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Viewpoint

Assessing estuarine quality under the ecosystem services scope: Ecological and socioeconomic aspects

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ABSTRACT

An increasing need for integrative assessments that measure the contributions of the environment to human welfare has recently been recognised. In the present study, a preliminary assessment of the services provided by the Mondego Basin in terms of system ecological quality was carried out. The ecological, economic, and societal relations of the Mondego estuarine services were analysed. An inventory of the main ecosystem services provided by the Mondego system was performed. The conditions and trends of the main services (food production, recreation and water quality maintenance) were determined, and the scale dependence of this assessment was interpolated on three different scales: Mondego Basin, Lower Mondego, and Mondego Estuary. The interdependence among services was quantified; an ecological assessment regarding water quality and ecological conditions was performed, and a preliminary valuation of the food production, recreation and tourism in the region was undertaken. In the study system, from 1992 to 2006, there was an increase in recreation activities and water uses and a simultaneous decrease in services such as food production (i.e., strong interdependence among services). Ecological quality improvement is reflected in both local communities' diversity and water quality. The market prices method was used to estimate the values for the three services considered; however, the Mondego catchment's full value cannot be calculated without estimating the real wetlands value because these are prone to underestimation. Uncertainties and shortcomings regarding the reliability of this kind of assessment for implementation on estuarine ecosystems are discussed.

1. Introduction

Most of the ecosystem analysis approaches adopt an anthropogenic perspective where the stocks of natural assets found within the system are connected to the flow of services that provide benefits to human society (Costanza et al., 1997; Turner et al., 2000; de Groot et al., 2002; Farber et al., 2002; MA, 2005). By definition, ecosystem goods (e.g., food) and services (e.g., water purification), hereafter ecosystem services, represent the benefits human populations derive directly or indirectly from ecosystem functions (Costanza et al., 1997). As such, ecosystem services are generated by ecosystem functions, which in turn are underpinned by biophysical structures and processes inherent to the system (de Groot et al., 2010). These concepts have been used by the Millennium Ecosystem Assessment framework (MA) (MA, 2005) to represent the flow of benefits to society generated by natural ecosystems and their consequences for human well-being. According to this framework, four categories of services were established (MA, 2005): provisioning (products obtained directly from the ecosystems); regulating (benefits obtained from the regulation of ecosystem processes); cultural (nonmaterial benefits people obtain from ecosystems through cognitive development and aesthetic experiences, for example); and supporting (those benefits that are necessary for the production of all other ecosystem services).

Through the integration of the ecosystem's inherent processes, the associated biodiversity and its sustainable use, the ecosystem approach focuses on conserving natural systems for their inherent value and for human well-being (Vitousek et al., 1997; Nunes and Bergh, 2001; de Groot et al., 2010). As so, it is necessary to identify all costs and benefits to the ecosystem of different human activities in order to protect the system's biodiversity and promote its sustainable use (Nunes and Bergh, 2001; Folke et al., 2004). This may be achieved through the identification of the impacts of human activities and through the quantification of their consequences for the supply of ecosystem services. When valuating a system, the intent is to provide a value for a specific asset, and to trace its condition and importance over time. This includes not

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only the ecosystem services that have a market price (e.g., agriculture products) but also services that currently have no market prices (e.g., disturbance regulation). According to Beaumont et al. (2006), there are two distinct approaches to working with the ecosystem services concept. Among economists, economic valuation methods prevail, which focus on the exchange values of ecosystem services (based on consumer preferences and cost-benefit analyses). On the other hand, there are ecological valuation methods that employ a more sustainability-oriented perspective, which are mainly advocated by natural scientists and ecologists, that derive ecological prices (measurement of biophysical units, rather than social or economic in nature) for ecosystem services via a cost-of-production approach (i.e., by modelling the interrelations between the biotic and abiotic components of a system). According to Costanza et al. (1997), both fields take into account concerns regarding the scale of the economy, distribution and efficient allocation of resources. Two scale-related problems are encountered when assessing ecosystem services (Heal & Kristrom, 2005): (i) the scale at which certain functions become important is not always the same and (ii) problems may arise when integrating and aggregating information at multiple scales where interrelations and feedback loops may operate at scales above the level being assessed. According to Limburg et al. (2002), scaling rules that try to describe the provision and delivery of ecosystem services have yet to be quantified and defined.

Using the Mondego estuary as a case study, we conduct a preliminary assessment of the services provided by the Mondego Basin under the constraint of the present limited data availability. Moreover, the aim of this work was to analyse the ecological/economic/societal costs and benefits of estuarine ecosystem services, giving special attention to their quality status, along the lines of the ecological sustainability trigon approach proposed by Marques et al. (2009). Specifically, we aimed to accomplish the following:

(i) provide a comprehensive inventory of the ecosystem services provided by the Mondego system;
(ii) determine the conditions and trends of the main ecosystem services;
(iii) interpolate the scale dependence of such assessments using three different spatial scales: the Mondego Basin, the Lower Mondego Valley, and the Mondego Estuary;
(iv) estimate the interdependence among services;
(v) perform an ecological assessment regarding water quality and ecological conditions; and
(vi) perform a preliminary valuation of the food production, recreation and tourism in the region.

2. Methodology

A generic framework has been implemented, assuming several steps in the ecosystem services valuation, together with the methodological tools necessary to provide a more comprehensive assessment. First, the characterisation of the system's condition and main uses was undertaken at different spatial scales. Second, an inventory of the main services provided by the Mondego Basin was carried out. It is important to note that biodiversity, despite not being considered an ecosystem service, was included in the assessment because it is assumed to play a necessary role in all of the considered services by promoting the correct performance of all ecosystem functions (Marques et al., 2009). Based on this inventory, the conditions and trends of the main considered ecosystem services were assessed and the interdependencies among them evaluated. The next step involved an ecological assessment of the main services and their relations with the biodiversity assets. Finally, the ecological valuation perspective was combined with a range of economic valuation methods (i.e., the economic perspective) in an attempt to provide a preliminary system valuation.

2.1. Spatial scales of the system and scale dependence

The Mondego Basin is located in the centre of Portugal and covers a 6670-km^2 catchment area with highly diverse characteristics in terms of hydrology, land use, and topography. It presents a peculiar and unique functional structure ranging from mountainous areas to a large alluvial plain discharging into the Atlantic Ocean (Marques et al., 2003) and supports a population currently estimated at 885,561 inhabitants (2006 data). The system can be divided into three main regions (PBH Mondego, 2001; Fig. 1):

(i) *Upper Mondego*: basin area located in the "Serra da Estrela" mountain range at the river headwaters, where it travels through glacial valleys.
(ii) *Middle Mondego*: basin area between the base of the "Serra da Estrela" and the city of Coimbra, where the river passes through deep valleys.
(iii) *Lower Mondego*: the final part of the river course, consisting of open valleys and plains, including the Mondego estuary ecosystem and a thick dune belt along the coastline.

Overall, the Mondego Basin has a high natural variability in environmental and social conditions (Table 1). In each of the three main regions, the secondary and tertiary sectors are well represented in the economic activities. However, in the Lower Mondego, a strong pressure is also evident from the abundant agriculture fields (primary sector), as well as from Figueira da Foz harbour. In summary, we may say that at the Basin level industrial activities related to wood extraction (due to the vast forest area), together with the glass, ornamental resources and beverage industries, dominate the economic activities taking place in the system. More specifically, in the Lower Mondego region (near the coastal area), the paper industry and aquaculture play the largest economic roles. The fibre and leather industries have the dominant position among the economic activities in the Upper Mondego area (PBH Mondego, 2001). These variations influence the system's management, water uses, and land occupation rates.

Under the Millennium Ecosystem Assessment (MA) scope, three main areas at different scales were considered for this study (Fig. 1): the Mondego Basin (basin scale), the Lower Mondego Valley (regional scale), and the Mondego Estuary (local scale). The scale dependency was mostly examined to infer the effects of upstream activities on local estuarine resources. To this end, several parameters were taken into account, including not only socioeconomic factors such as demographic pressures or activities around the basin but also ecological factors such as nutrient sources.

2.2. Comprehensive inventory of ecosystem services

The goal of the ecosystem services inventory was to provide a set of alternative ways to valuate estuarine services and thus provide insight into the economic perspective within the ecosystem approach. Several services provided by wetlands ecosystems have been identified (Costanza et al., 1997; Acharya, 2000; Atkins and Burdon, 2006). From this available set of services we considered two main factors that determine the Mondego Estuary services: the importance of its natural resources stock to local populations (i.e., estimation of their dependency upon the system) and the ecological importance of the system to the intrinsic biodiversity and human well-being (Fig. 2).

