ANNEX 3

AQUACULTURE DISCHARGES IMPACTS ON THE WATER COLUMN AND BIODIVERSITY. THE MONDEGO ESTUARY CASE-STUDY.

ABSTRACT

Ecosystem provide services and goods, which contribute to the satisfaction of human needs and well being in many ways, and deliver irreplaceable life support functions on which human life relies on. The Mondego estuary has been widely studied throughout the last two decades, with most of the research being focused on the response of biological communities to different types of environmental stress, namely eutrophication. With this work, we analysed this system from an ecosystem services and goods point of view, describing its present state and establishing scenarios regarding the foreseeable evolution of two different ecosystem services, respectively food production (through a estimation of the aquaculture and salt-works production), and water quality, and its association to biodiversity assets. This approach allowed us to check the interactions between each one of the ecosystem services and to establish that water quality is currently the service that influences the most all the rest. As a conclusion, it appears clear that appropriate water management procedures will have a positive influence upon all ecosystem services.

INTRODUCTION

What are ecosystem services?

The first references to the ecosystem functions, services concepts and their economic value date back to the mid-1960s and early 1970s. Nonetheless, the concept of ecosystem services became widely used only after the 1990s (see Daily 1997, Costanza et al. 1997, DeGroot et al. 2002).

The benefits that humans can acquire from natural systems (ecosystem services and goods) may be measured and evaluated through an estimation of the ecosystem functions (that can be defined as the processes and properties of the system). Ecosystem services are the conditions and processes through which natural ecosystems sustain and fulfil human life (Daily 1997) (e.g. recreation activities or the natural depuration capacity of a system). Ecosystem goods can be described as the products that can be obtained from natural systems for human use (DeGroot et al. 2002) (e.g. food production or raw materials). The services and goods provided by natural ecosystems form the basis of human welfare, so the evaluation of these ecosystem features must be done based on integrative approaches, since it comprises both human interests and biophysical processes. There are many categories defined for ecosystem services and goods, depending on the criteria used (see, for example, DeGroot et al. 2002, MA 2003, SA 2005). Regardless the chosen approach, the ultimate goal of this kind of analysis is the same: to evaluate and assess the stability of ecosystems in accordance to their natural capacity to sustain human activities. According to Armsworth and Roughgarden (2003), the dynamical stability of ecosystems and populations rules their responsiveness to variable environmental conditions and determines with what reliability these natural resources provide life-sustaining services to society. To treat the trade-off between the economic use of natural resources and the continuing provision of ecosystem services, a valuation of those services is unavoidable.

According to Beaumont et al. (*submitted*), there are two distinct approaches to work with the ecosystem services concept. Among economists, economic valuation methods prevail, which focus on the exchange value of ecosystem services (based on the consumer preferences and on cost-benefits analysis). On the other hand, there are ecological valuation methods, mainly advocated by natural scientists and ecologists, which derive ecological prices for the ecosystem services by a cost-of-production approach (modelling the interrelations between the biotic and abiotic components of a system). With this work, it is intended to provide an integrative view of both methodologies, providing an insight to the economic perspective within the ecosystem components in a balanced manner.

Ecosystems are made up of many components, for example, soil, water (lakes, rivers, and ponds), vegetation (prairies, forests), and animals (wildlife). Man-made ecosystems include urban and industrial centres and agricultural systems. To manage an ecosystem it is implicit that the interrelationships that exist between the various components of the system are understood. For instance, the management of one part of the system (such as, diverting water for irrigation) will affect other parts of the system (as for example the highly nutrient enriched runoff from the surrounding fields). In order to be able to deal with this complex network of interrelations, a decision-maker needs to develop a good knowledge of the ecosystem's structure and the extent to which different components can be exploited without risking the loss of the ecosystem's functional integrity.

Why estimate ecosystem values?

The ecosystem services and goods approach can be useful, allowing the integration of ecological and economic perspectives, enabling scientists and decision makers to link different parts' interests, land use development, and ecological systems conservation in a more feasible and balanced way. The importance of this new point of view is related to the interdependence existing among the different ecosystem services. An analysis of the evolution of each one of them will serve to determine management response actions, as well as the measures that should be implemented when ecosystem services condition is low or shows tendency to decrease. The quality of ecosystem valuations is only as good as the estimates of the changes in ecosystem condition generated by the ecological assessment (Suter 1995). This statement reveals the importance and extent of the inventory and of the determination of conditions and trends, among ecosystem services and goods that compose the initial phase of our assessment. According to Meyerson et al. (2005), it is the ability to report trends in the quantity of ecosystem services/goods that is critical to knowing whether or not these natural resources are being used in a sustainable way. In this context appear the stakeholders' concept that can be defined as those people who use, affect, or otherwise have an interest in the ecosystem. An analysis of their needs, values and perspectives is fundamental to ecosystem management. Stakeholders, in particular local communities, will usually have more interest in safeguarding the ecosystems they exploit if their rights to access and exploitation are recognized. The recognition of land tenure, rights of access or rights to use the natural resources in an area strengthens local incentives for management, and represents an important component of ecosystem-based management. Joint management agreements between local people and state agencies recognize that access rights to natural resource benefits may be coupled with responsibilities for management.

A wide range of goods and services are provided by ecosystems, and specifically by the Mondego estuary, resulting in significant ecological, social and economic benefits. This approach provides a comprehensive and transferable framework for a site specific assessment enabling the costs and benefits of exploitative activities to be evaluated, facilitating management and conservation processes. For this particular case-study, an assessment of the main ecosystem services and goods obtained from the system was performed (Table 1). Nevertheless it was provided a more detailed and exhaustive evaluation on only two of them: food production, water quality and their relation to the biodiversity assets. It is important to note that, biodiversity, although not considered as an ecosystem service, is a key and crucial component of systems, promoting the correct performance of all ecosystem functions.

Table 1. Mondego estuary ecosystem services and goods inventory.

	Category	Service/Good	Description/Function
Goods	Production services	Food production	Extraction of products for human consumption (aquaculture, agriculture, fisheries)
		Raw materials	Extraction of products for other purposes than human consumption (minerals)
		Pharmaceutics	Extraction of products for medicinal or pharmaceutics purposes
		Ornamental resources	Extraction of products for, for example, decorative purposes
		Renewable energy	Extraction of benefits from natural resources (e.g. electricity extraction)
	Cultural services	Eco-tourism	Use of ecosystems for leisure purposes (e.g. museums, parks)
Services		Recreation	Use of ecosystems for refreshment and stimulation by people, through the glance of species in their environment (e.g. bird watching)
		Cognitive values	Cognitive development, including education and research
		Cultural heritage	Value associated with the natural system components (e.g. religion, cultural and spiritual traditions)
		Non-use values	Value which we derive from systems species, without using them
	Regulating services	Gas & climate control	Balance and maintenance of the chemical composition of atmosphere and water by species
		Disturbance regulation	Dampening of environmental disturbances by biogenic structures (e.g. storm, flood or drought protection and mitigation; soil erosion and retention)
		C sequestration	
		Bioremediation	Removal of pollutants through storage, dilution, transformation, or burial (e.g. waste assimilation)
	Supporting services	Nutrient cycling	Storage, cycling and maintenance of availability of nutrients by organisms
		Water quality/availability	System capacity to provide water for human usage (both water usage *in situ* or water withdraw)
		Soil health	Soil fertility, formation and habitat measure
		Nurseries	System capacity to provide habitat band suitable conditions to some species juveniles to develop
		Habitat provision	Habitat provided by and for species and that contribute to a higher genetic diversity
		Pollination	System ability to promote genetic variability
		Resilience/Resistance	Extent to which ecosystems can absorb recurrent natural and anthropogenic perturbations and continue to regenerate

What is the relationship between ecology and economy?

