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Environmental indicators as tools for the management of estuaries – Methodology and case study of the Tejo estuary

Cardoso da Silva, Margarida[1*] & Carmona Rodrigues, António[2]

[1]*DHA-NEC, LNEC, Av. do Brasil, 1700 Lisboa, Portugal;* [2]*FCT- Universidade Nova de Lisboa, Monte da Caparica; E-mail acrodrigues@fct-unl.pt;* [*]*Corresponding author; Tel. +351218443758; E-mail mcsilva@lnec.pt*

Abstract. The need for a better management of estuaries requires an environmental characterization following a methodology that allows the comparison of distinct estuarine systems and the assessment of their evolution. The peculiar characteristics of estuaries, in particular their intrinsic variability, make this characterization difficult and there is no commonly accepted general methodology available. The approach followed in freshwater ecosystems is generally based on the concept of environmental indicators, but such a concept has not been developed for estuaries. Indeed, a different approach is needed here, due to the spatial heterogeneity and the different time scales associated with the processes that control water quality.

This paper presents a proposal for a methodology that starts with observed values and uses a procedure to integrate these values in time and space in order to calculate *significant values*, upon which *normalized indicators* are built which take into account criteria based either on legal, scientific or heuristic concentration limits. A normalization is carried out in two steps: (1) application of a mathematical operator to the *significant values*, (2) transformation using the concept of *penalty curves*. This methodology may be complemented with the definition of *quality classes*, particularly appealing and useful, as tools to communicate with decision makers and the public in general.

Water quality data pertaining to the Tejo estuary are used to test the methodology.

Keywords: Oxygenation; Water quality.

Introduction

Estuaries are coastal systems with a particular interest based on their ecological role and their socio-economic importance. In addition, they often provide scenic beauty and support recreational activities. Estuaries are often bounded by urban and industrial developments. In Portugal, the most important metropolitan areas grew around the estuaries of the rivers Tejo and Douro. These are also estuaries with important harbour activities.

The multiplicity of estuarine functions, some demanding on water quality, others aggressive to that quality, justifies the need to implement management systems that aim to harmonize the conflicts associated with the estuarine environment.

Any management activity starts with the characterization of the system of interest. Estuaries, as interface between land and sea, also have a particular scientific interest, as they are the place of complex mixing processes of salt and fresh water. This issues are the motivation and justification for the development of a methodology to guide the environmental characterization of estuaries.

This characterization must allow the comparison of the environmental state of different estuaries as well as a study of their evolution over time as a result of changing pressures due to management actions. The Water Framework Directive (2000/60/EC) of the European Union, which recently became operative, provides an extra motivation to search for this type of methodologies as it imposes procedures for the characterization of the ecological and chemical conditions of water bodies as well as a clear definition of their pristine state.

The objective of this paper is to contribute to the definition of a methodology that starts with observed values and uses a procedure to integrate these values in time and space in order to calculate *significant values*, upon which *normalized indicators* are built which take into account criteria based either on legal, scientific or heuristic concentration limits.

Conceptual framework

Environmental indicators

Most of the available environmental information, generated by both scientific studies and institutional observations, does not allow decision makers and the public to clearly understand the processes that control the values of the observed environmental variables and of the real meaning of those values. Consequently they lack criteria to decide on appropriate courses of action in terms of management. Hence an assessment system must be defined as a framework for systematic environmental observations and for processing results in such a way that they provide the means to identify existing or emerging problems and the pressures that create these problems (Cardoso da Silva & van de Wetering 1992).

A possible assessment system is based on the concept of *environmental indicator* (e.g. ten Brink et al. 1991; Anon. 1991a). Environmental indicators should give information on the condition of the system under study and of its uses and they should have a political value in such a way that it should be possible to set objectives for these indicators and to influence their levels. Indicators must also be easily perceived by the general public. Although environmental indicators are frequently used in freshwater systems (reviews by Ramos et al. 1996 and Hawkes 1997), their systematic use in the characterization of estuaries is limited. Some applications, mostly to regions with hydrologic and climatic conditions different from those of Portugal, were reported by Tomlinson et al. (1980), Anon. (1991b), Cooper et al. (1994) and Anon. (no date). Some proposals regarding Portuguese estuaries were presented by Cardoso da Silva (1993, 1997) and Ferreira (2000).

The proposed methodology follows the general concept of environmental indicator. According to Opschoor & Reijnders (1991), an environmental indicator is a quantitative descriptor of the pressures on and the environmental state of the system and of its changes. Environmental indicators may be considered as a simplified and aggregated form to present information pertaining to a certain region (Correia & Beja Neves 1993). The parameters or environmental variables to take into consideration are selected in relation to the objectives and the prevailing conditions in the case study of interest.