For the inventory assessment, several methods were considered, taking into account their specificities, to evaluate ecosys-

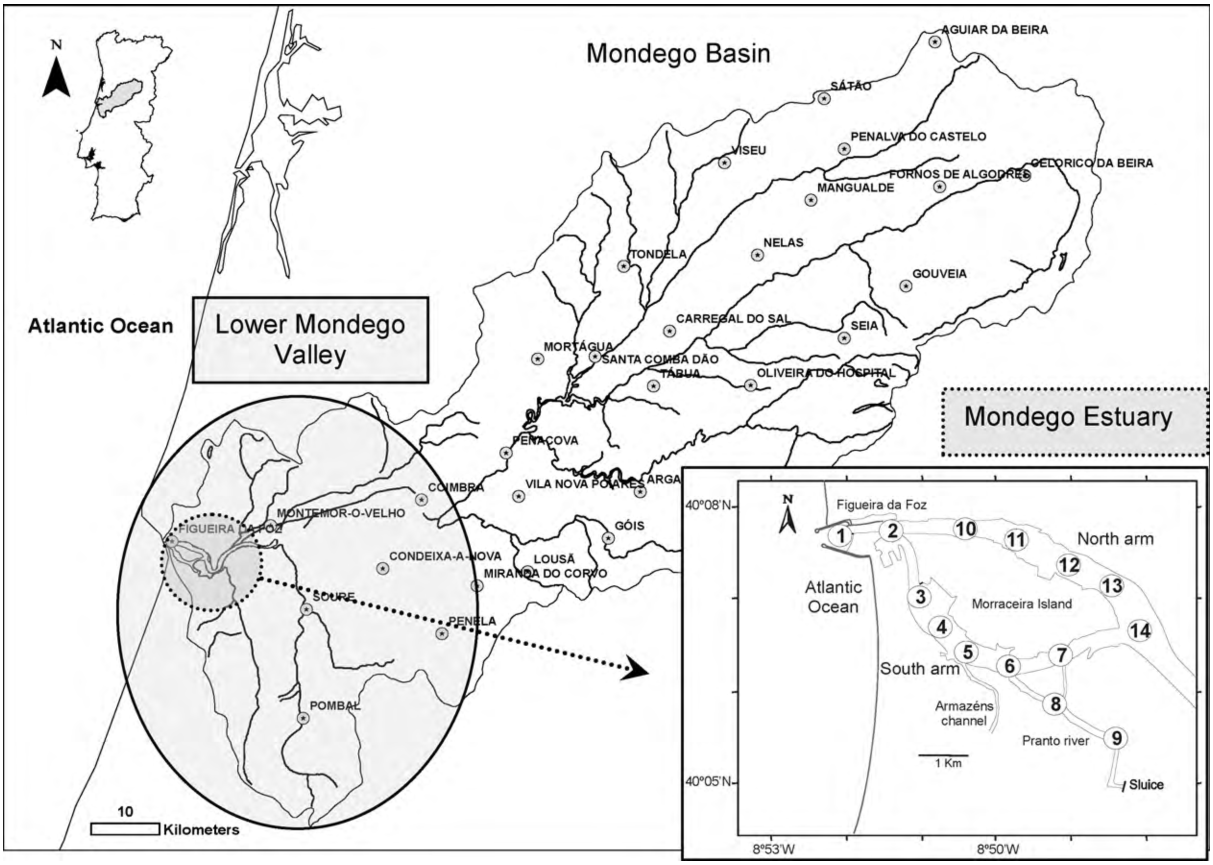

Fig. 1. The three different study site scales: Mondego Basin; Lower Mondego Valley; and the Mondego Estuary (with subtidal sampling stations).

tem services. In the total economic value (TEV) method, ecosystem services can be divided into use values and non-use values (Loomis et al., 2000; Turner et al., 2000; de Groot et al., 2002; Young, 2005; Atkins and Burdon, 2006). Generally, wetlands' non-use values (i.e., existence or bequest values) may be estimated through the use of contingent valuation methods (CVM). Within the wetlands' use values, three main categories can be identified: direct use values, which include services such as food production and tourism; indirect use values, e.g., recreation or aesthetic values; and option values, where benefits come from ensuring that a resource will be available for future use. Usually, the direct use values can be calculated through methods such as market analysis prices (MP), productivity loss (PL), hedonic pricing (HP), travel cost (TC), replacement/restoration costs (RRC), or even CVM. The indirect use values can be estimated through such methods as the damage costs (DC), production function (PF), HP, RRC, or CVM. The option values can also be assessed through the use of the CVM technique. According to Seyam et al. (2001), the use value derived from a certain production or information function is calculated as the product of the marginal value of the function and the area of the wetland that contributes to the function. The assumption is that there is a linear relationship between the area of the system that contributes to a certain function and the use value delivered by that function.

2.3. Conditions and trends of main ecosystem services

For the conditions assessments, the evaluation was performed based on the analysis of secondary data, i.e., data collected from the literature (available statistics and studies) and preferably published by governmental institutes (National Institute of Statistics–INE; www.ine.pt), for the period of 1992–2006.

For the trends analysis, we considered the evolution of the main services in the region between 1992 and 2006. The objective was to measure the productivity changes of an environmental resource to determine the actual benefit obtained so that it can be related to measures of human well-being.

Table 1
Main characteristics of the Mondego Basin, Lower Mondego and Mondego Estuary study sites using 2006 data.

	Area (km^2)	Population (no. of ind.)	Small basins included	Land use (ha)					
				RAN	REN	Urban	Industrial	Urban parks	Tourism
Portugal	92,391	10,599,095	–	x	x	481,082	75,151	37,837	18,707
Mondego Basin	6,645	885,561	9	27,983	466,482	77,560	9,965	3,154	1,209
Lower Mondego	250	334,161	3	x	x	23,078	3,098	1,404	724
Mondego Estuary	7.2	63,372	1	x	22,738	2,537	1,171	165	380

Sources: INE—Instituto Nacional de Estatística (National Institute of Statistics); INAG—Instituto da Água (Water Institute); RAN: Reserva Agrícola Nacional (National Agricultural Reserve); REN: Reserva Ecológica Nacional (National Ecological Reserve); x: data not available.

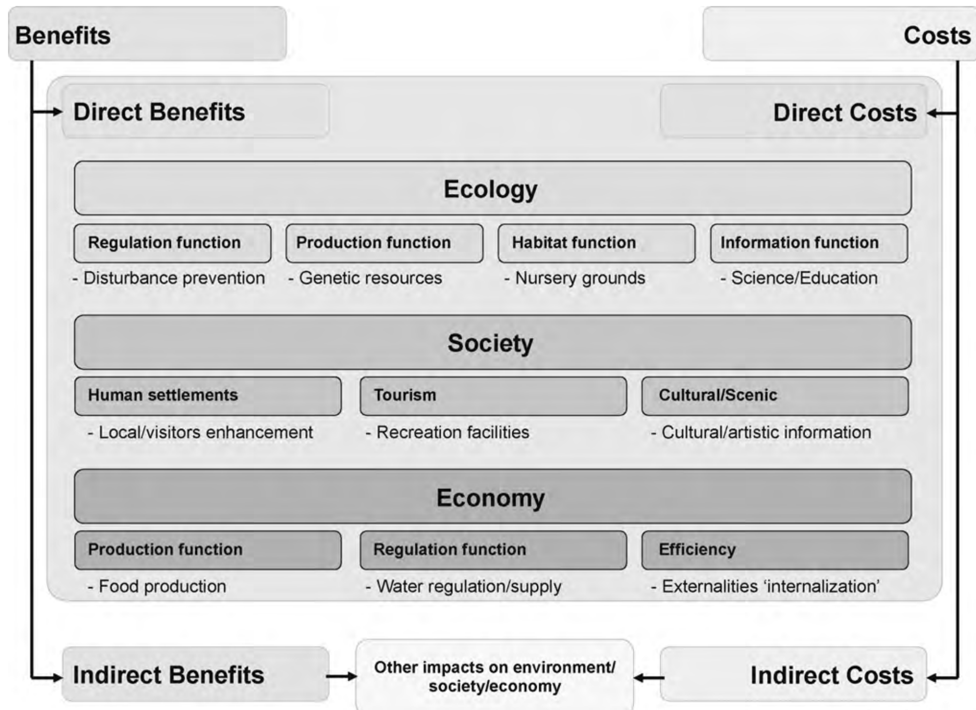

Fig. 2. Ecological/Societal/Economic costs and benefits of estuarine services with particular emphasis on the system's quality status (de Jonge and Pinto, 2009, *personal communication*).