Environmental functions are at the basis for all economic activity and can be described as the 'services' the environment provides to economy. According to Turner et al. (2000), system resilience maintenance and/or enhancement is linked to the ecological concept of functional diversity and the social science analogue, functional value diversity. The latter concept combines ecosystem structure, processes and functions with outputs of goods and services, which can then be assigned monetary economic and/or other values (Figure 1). A management strategy based on the sustainable use of ecosystems should have at its core the objective of ecosystem integrity maintenance, i.e., the maintenance of system components, interactions among them ('functioning') and the resultant behaviour or dynamic of the system.

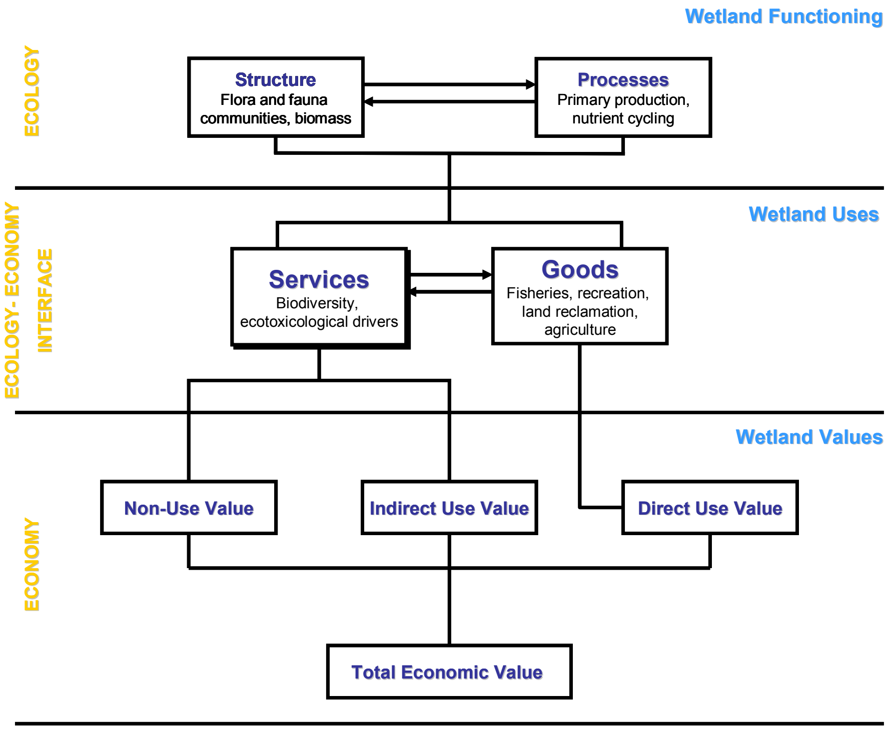


Figure 1. Overall relation between wetlands functions, uses and values (after Turner et al. 2000).

Furthermore, ecosystem services exhibit the two characteristics or properties of economic commodities (Beaumont et al. *submitted*):

i) their consumption increases human utility;

ii) they are scarce as both the natural resources and the funds to preserve them are limited.

The relevant questions to be asked when managing and assessing an ecosystem are where are we going and where we want to go, in order to understand how economic analysis can be used to contribute to the decision making processes. The total economic value (TEV) of an ecosystem service is defined as the total amount of resources that individuals would be willing to forego for increased amount of wetland services. The TEV is divided into different kinds of components:

1. Use values

    i) Direct use values: such as benefits derived from fish, agriculture, or recreation;
    ii) Indirect use values: indirect benefits derived from the wetland functions like nutrient retention, or shoreline stabilization;
    iii) Option value: in which an individual derives benefits from ensuring that a resource will be available for future use.
2. Non-use values
    i) Non-use value: derived from the knowledge that a resource is maintained (such as biodiversity, or cultural heritage).

What are estuarine values?

Estuaries are considered among the most productive and valuable natural systems around the world [for instance Costanza et al. (1997) roughly estimated the average economic value of 17 estuaries of different regions at 22,832 \$ ha $^{-1}$ yr $^{-1}$], acting namely as nurseries and refuges for many fish, bird, molluscs and crustaceans species. In terms of coastal zones' environmental quality and management, estuarine processes are crucial from the ecological and economic points of view, namely in ensuring fisheries' sustainability. Estuaries are expected to support a variety of human activities, ranging from commercial and recreational fisheries to marine transportation to discharge of chemical and thermal wastes. One measure of coastal condition is the assessment and evaluation of an estuary to maintain these human uses. As the demand for certain services increases, human actions often rely on the modification of ecosystems, in order to increase their provisioning capacity. This anthropogenic transformation of ecosystems often enhances the production of some services at the expense of others (Jackson et al. 2001).

The total economic value (TEV) of an ecosystem or environmental resource, established by Boyle and Bishop (1985), relies on identifying the interactions between environmental change and human activity, establishing the link between an environmental function and some service flow valued by people (Turner et al. 2000). The main aim of valuation approaches is to indicate the overall economic efficiency of the various competing uses of ecosystem resources. As so, two main categories may be defined to calculate the total economic values of a system: the use values, that can be further subdivided into a three class system and the non-use values, which relies on the existence value of an area (Table 2).

Table 2. Use and non-use values overview that may comprise the water total economic value for the Mondego estuary ecosystem (adapted from Pearce 1991).

Use values			**Non-use values**
Direct use values	**Indirect use values**	**Option values**	**Existence values**
Recreation	Recreation	Future uses as per direct and indirect use values	Estuarine zone as an object of intrinsic value, as a gift to others, and as a responsibility (stewardship)
Commercial fishing	Biodiversity value		
Agriculture	Landscape		
Industry	Research/Education		
Electricity production			
Drinking purposes	Tourism/Ecotourism		
Biodiversity value	Human health		
Landscape	Aesthetic value		
Research/Education			
Tourism/Ecotourism			
Human health			

How to quantify estuarine values?

Despite their increasing popularity, valuation methodologies are still developing and there still remains significant controversy regarding their use as assessment and management tools (Brito 2005). Several reviews have been published detailing the different valuation methods and the associated difficulties of their application (Farber et al. 2002; Barbier et al. 1997). It can be argued that valuing nature is implicit, by both individuals and society whenever a decision is made regarding environmental resources. According to Beaumont et al. (*submitted*) the use of monetary valuation only formalises this process. Nevertheless, this view can lead to the over-exploitation and degradation of the environment, once that without monetary valuation less apparent ecosystem services and goods (such as nutrient cycling or water purification) can be overlooked or be considered for granted.