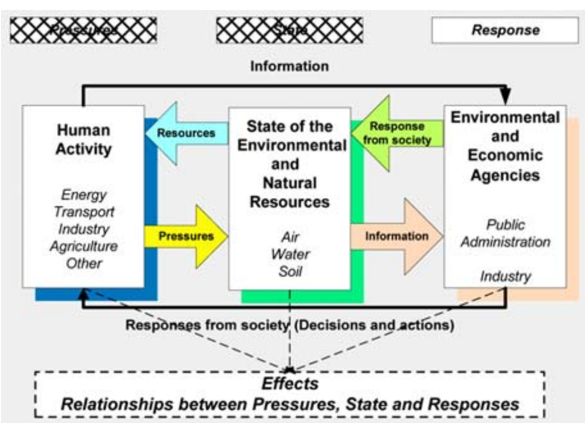

Fig. 1. Pressure – State – Response model.

The main distinction between environmental variables and environmental indicators is the fact that the latter contain information on the meaning of their value, i.e. they are associated with a spatial domain and a temporal interval and, in particular, with evaluation criteria, the *objective and reference values*. A *reference value* is the value that a parameter should have in a system where human influence has not yet been felt or implied environmental change, corresponding to the pristine situation. The *objective value* is defined not only on the basis of ecological and scientific considerations but it also takes into account management issues. In general, the objective value is less stringent than the reference value and may change in time when management measures become effective.

Framework models

Different conceptual models have been proposed to frame the development of a system of environmental indicators for the characterization of natural systems. Most of those models are based on the *Pressure – State - Response* model (Anon. 1989, 1993). This was proposed and is presently adopted by the Organization for Economic Cooperation and Development (OECD) and EUROSTAT on the environmental characterizations carried out by these institutions. This model is based on the concept of causality and can be described according to the scheme presented in Fig. 1. The human activities create *pressures,* which control the natural processes and the environmental *state*. When the desired state does not coincide with the present situation, there is the need to develop *responses* of the socio-economic system in order to reduce the identified gap through the execution of management measures.

Methodology

General considerations

The intrinsic variability of estuaries, in space and time, implies that its characterization is far from trivial, because of the difficulties in the adaptation of indicator systems which were developed for freshwater systems.

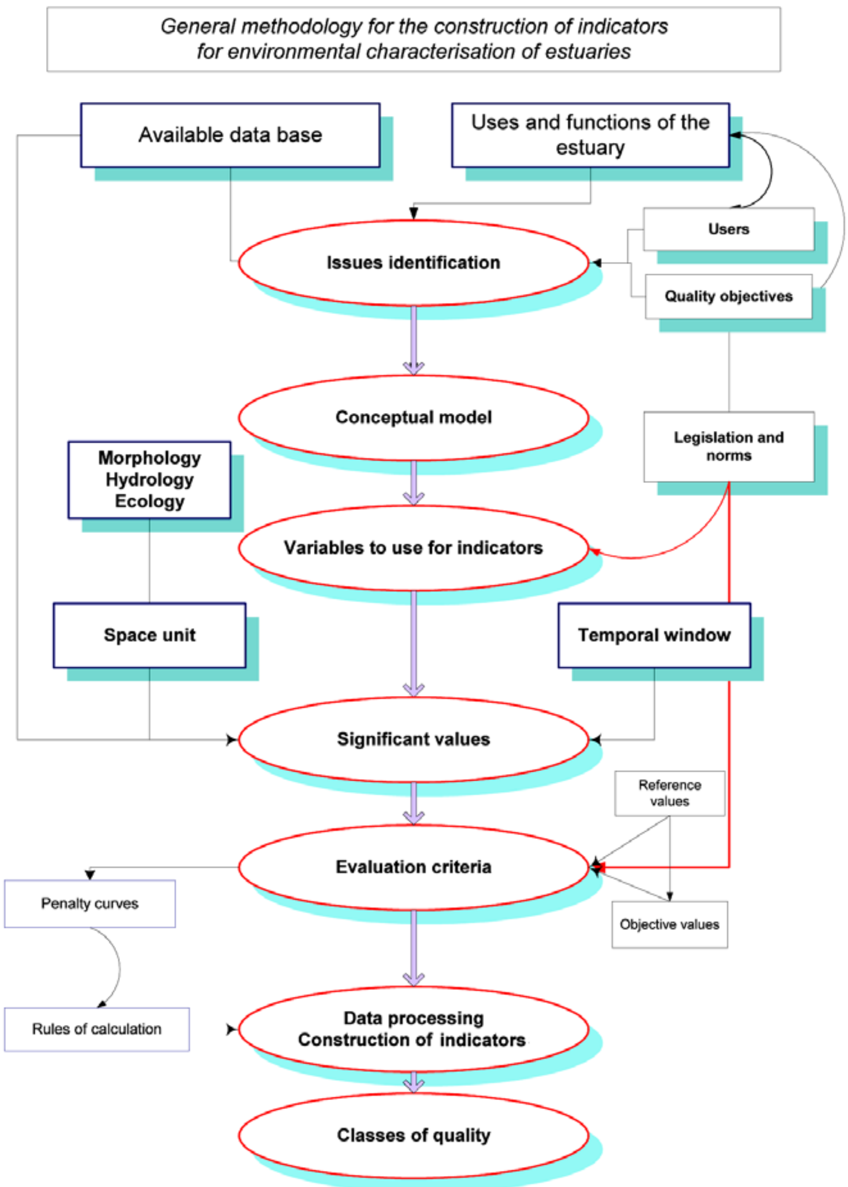

Fig. 2. Methodology for the construction of environmental indicators for the characterization of estuaries.

