.

The low estuary downstream of the bifurcation of the two channels has a surface of 6.4 km² and is about 7 km long. In this area the estuary is divided into two channels by the Murraceira island. The northern channel is deeper (5-10 m), while the southern is 2-4 m deep, making them hydrologically very different. The northern channel is hydrodynamically the most active, receiving most of the marine tidal water and most of the fresh water from Mondego River. As a consequence high daily salinity fluctuations are registered and residence time is low (typically 2 days). The southern channel receives irregular water from the Pranto River, regulated by a sluice located 3 km upstream of the mouth and it has longer residence time (9 days).

The anthropogenic pressure in the southern channel is lower than in the northern channel but the channel is considered to be more vulnerable to environmental stress, due to its low depth, restricted circulation and higher residence time. Table 1 shows some of the main physical properties of Mondego estuary.

Table 1. Main physical properties of the Mondego Estuary.

Parameter	Value
Volume (average)	$22 \times 10^6 \text{ m}^3$
Total Area (of the low estuary downstream of the bifurcation of the two canals)	6.4 km^2
River Discharge (Average Value)	Mondego River = $60 \text{ m}^3/\text{s}$ Pranto River = $2.3 \text{ m}^3/\text{s}$
Tidal Range (average spring tide)	0.35-3.3 m
Neighbouring	66 000 Inhabitants
Typical residence time	North channel: 2 days South channel: 9 days

4 Methods and data

The classification of the areas with regard to eutrophication was obtained appealing to actual and historical observations, resulting from comparison between the actual conditions and background conditions. The characterization of the actual situation in the estuary was based on the measurements from the monitoring program implemented since 2003, sampling 25 monitoring stations, uniformly distributed along the estuary, Figure 2. The samples are taken monthly, at high-tide, from surface and bottom waters. Physico-chemical factors (temperature, salinity and dissolved oxygen) were measured *in situ* and water samples were collected for subsequent quantification of dissolved nutrients concentrations – ammonia, nitrate, nitrite and phosphorus – in laboratory (APHA, 1980; Strickland & Parsons, 1972), as described in Marques *et al.* (2007). The concentration of chlorophyll *a*, following the method described by Strickland & Parsons (1972), is used as a phytoplankton proxy (Marques *et al.*, 2007).

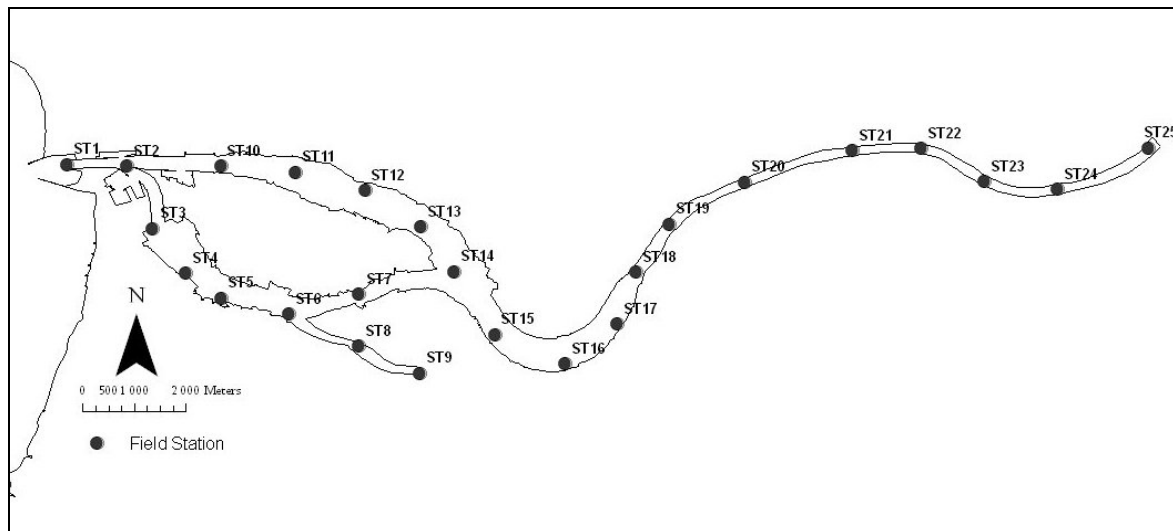


Figure 2. Field Stations included in the Mondego Estuary Monitoring Programme, since 2003.

The assessment was based on the four categories of properties proposed by OSPAR, 2005 (N.º 2005-3):

Category I – Degree of Nutrient Enrichment

Category II – Direct Effects of Nutrients Enrichment;

Category III – Indirect Effects of Nutrient Enrichment;

Category V – Other possible effects of Nutrient Enrichment.

In each category the set of parameters proposed were analyzed and in most cases compared with the background conditions in order to identify possible symptoms of eutrophic 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 consistent

values measured in the study area, since no alternative definitions have been found. It's important to notice that there is a relevant lack of historic field data, thus becoming difficult the process of establishing a trend of the system trophic evolution.