Resource valuation involves identifying changes in economic costs and benefits due to changes in environmental impacts. The flow of costs and benefits over time is used to determine the asset value of the resource. Determining changes in the asset value due to the use of resources, or degradation or depletion is the prime economic objective of a resource valuation. Once the change, or potential change, in the asset value of a target resource or ecosystem has been determined, decisions can be made based on the relative economic values that the community places on parts or all of the ecosystem and economic activities under study.

OBJECTIVES

Although there was an attempt to produce a more definitive list of all components, functions and attributes of the estuary, it was necessary to identify the key components, functions and attributes of the wetland under study and to use all the available ecological, hydrological and economic information to score these various characteristics. For more practical reasons (easiness of delimitation) it was chosen to initiate the Mondego estuary valuation by the economic activities taking place in the Morraceira Island and evaluating their impacts on the surrounding biodiversity.

The objective of this work is the evaluation of the environmental status and trends in the Mondego estuary, regarding the aquaculture farms taking place on the system. This study is bifolded and if by one hand it focus on the bilateral relation between this activity development and the progressive abandon of salt-works (where both activities compete for space and have different contributions to the local biodiversity assets), on the other hand it also tries to estimate the cause-effect relation between aquaculture discharges into the system that leads to progressive decline of their conditions, and consequently, of the quality of the uptake fish and water for the aquaculture farms. The main focus will be the relative economic importance a resource to certain activities, what resources need to be protected, or environmental resources minimized, so that economic benefits are protected over the long term. In this case, economic analysis could be used to identify critical economic relationships between activities which use and impact local environments and to support the decision to conserve local environments in order to protect local benefits.

STUDY APPROACH

A. STUDY-SITE DESCRIPTION

The Mondego estuary, western coast of Portugal, is the location of a mercantile harbour (Figueira da Foz). Besides the harbour facilities, the estuary supports industrial activities, salt-works, and aquaculture farms (Figure 2). The major environmental pressures affecting the Mondego estuary are related to agriculture activities, due to the use of fertilizers which caused clear eutrophication symptoms in the ecosystem. Consequently, many studies have been worked out in this ecosystem, namely in the last decade, to understand the ongoing processes and to evaluate the biological effects produced by nutrients increase in the water column (e.g. Marques et al. 1993a, 1993b, 1997, 2003; Flindt et al. 1997; Lopes et al. 2000; Martins et al. 2001). The estuary consists of two arms, north and south, which become separated by an island (Morraceira Island) in the estuarine upstream area, at about 7km from the sea, joining again near the mouth. The two arms exhibit very different hydrographical characteristics. The north arm is deeper (5 to 10m during high tide, tidal range about 2 to 3m), while the south arm is shallower (2 to 4m deep, during high tide) and was almost silted up in the upstream areas, which caused the freshwater of the river to flow essentially through the north arm. As so, the water circulation in the south arm was mostly due to tides and to the freshwater input of a tributary, the Pranto River, which is artificially controlled by a sluice, located at 3km from the confluence with the south arm of the estuary. In addition, due to differences in depth, the penetration of the tide is faster in the north arm, causing daily changes in salinity to be much stronger, whereas daily temperature changes are higher in the south arm (Marques et al. 1993a, 2003).

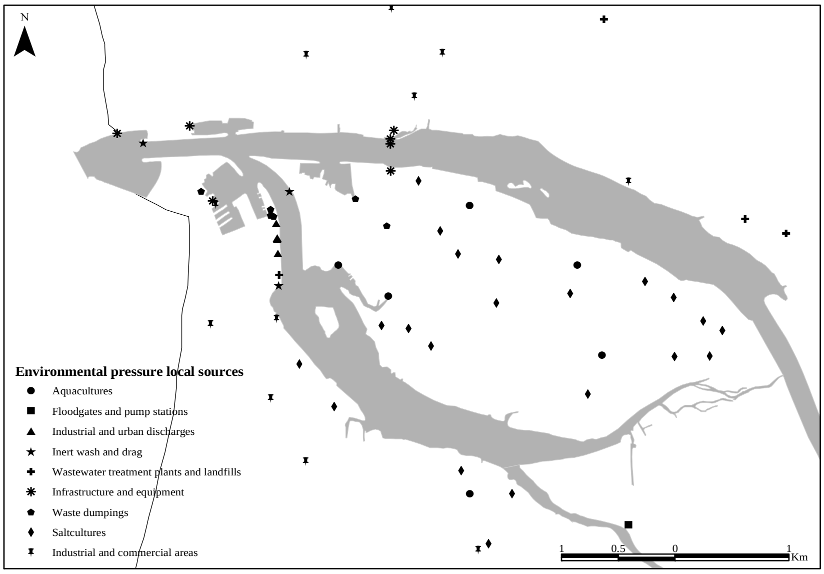


Figure 2. Environmental pressures in the Mondego estuary.

Moreover, the entire estuary is under permanent anthropogenic pressures and several impacts determine its maintenance and development as a system (Marques et al. 2003; Dolbeth et al. 2003). From 1998 onwards, several experimental mitigation measures have been applied attempting to reduce the eutrophication symptoms in the south arm (e.g. reduction of *Zostera noltii* beds). Among the interventions to restore the system environmental quality includes:

- the re-establishment of the communication between the north and south channels by an opening with a cross-section of 1 meter square. This experimental opening showed a subtle decrease in the water residence time in this subsystem; and,
- the diversion of the draining waters from agricultural fields from the Pranto River sluice opening into a channel discharging into the estuarine north arm (this arm presents a higher water flow and a lower water residence time than

the south arm and consequently the effects of extra nutrient supply will cause less impact).

With the experimental opening, water could then enter through the top of the south arm, which led to a reduction in the water residence time. This change, plus the reduction of water discharges through the Pranto sluice affected the production of green macroalgae and allowed the partial recovery of *Z. noltii* meadows (Figure 3). However, these measures have not helped to reduce the oxidized forms of nitrogen and phosphate, and so the input of nutrients into the system remains high.