2.4. Estimation of interdependencies between services

Comprehensive examples were supplied at both the regional and local scales. At the regional scale, the interaction and overlap between agricultural activities, water quality supply and biodiversity was considered, and at the local scale the interdependence between the four main assets (food production, recreation, water quality and biodiversity) was integrated (Table 2). Although this selection may seem limited, it was done for two main reasons: (i) these services have a greater economic or social importance for the region and (ii) there were more available data for these services. The present assessment can thus act as a basis for more detailed and inclusive studies. To estimate the food production, several items were considered: agriculture, fisheries, aquaculture and salt production. For the Basin comparative approach, only agricultural production was considered. Unfortunately, agricultural data were only available for the central region of Portugal, which encompasses not only the Mondego Basin but also other locations. Nevertheless, it was taken as indicative of the trends and conditions of the area. The remaining items (fisheries, aquaculture, and salt production) were analysed only at the scale of the Mondego Estuary. For the touristic activity, the number of tourists and touristic capacity, proxied by the number of hotel beds, were used as indicators. The recreational activities occurring in the system were also considered. Here, the term "recreation" refers to the benefits people enjoy from taking part in activities in the natural environment. Given the data problems, the result cannot be interpreted as a valid description of the area under investigation, but should rather be seen as a methodological exercise, an example of integrating different services into a valuation exercise.

The indicators (agricultural production, fisheries captures, number of tourists, effluents produced, organic matter content, nutrient concentrations in the water column and ecological conditions) were selected as indicative measures through which it was possible to observe the conditions, trends and changes in the services under study. A Pearson correlation was performed to quantify the relations between services.

Table 2
Ecosystem services analysed and data availability for the three spatial scales.

	Ecosystem services	Mondego Basin	Lower Mondego	Mondego Estuary
Food production	Salt			x
	Aquaculture			x
	Agriculture	x[a]		
	Fisheries			x
Recreation	Salt-works visits			x
Tourism	Tourists	x	x	x
	Establishments	x	x	x
Water	Quality			x
	Availability	x	x	x
	Effluents	x	x	x
	Treated	x	x	x
Biodiversity				x

[a] For the total central region.

2.5. Ecological assessment

A large amount of information regarding the Mondego Basin's physical structure and functioning is available in the literature (e.g., Marques et al., 1997, 2003, 2007; Graça et al., 2002; Feio et al., 2007; Flindt et al., 1997). Most studies have focused on the macroinvertebrate communities' biotic integrity as well as on the water quality status, mainly in the scope of the Water Framework Directive (WFD) implementation (EC, 2000). To estimate biodiversity and water quality in the Mondego Estuary (local scale), the chosen data set was provided by a programme monitoring the estuarine subtidal soft bottom communities. These data characterised the local system with regard to species composition/abundance and water and sediment physicochemical parameters. Samplings were carried out at 14 stations along the two estuarine arms during spring in 1990, 1992, 1998, 2000 and every year from 2002 to 2006: Euhaline estuarine sand (stations 1, 2 and 10), North

Table 3
Reference conditions for benthic quality assessment (A) and water quality status (B).

	Euhaline	Polyhaline Sand	Polyhaline Muddy
(A) High statuses for the Margalef, Shannon-Wiener and AMBI indices used in BAT to assess the different estuarine stretches of Portuguese transitional water bodies (after Teixeira et al., 2009)			
Margalef	5.0	4.0	3.0
Shannon-Wiener (bits/ind)	4.1	4.0	3.8
AMBI	0.8	1–1.5	2.4

Quality status	$NO_2^- + NO_3^-$ (μmol L^{-1})	PO_4^- (μmol L^{-1})
(B) European Environmental Agency criteria for assessing nutrient levels in transition, coastal and marine waters (EEA, 1999)		
Good	<6.5	<0.5
Fair	6.5–9	0.5–0.7
Poor	9–16	0.7–1.1
Bad	>16	>1.1

Arm Polyhaline sand (stations 11 to 14), South Arm Polyhaline sand (stations 3 and 4), South Arm Polyhaline muddy sand (stations 5 to 9) (Teixeira et al., 2009) (Fig. 1).

For the biodiversity analysis, a 1-mm mesh screen was used to sieve the samples and the collected organisms were identified and counted. To estimate the ecological condition, the Benthic Assessment Tool (BAT) was applied (Teixeira et al., 2009) based on the ecological quality of benthic macroinvertebrates and following the reference conditions proposed for Portuguese transitional water bodies (Teixeira et al., 2009) (Table 3A).

The water quality in the estuary was characterised by the concentrations of dissolved nutrients (nitrate-nitrogen, nitrite-nitrogen and phosphorus) in surface and bottom water samples (Strickland and Parsons, 1972; APHA, 1980). The assessment of nitrite + nitrate (μmol L^{-1}) and phosphate (μmol L^{-1}) levels followed the EEA proposal (EEA, 1999) (Table 3B) prepared by the European Topic Centre on Inland Waters (ETC/IW) for transition, coastal and marine waters. This methodology does not take into account the salinity gradient typical of transition systems, but in the absence of a better set of tools, we decided to use it to assess water quality in the Mondego Estuary (Fig. 1).

2.6. Economic assessment

For the economic and social assessments, evaluations were performed based on the analyses of secondary data, i.e., data collected from the literature (available statistics and studies) and preferably published by governmental institutes (e.g., INE data) for the period of 1992–2006. In a preliminary step, an overview of the Basin conditions was assembled, integrating both social (total population and population density) and socioeconomic factors such as the Human Development Index (HDI; United Nations Development Programme, UNDP, data), which is considered as a valuable indicator for population welfare development (Ambuj and Najam, 1998; Hoagland and Jin, 2008), and the population distribution by economic sector (primary, secondary and tertiary).

In this particular case study, the market prices method (MP) was employed. This approach was used for services such as food production (agriculture, fisheries and salt outputs), tourism activities (occupation rates given by number of beds) and recreational purposes (salt-works visiting). The MP method uses market transactions as an indicator of value based on the fact that the value that people attribute to a commodity is reflected in its price. Through the estimation of market prices in relation to total production, it was possible to obtain the demand curves for the considered services. These functions provide the consumer surplus in a perfectly competitive market (Barbier et al., 1997; Lambert, 2003; Tietenberg, 2003). To obtain these curves, time-series data (1992–2006) on the quantities demanded at different prices were considered. On the other hand, for outdoor recreational uses of the Mondego Estuary, and more specifically visits to the traditional salt-works, the fees paid by visitors were used as indicator for the service value, although it does not provide a valid information regarding the service value. This approach relies on the premise that the time and expenses that people invest to visit an ecosystem represent the value that they give to the service enjoyed. However, to achieve a meaningful estimate the travel time (as opportunity cost) and the travel expenditures should also be included.

3. Results

3.1. Spatial scales of the system and scale dependence

The economic, social and ecological profiles of the Mondego's catchment area are shown in Table 1, including an overview of its main characteristics, proportions and land use distributions at the three assessed scales in 2006. Additionally, to obtain a general profile of the region for the full study period, the total population data (total number of individuals) and population density (inhabitants per km^2) variations were analysed (Fig. 3A and B) and compared with the HDI value for Portugal, an indicator of individuals' purchasing power and standard of living (Fig. 3C). The distribution of the population among economic sectors (i.e., primary, secondary and tertiary) was considered to account for the importance of local resources for human well-being and quality of life. Included in the primary sector were those activities implying the direct use of natural resources, such as agriculture or fisheries. Extractive and transforming industries were included in the secondary sector and services provided by society to the local population (e.g., banks, transportation) were included in the tertiary sector (Fig. 3D–F). Although the population distributions for the Mondego Basin as a whole and the Lower Mondego specifically do not show a constant pattern, it was possible to see that it was registered a decrease for both primary and secondary sectors, contrasting with the strong tertiary sector increase on the estuarine region. In general, the total number of individuals depending on the Mondego catchment area has been increasing, which is reflected in the increasing population density along the basin. This increase is especially significant in the Mondego Estuary region. Concomitantly, the GDP, one of the components of the HDI measure, increased by 25% from 1995 to 2007; it now, with an employment base of 163,395 individuals (2004 data), represents 19.2% of the Portuguese GDP.

3.2. Comprehensive inventory of ecosystem services

An inclusive set of ecosystem services provided by the Mondego's catchment area was assessed (Table 4), based on the system knowledge and literature review. Within the provision category, services such as food production, raw materials, renewable energy and even ornamental resources could be identified. Such services as aesthetic resources, tourism and recreation activities, cognitive values, cultural heritage and non-use values were found within the cultural category. Within the regulation category, we were able to identify such services as gas and climate regulation, disturbance regulation, carbon sequestration, bioremediation, soil erosion prevention, nursery grounds, habitat provision for certain species, nutrient cycling and water supply and water quality assurance. This kind of approach will enable decision makers to consider several alternatives for management based on several available parameters (e.g., uncertainty of results or even reliability of estimates) (Table 4).