The proposed methodology aims at defining a set of procedures, some based on ideas presented previously (e.g. Horton 1965; Opschoor & Reijnders 1991; Bricker et al. 1999; Alegre et al. 2000), which will allow the transformation of a set of observations, performed at different regions of the estuary and in different occasions, in *significant values*, that will be the basis of the calculation of the final *normalized indicators*. The methodology also proposes the definition of *classes of environmental quality* that, when associated with a colour code, are a powerful tool of communication of results to audiences with a lower degree of knowledge in the technical details of the environmental issues.

Outline of the methodology

Fig. 2 presents schematically the general outline of the methodology. The first step is the identification of the *issues* to be taken into consideration. They are selected while taking into account the uses and functions and the natural characteristics of the estuary, legal impositions, as well as the available or potential database to use in the process of the calculation of the indicators.

The next step is the selection of the conceptual model. As mentioned, the *Pressure – State – Response* model (Fig. 1) was selected as it is a fair compromise between complexity and clarity of results. The definition of the variables to consider is the next task. In general terms, the variables to consider fall into two categories:

1. Reference or integration variables, needed to create a context within which the values of all other variables are processed and interpreted. These variables pertain to natural characteristics of the system under study, such as the morphological, hydrographical and hydrologic characteristics.

2. The variables that lead to each of the types of indicators, according with the selected conceptual model, such as pollution loads of selected materials, and their concentrations.

The next step refers to the integration of the observations in space and time. For the definition of the domain of integration in space we need to identify units with certain common characteristics, the *homogeneous zones*. The temporal variability has several temporal scales due to multiple conditions created by the joint influence of tides and freshwater flow. The detailed methodology for the selection of the integration domains was presented elsewhere (Cardoso da Silva 2002). Homogeneous zones are defined based on multiple criteria of homogeneity, in particular regarding morphology, variability of the salinity and management criteria associated with uses and quality objectives. The temporal domains are determined according to the temporal variability of some reference parameters, namely salinity and temperature, as they are the most relevant controls of the processes that condition environmental quality.

Processing the observations is often different when dealing with environmental pressures, or with state variables. For the variables used to build state indicators, the variability associated with the diurnal and lunar tidal cycles in combination with the freshwater flow has to be taken into consideration in the calculation of the *significant values*. For pressure indicators much longer periods of integration are necessary.

The next step concerns the definition of the *criteria of evaluation*, i.e. the definition of objective and reference values. In practice this means answering the question: What is the state of the system that better guarantees its sustainable use? The definition of *reference values* is often problematic although it may be done on the basis of old information and by comparison between systems of similar natural characteristics that suffered a lower degree of human disturbance (Cardoso da Silva & van de Wetering 1992). The definition of *objective values* implies a compromise between the economic costs associated with the implementation of the measures needed to achieve or maintain these values and the loss of the guarantee of sustainability. They are set up between the present values and the reference values. Nevertheless, the approach may vary according with the environmental status of the zone. A natural reserve will be in need of a higher level of protection, with more stringent values, than a harbour. It is not always possible or adequate to set up reference values for the pressure and response indicators. Nevertheless, the analysis is still useful just by observing the tendency of evolution of their values.
For the state indicators, the calculation procedure starts from the *significant values* of the variables and is achieved by performing a set of operations that use the criteria of evaluation previously selected to remove the dimension. Finally, the *normalized indicators* are calculated in a limited scale, using an algebraic operator or penalty curves (Horton 1965; Cooper et al. 1994; Coelho 1997). This normalization allows the verification of the compliance with the objectives previously set and to assess the distance from these objectives in a common scale for all the variables of interest. The details of this procedure are described below.

The final step of the methodology defines *classes of environmental quality*, based on all or a subset of the *normalized indicators*. The classes of environmental quality are foreseen in the legislation in force and in most cases defined by the application of the *operator of the minimum*, this is, the class is a function of the indicator which has the 'worst' value, as is suggested by some authors (e.g. Smith 1990).

Calculation of indicators

Previously to the calculation of any indicator the context information has to be organized in a format as presented in Table 1.

Each type of indicators has its own rules for calculation. Some require some of the values calculated as context information for their estimation, as it is needed to use the identified homogeneous zones and the relevant time scales to perform the spatial and temporal integration.

Pressure indicators

The indicator of *estuarine susceptibility to pollution loads*, which provides the information on the comparable degree of influence of the pressures represented by pollution loads on their environmental characteristics, is the first indicator to be calculated. It uses the flushing time (T_f) and its variation with fresh water flow, the fluxes and renovation ratios. An estuary has different susceptibility to pressures according with the possible combinations of those three parameters.

For the calculation of the *susceptibility indicator* the *dilution criteria* are used, based on P/V_{HW}, and the *exporting capacity criteria*, a function of T_f, according to the decision matrix presented in Table 2. These pa-

Table 1. Context information. Physical and morphodynamic characteristics of the estuary.

