

# Trade-offs across value-domains in ecosystem services assessment



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## ABSTRACT

One of the key challenges for ecosystem services research is to develop a comprehensive methodological approach in which biophysical, socio-cultural and monetary value-domains can be explicitly considered and integrated into decision making processes. This paper operationalizes a methodological approach for ecosystem service assessment on the basis of value pluralism. We assessed eleven ecosystem services delivered in the Doñana social-ecological system (SW Spain). We found that different ecosystem service trade-offs came into view depending the value-domain in which services were assessed. The use of different valuation methods uncovers the fact that methods to elicit value actually shape and define the values being elicited. In this context, the prevalence of biophysical and monetary value-domains in scientific literature entails two main concerns: (1) the ecosystem service concept reflect in a limited extent the concerns of their beneficiaries, and (2) ecosystem service assessment results are biased towards the information provided by markets at the expense of other value-articulating institutions. Recognizing the role of ecosystem service assessment methods as value-articulating institutions, we call for a methodological framework able to contemplate the multidimensional nature of ecosystem services.

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## 1. Introduction

Since the publication of the Millennium Ecosystem Assessment (MA, 2005a), interest on ecosystem service assessment has grown exponentially in environmental science and policy (Fisher et al., 2009; Vihervaara et al., 2010). However, despite the academic progress, many important issues are still to be resolved in order to fully incorporate the ecosystem service framework on environmental policy targets (Anton et al., 2010; Burkhard et al., 2010; de Groot et al., 2010; Seppelt et al., 2011). A key challenge to be addressed is developing comprehensive assessment frameworks, in which biophysical, socio-cultural, and monetary values can be properly integrated (de Groot et al., 2002; Chan et al., 2012). Thus, there is an increasing request in scientific literature to: (1) develop standardized comprehensive frameworks that integrate and organize the different sources of information and indicators of ecosystem services values (de Groot et al., 2010; Layke et al., 2012; Seppelt et al., 2011), (2) combine the information from the biophysical-supply to the users' demand (Tallis and Polasky, 2009); and (3) explore the multiple value-domains of ecosystem services (Anton et al., 2010; de Groot et al., 2010). Various frameworks have been developed to integrate different aspects of ecosystem services, such

as (1) the function analysis framework (de Groot et al., 2002); (2) the Millennium Ecosystem Assessment framework (MA, 2003); (3) the 'cascade model' (Haines-Young and Potschin, 2010); or (4) the Ecosystem Properties, Potentials, and Services (EPPS) framework (Bastian et al., 2012). More recently, CSIRO (2012) has assessed ecosystem services provided in a watershed using biophysical, socio-cultural, and monetary methodological approaches. However, to the best of our knowledge, this study is the first one that compares the information obtained from biophysical, socio-cultural, and monetary assessment approaches using empirical data. We propose a methodological approach that consistently incorporates the different value dimensions of ecosystem services, from both the supply-side (through biophysical indicators) and the demand-side (through socio-cultural and monetary indicators).

The main objective of this research is to advance towards the operationalization of the proposed methodological framework for assessing ecosystem services, integrating biophysical, socio-cultural, and monetary value domains and to test the level of consistency of the information provided. To cope with this challenge, we specifically aimed to: (1) assess the ecosystem services delivery from a biophysical perspective; (2) assess the demand of ecosystem services from a socio-cultural viewpoint, analyzing the importance people give to particular services; (3) assess the demand of ecosystem services using monetary valuation techniques; and (4) analyze whether these different value-domains (i.e., biophysical, socio-cultural, and monetary) provide similar or

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dissimilar information regarding ecosystem service assessment, exploring major trade-offs emerging across these domains.

## 2. Study area

The Doñana region is placed at the end of the Guadalquivir watershed, located in Andalusia, SW Spain (Fig. 1). In this research, we conceptualized Doñana as a social–ecological system (SES) because as a Mediterranean region, its evolution is greatly

influenced by the different human uses occurred in its ecosystems through its history (Gómez-Baggethun et al., 2010a, 2012).

Ecological values of Doñana relate to a biophysical system formed by four ecodistricts: marshes, aeolian sheets, coastal system, and the Guadalquivir Estuary (the largest estuary in the Gulf of Cadiz), which together form the so-called Greater Fluvial-Littoral Ecosystem of Doñana (220,070 ha) (Montes et al., 1998). Doñana is also an important European biodiversity hotspot that provides refuge to many endemic and endangered species (Fernández-Delgado, 2005). For these reasons, Doñana has been recognized