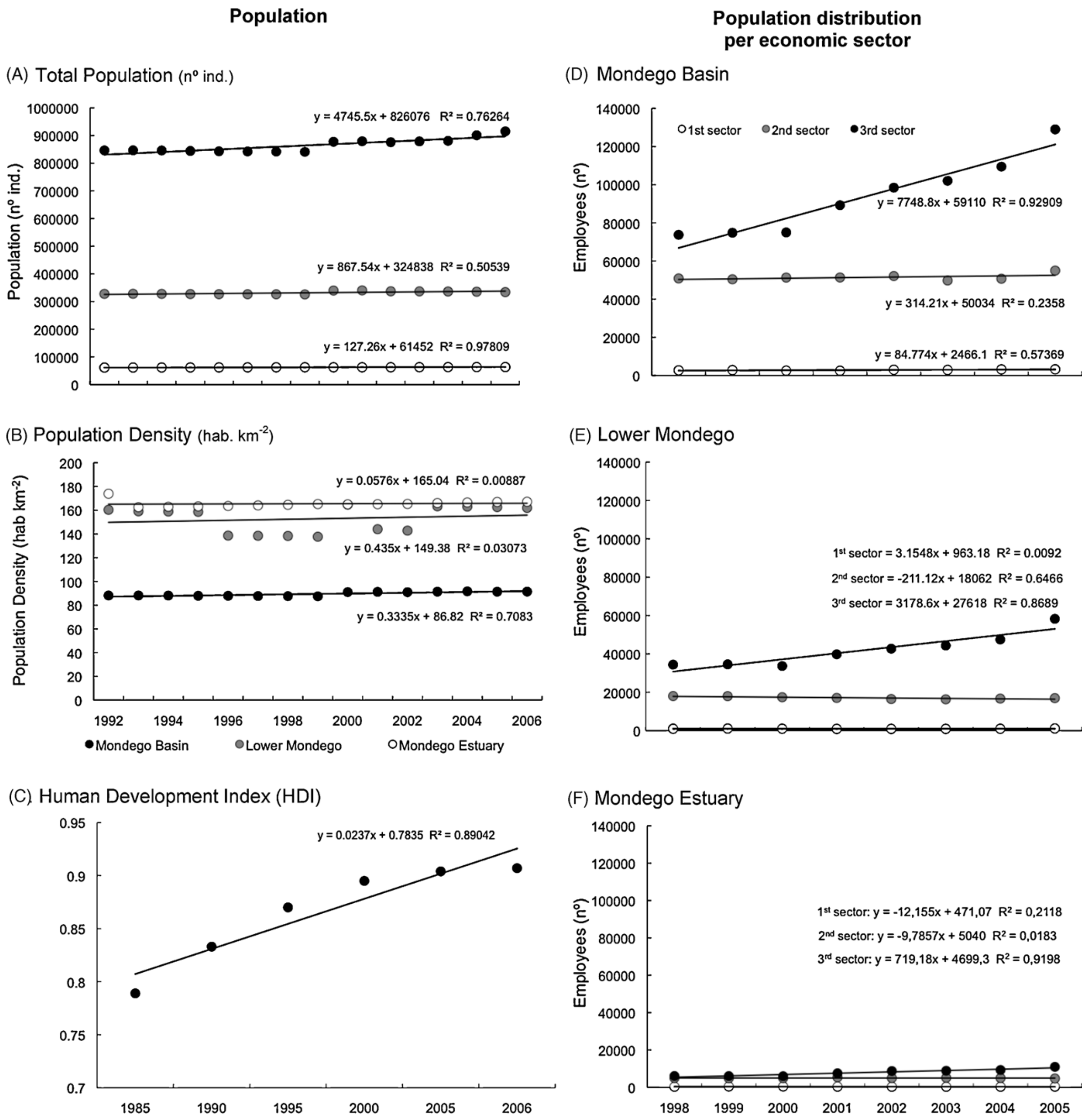

Fig. 3. Population data and socioeconomic characteristics of the study area from 1992 to 2006 in the three scales under study (Mondego Basin, Lower Mondego and Mondego Estuary): (A) population data (total number of individuals); (B) population density (hab. km^{-2}); (C) HDI. Population distribution per economic sector (from 1998 to 2005): (D) Mondego basin; (E) Lower Mondego; and (F) Mondego Estuary (solid line: trend).

3.3. Conditions and trends of main ecosystem services

A more detailed evaluation was provided for three services: food production, water quality and recreation, as well as for their relation with the biodiversity assets, as a demonstrative example of how assessments can be conducted when evaluating services trade-offs. For this evaluation, only the Mondego Estuary scale was taken into account (Table 4).

3.3.1. Food production

Agricultural productivity was considered as a measure of the system's capacity to support and maintain agricultural activities (Fig. 4). Among the seven main crops grown in the region (i.e., potatoes, rice, maize, rye, beans, apples and peaches), there were overall significant decreasing trends in the area, production and productivity of cropland. The main crops' production decreased from 946,298 tonnes in 1992 to 383,165 tonnes in 2006. Data on fish catch and prices for the Mondego Estuary (Figueira da Foz harbour) were used to assess the fisheries' production value. A gradual reduction in the total fish catches (from 16,358 tonnes in 1992 to 11,008 tonnes in 2006) was observed along with an increase in fish prices in agreement with the worldwide trends among fisheries (MA, 2005). The continuous abandonment of commercial fishing is reflected in a significant reduction in the

Table 4
Inventory of ecosystem services in the Mondego estuary following the MA classification (MA, 2003), the valuation method mostly used for each service, its estimated value and level of reliability, uncertainty of results and the level of its impact on biodiversity.

Ecosystem service category	Ecosystem service	Valuation method	Estimated value (1000 €)	Value reliability	Results uncertainty	Impact on biodiversity
Provision services	Food production	MP*; PL	Fisheries: 7,078–14,831 Agriculture: 897–1,217	Underestimated	High	High
	Raw materials	MP	–	–	–	–
	Renewable energy	CVM	–	–	–	–
	Ornamental resources	MP	–	–	–	–
Cultural services	Aesthetic resources	CVM; BT; HP	Insufficient data	–	–	–
	Tourism	MP*; CVM; TC	8,102 – 12,821	Underestimated	Medium	High
	Recreation activities	CVM; MP*; TC	1.5–2.2	Underestimated	Very high	–
	Cognitive values	CVM	–	–	–	–
	Cultural heritage	CVM; HP	–	–	–	–
	Non-use values	CVM	–	–	–	–
Regulation services	Gas and climate control	PF	–	–	–	–
	Disturbance regulation	PF; AC; RRC; DC	–	–	–	–
	Carbon sequestration	PF	–	–	–	–
	Bioremediation	RRC; PF	–	–	–	–
	Soil erosion prevention	AC; RRC; DC	–	–	–	–
	Nurseries	PF; PL; AC; RRC; DC	–	–	–	–
	Habitat provision	PF; AC; RRC; DC	–	–	–	–
	Nutrient cycling	PF	Insufficient data	–	–	High
	Water supply	MP	Insufficient data	–	–	High
	Water quality	CVM; AC; RRC; DC	Insufficient data	–	–	High

Note: MP: market prices method; PL: productivity loss; AC: avoided cost; TC: travel cost; RRC: replacement and restoration costs; HP: hedonic pricing; CVM: contingent valuation method; DC: damage costs; PF: production function; *used in this study.

number of fishing boats observed from 1994 to 2006 (Fig. 4D). Along with the significant progressive decline and abandonment of production units, salt production has been declining as well, although this decrease is less marked (Fig. 5). On the other hand, since the 1980s, some of the inactive salt-works have been reoriented to fish farming, mainly for intensive production of local species like the gilt-head bream (*Sparus aurata*) and the sea bass (*Dicentrarchus labrax*). Despite the increasing area devoted to fish farming in the estuary, the same trend was not followed by production. In fact, the total aquaculture production in 2003 was 200 tonnes year^{-1}, while 10 years earlier each of the companies involved in such activity produced approximately 120 tonnes year^{-1}.

3.3.2. Recreation

The touristic activity in the Mondego catchment area is socially and economically significant (Fig. 6). Fig. 6A shows a significant progressive increase in the number of tourists visiting the study area, reflected also in the number of facilities provided for tourists. It is also important to consider seasonal impacts, mainly during the summer period (July–September) at the scale of the Mondego Estuary, when the tourist activity reaches a peak (percentage of tourists increase: Mondego Basin: 20.4%; Lower Mondego: 38.3%; Mondego Estuary: 47%; 2006 data).