As a complement, the assessment includes some results obtained with MOHID, a three-dimensional water modelling system, simulating the actual environmental conditions in the estuary, considering ocean tide and fresh water discharge forcing (www.mohid.com). The model results are in good agreement with field data, being able to show the most relevant trends (INAG/IMAR, 2004) of the environmental conditions in the system. The model allows filling the information gapes and, above all, gives an insight of the system itself enabling a process oriented study of the system evolution. 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 for computed water properties (e.g. salinity, phytoplankton, DIN) in each domain cell. These results were then represented in spatial maps using the classes established after the definition of the background concentrations. The purpose of these maps is to show that there are significant concentration gradients that should be considered. More information about the implementation of the model and assumptions can be found in the national reports INAG/MARETEC (2002) and INAG/IMAR (2004 and 2005).

5 Eutrophication Assessment

The next tables present for each category and for each property, the results of the assessment proposed by OSPAR, implemented in the Mondego Estuary.

Key to the Score

- + = Increased trends, elevated levels, shifts or changes in the respective assessment parameters
- = Neither increased trends nor elevated levels nor shifts nor changes in the respective assessment parameters
- ? = Not enough data to perform an assessment or the data available is not fit for the purpose

Category I – Degree of Nutrient Enrichment										
Assessment Criteria	Actual Situation ¹		Criteria of Classification		Partial Classification	Notes				
1. Riverine Total N and/or Total P inputs and direct discharges (RID)	<p>Nitrogen 4211 (ton N/year)</p> <p>Phosphorus 227 (ton P/year)</p>	<p>Description: Based on monthly registers in stations near the rivers discharge, between 2003 and 2006 (43 field data points).</p> <p>Mondego and Pranto River 3900 ton N/year 223 ton P/year</p> <p>Domestic Load 311 ton N/year 4 ton P/year</p>			<p>++++</p> <p>+</p>	<p>After 1998 the values obtained for the Riverine Total Nitrogen input are higher than the years before. Differences in the location of stations and the sampling methodology can have some influence in the results. Since 1998 until 2006 the total nitrogen input had some oscillations with a small tendency for increase. In terms of phosphorus there is a significant oscillation of the values, although between 2003 and 2006 the values tend to be in the same order of magnitude.</p>				
			<p>Background Value²</p> <p>44 µmol/l</p>				<p>Elevated Value³</p> <p>66 µmol/l</p>		<p>----</p> <p>-</p>	<p>Complementary information including annual average values and model results for the actual situation are reported in Section 7 (<i>Additional Information</i>).</p>
			<p>2. Winter/Autumn DIN and/or DIP Concentration</p> <p>50 µmol/l (average)</p> <p>100 µmol/l (Percentile90)</p>				<p>Description: Based on monthly registers in 23 stations located almost uniformly in the estuary, between 2003 and 2006 (479 data points in Winter/Autumn).</p>			
3. Increased Winter /Autumn N/P ratio	<p>60 (average)</p> <p>151 (Percentile90)</p>	<p>Description: Based on monthly registers in 23 stations located almost uniformly in the entire estuary, between 2003 and 2006 (475 data points in Winter/Autumn).</p>			<p>?</p>	<p>The actual N/P ratio values can not be compared with previous years because the data is not available. So even having values for the actual situation (2003, 2004, 2005 and 2006) this topic will not have a classification. It is however important to notice that the most part of the values are located above the Redfield ratio (black line), which may indicate phosphorus as the most important limiting nutrient in the estuary.</p>				

1 Actual Situation is obtained using values registered in 2003,2004, 2005 and 2006.
 2 Assumed as the average value corresponding to 1993, the oldest registered data available.
 3 Assumed as 50% above the background concentration.

Category II – Direct Effects							
Assessment Criteria	Actual Situation ⁴		Criteria of Classification		Partial Classification		Notes
		Description:	Background Value ⁵	Elevated Value ⁶			
1. Maximum and Mean Chlorophyll-a Concentration	7.4 µg/l (average) 15.1 µg/l (Percentile90)	Based on monthly registers in 23 stations located almost uniformly in the estuary, between 2003 and 2006 (486 data points in Spring/Summer).	6 µg/l	9 µg/l	----	-	Complementary information including annual average values and model results for the actual situation are reported in Section 7 (<i>Additional Information</i>).
2. Region/Area Specific phytoplankton indicator species	Data Not Available			?			
3. Macrophytes including macroalgae (region specific)	Description: In Mondego estuary hard substrates extend along 60% of the total estuarine perimeter dominating the South channel and are primarily covered by the genera <i>Enteromorpha</i> , <i>Fucus</i> and <i>Ulva</i> . Soft substrates, which in the past were predominantly covered by the seagrass <i>Zostera noltii</i> and the saltmarsh species <i>Spartina maritima</i> , have been gradually replaced by the opportunistic green algae <i>Enteromorpha</i> , <i>Ulva</i> and the red seaweed <i>Gracillaria verrucosa</i> – these are classified as the main epiphytes in the system. Regular <i>Enteromorpha</i> blooms have been observed, especially in the inner areas of the south channel (Ferreira et al., 2002). This trend apparently reversed from 1998, after the decrease in the freshwater discharge from the Pranto River sluice and the limited re-establishment of the communication between the two channels.				+		Changes in hydrodynamic regime of the southern channel have been implemented and some improvements have been observed, particularly in terms of fewer occurrences of macroalgal blooms. However, the evaluation of these actions impact in the system dynamics requires longer time series analysis. For this reason this topic should be maintain positive in this assessment. Look for complementary information in Section 7 (<i>Additional Information</i>).