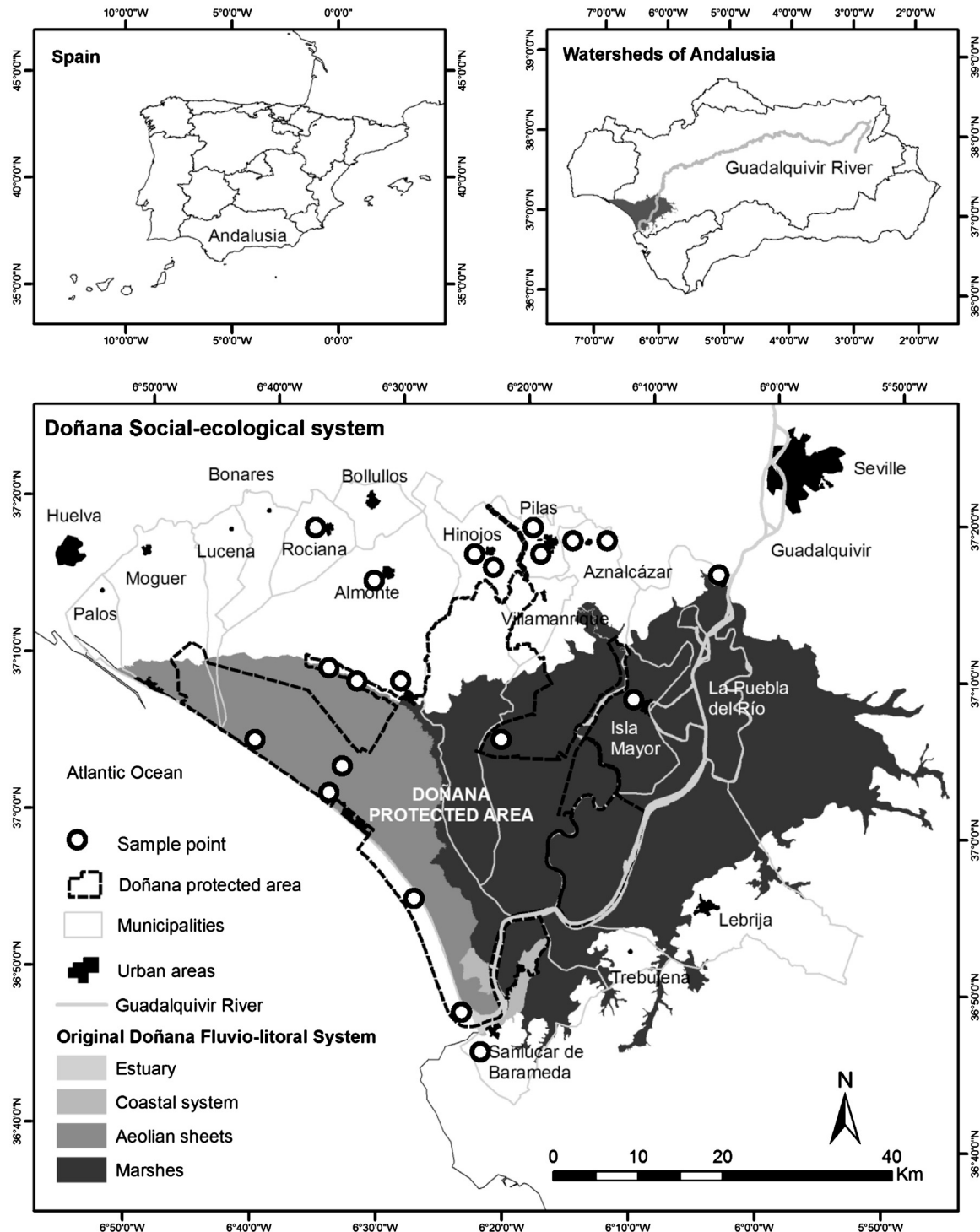


Fig. 1. Map of the study area. Sample points of the socio-cultural valuation and monetary valuation surveys are shown.

by different protection figures from the sub-national to the international level, including a National Park declared in 1969 by the Spanish Government and a Natural Park declared in 1989 by the Andalusia Government. At the international level Doñana has been declared an International Biosphere Reserve and a World Heritage Site and its wetlands have been recognized by the Ramsar Convention. Regarding its socio-cultural importance, Doñana holds outstanding spiritual and religious cultural values (Martín-López et al., 2007a; Gómez-Baggethun et al., 2012) and has an important cultural heritage related with traditional management practices (Gómez-Baggethun et al., 2010a).

### 3. Methods

#### 3.1. Methodological framework

We analyzed either the dimensions related to ecosystem service assessment (from the supply- to the demand-sides; Fig. 2), or the three value-domains of ecosystem services considered in this research – i.e., biophysical, socio-cultural, and monetary (de Groot et al., 2002, 2010)–.