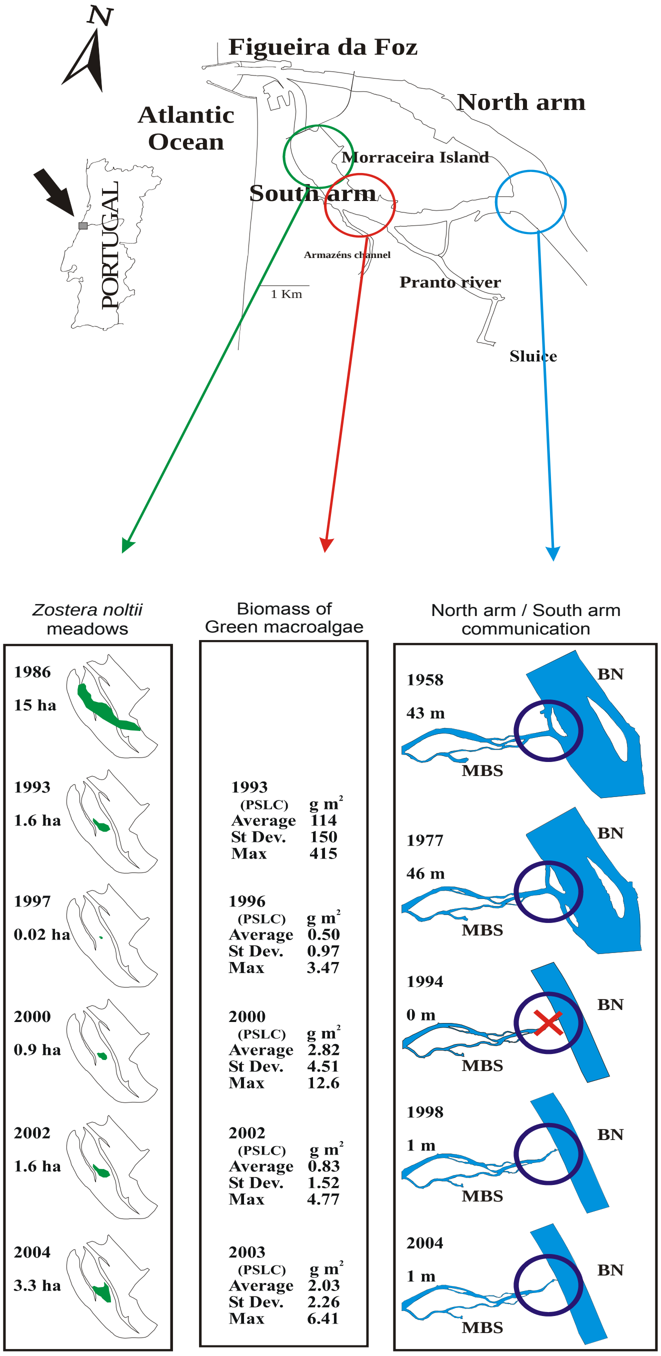


Figure 3. Fluctuation over time of plant cover area (*Z. noltii*), green macroalgae biomass and width of connection channel between the two estuarine arms.

B. METHOD OF ANALYSIS

1. Data Used

Data collection was based on a literature survey of available statistics and existing studies. A data set was chosen to estimate biodiversity and water quality in the Mondego estuary. It was provided by a monitoring programme on the subtidal soft bottom communities, which characterized the whole system with regard to the species composition and abundance and to the physicochemical parameters of water and sediments. Samplings have being carried out in 1990, 1992, 1998 and 2000, in spring, along the two arms of the estuary (Figure 4).

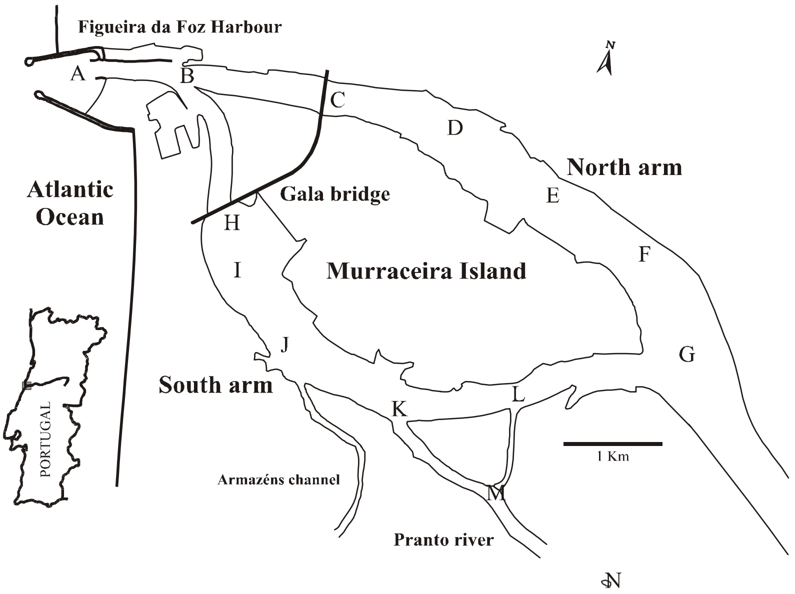


Figure 4. The Mondego estuary. Location of the subtidal sampling stations used to estimate the biodiversity assets and the water quality service.

The Shannon-Wiener (Shannon and Wiener 1963) and Margalef (Margalef 1968) indices were applied to estimate biological diversity. Regarding the food production service the main sources of information have been INE (Instituto Nacional de Estatística), and IPIMAR (Instituto de Investigação das Pescas e do Mar). Besides that, data on the salt extraction were obtained in terms of number salt factories and quantity of salt produced (Tons) produced from 1994 to 2001. Fish farming activities were also taken into account, as it is one of the food producing activities in the estuary, although data obtained concern only the years 1994 and 2003.

- Data requirement for evaluation

i) Ecological approach

Furthermore, the fact that data corresponding to water quality service and biodiversity assets were obtained at a fixed set of sampling stations allowed us to apply analysis of variance (One-way ANOVA) to detect possible significant inter annual differences.

The Shannon-Wiener Index (Shannon and Wiener, 1963) is based on information theory (Zar, 1999) and is one of the most used metrics in ecology. The main goal of this index is to determine the species diversity (relative species abundance). It combines the components of species richness and the distribution of populations of a species (evenness). It assumes that individuals are sampled randomly and that all the species are represented in the sample. It is given by:

$$H' = -\sum pi \times \log_2 \times pi$$

where p_i is the proportion of individuals found in the species i. In the sample, the real value of p_i is unknown, but it is estimated through the ratio Ni/N, for Ni=number of individuals of the species i and N=Total number of individuals.

The index can take values between 0 and 5, representing the progressive increase of diversity (Table 3). High species diversity values usually indicate diverse, well-balanced communities (higher diversity as influenced by a greater number or a more equitable distribution of species); while low values indicate stress or impact. In the literature, index low values are considered an indication of pollution.

The index is highly affected by the middle species, while the abundances of the common and rare species have less influence on the values (Kennish, 1986).

Table 3. Shannon-Wiener scores ranges and correspondent WFD classifications.

Index Value (bits/ind)	Classification
> 4	High Status
3 – 4	Good Status
2 – 3	Moderate Status
1 – 2	Poor Status
< 1	Bad Status

The Margalef Index (Margalef, 1958) is based on how specific richness is related with the total number of individuals giving this way a quantitative measure of community diversity. The formula of this index is:

$$D = \frac{(S-1)}{\log_2 N}$$

where S is the number of species; and N the total number of individuals.

One disadvantage of this index is that the absence of a limit value makes it difficult to establish reference values.

ii) Activities valuation

The following are some of the data collecting techniques useful in quantifying various resources or activities (Table 4):

Table 4. Valuation methods and data requirement for the assessment of the ecosystem services under evaluation in the Mondego estuary.