Visitors attracted to the sites derive benefits from visiting traditional salt-works (Table 5). The area also offers a wide range of opportunities for leisure, bird watching and even a museum. This particular ecosystem represents one of the key green spaces for outdoor activities in the region, contributing to 75% of visitors that are interested in ecotourism activities.

3.3.3. Water resources

Water resources are presented at the different scales in terms of water usage and volume of effluents produced by human activities (Fig. 7). Increasing water usage was registered, this being particularly significant for the basin and Lower Mondego regions. Regarding effluent production, there was an increasing trend at all of the considered scales. Due to a lack of data regarding the entire basin, the water quality was assessed only for the Mondego Estuary area. Table 6 gives the results obtained by applying the EEA classification criteria with respect to the nitrite + nitrate and phosphate parameters. A progressive decline in the classification criteria was apparent, with consistently higher levels of nitrite + -nitrate in surface waters.

3.4. Estimation of interdependence between services

The Pearson correlation analysis (Table 7) revealed a strong relation between population metrics and several activities taking place in the area. Moreover, there is also a negative relation between tourism activities (expressed by the number of visitors to the region) and activities in the primary sector, like agricultural production.

3.5. Ecological assessment

Due to a lack of data regarding the larger scales, only the Mondego Estuary was analysed in the biodiversity assessment (Table 6). The north arm (euhaline estuarine, polyhaline sand north arm) presented a strong biodiversity decline in 1992 followed by some recovery. From 1998 onwards, the estuarine mouth and north arm showed significant improvement from moderate to good Ecological Quality Status (EQS). The south arm also presented a significant decline in biodiversity until 1998. In 1998, following the implementation of several experimental mitigation measures (Teixeira et al., 2009), the system's biodiversity began to show signs of improvement. As a whole, a gradual enhancement of the system's ecological condition has been taking place.

Based on the Pearson correlation analysis performed (Table 7), the impact of ecosystem services in the area on biodiversity assets was assessed (Table 4). This analysis shows that such services as tourism activities and agriculture have strong negative impacts on the system, while factors like salt-works and water uses make only minor contributions.

3.6. Economic assessment

An overall estimation of the ecological and social importance of the considered services was performed in light of the benefits

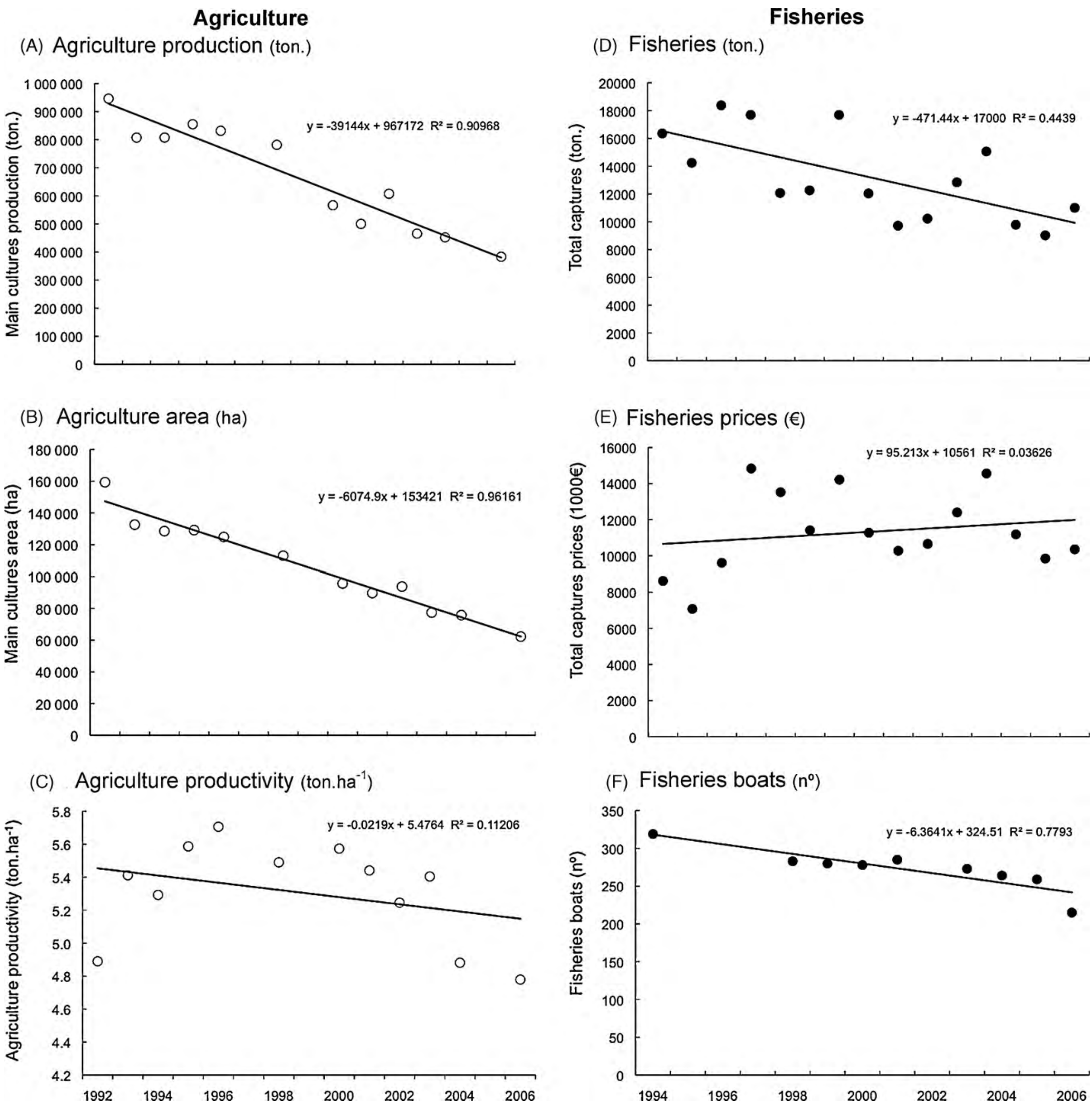

Fig. 4. Food production estimation for the Centre Region from 1992 to 2006: (A) agriculture production (tonnes); (B) agriculture production prices (1000 €); (C) Agriculture productivity (tonnes ha^{-1}); (D) Fisheries catches (tonnes); (E) fisheries catch prices (1000 €); and (F) fisheries boats (no.) from 1994 to 2006 (solid line: trend).

obtained. Our findings (Figs. 4–6) roughly suggest that the estuarine ecosystem makes a significant contribution to society, especially in terms of food production (e.g., fisheries, 7078–14,831,000 €) and tourism activities (8102–12,821,000 €) (Table 4). Nevertheless, it should be recalled that this is only a demonstrative application of the methods available, and do not intent to assess the entire basin value.

From the estimation of demand curves (Fig. 8), it was possible to see that for any given service reduction, the value for the more elastic uses (agriculture and fisheries) was less than the value for the more inelastic uses (e.g., tourism, although this service also exhibited elastic behaviour).

4. Discussion

4.1. Spatial scales of the system and scale dependence

The scale effect in this study is particularly highlighted when integrating the biodiversity results (local scale) with Lower Mondego agricultural production (regional scale). The upstream activities may influence local biodiversity, having an evident scale effect. In 1993, the south arm exhibited strong eutrophication symptoms, leading to a severe reduction of local biodiversity. It appears that agricultural activities on the Lower Mondego regional scale, mostly due to the release of nutrient-enriched