4 Actual Situation is obtained using values registered in 2003,2004, 2005 and 2006.

5 Assumed as the average value corresponding to 1993, the oldest registered data available.

6 Assumed as 50% above the background concentration.

Category III and IV – Indirect Effects					
Assessment Criteria	Actual Situation ⁷		Criteria of Classification	Partial Classification	Notes
1. Degree of oxygen deficiency	8.4 mgO ₂ /l (average) 6 mgO ₂ /l (Percentile90)	Description: Based on monthly registers in 23 stations located almost uniformly in all the estuary, between 2003 and 2006 (541 data points in Spring/Summer).	$\left\{ \begin{array}{l} < 2 \text{ mgO}_2 / \text{l} \rightarrow \text{Acute toxicity} \\ 2 - 6 \text{ mgO}_2 / \text{l} \rightarrow \text{Deficiency} \end{array} \right.$	---- -	Complementary information including annual average values and model results for the actual situation are reported in Section 7 (<i>Additional Information</i>).
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	3.4 mgPOC/l (average) 4.9 mgPOC/l (Percentile90)	Description: Based on monthly registers in 23 stations located almost uniformly in the estuary, between 2003 and 2006 (673 data points).		?	Measurements have been done in the recent years. The lack of historical data unable the classification of this topic, although the recent values obtained suggest some decrease.
4. Other Possible effects: algal toxins (DSP/PSP mussel infection events)	Description: No nuisance or toxic blooms have been reported in the literature.			-	

⁷ Actual Situation is obtained by the values registered in 2003,2004, 2005 and 2006.

6 Overall Classification

Key to the table

NI	Riverine inputs and direct discharges of total N and total P	Mp	Macrophytes including macroalgae
DI	Winter DIN and/or DIP concentrations	O ₂	Oxygen deficiency
NP	Increased winter N/P ratio	Ck	Changes/kills in zoobenthos and fish kills
Ca	Maximum and mean chlorophyll <i>a</i> concentration	Oc	Organic carbon/organic matter
Ps	Area-specific phytoplankton indicator species	At	Algal toxins (DSP/PSP mussel infection events)

+ = Increased trends, elevated levels, shifts or changes in the respective assessment parameters
 - = Neither increased trends nor elevated levels nor shifts nor changes in the respective assessment parameters
 ? = Not enough data to perform an assessment or the data available is not fit for the purpose
 Note: Categories I, II and/or III/IV are scored '+' in cases where one or more of its respective assessment parameters is showing an increased trend, elevated levels, shifts or changes.

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 (concerning the harmonised assessment parameters, their respective assessment levels and the supporting environmental factors)	Final classification	Assessment period
MONDEGO ESTUARY	NI	+	Ca	-	O ₂	-	At	-	Data and modelling confirms that the north channel is a non-problem area, mostly because of its short residence time. Local characteristics of the south channel are consequence of hydrodynamic conditions instead of nutrients overenrichment. Mitigation actions have been implemented and improvements in the environmental quality of the southern channel are expected.	Potential Problem Area	2003-2006 (Actual Situation)
	DI	-	Ps	?	Ck	-					
	NP	?	Mp	+	Oc	?					
	Global	+	Global	+	Global		-				

7 Additional Information

7.1 DIN and Salinity Distribution

The next figures represent a time series evolution of dissolved inorganic nitrogen (DIN) and phosphate concentrations measured in the Mondego estuary between 1993 and 1997 and also from 2003 to 2006. Each year is represented by the average of all field data in the Winter/Autumn season (January, February, September, October, November and December) and the values can be consulted in Table 2. The black line represents the moving average of two years. The moving average enable to find a trend of evolution and even with an obvious lack of measurements it is possible to assume no significant variation on the winter DIN and Phosphate Concentration. The values of the last four years (2003, 2004, 2005 and 2006) were used to obtain the average values of the actual situation. The oscillations between the different years could be explained by different hydrological regimes, leading to differences in rivers flow.