Type	Indicator		Calculation rule
	Main river		
		Modular flow	
		Minimum flow	
		Maximum flow	
Inflows	Tributaries		Analysis of historical time series and hydrological studies
		Modular flow	
		Minimum flow	
		Maximum flow	
Hydrography	Tide characteristics		Harmonic analysis of time series of elevations
Morphology	Surface at mean sea level Volume at mean sea level Hypsometric curves		Calculation from bathymetric data, using tools of graphic software (*GIS* and *DTM*)
Characteristic parameters	Flushing time	T_f	Using e.g. Dyer (1997)
	Fluxes ratio	R_T/P	
	Renovation ratio	P/V_{HW}	
	Froude number	F_B	

R_T – River discharge per tide; P – Tidal prism; V_{HW} – Estuarine volume at high tide.

rameters incorporate the effects of morphology, fresh water flow and tide.

Combining the two criteria and following the rule presented in Table 3, that also takes into consideration the fluxes ratio, the *indicator of susceptibility to pollution* is defined, which can take three levels – High, Moderate and Low.

There are two other useful pressure indicators, pertaining to permanent pollution loads, one assessing the *compliance* with the limits of emission and the other pertaining to the *pollution loads*, their development over time and their significance when *normalized* with a morphological characteristic of the estuary. For the *compliance indicator*, the significant value to compare with the emission limit [*VLE*] is the concentration [*S*] of the substance under appraisal in the effluent. The indicator is determined using a penalty curve as presented in Figs. 3. The indicator takes the value 100 when the concentration in the wastewater complies with the established limit, and takes the value 0 when the established norm is exceeded by more than 75%. The analysis may be performed parameter by parameter although it may be of interest to integrate the result of several parameters, using the minimum operator, to obtain a more general assessment of the compliance of the pollution loads.

The *indicators of pollution loads* may be derived from a 'loads matrix' where the relevant information is organized. The loads are not by themselves the indicator. They must be normalized with the volume of the receiving body of water, which can be the estuary or each of its homogeneous zones, and their change assessed over time with the *evolution indicator*. The rule of calculation is presented in Table 4.

State indicators

The construction of state indicators starts with the removal of the dimension, the determination of the test values (V_{test}), using one of the assessment criteria, the reference or the objective value. As an operational rule, when legislation sets *maximum admissive values* (*MAV*) or *maximum recommended values* (*MRV*) these are used as, respectively, objective and reference values. These calculations are performed by the application of an algebraic operand. In the present context a hyperbolic transformation was selected:

$$V_{test} = \text{Criteria} / V_{significant} \quad (1)$$

This method implies that there is compliance with

Table 2. Criteria of the dilution and exporting capacity.

P/V_{HW} Dilution ratio/tide	> 30%	High
	30-5%	Moderate
	< 5%	Low
T_f (days)	< 15	High
	15-45	Moderate
	> 45	Low

Table 3. Criteria of the dilution capacity.

Dilution + exporting	Susceptibility	
	$R_T/P \leq 0,25$ Tendency to vertical saline homogeneity	$R_T/P > 0,25$ Tendency to vertical saline stratification
High + High	Low	Low
High + Moderate	Low	Moderate
High + Low	Moderate	High
Moderate + Mod.	Moderate	Moderate
Moderate + Low	Moderate	High

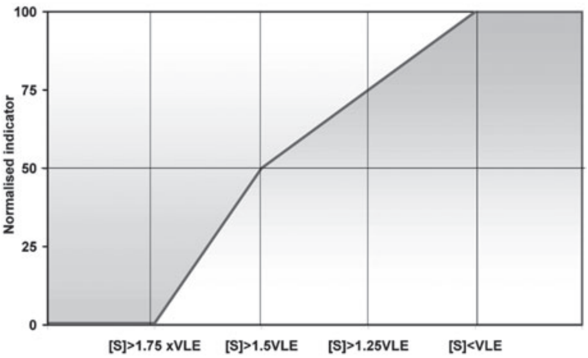

Fig. 3. Penalty curve for the determination of the pressure indicator of compliance with emission limits.

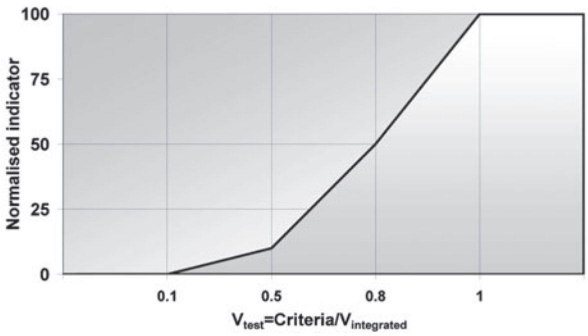

Fig. 4. General shape of a penalty curve to determine the normalized indicator.