Resource/Activity	**Aquaculture farms**	**Salt-works**
Valuation Method	Change in productivity method Market price method Contingent valuation method	Change in productivity method Market price method Contingent valuation method
Data requirement	Catch/effort Size of the fishing fleet (including number of fishermen) Cost of fishing (wages and fuel costs) Prices of fish by species Species composition of catch Type of fishing gear Boat capacity and type Area of wetlands Water quality Any other information relevant	Catch/effort Cost of extraction (wages and fuel costs) Area of wetlands Water quality Prices of salt Any other information relevant

For start, the productivity method and the market price method will be applied. Further development and studies will allow the contingent valuation method application (after the performance of surveys to local communities). When the type of data consisted of a complete long-term series, trend lines were built using the method of the least squares, reflecting the development to be expected over time. In the case of incomplete temporal data series a simple method was used, dividing data in the last year by the data of the first year of the period considered. Despite being simple, this method is well straightforward to detect trends when the quality of the data does not allow us a more sophisticated analysis.

2. Valuation Procedure

- Choosing the appropriate assessment approach

Based on the full range of ecosystem services and goods identified (Table 1) and specifically on the Mondego estuary water usage and corresponding benefits/values (Table 2), it was crucial to identify the appropriate economic assessment approach, based on the particular features that compose and determine the development of the system under analysis. According to Rmachandra & Rajinikanth (2001) there are three approaches or issues most relevant to the economic analysis of wetlands (Figure 5):

i) Impact analysis– would be appropriate if the problem is a specific external impact (e.g. effluent from a textile industry polluting a wetland, oil spills on a coastal wetland, etc.);

ii) Partial valuation– would be suitable if the problem is the necessity of making a choice between wetland use options (e.g. conversion of wetland to residential land or sports complex, whether to divert water from the wetlands for other uses, or to convert/develop part of the wetlands at the expense of other uses);

iii) Total valuation– if the problem is more general (e.g. developing a conservation/restoration strategy requires assessment of total net benefits of the wetland system).

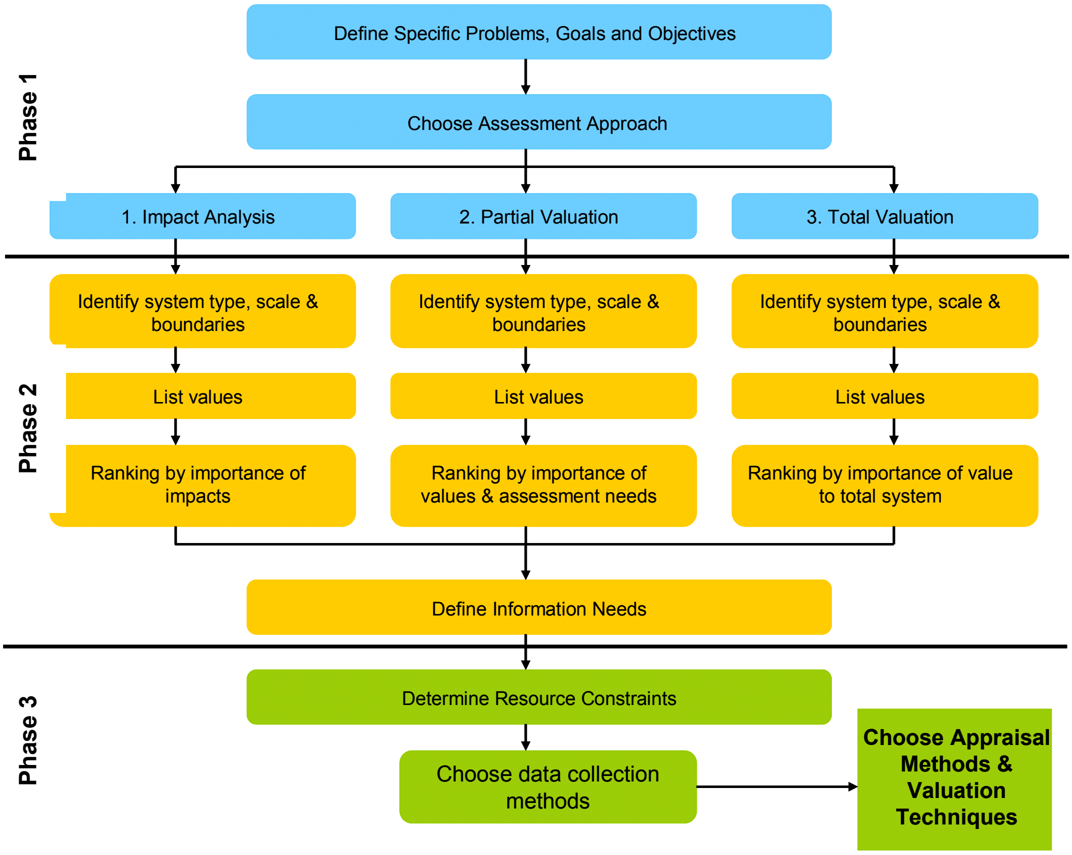


Figure 5. Trifolded economic approach to assess a wetland value (adapted from IIED 1994).

- Methodology description

Economic valuation includes every accountable item in a financial valuation (costs and benefits directly associated with a project) plus any costs and benefits which do not affect financial results but affect or will affect, positively or negatively, the wider economy, e.g. water pollution costs.

i) Productivity method

The productivity technique, mostly due to its broad applicability and flexibility in using a variety of data sets, consists of tracing through chains of causality the impact of changes in the condition of an ecosystem so that it can be related to measures of human well-being. Such impacts are often reflected in goods or services that contribute directly to human well-being (such as production of crops or of clean water), and as such are often relatively easily valued.

ii) Market price method

Using market transactions as an indicator for value is the most commonly used valuation approach. Given that goods and services are exchanged in the market place, the value people place on the commodity is reflected in its price. Prices are therefore used to determine an ecosystem feature value. Market price methods rely on observing changes in prices for goods and services that are traded in a market, based on a change in environmental quality.

RESULTS

1. Ecological perspective analysis

1.1. The discharge of waste nutrients and their interaction in the environment

Having as main focus the interactions between the activities currently on going in the Morraceira Island and the water column and biodiversity attributes of the Mondego estuary is possible to identify and categorize several types of relations, with different intensities and degrees of actions (Figure 6). Besides the direct relation between the salt-works replacement by aquaculture farms, it is possible to observe that the several components are always interlinked and overlap in several system functions. Moreover, it is possible to observe that the aquaculture farms and the salt-pans systems have opposite effects on local biodiversity. While the salt-pans, through the provision of specific habitats for some migratory and resident bird species increases local diversity, aquaculture farms, through the release of highly nutrient enriched waters into the system, provokes a decrease on biodiversity assets both directly (such as in macroinvertebrates communities) as indirectly (affecting the water quality and so the fish communities present in the system). Furthermore, it is possible to see that the water quality influences the salt-pans environmental quality and the aquaculture production itself, once that the aquaculture production system allows the entrance of the estuarine water and fishes into the tanks, where the animals grow, and after the process completed, the water remaining and some fishes are released again into the system.