On the supply side, we addressed the domain of biophysical (or ecological) value using biophysical indicators that show the trend of the ecosystem service delivery (see Section 3.2). On the demand side, we incorporated the socio-cultural and monetary value-domains of ecosystem services (Fig. 2). Here, the contribution of ecosystem services to human well-being can be socio-cultural – i.e., the direct and indirect contributions of ecosystem services to user's cultural identity and heritage, spiritual values, or good social relationships obtaining through the use or management of ecosystem services (Chan et al., 2012) – or monetary – i.e., the direct and indirect contributions of ecosystem services to user's welfare and well-being, which is conceived in terms of utility (or preference satisfaction) (Wegner and Pascual, 2011)–. The socio-cultural value given by users to ecosystem services was measured through indicators that express the importance users allocate to them in a non-market value elicitation context (de Groot et al., 2010). The monetary value of ecosystem services was estimated using the Total Economic Value framework (Pearce and Moran, 1994). Further details on the methods used to measure the socio-cultural and monetary value-domains of ecosystem services are provided in Sections 3.3 and 3.4, respectively.

It is important to note that socio-cultural values have an influence in monetary values, because preferences determining the

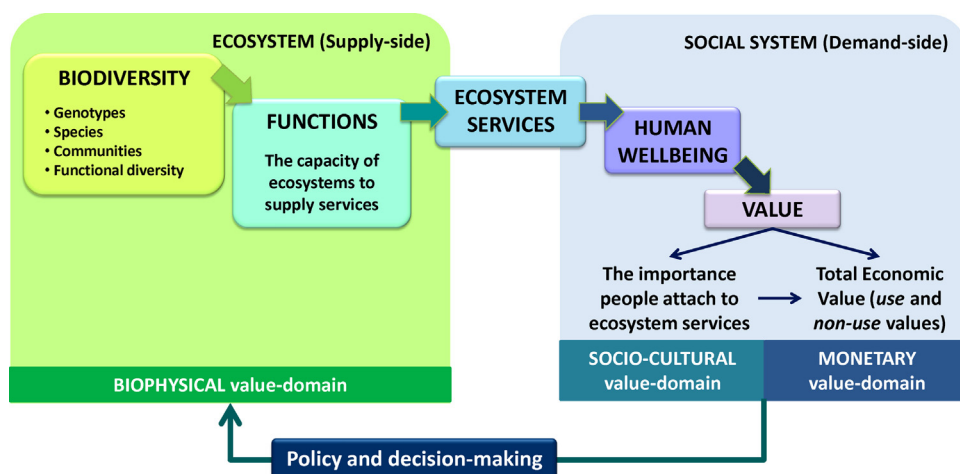
'utility' that a person obtains from a particular ecosystem service are usually influenced by non-economic factors related to ethical and moral motivations (Kahneman and Knetsch, 1992; Spash, 2006; Kumar and Kumar, 2008; Martín-López et al., 2007b). Similarly, the ecosystem's capacity to supply services determines the range of potential uses by society, thereby having an influence on socio-cultural and monetary values. Consequently, ecosystem service assessment should contemplate biophysical, socio-cultural, and monetary value-domains (Fig. 2).

This methodological framework was applied to assess 11 ecosystem services delivered by biodiversity in the Doñana SES, including provisioning (food from agriculture, cattle, fishing, and shell-fishing), regulating (climate regulation, water quality, soil formation, and biological control), and cultural services (ecotourism, scientific knowledge, environmental education, and satisfaction for conserving biodiversity (i.e., existence value)).

#### 3.2. Assessing the supply-side of ecosystem services: biophysical value-domain

As a proxy for biophysical values, we compiled different indicators that describe the performance of the selected ecosystem services or specific ecological properties underlying their supply. Based on Layke et al. (2012), the criteria used to select indicators of ecosystem services delivery were (1) the ability to convey information – i.e., the indicator's capacity to summarize the characteristics of the ecosystem service delivery–, and (2) the data availability – i.e., data should be available at least from a period of five years during the last decade with the aim of detecting changes (trends) in ecosystem service supply–. Table 1 summarizes the indicators used to assess the ecosystem services supply, their measurement units, the years for which data were available, and the source of information.

When possible, biophysical values were measured directly from physical quantities of ecosystem service supply, i.e., livestock units, tonnes of agricultural output, fish, and shellfish harvest, number of tourists, and so on. For those ecosystem services that could not be directly measured in physical terms, proxy measures were used. For example, to measure the biological control service, we reviewed 48 historical documents, scientific publications, and reports covering the period of 1887–2005 in order to determine the number of non-native species and the first register of their introduction in the Doñana SES. We also carried out an in-depth review through the compilation of more than 1000 ecosystem-related publications



**Fig. 2.** Methodological framework for assessing ecosystem services based on both performance of ecosystem services delivery (supply-side) and the use, enjoyment and value by users (demand-side). Within the demand-side, users can value ecosystem services from socio-cultural or monetary perspectives.

Inspired from Haines-Young and Potschin (2010).