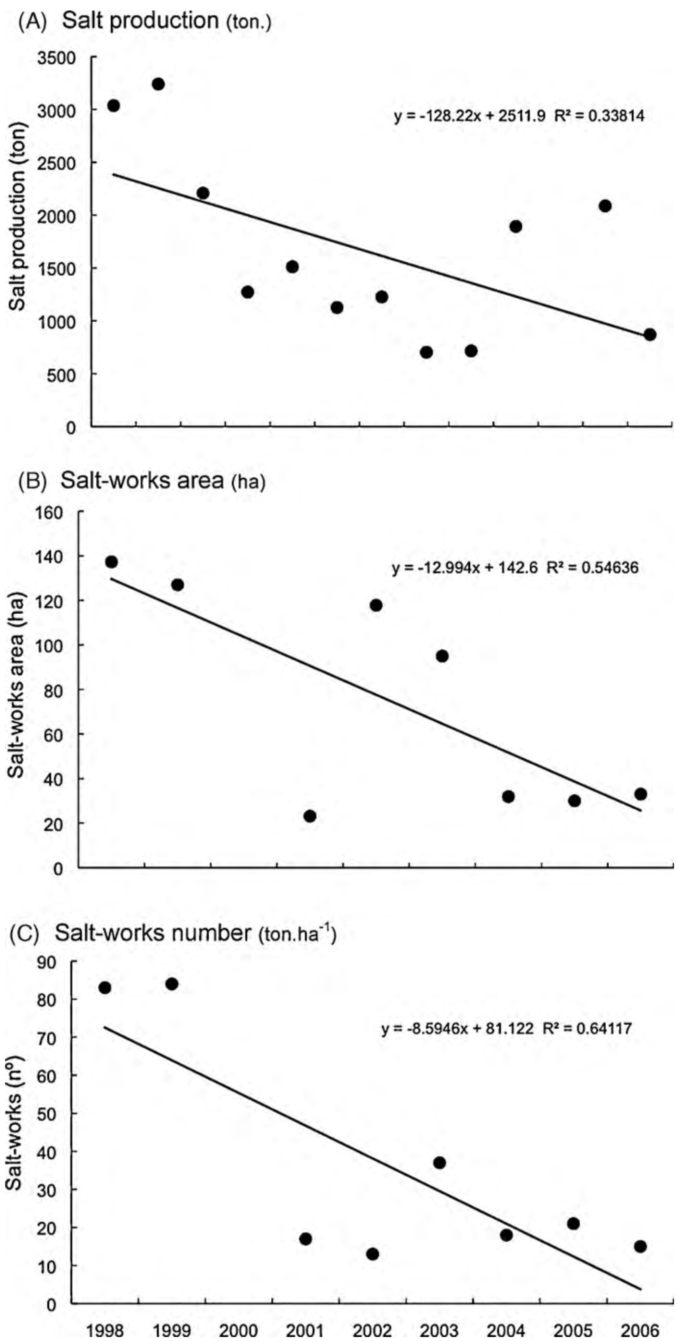

Fig. 5. Food production estimation in the Mondego Estuary: (A) salt production (tonnes) from 1994 to 2006; (B) salt-works area (ha) from 1998 to 2006; and (C) salt-works number (no.) from 1998 to 2006 (solid line: trend).

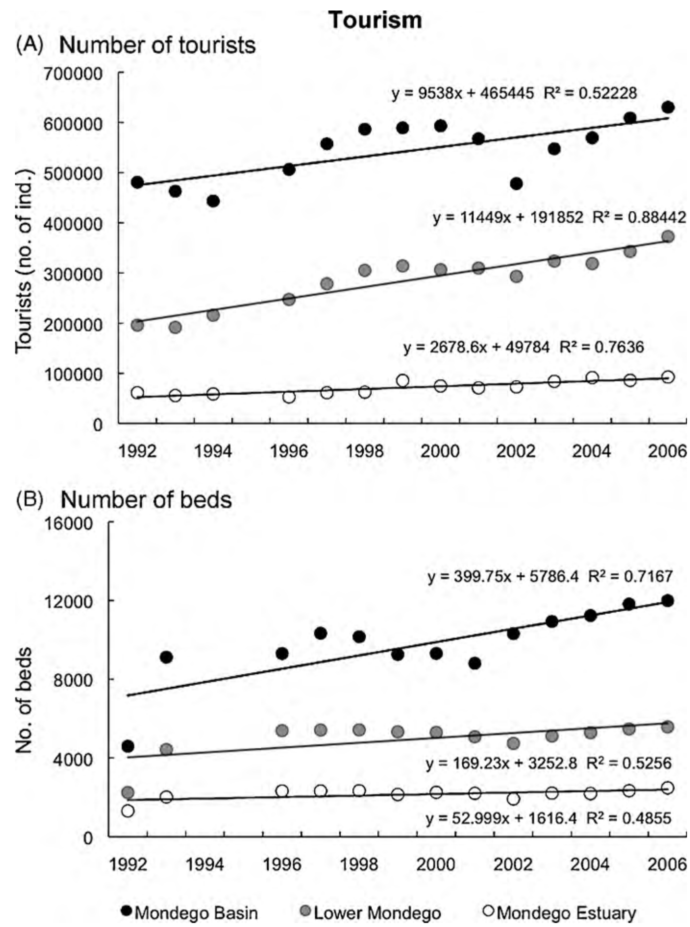

Fig. 6. Touristic activities in the Mondego study area at the three studied scales (Mondego Basin, Lower Mondego and Mondego Estuary) from 1992 to 2006: (A) Number of tourists and (B) Number of hotel beds (solid line: trend).

waters from fields, were partly responsible for the eutrophication symptoms observed in the estuary. In the face of this problem, two major mitigation measures were undertaken in 1997/98: (i) the agriculture fields' runoff was diverted into the north arm and (ii) the connection between the two estuarine arms was improved (Marques et al., 2003). As a consequence, the local estuarine biodiversity started to improve (Marques et al., 2003). On the other hand, when considering the trade-off between food production and ecosystem assets such as biodiversity or ecosystem integrity, it is important to keep in mind that food production is economically crucial in the Lower Mondego River Valley area. Measures that might be undertaken to solve any environmental problem must also take into account the socioeconomic reality of the region. It can be assumed that the highly structured and man-modified environment provides suitable conditions for the achievement of a balanced interaction between services and assets, even at different scales. This study revealed the importance of scale assessments when quantifying areas of concern for provision of ecosystem services and its relation to human well-being, which is in accordance with previous assessments (e.g., Jaarsveld et al., 2005; Barbier et al., 2008).

Table 5
Profits from recreational activities (2008 data).

Visitors	%	Total number	Minimum price	Maximum price	Total prices	
Adults	58	81	12	17	967.44	1370.54
Teenagers	22	31	10	15	305.8	458.7
Children	3	4	3.5	3.5	14.595	14.595
Seniors	17	24	10	15	236.3	354.45
Total	100	139			1,524.135	2,198.285

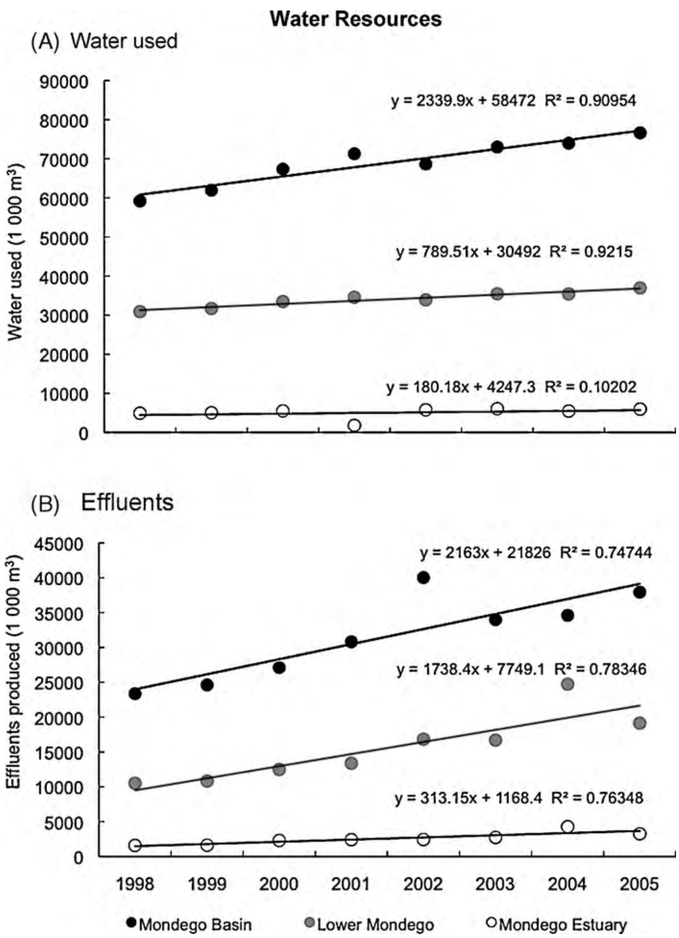

Fig. 7. Water resources statistics for the Mondego study area, comparing the three studied scales (Basin, Lower and Mondego Estuary) from 1998 to 2005: (A) Water uses (1000 m^3) and (B) Effluents produced (1000 m^3) (solid line: trend).

4.2. *Comprehensive inventory and conditions/trends of main ecosystem services*

The use of a comprehensive approach (e.g., inventory) to evaluating significant ecological, social, and economic costs and benefits facilitates the work of decision makers regarding the implementation of management and conservation strategies (Fig. 2). The findings give insight into how aggregating all of the services into one value could be achieved. Therefore, when implementing a management program, several processes and characteristics of the system have to be taken into account. As demonstrated in Fig. 2, both direct (e.g., habitat maintenance, tourism facilities or preservation and functioning of regulatory processes) and indirect (e.g., environmental/societal outcomes) benefits and costs have to be considered, assessed and valuated to ensure an accurate and precise choice of policies.