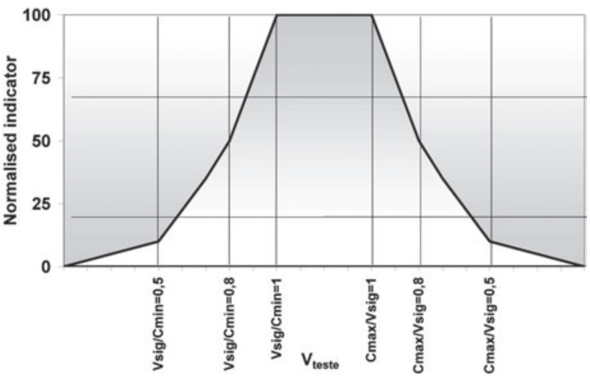

Fig. 5. General shape of a penalty curve when the criterion is an interval.

Table 4. Pressure indicators. Calculation rule for indicators of pollution loads – normalized load and evolution load.

Pollution loads indicator Normalized	Development
I_NP_1 (S) = W_1(S)/V	I_E(S) = 100
I_NP_2 (S) = W_2(S)/V	if [W_1(S)/ Wi + $_1$(S)] ≥ 10
....	I_E(S) = 10 × [W_1(S)/Wi + $_1$(S)] if
I_NP_n (S) = W_n(S)/V	[W_1(S)/ Wi + $_1$(S)] < 10

the criteria when V_{test} ≥ 1, if the criterion is an upper limit for the observed concentrations. The calculation of the final indicator, with a domain of variation between 0 and 100, may be performed by two alternative ways, using another algebraic transformation or a penalty curve, in a similar way that was described for the *pressure indicator of compliance*. If the algebraic transformation is adopted, the indicator value is given by:

$$\text{Indicator} = 100 \times V_{aux} \quad (2)$$

With: $V_{aux} = 1$ if $V_{test} \geq 1$ (compliance)
and: $V_{aux} = V_{test}$ if $V_{test} < 1$

The *penalty curves* represent the distance from the desired situation and relate each significant value of the variable or each V_{test} to a value of the normalized indicator. They are arbitrarily defined in a way that *penalizes* the deviations from the selected criteria, reference or objective. Fig. 4 presents a general penalty curve. For substances where the criterion is an interval as, for example, in the case of pH, the penalty curve has the shape presented in Fig. 5.

Response indicators

Reference or objective values cannot always be linked to the parameters that are the basis of response indicators. These indicators may then be defined on the basis of the existence or absence of actions aiming at correcting identified dysfunctions or non-compliance with the defined environmental criteria. Nevertheless, it may be possible in some cases to set a quantifiable objective, for instance the percentage of population served by adequate wastewater treatment.

Developing response indicators will follow two alternative methodologies depending on the possibility to define numerical evaluation criteria. When these criteria are available the methodology will be similar to the one previously described for pressure and state indicators, in particular, applying appropriate penalty curves.

Classes of quality

The representation of the environmental quality of an estuary is particularly suggestive when a graphical format is used based on the definition of quality classes associated with a colour code. The present proposal uses

Table 5. Rule for the construction of classes of quality on the basis of the state indicators.

State indicators	Quality state
All state indicators = 100	Excellent
More than 1/2 of the indicators =100 and all ≥ 50	Good
Less than 1/2 of the indicators =100 and all ≥ 50	Degraded
One (or more) indicators ≤ 50	Bad

the pressure and state indicators and allows the definition of four classes of quality as follows:

Excellent: when the quality of the system does not show any disturbances caused by human activity and the natural processes are similar to those of the pristine state;

Good: when the pressures did not cause disequilibria and when the compliance with quality requirements for present and future uses is verified;

Degraded: when disturbances cause limitation to uses, although the implementation of management measures can correct the observed limitations and there is no irreversible damage to the ecosystems;

Bad: when the uses are impaired and the recuperation of the ecological equilibrium is difficult and requires demanding intervention in technical and economic terms.

The definition of quality classes may be applied to an issue-by-issue basis to obtain a disaggregate classification, which contains information on which issues are the cause of the discrepancies between desired and existing quality. It may be of interest to further generalize the classification, aggregating the results of different issues, selected on the basis of management considerations. The rule for the definition of the classes of quality based on the state indicators is presented in Table 5. This classification pertains always to a defined time interval and the observation of its occasional evolution provides a measure of the efficiency of management measures or an alert of a degrading situation.

Case study

General characteristics of the Tejo estuary

The Tejo estuary (Fig. 6) is a coastal system with great diversity in its characteristics and uses. The inner part of the estuary is a delta with channels and islands surrounded by land with intensive agriculture. Downstream, the estuary forms a wide basin with the characteristics of an internal sea, with extensive salt marshes and mudflats of great ecological importance. The adjoining banks, however, are the site of important industry. The outer part of the Tejo estuary is a deep narrow channel bordered at either side by Greater Lisbon with a population of ca. two million. The estuary is also an important commercial harbour. The immediate seaward vicinity is a zone of recreational beaches.

The morphological and dynamic characteristics of the Tejo estuary are summarized in Table 6, which gives context information according to the proposed methodology.

Integration in time and space

The calculation of the indicators starts with the identification of the integration domains, this is, the delimitation of the homogeneous zones and of the relevant time scales of the processes that control the variables of interest.