**Table 1**  
Ecosystem service indicators used for the biophysical assessment.

Ecosystem service	Indicator	Data unit	Years assessed	Data source
Provisioning				
Food from Agriculture	Crop production	Tonnes	2001–2008	CAP (2007, 2009a,b), CMA (2009)
Cattle	Trend in animal population	Number of livestock units (LSU)	2004–2008	Annual Reports of Activities of the Doñana PA
Fishing and shell-fishing	Fishing and shell-fishing harvest	Tonnes	2001–2008	CAP (2001) Annual Reports of Activities of the Doñana PA Interviews to key informants (N = 5)
Regulating				
Climate regulation	Natural and semi-natural forest surface	Hectares	1977–2006	Land-cover analysis (own data)
Water quality	Eutrophication level in surface waters	Nutrient concentration (mg/L)	1982–2005	Serrano et al. (2006)
Soil formation	Soil loss measured as sedimentation rates	Sedimentation rates (mm/year) and sedimentation cones (ha)	1984–2007	Rodríguez Ramírez et al. (2005) Scientific monitoring of Doñana Biological Station ( <a href="http://icts.ebd.csic.es">http://icts.ebd.csic.es</a> )
Biological control	Conductivity	Conductivity (mS/cm)	1982–2005	Serrano et al. (2006)
	Alien species registered	Number of species	1980–2005	Systematic review of literature (own data)
Cultural				
Ecotourism	Tourists visiting for nature tourism	Number of visitors	2000–2009	Annual Reports of Activities of the Doñana PA
Scientific knowledge	Scientific publications	Number of scientific publications	1980–2005	Systematic review of literature (own data)
Environmental education	Environmental volunteering initiatives	Number of environmental volunteering initiatives	2002–2006	Annual Reports of Activities of the Doñana PA
Satisfaction for conserving biodiversity <sup>a</sup>	Trend in populations of emblematic species		1988–2008	Scientific monitoring of Doñana Biological Station ( <a href="http://icts.ebd.csic.es">http://icts.ebd.csic.es</a> ), Ferrer and Penteriani (2008)

<sup>a</sup> Based on Martín-López et al. (2007b), the satisfaction for conserving biodiversity in Doñana is highly related to charismatic species, i.e., Iberian lynx (*Lynx pardinus*) and the Spanish imperial eagle (*Aquila adalberti*).

in the Doñana SES in order to assess the scientific knowledge service. Here, the criteria used to select studies were: (1) results had been published in peer-reviewed journals or books, and (2) studies focused specifically on Doñana's ecosystems and biodiversity. While the systematic review for the ecosystem services 'biological control' and 'scientific knowledge' covered the period 1880–2005, here we analyzed both ecosystem service indicators (i.e., number of registered non-native species and number of scientific publications) for the period 1980–2005 in order to allow comparability with the biophysical indicators used for other ecosystem services. Finally, in order to assess the service of climate regulation we analyzed land-cover data using GIS techniques to estimate changes in land-cover of natural and semi-natural forests as a proxy indicator of carbon storage (Layke et al., 2012; van Oudenhoven et al., 2012).

For all biophysical indicators of ecosystem services, we calculated the tendency rate relative to the mean value in the analyzed period so as to determine if the delivery of ecosystem service was increasing, stable, or decreasing. For more details of the methodological aspects of biophysical valuation of ecosystem service in the Doñana SES, see Martín-López et al. (2010).

### 3.3. Assessing the demand-side of ecosystem services: socio-cultural value-domain

To analyze the socio-cultural importance of different ecosystem services, direct face-to-face questionnaire surveys were conducted during two field campaign periods (September–October 2007 and July 2008–March 2009) in 20 sampling points including Protected Area offices, urban zones, recreational areas, visitor centres, beaches, and agricultural fields (Fig. 1). The total sample was made up of 796 respondents (including locals, tourist population, and environmental professionals) who selected what they perceived to be the most important ecosystem services for human well-being from a panel of ecosystem services provided by the area. The panel consisted of a comprehensive list of 21 ecosystem services

– i.e., provisioning (food from agriculture, food from cattle, food from fishing and shell-fishing, food from aquaculture, gathering, and forest products), regulating (micro-climate regulation, water regulation, soil formation, air purification, biological control, pollination, and habitat for species), and cultural services (ecotourism, scientific knowledge, environmental education, aesthetic values, local ecological knowledge and sense of place, recreational hunting, spiritual values, and the satisfaction for conserving biodiversity)–. We identified these ecosystem services using the information obtained from a review of scientific and non-published information of the Doñana SES, from interviews with key local stakeholders (N = 33) with direct experience in traditional management practices and on the basis of previous experimental studies in the Doñana SES (Martín-López et al., 2007a). Then, the previous list of ecosystem services obtained in this phase was adapted using the ecosystem services classification of the Millennium Ecosystem Assessment (MA, 2005b) and The Economics of Ecosystems and Biodiversity (Kumar, 2010).

From the information compiled with questionnaires, we calculated the percentage of people that recognized each ecosystem service as important (N = 796 respondents).