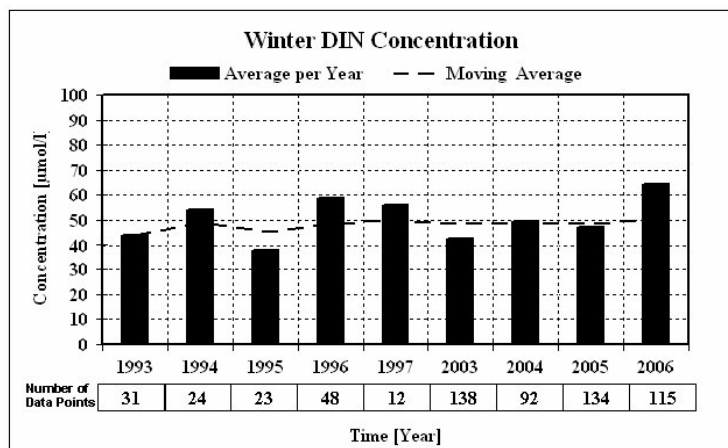


Figure 3. Winter DIN Concentrations in Mondego Estuary.

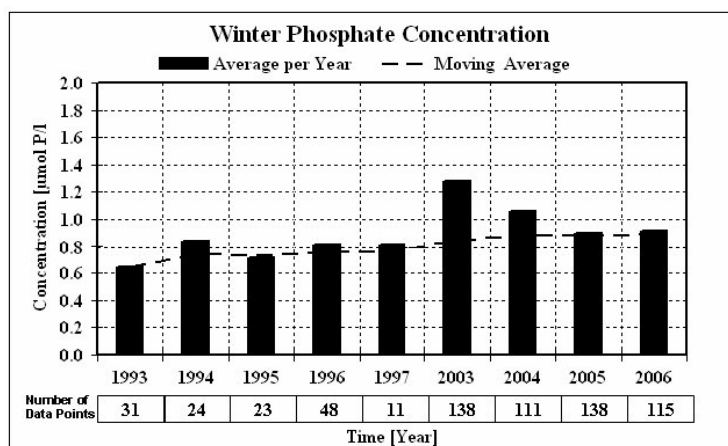


Figure 4. Winter Phosphate Concentration in Mondego Estuary.

Table 2. Annual Average DIN Concentration [µmol/l] (Winter/Autumn) assessment.

Year	2003	2004	2005	2006
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Average DIN Concentration (Winter/Autumn)	42	50	47	64
Elevated Value		66		
Classification	-	-	-	-

Figure 5 and Figure 6 represent average spatial distribution of the DIN and Salinity computed by MOHID Modelling System for 2003 in the Mondego estuary. Figure 5 establishes 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 and Figure 6 shows 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. The limits of these areas for DIN and salinity distributions are identical. Thus, it is possible to say that, according to MOHID results, higher values of salinity correspond to areas of lower DIN concentrations and the range of DIN concentration between the background value and the elevated value correspond to the mixing area with salinity values that can range between 20 and 30. 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 $\mu\text{mol/l}$.

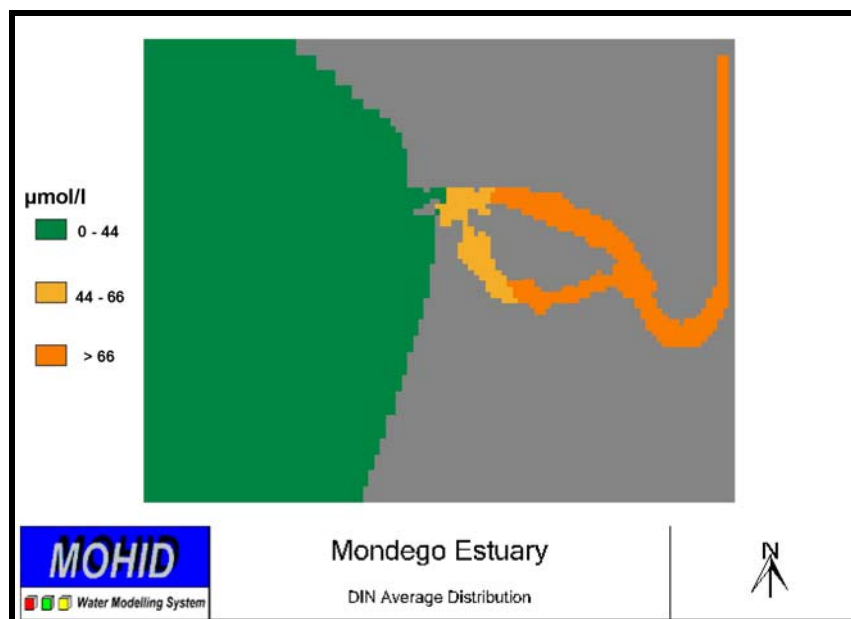


Figure 5. Spatial Average Distribution of DIN concentration [$\mu\text{mol/l}$] computed by the model for the actual situation in Mondego Estuary.