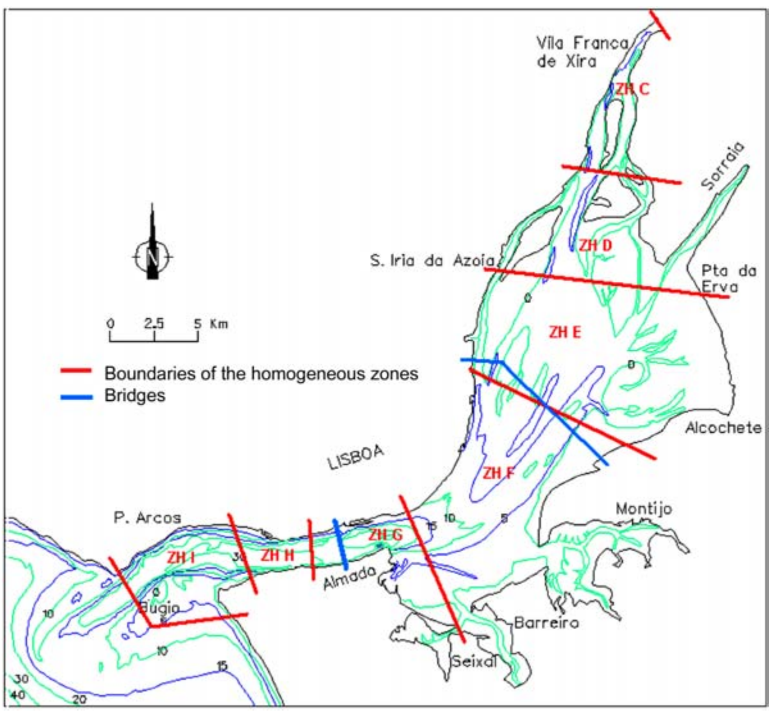

Fig. 6. Tejo estuary (up to Vila Franca de Xira, not including the fluvial or upper estuary).

Table 6. Context information on the Tejo estuary.

Indicator	Values			
Freshwater input:- Tejo				
Q_modular	340 $m^3.s^{-1}$			
Q_max.	950 $m^3.s^{-1}$			
Q_min	35 $m^3.s^{-1}$			
Tide				
Harmonic constants(Lisboa, T. Paço)		T hours	A (m)	φ (rad)
	M2:	12.42	1.138	1.69
	S2:	12	0.407	2.36
Max. tidal range (spring tide)	4.3 m			
Min. tidal range (neap tide)	0.75 m			
Tidal prism	831 × 10^6 m^3 (average tide)			
	1200 × 10^6 m^3 (max. spring tide.)			
Morphology				
Area at mean sea level	307 km^2			
Volume at mean sea level	1.780 × 10^9 m^3			
Characteristic parameters				
Flushing time, T_f	9 days (Q_f ≅ 900 $m^3 s^{-1}$)			
	≅ 60 days (Q_f = 35 $m^3 s^{-1}$)			
Flux ratio *Rt*/P	0.02 ($Q_f = Q_{modular}$)			
Renovation ratio P/V_{PM}	≅ 40%			
Estuarine Richardson number R_{i_est}	0.0033 (spring tide, Q = 35 $m^3 s^{-1}$)			
	0.144 (neap tide, Q = 950 $m^3 s^{-1}$)			
Densimetric froude number, F_m	0.06 (Q = 35 $m^3 s^{-1}$)			
	0.150 (Q = 950 $m^3 s^{-1}$)			

Applying the morphological and salinity criteria, while taking into consideration the distribution of uses as a management criterion, and following the methodology described by Cardoso da Silva (2002), nine homogeneous zones were identified in the Tejo estuary, two in the upper estuary and the other represented in Fig. 6.

The definition of the domain for the temporal integration is different for the pressure and state indicators. The temporal scale associated with pressures is seasonal or annual, while the state variables are a function of shorter scales, associated with the combination of tidal and hydrologic conditions. An analysis of the temporal variation of the reference parameters, salinity and temperature, as well as the order of magnitude of the flushing time for the several homogeneous zones lead to the identification of a primary temporal *stratum*, associated with three intervals of fresh water flows (Table 7).

The analysis of the reference variables showed that the tidal state is relevant for the variability of the analysed parameters, in particular the salinity. The type of tide seems to have a comparatively minor influence. This analysis is illustrated by the time series of Fig. 7 where the values for spring and neap tide, in most of the homogeneous zones are similar, although the high tide (HW) and low tide (LW) situations are significantly different. The significant values are then calculated by integration of the observation first in space, to be referred to each homogeneous zone, and then in time, in a procedure that integrates for seasons and later for tidal conditions.

Table 7. Freshwater flow intervals for the temporal integration in the Tejo estuary.

Season	Summer	Intermediate	Winter
Fresh water flow ($m^3.s^{-1}$)	< 200	200 - 600	> 600

Calculation of the indicators for the Tejo estuary

The test of the methodology was done by calculating indicators pertaining to the issue of oxygenation as an example. The basic data were taken from the *Environmental study of the Tejo estuary* (Martins & Duffner 1982; Martins et al. 1983 a, b; Cardoso da Silva et al. 1986 a, b).