### 3.4. Assessing the demand-side of ecosystem services: monetary value-domain

We used the Total Economic Value framework to value ecosystem services in the Doñana SES (Martín-López et al., 2011). We estimated (1) the direct consumptive use values of provisioning services; (2) the direct non-consumptive values of ecotourism, scientific knowledge, and environmental education services; (3) the indirect value of regulating services; and (4) the existence value of biodiversity, understood as the moral satisfaction obtained by individuals for conserving biodiversity (Kahneman and Knetsch, 1992). Different economic valuation techniques were used based on their suitability to value different ecosystem services (Farber



**Table 2**Description of the economic valuation methods used for each ecosystem services and its estimated value (2008€ ha<sup>-1</sup> year<sup>-1</sup>). Based on Martín-López et al. (2011).

Ecosystem service	Valuation method	Sample size <sup>a</sup>	Sample period <sup>a</sup>	Estimated value	Source
Provisioning					
Food from				5891.4	Martín-López et al. (2011)
Agriculture	Market based			2686.2	
Cattle	Market based			14.4	
Fishing and shellfishing	Market based			3190.8	
Regulating					
Climate regulation	Contingent valuation	N = 404	July 2008–March 2009	56.4	García-Llorente et al. (2011a); Martín-López et al. (2011)
Water quality	Contingent valuation	N = 404	July 2008–March 2009	104.6	
Soil formation	Contingent valuation	N = 404	July 2008–March 2009	20.6	
Biological control	Contingent valuation	N = 472	June 2006–September 2007	531.6	García-Llorente et al. (2008, 2011b)
Cultural					
Ecotourism	Travel cost	N = 672	February–October 2004	1879.4	Martín-López et al. (2009a)
Scientific knowledge	Public investments			6.7	Martín-López et al. (2009b)
Environmental education	Public investments			3.0	Martín-López et al. (2011)
Satisfaction for conserving biodiversity (existence value)	Contingent valuation	N = 649	February–October 2004	485.8	Martín-López et al. (2007b)

<sup>a</sup> Only for those valuation methods that required social sampling.

et al., 2006; Liu et al., 2010; Pascual et al., 2010): (1) market-based techniques were used to estimate the monetary value of provisioning services; (2) analyses of public investments was utilized as a proxy of the monetary value of environmental education and scientific knowledge; (3) travel cost method was used to estimate the monetary value of ecotourism; and finally (4) contingent valuation was used to value regulating services and the satisfaction for conserving biodiversity. Table 2 illustrates the valuation techniques used for each ecosystem service.

Travel cost and contingent valuation methods were conducted using direct face-to-face questionnaires. The population sampled was randomly selected, covering a wide range of stakeholders (local people, tourists, environmental managers, and scientists). Sampling was restricted to informants above 18 years old.

All values were transformed to 2008€ (1€ = 1.253\$) using the Consumer Price Index and are given in 2008€, regardless of the date to which they refer. When temporal series of data were available (e.g., prices of agriculture, cattle, or fishing; or public investments on environmental education and scientific knowledge), we estimated the mean economic value of the total benefits. Finally, we estimated the annual monetary values of ecosystem services (i.e., the mean annual value of the flow of services) per hectare.

### 3.5. Integrating biophysical, socio-cultural and monetary information

We used three variables to compare the output of the different ecosystem service value-domains assessed in this study. In order to compare information obtained from the three value-domains examined in this research, we standardized the results from each ecosystem service in each of the biophysical, socio-cultural, and monetary approaches. We firstly standardized the three variables (i.e., biophysical, socio-cultural, and monetary) by subtracting the mean of each value and dividing by the standard deviation and then we rescaled the values obtained from –1 to 1. Finally, we used the Shapiro–Wilk test to check normality (Shapiro and Wilk, 1965).

Using these normalized variables, we compared the trade-offs that became apparent across different value-domains. Ecosystem service trade-offs arise when management choices made by humans entail the optimization of few ecosystem services or a

single ecosystem service leading to reduction or deterioration of other services (Rodríguez et al., 2006). Hence, ecosystem service trade-offs may be measured by different indicators: such as (1) biophysical indicators regarding the ecosystem service delivery (e.g., MA, 2005a; EME, 2011), (2) socio-cultural preferences (e.g., Martín-López et al., 2012); and (3) monetary values (e.g., Hicks et al., 2009; Martín-López et al., 2011). Then, we explored the match level between different value-domains and ecosystem service categories (i.e., provisioning, regulating, and cultural). Finally, a principal component analysis (PCA) was applied to analyze the relationships among the three variables considered, i.e., biophysical, socio-cultural and monetary. By this means, we were able to reduce the three-dimensional space when different valuation approaches provided similar information. The Kaiser criterion (i.e., eigenvalue  $\geq 1$ ) was used to select the principal components accounting for most of the variance of the different ecosystem services' measures (Kaiser, 1960).