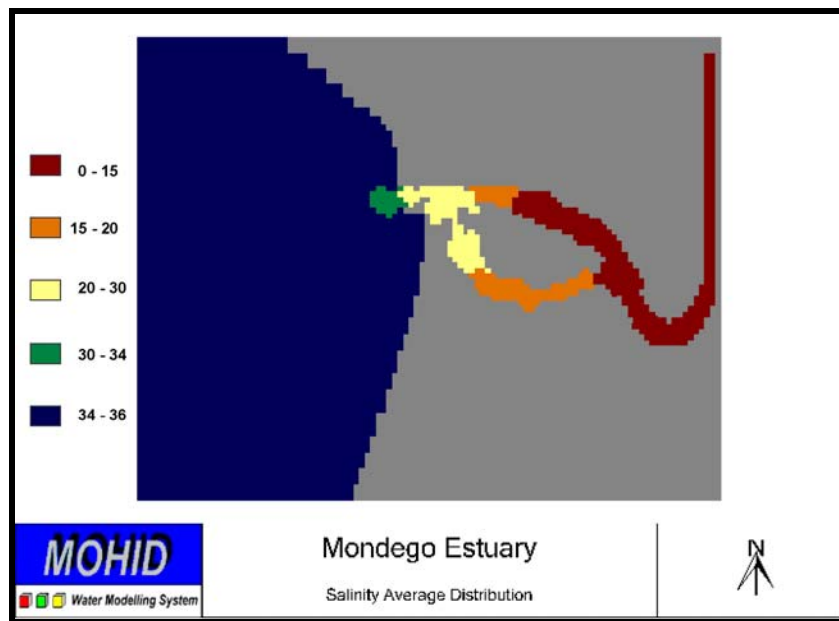


Figure 6. Spatial Average Distribution of Salinity computed by the model for the actual situation in Mondego Estuary.

Figure 7 represents the DIN vs. Salinity curve, based on field data registers. From the figure it is possible to observe a higher cloud of points corresponding to high values of salinity and lower DIN concentration. Looking at the high values of salinity it is possible to identify an irregular distribution of DIN concentrations in the historical values, which can be related with the Pranto river discharge. The characteristics of the south channel can change in a very significant way, if the sluice controlling the Pranto river is closed the salinity increases, as a consequence of hydrodynamic conditions changes. The figure shows all the existing samples, since it was not possible to distinguish the sluice state in the registers, which means that includes both conditions.

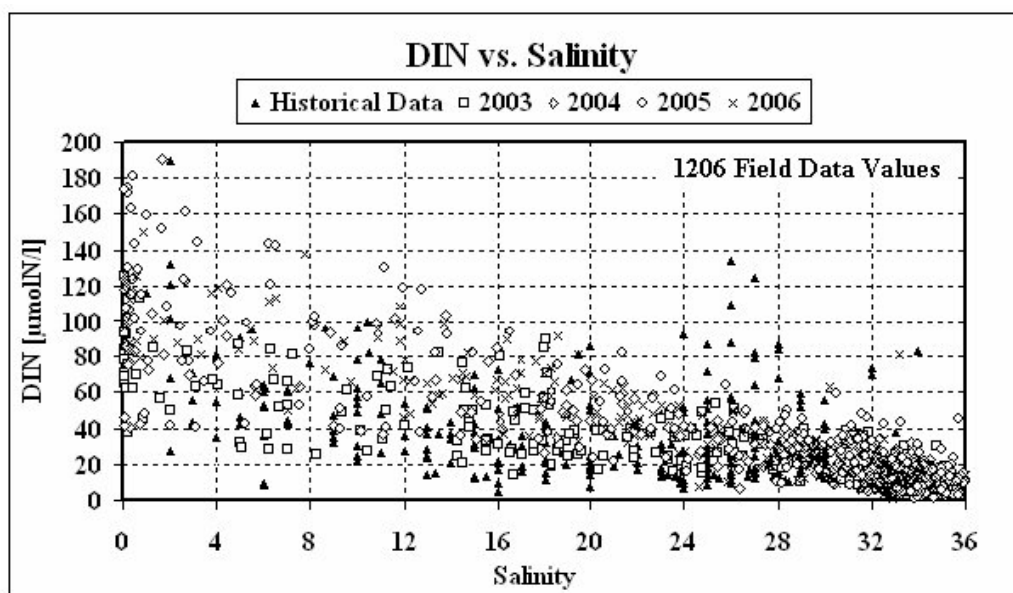


Figure 7. DIN vs. Salinity in the Mondego Estuary: Historical and actual data.

7.2 Chlorophyll a Distribution

Table 3 show the assessment for Chlorophyll_a obtained for the years between 2003 and 2006.

Table 3. Annual Average Chlorophyll a Concentration [$\mu\text{g/l}$] (Spring/Summer) assessment.

Year	2003	2004	2005	2006
Average Chlorophyll <i>a</i> Concentration (Spring/Summer)	6.9	5.7	8.7	7.4
Elevated Value			9	
Classification	-	-	-	-

Figure 8 represent the average chlorophyll spatial distribution computed by the model for 2003, where it is possible to conclude that the North Channel has concentrations below the elevated level while in the South channel, the values can reach to 14 $\mu\text{g/L}$.