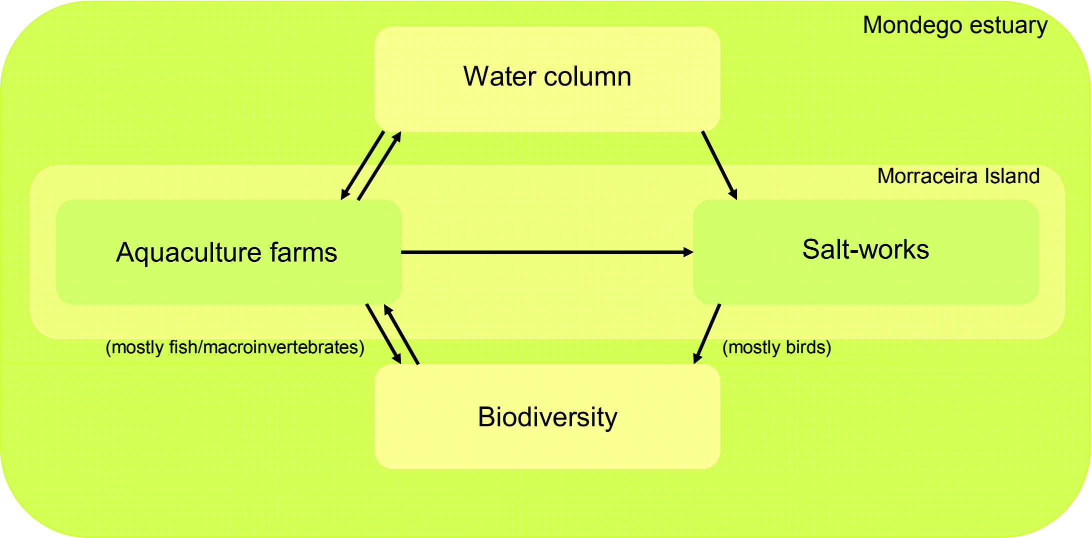


Figure 6. Interrelations between the environmental components and system features in the Mondego estuary.

Results obtained from the analysis of physicochemical parameters throughout a decade (1990-2000) in the two arms of the estuary show that the concentration of nutrients in the water column significantly increased (*p*<0.001) (Table 5). Such increment gives rise to classifying the system as under low eutrophication in 1990, following the criteria for the assessment of water quality proposed by Briker et al. (2003) (see Table 6), whereas in 2000 the system turns to be considered as medium eutrophied.

Table 5. Application of a One-way ANOVA test considering the nutrient concentrations obtained in 1990 and 2000 (*p*<0.05).

		NO_3^{2-}		
	n	Mean	*F*	*p*
1990	13	0.008	29.40	1.25 E-05
2000	14	0.045		
		NO_2^{2-}		
	n	Mean	*F*	*p*
1990	13	0.058	11.92	0.001
2000	14	0.170		
		PO_4^{2-}		
	n	Mean	*F*	*p*
1990	13	0.016	22.73	6.79 E-05
2000	14	0.034		

Table 6. Criteria for assessment of nutrients' levels in transitional water (in Bricker et al. 2003).

Quality status	**Nitrogen (mg/l)** (maximum dissolved surface conc.)	**Phosphorus (mg/l)** (maximum dissolved surface conc.)
High eutrophication	≥1	≥0.1
Medium eutrophication	≥0.1 - <1	≥0.01 - <0.1
Low eutrophication	≥0 and <0.1	≥0 and <0.01

In the study period, symptoms of eutrophication were in fact evident in the South arm of the estuary, appearing to be related with water circulation problems, and not only with nutrients loading. The most visible feature of this environmental stress was the occurrence of seasonal green macroalgae blooms (mainly of *Ulva* spp.), which have been reported in the south arm for several years (Marques et al. 1993a, 1993b, 1997, 2003; Flindt et al. 1997).

1.2. Effluents discharges and their impacts on biodiversity

For estimating biodiversity impacts it was used the estuarine macroinvertebrates communities. In 1990 samples carried out on the Mondego estuary subtidal communities, which provided an average 10297 macroinvertebrates per m^2 belonging to 31 species. Polychaetes were the dominant phylum (87.56 %), while 7.9% were molluscs, 8.9 % crustaceans and 3% of all taxa belonged to minor phyla. This proportion of the different groups stands approximately the same in 2000, but with a lower number of individuals (8018 per m^2), and a higher number of species (48). Overall, the dominance of certain species, such as *Alkmaria romijni*, *Cyathura carinata*, *Hediste diversicolor* and *Scrobicularia plana* was clearly stated in the estuary. Biological diversity of subtidal communities measured by Shannon-Wiener diversity index, are in a range from 1 to 3 bits/ind, with most of the sampling stations exhibiting low values near to 1 (Table 7). Similarly, values of the Margalef index show low figures (Table 8), which in rare occasions (like in station I in 1990) go beyond 3.

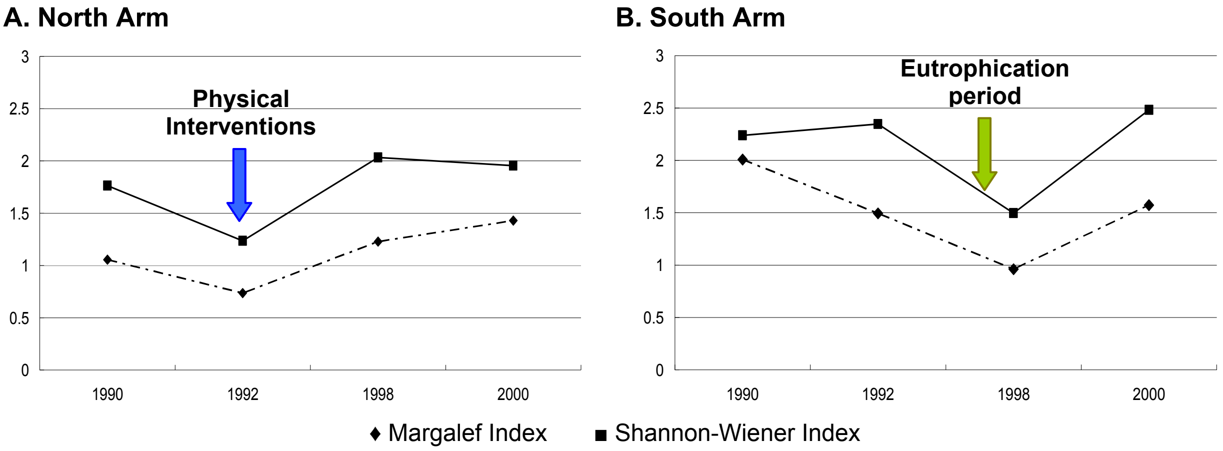
Table 7. Values of the Shannon-Wiener index estimated at the sampling stations in the Mondego estuary (campaigns from 1990 to 2000).

	Shannon-Wiener Index			
Stations	**1990**	**1992**	**1998**	**2000**
A			2.64	0.90
B	1.55	1.73	2.45	3.44
C	1.50	0.96	1.36	2.40
D	1.84	2.44	2.77	1.84
E	1.55	0	2.14	0.65
F	2.94	1.75	2.61	1.37
G	1.20	0.54	0.87	2.03
H	2.55	2.94	0	2.55
I	3.11	2.41	1.43	2.92
J	1.22	2.73	2.03	2.51
K	0.71	1.88	1.91	1.46
L	1.61	1.44	1.66	2.39
M	1.93	2.34	1.32	1.68
N	2.30	0.34	0.63	1.38

Table 8. Values of the Margalef index estimated at the sampling stations in the Mondego estuary (campaigns from 1990 to 2000).