## 4. Results

### 4.1. Supply of ecosystem services: a biophysical approach

While the agricultural land-use in the Doñana SES has increased over the last five decades, the production of rice and vine grape has declined 32% and 35%, respectively during the 21st century. On the contrary, the production of strawberries and olives has increased in 2% and 41%, respectively, because of the process of agricultural intensification. Overall, the agriculture production has remained stable during the last years. Regarding food from livestock, the average number of Live Stock Units (LSU) has declined 5% between 2004 and 2008, mainly through reductions in livestock units motivated by the Cattle Use Plan, which was designed by the Doñana National Park to adapt grazing pressure to the marsh's carrying capacity. Finally, food from fishing and shell-fishing decreased by 18% in the last decade, because the reduction of fish catches in the Guadalquivir estuary and because the reduction of the red-swamp crayfish (*Procambarus clarkii*) in the marshland. While the first one was motivated by river pollution and increasing harvesting pressure of larvae and juveniles fish; the decline in the harvest of crayfish was mainly motivated by falls in their market price (Martín-López et al., 2011).

**Table 3**

Descriptive statistics of respondents' preferences towards ecosystem services based on the percentage of people ( $N=796$ ) that recognized each ecosystem service as important for human well-being. S.D. refers to standard deviation.

Ecosystem service	N	Mean (%)	S.D.
<i>Provisioning</i>			
Food from Agriculture	355	44.6	0.50
Cattle	265	33.3	0.47
Fishing and shell-fishing	148	18.6	0.39
<i>Regulating</i>			
Climate regulation	373	46.9	0.50
Water quality	529	66.5	0.47
Soil formation	321	40.3	0.48
Biological control	148	26.8	0.44
<i>Cultural</i>			
Ecotourism	378	47.5	0.50
Scientific knowledge	281	35.3	0.48
Environmental education	431	54.1	0.50
Satisfaction for conserving biodiversity	475	59.7	0.47

Regulating services have declined significantly since 1980, except for climate regulation due to the increase (64%) from 1977 in the surface of forests (see also Gómez-Baggethun et al., 2011a). In 2005, the Doñana rivers *El Partido* and *La Rocina* experienced an increase in nitrates, ammonia, and phosphates concentration from the use of fertilizers and pesticides in agriculture, as well as from urban and industrial wastewater discharge upstream (Serrano et al., 2006; Appendix A). In addition, Rodríguez Ramírez et al. (2005) showed that sedimentation rates increased during the last three decades in the Doñana marshes because of the hydrological alteration of the main rivers (Fig. 1). Moreover, the water conductivity of the *El Partido* and *La Rocina* rivers has increased in 153% from 1982 to 2005, despite the annual precipitation was similar in both dates (Serrano et al., 2006; Appendix A). This indicates that the flow reduction of both rivers may have also been partly motivated by increasing sedimentation rates, which in turn suggest a decline in the ecosystem service of soil formation. Finally, we found that the performance of the service biological control of alien species has also declined, involving a rise of about 500% of registered species in scientific literature from 1980 to 2005 (see Fig. C of Appendix A).

Finally, all cultural services assessed in this research have increased or maintained stable during the period analyzed (see Fig. A of Appendix B). Scientific knowledge and environmental education services have increased significantly during the assessed period (Appendix B). Regarding the satisfaction for conserving biodiversity, Martín-López et al. (2007b) found that it was strongly related to the presence of Iberian lynx (*Lynx pardinus*) and the Spanish imperial eagle (*Aquila adalberti*) species. Thus, the population trend of both species in the Doñana SES was used as an indicator for this service (Table 1). The lynx population has suffered a continuous decline until 2000 (Delibes et al., 2000), after which it has stabilized. As for the Spanish imperial eagle, while the breeding population remained stable at a threshold of 15–16 breeding pairs between 1988 and 1991; the population notably declined after 1992 to only seven pairs in 2008 (Ferrer and Penteriani, 2008).

Supplementary material related to this article found, in the online version, at <http://dx.doi.org/10.1016/j.ecolind.2013.03.003>.

#### 4.2. Demand of ecosystem services: a socio-cultural approach

Regulating services were the most important services according to the respondents' perceived importance for human well-being (Table 3). In particular, water quality was the one showing highest saliency (66.5% of respondents selected it as being of primary importance). Cultural services of highest perceived importance

included the satisfaction for conserving biodiversity (59.7% of respondents selected it as important) and environmental education (54.1% of respondents selected it as important). Provisioning services obtained the lowest socio-cultural value.

#### 4.3. Demand of ecosystem services: a monetary approach

A thorough estimation of the ecosystem services value suggests that the ecosystems of Doñana make a significant contribution to society's welfare in monetary terms (see Table 2), especially agriculture, fishing, and ecotourism, which account for the 86.4% of the total annual value of ecosystem services provided by the Doñana's ecosystems. In total, provisioning services accounted for 65.6% to the monetary value, regulating services accounted for 7.7%, and cultural services accounted for 26.4%. The monetary importance of provisioning services is explained by the fact that the lands surrounding the Doñana protected area are intensively managed for the delivery of provisioning services for exportation to national and global markets (i.e., agriculture, fisheries, and tourism). Previous research suggests that this land use policy has negatively affected the ecological integrity of the ecosystems of Doñana and, therefore, the ecosystem's long-term capacity to supply regulating services (Martín-López et al., 2011; Gómez-Baggethun et al., 2011b).