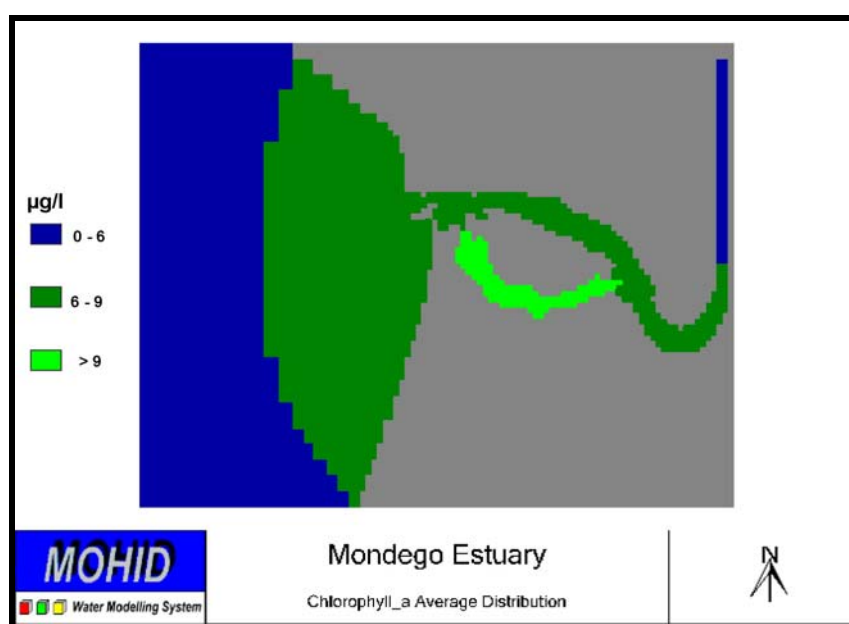


Figure 8. Spatial Average Distribution of Chlorophyll *a* concentration [$\mu\text{g/l}$] computed by the model for the actual situation in Mondego Estuary.

7.3 Oxygen Distribution

Figure 8 represents the annual average of oxygen spatial distribution in the estuary resulting from the model simulation and Table 4 show the annual assessment obtained in this topic. 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.

Table 4. Annual Average Oxygen Concentration [mg/l] (Spring/Summer) assessment.

Year	2003	2004	2005	2006
Average Oxygen Concentration (Spring/Summer)	7.7	9.2	9.1	8.4
Deficiency Range		2-6		

Classification

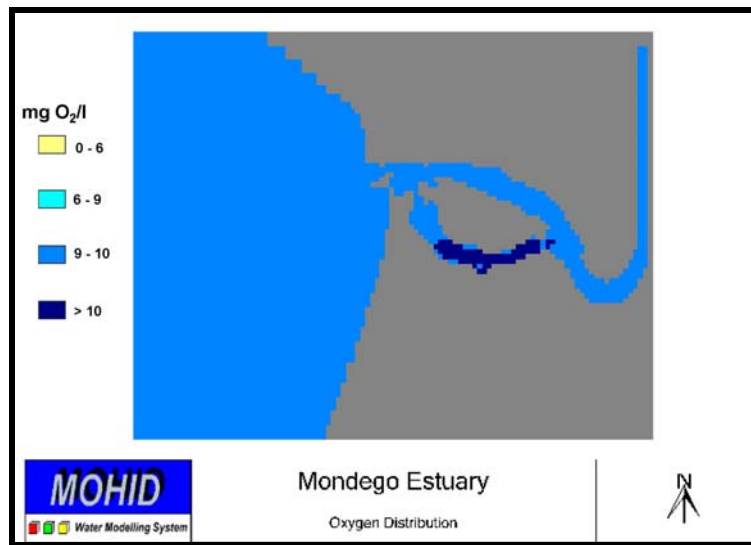


Figure 9. Spatial Average Distribution of Oxygen concentration [mg/l] computed by the model for the actual situation in Mondego Estuary.

8 Perspectives

8.1 Implemented and further planned measures

Since 2003 an extensive monitoring programme is monthly running in the Mondego Estuary, including 23 stations uniformly distributed inside the estuary and 2 stations located next to the main fresh water discharges (Mondego and Pranto Rivers). The results from the monitoring programme have been an important achieve during the last years, enabling the establishment of some conclusions about the system behaviour.

The assessment presented in this report refers to the environmental conditions observed from 2003 to 2006, when the communication between the two channels of the estuary was very limited, through a section of only 1 m² (Lillebø et al., 2005). This situation can be considered as an intermediate mitigation action implemented in 1998, including also the control of the Pranto River discharge by a sluice. The full re-establishment of the communication between both channels was implemented in May 2006 and the evaluation of the system response to this change can not be shown in this assessment, requiring at least two years of measurements in the new conditions to allow a first conclusion about the impact of the action.