	Margalef Índex			
Stations	**1990**	**1992**	**1998**	**2000**
A			2.32	1.44
B	0.91	1.25	1.08	4.01
C	0.76	0.71	0.89	1.52
D	0.94	1.37	1.99	0.89
E	0.99	0	1.26	0.27
F	1.94	0.73	1.55	0.66
G	0.79	0.36	0.60	1.23
H	1.46	2.01	0	1.73
I	3.14	1.46	0.94	1.99
J	2.10	1.91	1.07	1.34
K	1.17	1.32	1.25	1.02
L	1.57	0.71	0.81	1.43
M	1.24	1.17	0.98	1.14
N	1.37	0.38	0.72	0.79

The analysis of the Shannon-Wiener and Margalef indices (Figure 7) allowed some pattern observations of the ecological condition of the macrobenthic communities on the Mondego estuary. During the study period significant changes occurred. The system was divided in south and north arms due to the different hydromorphological differences between the two sub-systems. It is possible to observe that the north arm presents a strong biodiversity decline in 1992 and after it shows some recoveries (Figure 7A). This situation may have been caused by the regularization actions made on this system. The south arm presents also a significant biodiversity decline, reaching its peak in 1998; nevertheless, this reduction was provoked by the eutrophication symptoms felt in this sub-system. Since the mitigation measures to recover the system diversity began the system started to improve its condition (Figure 7B).


A. North Arm

B. South Arm

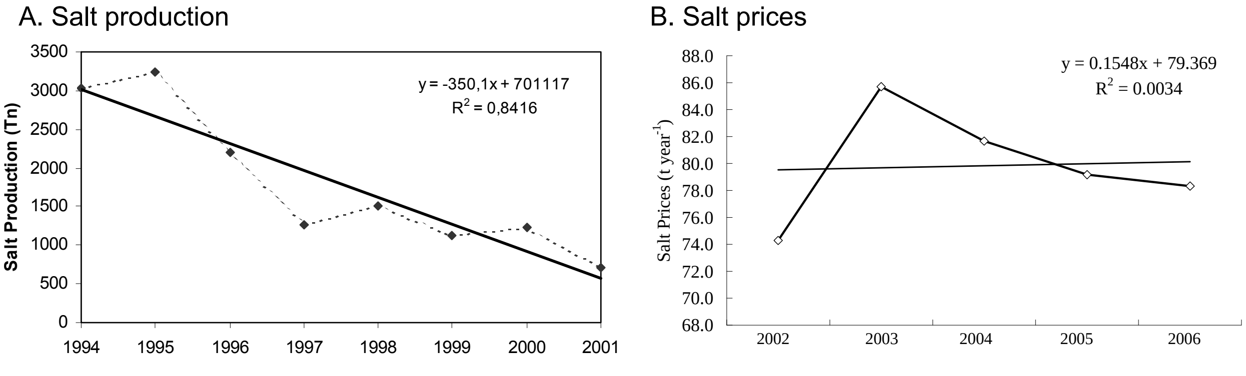
Figure 7. Margalef and Shannon-Wiener indices behaviour along our study period, in the sub-systems: A. north arm, and B. south arm in the Mondego estuary.

Such values might indicate, according to the European Water Framework Directive (WFD; 2000/60/EC), a poor to moderate ecological status, following the classification developed by Molvaer et al. (1997) for the Shannon index and by Bellan-Santini (1980) and Ros et al. (1990) for the Margalef index. On the other hand, with regard to the intertidal communities, several studies showed during this study period that the *Z. noltii* beds, which represent the richest habitat with regard to productivity and biodiversity (Marques et al. 1993b, 1997), have been drastically reduced in the south arm of the Mondego estuary, most likely as a function of competition with *Ulva* spp., resulting from the different strategies of macroalgae and macrophytes to uptake nutrients, and also from the shading effects of macroalgae on macrophytes (Hardy et al 1993; Hartog 1994). In fact, in the beginning of the 1980s, the *Zostera* beds covered a large fraction of the intertidal area, extending to the upstream section of the south arm, along the Morraceira Island, while by the end of the 1990s this species distribution was restricted to its downstream section. To try to solve this situation some mitigation measures were implemented, and after 1998 the *Zostera* beds started to recover.

2. Economic perspective analysis

2.1. Production and value of production: Aquaculture *vs.* Salt-works

Salt production is another activity still present in the Mondego estuary, although high costs resulting of the traditional way of extraction, together with the great offer of product in better conditions from other areas of the country and abroad, have lead to its progressive decline (Figure 8A) due to the production units abandon.


A. Salt production

B. Salt prices

Figure 8. Trend lines showing evolution of the amount (A) and prices variation (B) of salt production in Mondego estuary.

Since the 80's some of the inactive saline industries have been reoriented into fish farming factories, mainly of intensive production, where local species like *Sparus aurata* and sea bass (*Dicentrarchus labrax*), are grown. Despite the fact that the area devoted to fish farming has been increasing in the estuary, the same has not occurred with regard to production. In fact, the total production in 2003 was 200 tons per year, while ten years before each company devoted to such activity produced approximately 120 tons per year. The drop in the fish farming production appears to be mainly related to water quality, since presently it is only possible to cultivate 1kg.m^{-3}, compared to the 2-3kg.m^{-3} obtained in the past. The nutrients enrichment of the system and the subsequent eutrophication effect, leading to a fall in the oxygen dissolved in the water column, might have been affecting the survival of the organisms.

2.2. The Value, and economic impact, of aquaculture

When considering the development options for a specific environmental resource, as the increasing exploitation trend of aquaculture farms, it should be not only taken into account the direct costs of this conversion, but also the lost values that the converted resource can no longer continue providing. In this specific case, we have values such as amenities, biological resources, important trophic links in the environmental networks, as well as important environmental functions. Nevertheless, as most of these values (exception made for the salt obtained and that can be sold, Figure 8B) have no market price, their disappearing is not directly perceived and recognized by national or even local populations during decision processes.

DISCUSSION AND GENERAL CONCLUSIONS

On top of the environmental problems, social, cultural and economical ones are overlapped, finding then those activities are never isolated or take place in the environment through cause effect linear relations, otherwise they interact, meet and compete for area, summing effects up and producing there a complex net of interrelations which make even more difficult to analyze the situation. A typical example of the interaction of different activities can be seen in the Mondego estuary, and such interaction is one of the factors that influence on the condition of ecosystem services.