Pressure indicators

As mentioned, the indicator of susceptibility to pollution provides insight in the relevance of pollution loads. For the Tejo estuary, using the information presented before (Table 6) and the decision rules proposed in Tables 2 and 3, it is possible to calculate the indicator for the three temporal strata of first order (Table 8).

The indicator of compliance with emission limits

Table 8. Indicator of susceptibility to pollution.

Season	Dilution + Export	Susceptibility
Winter	High + High	Low
Intermediate	High + High	Low
Summer	High + Moderate	Low

was calculated for the loads of organic matter expressed as biochemical and chemical oxygen demand from a set of sources on the basis of historic information (in the absence of updated adequate information). A sample result of the calculated indicators, obtained using the penalty curve of Fig. 3, is presented in Table 9.

State indicators

The state indicators presented as an illustration of the application of the proposed methodology (Tables 10 and 11) use the dissolved oxygen concentrations, integrated in time and space. From the significant values two distinct test values were computed, one based on the *minimum value* of the discrete observations pertaining to each homogeneous zone and to each temporal *stratum*, and another based on the *mean value* of the same set of observations. The indicator pertaining to the reference value adopted (from the Decree of Law 236/98, 1 August 1998) which in this case is an interval (between 80% and 129% saturation) was calculated for both test values, while for the objective value (70% saturation, also according with the mentioned legislation), only the mean value was considered.

Definition of the quality classes

The definition of the quality classes (Fig. 8) uses the state indicators pertaining to the objective values, as those are associated with the maximum admissible value of mandatory compliance when the quality criteria is based on legal imposition. These classes may also be associated with the pressure indicators, in particular with the indicator of susceptibility and of evolution of the pollution loads. In the present case study, the classes of quality combining the two indicators were not built, as the available data were not adequate for the calculation of the evolution indicator.

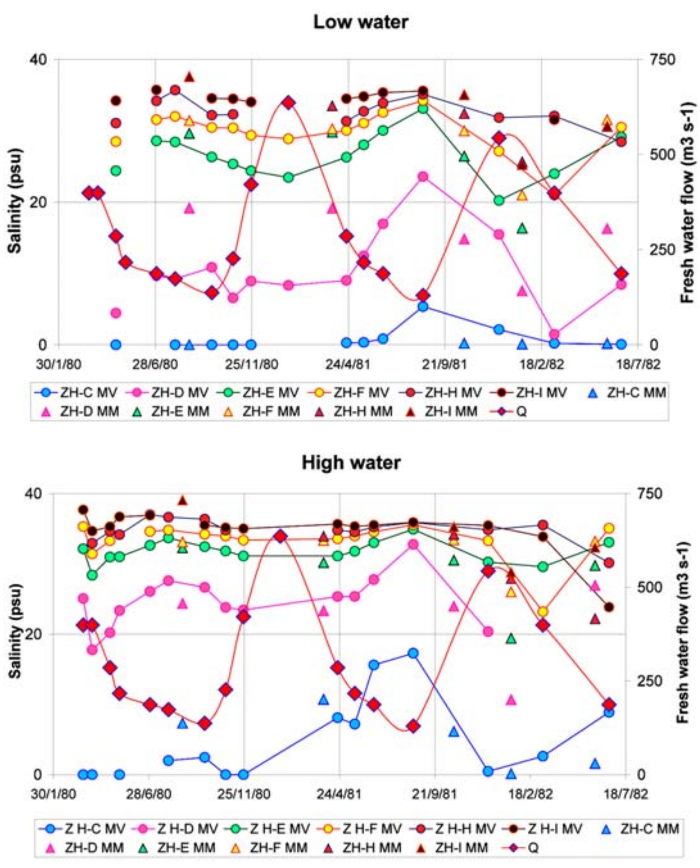

Fig. 7. Temporal variation in salinity in the Tejo estuary.