8.2 Outlook

(i) Expected trends

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 macroalgae). This seems to be a consequence of the hydrodynamical properties of this channel.

Recent studies suggested the fully re-establishment of the communication between the two channels as an important action to improve the environmental quality of the southern channel of the estuary. Recovering the hydrodynamic conditions will (i) decrease the residence time of the water and (ii) increase the salinity range in the southern channel. As a consequence, the occurrence of macroalgal blooms will be reduced and the recovery of the area occupied by the seagrass meadows should be observed. Based on modelling results, data analysis and the knowledge of the insight of the system itself, it is possible to say that an improvement in the environmental quality in the southern channel of Mondego Estuary should be expected and some recent studies have already identified some signal: (i) *Zostera noltii* is gradually recovering, both in biomass and coverage (Leston *et al.*, *in press*) and (ii) no further green macroalgal blooms were reported (Cardoso *et al.*, 2005; Lillebø *et al.*, 2005).

(ii) Improvement of assessments

The concept of background conditions, or reference conditions, is the basis of the assessment and it aims to represent the conditions existing before remarkable anthropogenic inputs. Due to the obvious lack of data and knowledge to consistently support the determination of those conditions, in this study, the background concentrations are considered to be the oldest consistent values measured in the study area, since no alternative definitions have been found. The improvements of the assessment will necessary include the development of new methodologies to determine the background concentrations in the estuary. The lack of old field data, previous to the most important anthropogenic changes in the system, lead to the implementation of alternative tools – numeric models – considered able to simulate properties evolution under different environmental conditions. In the Mondego estuary effort will be made to improve the estimation of Nitrogen and Phosphorus input from the basin to the estuary, using a catchment river model (SWAT) to simulate “pristine” conditions. The results will than be used by a new simulation of the estuary conditions using the MOHID Modelling System, which will compute the properties concentration expected for the estuary in the “pristine” conditions.

The amount of field data measurements obtained by the monitoring programme implemented since 2003 was an important achieve in the second application of the comprehensive procedure and the programme will be maintained in order to evaluate the expected changes from the re-opening of the channels communication.

9 Conclusions

In the early 90's the Mondego Estuary was object of important geomorphological modifications in order to improve navigability and the upper communication between the two channels was closed. Artificial closing of the upper connection between channels has stimulated the settling characteristics of the southern channel and in late 90's symptoms of eutrophication have been identified with a reduction of the area occupied by *Zostera noltii* and an increase of the areas occupied by macroalgae, mainly *Ulva* spp. The causes of the macroalgal blooms were apparently linked to the management of the Pranto sluice. When the sluice is opened, high concentrations of nutrients are discharged to the southern channel, leading to organic enrichment in the sediment. When the sluice is subsequently closed, the salinity increase and associated to nutrient availability, is a trigger for seaweed blooms (INAG/MARETEC, 2002).

In 1998, a restoration programme was implemented to reverse this process and the communication between both channels was re-established although still very limited, through a section of only 1 m² (Lillebø *et al.*, 2005). This situation can be considered as an intermediate mitigation action which also included the control of Pranto River discharge. After the first implementation of the comprehensive procedure, in 2002, when Mondego Estuary was classified as “potential problem area”, a monitoring programme was implemented, including 25 stations covering the whole estuary area. Results from the monitoring programme complemented by modelling studies (INAG/IMAR, 2005; INAG/MARETEC, 2002) suggested that the fully

re-establishment of the communication between channels could reduce the occurrence of macroalgal blooms in the southern channel by: (i) decreasing the residence time of the water and (ii) increasing the salinity range. In May 2006 the communication between north and south channels was re-established, recreating the previous conditions, and improvements in the trophic conditions of the southern channel have been already detected: (i) *Zostera noltii* meadows are revealing an increasing tendency both in biomass and coverage and (ii) green macroalgal blooms are showing a significant decrease in biomass (Leston *et al.*, *in press*), which confirms the effectiveness of the mitigation action. Although, a complete evaluation of the system response to this change requires at least two years of measurements in the new conditions to allow a first conclusion about the impact of the action. Thus, the classification status of Mondego estuary as a “Potential Problem Area” will remain unchanged up to the confirmation of field data and modelling results.

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OSPAR CONVENTION FOR THE PROTECTION OF THE MARINE ENVIRONMENT OF THE NORTH EAST ATLANTIC

COMPREHENSIVE PROCEDURE DATA AND INFORMATION USED IN THE NATIONAL ASSESSMENT **MONDEGO ESTUARY - PORTUGAL**



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1 Monitoring Program Description

The classification of the areas with regard to eutrophication was obtained appealing to actual and historical observations, resulting from comparison between the actual conditions and background conditions. The assessment was based on the measurements from the monitoring program implemented since 2003, sampling 25 monitoring stations, uniformly distributed along the estuary, Figure 1. The samples were taken monthly, at high-tide, from surface and bottom waters. Physico-chemical factors (temperature, salinity and dissolved oxygen) were measured *in situ* and water samples were collected for subsequent quantification of dissolved nutrients concentrations – ammonia, nitrate, nitrite and phosphorus – in laboratory (APHA, 1980; Strickland & Parsons, 1972), as described in Marques *et al.* (2007). The concentration of chlorophyll *a*, following the method described by Strickland & Parsons (1972), is used as a phytoplankton proxy (Marques *et al.*, 2007). The monitoring program was implemented by IMAR (Instituto do Mar, University of Coimbra, Portugal) coordinated by Prof. João Carlos Marques.