Overall, human activities cause a series of environmental damages and stress, which may alter natural processes in ecosystems. The most important problems in aquatic environments have to do with the input of nutrients (eutrophication), erosion, and the input of swept away materials from the land (increase of water turbidity), the sewage drain and the alteration of water quality, microbiological pollution, changes in the original structure of the communities and input of aloctone species, pollution in general, habitat destruction and loss of diversity (Marcos and Pérez-Ruzafa 2003). Regarding the eutrophication, Bricker et al. (1999) identifies a range of ways in which the services flow offered by an estuary may be diminished by deteriorating water quality. Bricker et al. (1999) refer to these as “estuarine use impairments” following from increased enrichment and examples include loss of habitat and its integrity impacting on commercial/recreational fisheries and on tourism, human health and water sports. The subtle decrease in the estuarine water quality and consequently of biodiversity is a clear demonstrations of the impacts that poorly designed environmental measures may have on local systems. In general, the increasing concentration of nutrients in the water column due to the waste of both agriculture and aquiculture activities produces not only a worsening in water quality, but influences also the aquiculture production itself. On top of that, the worsening in water quality tends to affect the diversity of the aquatic communities. At present, with regard to the subtidal communities, diversity appears to be improving its status, after the mitigation measures and management procedures undertaken. A lower biological diversity in benthic communities, that serve as food for many fish species, might then, eventually, originate a decrease in the fishing production.

Besides, regarding the food production service, if we focus on the salt extraction activity, it is reasonable to consider that a decrease in the area occupied by salt will not only mean an obvious drop in local salt production, but also an inconvenience to many bird species (and consequently to biodiversity), as salt pans constitute an important area for waders foraging and breeding, acting as a complementary habitat of salt-marshes during high-water periods. This system is one of the main stopover and refuge areas for migrating birds along the northwestern coast of Portugal and is particularly important for waders, especially for species as the Pied avocetta (*Recurvirostra avosetta*) and Greater Flamingo (*Phoenicopterus rubber*). During the breeding season the site is regionally important for species such as Black-winged Stilt (*Himantopus himantopus*) and Little Tern (*Sterna albifrons*). Portuguese salt-pans are usually regarded as mainly providing supplementary feeding over high-water, on the assumption that this habitat is less suitable than the mudflats for most waders (Rufino et al., 1984; Múrias, et al., 1997, 2002; Luís, 1999; Lopes et al., 2001). In the Mondego estuary, for example, up to 42% of the total number of waders present can be found feeding in the salt-works at low-water, irrespective of the season, against some 70% at high tide (Múrias et al., 2002). The lack of winter management of this habitat also causes many ponds to be flooded from October to March, thus preventing their use by birds over that period (Múrias et al., 1997). Nevertheless, the salt-pans may still play an important role by providing both extra feeding places and extra feeding time at low-water and at high-water (Múrias et al., 2002) and this system was considered as a Ramsar site Ramsar site 1617). Consequently, their loss may be detrimental to many species. The loss of salt-pans would affect the feeding conditions of the birds in two ways. It would remove feeding areas in the salt-pans, thereby reducing the total quantity and area of food available to the birds over low-water. It would also remove a source of food that is used over high-water by birds that, over low-water, feed either in the salt-pans or on the inter-tidal flats of the estuary itself. It would therefore reduce the amount of time available to all birds for feeding from its present level of 12.15 h/tidal cycle to ca. 8 h/tidal cycle; i.e., the time for which the intertidal mudflats are exposed (Múrias et al., 2005).

Biodiversity in the broad sense is the number, abundance, composition, spatial distribution, and interactions of genotypes, populations, species, functional types and traits, and landscape units in a given system (Díaz et al. 2006). Biodiversity influences ecosystem services, that is, the benefits provided by ecosystems to humans, which contribute to making human life both possible and worth living. As well as the direct provision of numerous organisms that are important for human material and cultural life, biodiversity has well-established or putative effects on a number of ecosystem services mediated by ecosystem processes. Also, by affecting ecosystem processes such as biomass production by plants, nutrient and water cycling, and soil formation and retention, biodiversity indirectly supports the production of food, fibers, potable water, shelter, and medicines. The links between biodiversity and ecosystem services have been gaining increasing attention in the scientific literature of the past few years (Díaz et al. 2006); nevertheless its direct connection to the provision of services and goods is still unclear. More information linking biodiversity to the provision of goods and services, or ecosystem function, is essential to a full understanding of the implications of declining biodiversity on society and economy.

Despite the trends analysis, the market economy fails to regulate the flow of pollution into the environment, known as a negative externality, or negative consequence of a human activity, the costs of pollution are not experienced by the polluter. As so, the social costs of pollution, i.e., the lost income due to the bird nidification spots or migratory routes across the Mondego estuary, due to the loss of their habitat (salt-pans), may be greater than the private cost, i.e. no private costs associated with the aquaculture water tank release into the environment and water contamination. Others in society pay an economic price to an environmental impact that hey may not have caused. Although the reflexion in the number of visitors and people that spend their leisure time in the island may suffer decreases, this impact has also consequences in the biodiversity value of the area, for example the system is a nidification spot for species as the Greater Flamingo that are one species highly valued by public opinion. Nevertheless, in order to achieve a precise measure of this impact and relation, a survey must be conducted in the area to evaluate the value that people give to the system’s natural features.

A wide range of goods and services are provided by the Mondego estuary, resulting in significant social and economic benefits. According to McMichael et al. (2003), a conceptual framework for understanding the variable and often apparently contradictory relationship between ecosystem services level and human well-being is illustrated on Figure 9.

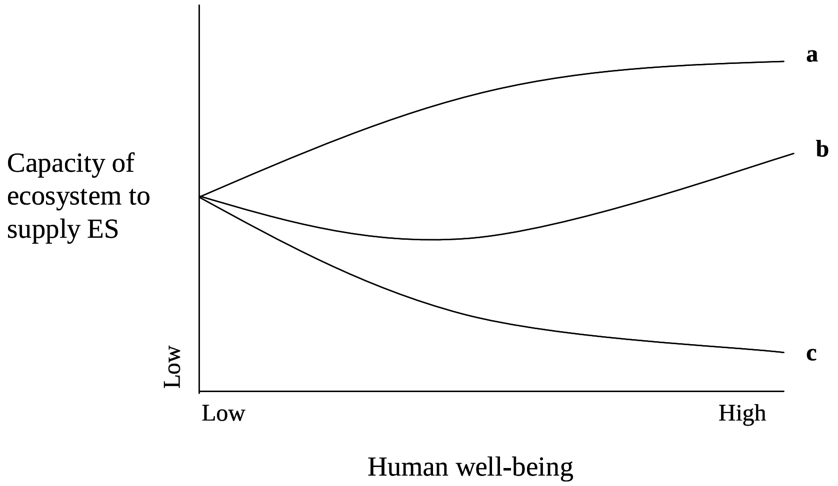


Figure 9. Examples of some possible shapes of the relationship between human well-being and ecosystem services supply. The hypothesised relationship are for a single ecosystem service, from a particular location, followed over time as the human well-being in that location increases over time. In some cases, such as food production (a) the capacity rises to an asymptote. In others, such as services related to biodiversity (c) it typically falls to an asymptote. Yet, in others, such as water quality (b), it may initially decline the recover somewhat (adapted from McMichael et al. 2003).

In general, we are lead to think that any measure undertaken to improve any of the ecosystem services in isolation will directly or indirectly have repercussions on the other ones. Possibly, at the moment, the water quality service is the one that requires a higher attention as it influences in a great extent on the evolution of the others. Despite the impacts that each of the activities around the estuary may have on the ecosystem it is important to retain that all are for the economy of the whole area of the Low Mondego River Valley. Therefore measures that might be undertaken must account for this socioeconomic reality.

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