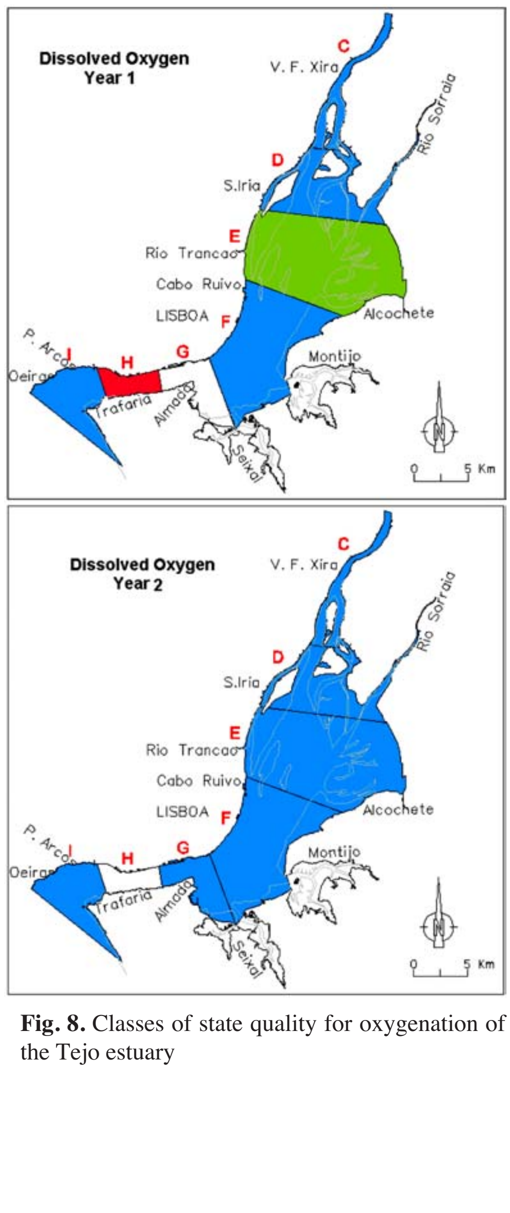

Fig. 8. Classes of state quality for oxygenation of the Tejo estuary

Table 9. Pressure indicator of compliance with emission standards in the Tejo estuary.

				BOD	COD
		Mandatory emission limits - VLE		40	150
		Aggregated indicator			
	Significant value S			141	806
Chemical industry 1	[S]/VLE			3	5
	Indicator	0	Incompliance	0	0
	Significant value S			79	1563
Chemical industry 2	[S]/VLE			2	10
	Indicator	0	Incompliance	3	0
	Significant value S			174	1592
Industry of edible oils	[S]/VLE			4	11
	Indicator	0	Incompliance	0	0

Conclusions

The importance of an integrated study of estuaries is generally recognized. Estuaries have an intrinsic ecological value but also support a diversity of uses, which are often in conflict with each other. This implies the need for the establishment of a management system and the use of management tools. Environmental indicators are technical and scientific management tools of particular interest to assist in the characterization of estuaries and to translate the scientific information into a format that is easily understandable to wider audiences, including decision makers and the public.

Most of the available systems of indicators were developed to characterize freshwater systems. The proposed methodology was designed taking into account the intrinsic characteristics of estuaries, namely the intrinsic variability of their physical properties, which also determine the variability of biochemical processes and state variables.

The proposed methodology implies the knowledge of freshwater inputs and of estuarine morphology. Knowledge of the salinity distribution is also needed, either based on observations or on calculations using simulation models of various degrees of complexity. The concept of penalty curves is used as a way of calculating the normalized indicators. The proposed curves are always arbitrary, but this does not constitute a limitation to the proposed method when the characterization is done in the context of a management activity. In fact, the main interest of the exercise is the availability of a tool that allows not only the verification of the compliance with selected criteria, but also the comparison between systems or the evolution of that condition over time. In this context, as far as there is consistency of the methodology across systems and time, its arbitrary character does not represent any limitation to the proposed methodology.

The methodology was illustrated using the Tejo estuary, selecting the oxygenation issue, this is, the

Table 10. State indicator for the reference value (with V_{test} of the minimum).

Criteria Homogeneous zone	Year	Q	80 - 120% sat < 200	 200 - 600	 > 600
	1	HW	55	100	82
C		LW	100	100	100
	2	HW	100		
	1	HW	19	37	63
D		LW	96	90	83
	2	HW	100		
	1	HW	43	87	77
E		LW	92	100	63
	2	HW	100		
	1	HW	35	97	100
F		LW	100	91	100
	2	HW	100		
G	2	HW	100		
H	1	HW	49	35	100
		LW	78	36	100
	1	HW	93		
I		LW	100		
	2	HW	100		

Table 11. State indicator for the objective value (with V_{test} of the mean.

Criteria Homogeneous zone	Year	Q	70 % sat < 200	 200-600	 > 600
	1	HW	100	100	100
C		LW	100	100	100
	2	HW	100		
	1	HW	100	100	
D		LW	100	100	
	2	HW	100		
	1	HW	100	100	
E		LW	100	100	
	2	HW	100		
	1	HW	100	100	100
F		LW	100	100	100
	2	HW	100		
G	2	HW	100		
H	1	HW	100	79	100
		LW	100	80	100
	1	HW	100		
I		LW	100		
	2	HW	100		

loads of organic matter with oxygen demand for the pressure indicators and the oxygen concentration for the definition of the state of the system. The context information was previously organized and the indicator of susceptibility to pollution determined on the basis of this data, showing that the Tejo has a low susceptibility to pollution. This may explain the fact that in spite of the heavy loads that have been discharged for decades to the estuary, it still is an important ecological system supporting aquatic life and commercial fisheries.

The results show that the methodology is applicable even when we deal with a complex estuary such as the Tejo. The quality classes show that the estuary is well oxygenated but also show that the method is able to detect different situations at different points in time.

Nevertheless, the validation of the method requires its application to more detailed data, in particular on other estuaries with diverse morphologic and hydrographic characteristics.

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