Table 2 shows the estimated annual monetary value per hectare for each ecosystem service.

#### 4.4. Do the three value-domains of ecosystem services assessment provide overlapping information?

The trade-offs analysis suggests that the biophysical, the socio-cultural, and the monetary value dimensions of ecosystem services examined in this research generates different information outputs (Fig. 3). Biophysical indicators showed a clear trade-off between the delivery environmental education and scientific knowledge which are increasing, and all regulating services (except of climate regulation) (Fig. 3A). Biophysical trends in ecosystem service performance assessed in this study partially match with socio-cultural preferences towards services, which illustrate that people perceived environmental education and climate regulation services to be of primary importance. However, other important services selected by the respondents, such as water quality, ecotourism, and the satisfaction for conserving biodiversity (Fig. 3B), showed a stable or decreasing trend in their delivery (Fig. 3A). Finally, results obtained from the monetary valuation showed that provisioning services and ecotourism held higher market values than the rest of services, representing the classical trade-off between provisioning services (and ecotourism) and regulating and most of cultural services (Fig. 3C). Thus, monetary value seemingly prioritized marketed services, such as provisioning services and ecotourism, obscuring the socio-cultural importance given by stakeholders to regulating services. In fact, while regulating services were recognized by respondents as being those of highest importance for human well-being, they have the lowest monetary value and their delivery (measured in biophysical terms) was decreasing (Fig. 4).

We reduced the three-dimensional space to two dimensions, where the selected factors (F1 and F2) had an eigenvalue  $\geq 1$  and account for 77.1% of the total variance. Table 4 summarizes the PCA results, including factor loadings, squared cosines, the eigenvalues, the amount of variance explained by each factor, and the total variance. The first factor (F1), which accounts 43.9% of total variance, showed that the information obtained from socio-cultural values was highly different from the monetary information. On the other hand, F2 (33.3% of total variance) showed that different information

**Table 4**

Factor loadings and squared cosines derived from the principal component analysis (PCA). Bold squared cosines denote most influential variables.

Variables	Factor loadings		Squared cosines	
	F1	F2	F1	F2
Value-domains				
Biophysical indicators	−0.106	0.994	0.011	<b>0.988</b>
Socio-cultural ind. (% of people)	−0.806	−0.094	<b>0.650</b>	0.009
Monetary indicators	0.809	0.037	<b>0.655</b>	0.001
Eigenvalue	1.316	1.008		
Variance explained (%)	43.873	33.259		
Variance accumulated (%)	43.873	77.132		

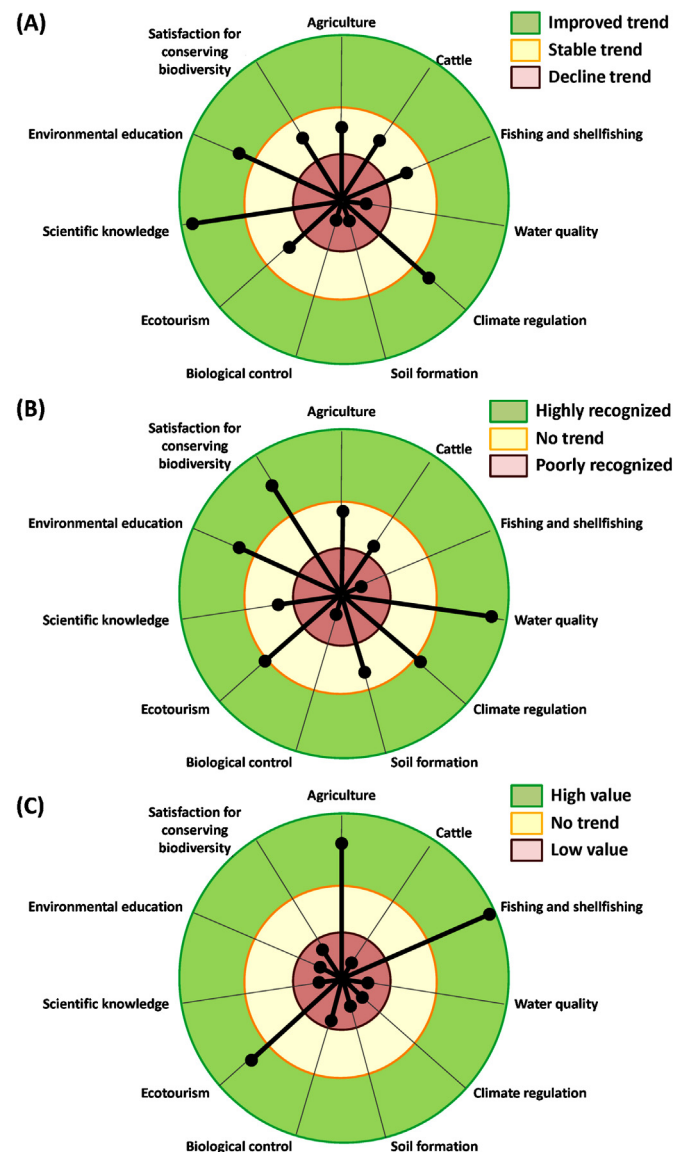
was obtained from biophysical indicators and socio-cultural values, where biophysical values had positive contributions to F2, and socio-cultural values had negative contributions to F2.