In the Mondego River Basin, population pressure has triggered changes in water use. Shipping, fishing, agriculture and recreation were the most important uses reported. Across the entire Basin, there was a positive trend among all of the economic sectors considered; nevertheless, through a scale refinement, it was possible to recognise a negative trend for the secondary sector at the other two spatial scales (Lower Mondego region and Mondego Estuary). In the estuary, there was also a decrease in the activity of the primary sector, reflecting the abandonment of activities such as agriculture and commercial fishing combined with an important augmentation of provision of services, mainly in the forms of tourism and recreational activities. Regarding the water resources, the variables showed an increasing trend across the three assessed scales. Not surprisingly, these variables followed the population data tendency. Nevertheless, industrial water use and water extraction for domestic usage and irrigation also appear to play an important role at each of the three scales analysed in the system. Land use and water resources are obviously linked. The impact of land use and its different practices and intensities on water quantity or quality can be substantial. Currently, the maintenance of water quality seems to require the most attention as it influences, to a large extent, the courses of all of the other variables. For instance, the decline in fish farming production appears to be mainly related to decreasing water quality. As the population increases, a

Table 6
EEA classification with respect to the nitrate + nitrite and phosphate water concentrations (surface and bottom), as well as BAT assessment of Ecological Quality Status (EQS) based on macrofaunal communities during spring months (April–June) from 1990 to 2006 in four estuarine areas (E: Euhaline estuarine; PNA: Polyhaline North Arm; PSSA: Polyhaline Sand South Arm; PMSA: Polyhaline Muddy South Arm). EEA classifications—Red: Bad; Yellow: Poor; Green: Fair, Blue: Good. EQS classifications: Orange: Poor; Yellow: Moderate; Green: Good; Blue: Excellent.

	NO3+NO2								PO4								Benthic Macrofauna (EQS)			
	SURFACE WATER				BOTTOM WATER				SURFACE WATER				BOTTOM WATER							
Year	E	PNA	PSSA	PMSA	E	PNA	PSSA	PMSA	E	PNA	PSSA	PMSA	E	PNA	PSSA	PMSA	E	PNA	PSSA	PMSA
90					1.5	5.3	5.9	4.9					0.96	0.59	0.92	1.19	M	G	G	M
91																				
92					5.9	15.1	16.0	11.0					7.21	12.47	15.52	11.75	M	M	G	G
93																				
94																				
95																				
96																				
97																				
98					15.9	31.1	16.6	22.6					0.55	0.57	0.24	0.66	G	G	P	M
99																				
00					1.5	23.1	18.4	16.5					1.02	2.25	2.08	2.15	G	M	G	G
01																				
02					12.7	13.8	8.9	8.2					3.20	3.70	3.71	3.46	G	G	M	G
03	10.2	18.2	5.7	21.6	4.5	8.2	4.4	13.6	0.96	1.39	0.71	1.80	0.79	1.03	0.67	1.70	M	M	M	G
04	5.8	11.6	3.8	14.6	1.8	7.1	2.9	13.2	0.68	0.96	0.64	2.13	0.39	1.11	0.51	1.85	G	G	M	G
05	5.9	8.1	5.9	11.5	6.6	7.3	5.7	12.2	0.55	0.88	0.72	2.00	0.49	0.80	0.71	1.89	G	G	G	G
06	17.3	20.4	12.1	20.0	12.8	10.5	13.7	19.9	1.18	1.18	0.87	1.99	0.58	0.78	0.78	1.94	G	M	M	H

Table 7
Correlation analysis between ecosystem services and biodiversity assets.

	Total population	Population density	Agriculture production	Fisheries captures	Salt production	No. tourists	Effluents produced	Water used	O_2 (mg/l)	NO_3 (mg/l)	NO_2 (mg/l)	PO_4 (mg/l)	%OM	BAT E	BAT PSM	BAT PMS	BAT PS
Total population		0.9989	−0.9086			0.9210								0.8985			
Population density			−0.9261			0.939								0.9069			
Agriculture production				0.8562		−0.9722								−0.8699			
Fisheries captures															−0.8277		
Salt production																	
No. tourists														0.8223			
Effluents produced																	
Water used										−0.8739							
O_2 (mg/l)											0.8356						
NO_3 (mg/l)																	
NO_2 (mg/l)																	
PO_4 (mg/l)																	
%OM																	−0.9236
BAT_E																0.9590	
BAT_PSM																	
BAT_PMS																	
BAT_PS																	

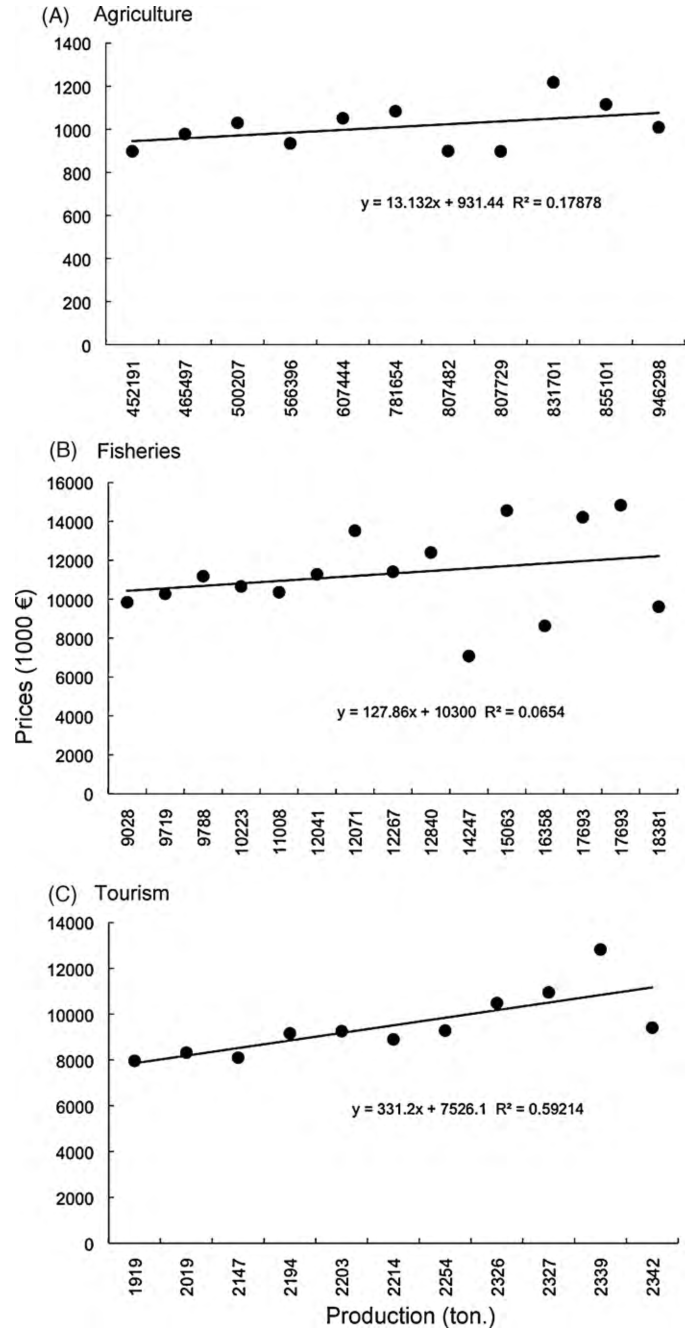

Fig. 8. Demand function estimations based on market prices of the study area from 1992 to 2005: (A) agriculture and (B) fisheries; and C. Tourism (solid line: trend).

consequent increment of activities drives water use enhancement and increased effluent production. Moreover, the higher levels of nitrates and nitrites on surface waters than in bottom waters suggest that the main source of these nutrients is upstream of the study area. The system's nutrient enrichment and the subsequent eutrophication effect leading to a decrease in water dissolved oxygen is one of the possible factors affecting the production conditions on the system. Overall, human activities cause a sequence of environmental damages and stresses that may alter the ecosystem's natural processes and thus alter its equilibrium. Based on this specific assessment, several factors were identified as promoters of changes, such as high nutrient concentrations, land occupation rates and habitat maintenance.

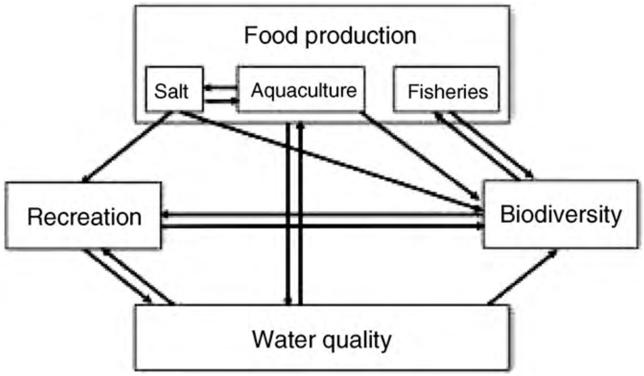

Fig. 9. Interrelations between the different services in the Mondego Estuary.