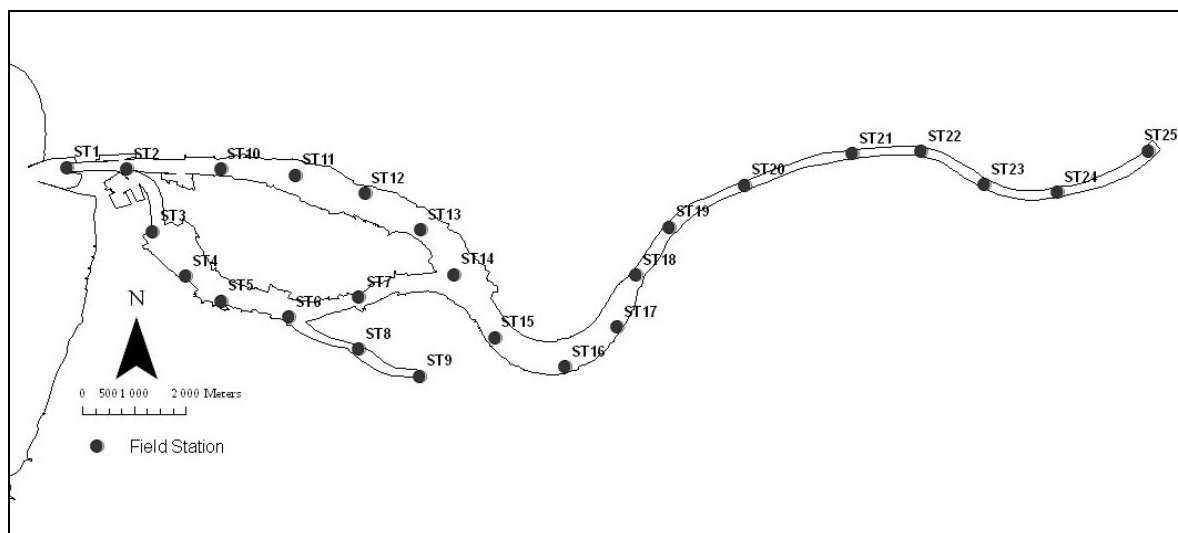


Figure 1. Field Stations included in the Mondego Estuary Monitoring Programme, since 2003.

2 Fresh Water Discharge

The actual input from the fresh water discharges were obtained as the average of the field values obtained in 2003, 2004, 2004 and 2006 in Station ST9 (representing Pranto river discharge) and Station ST25 (Mondego river discharge). Because no data on the discharges flow is available, average values for Mondego and Pranto rivers were considered (60 m³/s and 2.3 m³/s, respectively). The average flow for Mondego river was calculated from the monitoring stations Ponte de St^a Clara (Ref. 12G/04) and Açude de Coimbra (Ref. PVR25), managed by the Portuguese Water Institute (INAG), which values can be found in <http://www.inag.pt/>.

3 Actual Conditions

The actual conditions in the estuary were obtained as an average of the values obtained in the monitoring program between 2003 and 2006. All the stations were considered with exception of Station ST9 and ST25, previously considered as representing the fresh water discharge to the estuary.

4 Background Conditions

The concept of background conditions, or reference conditions, aims to represent the conditions existing before remarkable anthropogenic inputs. In the Mondego estuary there is a relevant lack of historic field data, thus becoming difficult the process of establishing a trend of the system trophic evolution. The historical data used in the assessment was obtained from BarcaWin2000 data base (<http://www.barcaweb.com/>), where some field observations located in particular areas of the estuary (mainly the south channel) can be found from 1993 to 2000. Although the data obtained was considered not enough to characterize the whole system, since no alternative was found, the values obtained in 1993, the oldest register available, were considered as background conditions.

5 Model data

The study is complemented with results obtained through a three-dimensional water modelling system (www.mohid.com), simulating the actual environmental conditions in the estuary, considering ocean tide and fresh water discharge forcing. Model results were annually averaged in each computing cell for comparing

with field data (e.g. salinity, chlorophyll *a*, DIN) which is too scarce for comparing on a time basis. The model results are in good agreement with field data, being able to show the most relevant trends (INAG/IMAR, 2004) of the environmental conditions in the system. The model allows filling the information gaps and, above all, gives an insight of the system itself enabling a process oriented study of the system evolution. More information about the implementation of the model and assumptions can be found in the national reports INAG/MARETEC (2002) and INAG/IMAR (2004 and 2005).

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