4.3. Estimation of interdependence between services

On top of the environmental challenges, social, cultural and economic problems overlap. Activities are never isolated or result from cause-effect linear relations; they interact and compete for area. They sum up effects and produce a complex network of interrelations, which becomes even more difficult to analyse than each ecosystem service is alone (Fig. 9). A typical example of such interactions between different activities can be seen in the Mondego Estuary (Table 7). The selection of only three services for this approach may reduce the validity of valuations for decision-making; nevertheless, the intent was to compile an overview of some of the region's services and examine the interrelations among them. We hope this will provide a basis for further insightful valuations.

The increasing nutrient concentration in the water, essentially due to agricultural runoff, influences aquaculture production and affects the aquatic communities' diversity. Impoverished benthic communities, which serve as food for many fish species, might eventually cause a decrease in fish production. In general, due to this intrinsic and complex network of interrelations and interdependencies, any measure undertaken to improve one ecosystem service in isolation will directly or indirectly have repercussions on the others, as also demonstrated by, for example, Acharya (2000), Atkins and Burdon (2006), and Young et al. (2006).

4.4. Ecological assessment

Despite its decline due to the progressive abandonment of production units (implying a drop in salt-related income as well as a drawback for many bird species and, consequently, a decline in biodiversity), the salt-works possess a strong social and cultural inherent value and serve as important stopover and refuge areas for birds migrating along the northwestern coast of Portugal. These areas are particularly important for waders, especially such species as the Pied Avocet (*Recurvirostra avosetta*) and Greater Flamingo (*Phoenicopterus rubber*). During the breeding season, the Mondego Estuary is regionally important for species such as the 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 (Lopes et al., 2001; Múrias et al., 2002). A decline of the macrobenthic estuarine biodiversity, usually associated with a degradation of the water quality status, can lead to a reduction of opportunities for these birds to feed. This situation may decrease the ecological and economic potential of this region. Furthermore, the diminishing or absence of certain species may also influence all of the trophic relations in the area while altering prey-predator relations. Moreover, this system was considered as a Ramsar site (Ramsar site 1617) and, consequently, its eventual loss may be detrimental to many species.

The traditional salt-works systems, such as the one in the Mondego Estuary, due to its unique characteristics, tend to attract visitors from far away. In theory, if they are near urban areas and are heavily used, such destinations will present higher average values than most similar ecosystems (Gibbons, 1986). In this particular situation, a complex network of interrelations is verified that may not be well described by the regression reported here. The full value of this particular ecosystem has to take into account several parameters: the recreational value (environmental asset values depend on both the unit value of a user-day and how many consumers visit the site); the food production (including salt and fish values); the biodiversity maintenance value (including the entire trophic network that depends on the system); and also the existence value of the ecosystem. Despite the trend analysis, the market economy fails to regulate the pollution flow to the environment, which is known as a negative externality or negative consequences of human activity. As such, pollution's social costs (i.e., the lost income due to the considerable loss of bird nidification (or nesting) spots or migratory routes across the Mondego Estuary as a consequence of habitat loss, in this case salt-pans) may be greater than the private cost (i.e., no private expenses are associated with the contamination of water by aquaculture). Others in society have to pay the economic price of these environmental impacts that they may not have caused (Fig. 2). Nevertheless, to achieve a precise impact measure, a survey must be conducted in the area to evaluate the value given by the local people to the system's natural features in order to protect and preserve it.

4.5. Economic assessment

In addition to the spatial or geographical scales, the valuation and assessment of services are also affected by the temporal scale of analysis. Uncertainty is inherent in the valuation process, not only due to limited data availability but also due to constraints in evaluating services' impacts. As such, the values considered in this study should be considered with caution as they are mainly approximations (Table 4). Because demand usually becomes more inelastic as supply is reduced (Gibbons, 1986), the marginal values calculated may underestimate the real services' values (Table 4). Additionally, the price data used in the demand studies are rather limited, which may also contribute to our results. In addition, the values considered are averages rather than marginal values of services, which influences the final outcome. Another point to be taken into account is that both agriculture and fisheries (Fig. 8A and B, respectively) are essential goods, while tourism activities may be considered as secondary goods. This can then influence consumers' preferences and needs when making a choice to consume a good, especially if the aggregate economic value is made the basis of conservation decisions. Nevertheless, to accurately inform policy makers and design better management options, the uncertainties that result from these attempts at valuation of services must be incorporated into decision-making processes (Costanza, 1993). One way to deal with this is through the application of the Precautionary Principle (Andorno, 2004; Myers and Raffensperrger, 2005), which assumes sequential management implementations where decisions are made cautiously until the evidence becomes more sound (Perrings, 1991; Costanza, 1993).

Considering the prices charged for the opportunity to engage in wetlands recreation, such as visiting the traditional salt-works, the minimum value attributed to this opportunity can be equated with its price to estimate the consumer demand function (Gibbons, 1986). For the Mondego Estuary, it was not possible to obtain a time-series analysis for this particular service, mostly because these activities (and the charges associated with them) have recently begun in the area. A drawback of this kind of analysis is that it mainly focuses on the value of a recreational activity in Euros per day or per visitor. If a total site value is estimated, it can be ascribed to various constituents of the site, such as the water itself, the aesthetics of the site as a whole, the associated biodiversity or even the available facilities. This analysis may be the starting point for a more exhaustive valuation. Based on a user-day estimation for the Mondego Estuary, it becomes possible to relate visitation rates and flow levels in the future either through direct methods (such as the MP used here) or through stated-preference methods (such as the TC or CV methods). Although monetary values may not translate into cognitive benefits, non-use values or supporting services, these services must not be ignored as they are thought to play a significant role in maintaining human well-being (Marques et al., 2009). Economic valuation cannot place a value on species survival or on the ecosystem's functional and ecological role, except from the human perspective (MA, 2005). Nevertheless, it must be highlighted that even when benefit revenues are not the primary objective of wetland exploitation and conversion, activities such as agriculture, aquaculture, and urban and industrial facility expansion are normally considered important for the economic development and social growth of the region (Fig. 2).

Moreover, this study shows the applicability as well as the hurdles to valuation and the limited contributions of it, given an non-exhaustive data availability: effective measures leading to biodiversity improvement have been taken in the past without valuation, and a price tag while supporting the argument would add limited new information. It would further require an accurate valuation of biodiversity assets, which implies an enormous task with uncertain outcome. This fact has been leading to the gradual shift of biodiversity indicators development from assessing the state to monitoring pressures (e.g., Levrel et al., 2010).

5. General conclusions

The Mondego catchment's full value cannot be calculated without taking into account all of the direct and indirect uses' values or without estimating the real wetlands' value; focusing solely on market prices may lead one to underestimate the real value of the region. With this study it was attempted to exemplify how services values may be estimated, but not the value of the catchment as a whole. Also, assessing the system value would require aggregation over time including the inherent depreciation rates of flows and outputs. Our preliminary values may provide a starting point for a more exhaustive and detailed valuation of the Mondego wetlands. Nevertheless, regarding the Mondego River Basin, some general conclusions may be drawn:

1. Three services were identified in this assessment: food production, water quality and recreation. An increase of services such as recreation activities and water uses has been verified, while there has been a decrease in services like food production.
2. Some promoters have been modifying ecosystems' structures and functions (e.g., population and nutrients concentrations), where we can observe a progressive loss of natural and agricultural lands to development and services provision (e.g., tourism).
3. There is a strong influence of upstream activities on local assets, and so, when performing an integrative analysis, it is extremely important to include the scale effect.
4. The ecological quality of the system has improved, as reflected in both local communities' diversity and water quality.
5. There is a clear need to evaluate the links between land uses, water quality/quantity and biodiversity to achieve good resource management.
6. More insightful uncertainties and valuation studies are needed to clarify the links that leads to changes in ecosystem services supply to ensure adequate management strategies.

Water management plays a crucial role in the provision and delivery of all services considered here. Therefore, it becomes crucial to simultaneously achieve economic efficiency, environmental protection and sustainability within a system. Along with water management and protection, an accurate biodiversity asset evaluation is needed to better understand what ecosystem services that are essential for human populations' well-being can be supplied. Both water management and protection and accurate biodiversity asset evaluation are fundamental to ecologically sustainable social and economic growth and development (Fig. 2).

Acknowledgements

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