## 5. Discussion

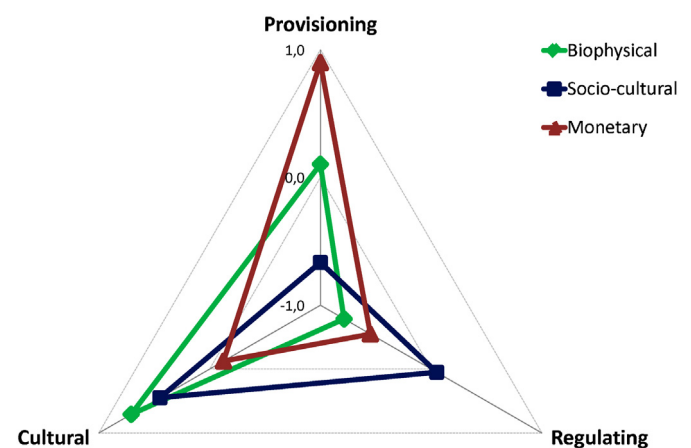
One of the most outstanding insights that emerge from this research is that the specific value-domain addressed by a

particular assessment method defines the ecosystem service trade-offs (Fig. 3). Specifically, our results show that the methods used to assess ecosystem services revealed different information (Table 4) and, thus different ecosystem service trade-offs (Fig. 4). This finding is consistent with current theoretical debate about the role of methodological assessment techniques as value-articulating institutions (Jacobs, 1997; Vatn, 2005) where the methods use to elicit value actually define the values elicited (Brondizio et al., 2010). Recognizing that the ecosystem service assessment methods are in fact value-articulating institutions, supports previous claims that valuation methods are not neutral (Gómez-Baggethun and Ruiz-Perez, 2011) and further, that the choice of the methodological approach may be as important as the assessment result itself because assessment methods do not simply ‘uncover’ but also ‘construct’ values (Vatn and Bromley, 1994). If the choice of the techniques used for ecosystem service assessment (or the selection of the value-domain in the ecosystem service framework) effectively determines the result; then ecosystem service research should combine different and irreducible value-domains in order to properly inform environmental decision-making process (de Groot et al., 2010; MA, 2005a; Tallis and Polasky, 2009). Yet, recent reviews of the scientific literature on ecosystem services show there is a bias towards biophysical value-domain related to regulating services (Vihervaara et al., 2010) and monetary value-domain (Chan et al., 2012; Seppelt et al., 2011). This entails two significant concerns: (1) the ecosystem services concept, which was born to examine the links between ecosystems and human well-being, may have reflected the concerns of their beneficiaries only to a limited extent, and (2) the demand-side of ecosystem services is biased towards the information obtained in monetary valuations.

Regarding the first point, it should be noted that the ecosystem service discipline was gestated with the idea of emphasizing the human dependence on nature (Díaz et al., 2006) in order to build



**Fig. 3.** Amoeba plots for the eleven ecosystem services to illustrate trade-offs based on (A) biophysical indicators, (B) socio-cultural preferences, and (C) monetary value.



**Fig. 4.** Mean value of provisioning, regulating, and cultural services using different types of information sources: biophysical, socio-cultural, and monetary valuation.



social support towards conservation policies (de Groot et al., 2002; Gómez-Baggethun et al., 2010b) and to facilitate the environmental decision-making through uncovering the importance of ecological processes behind the delivery of ecosystem services (de Groot et al., 2010). Because of that, ecosystem service assessment should incorporate socio-cultural information able to identify relevant services for different users and potential social conflicts due to different needs and perceptions (García-Llorente et al., 2011a; Martín-López et al., 2012).

Regarding the second concern, on the one hand, there is ample evidence that because ecosystem management mainly focuses on the production of marketed services, the most common ecosystem service trade-off appears between regulating and provisioning services (Carpenter et al., 2009; MA, 2005a). As market forces underlying this frequent trade-off, market-based valuation methods have drawn attention to it partially because robust valuation techniques do not exist for non-marketed services, i.e., most regulating and cultural services (Turner et al., 2010; Wegner and Pascual, 2011). Because commodifying most cultural and regulating services is unachievable (Vatn and Bromley, 1994) and probably undesirable (Gómez-Baggethun and Ruiz-Perez, 2011), economists use to develop hypothetical markets (i.e., stated preference methods) to ascertain their monetary value (Farber et al., 2006; Pascual et al., 2010). However, it is broadly recognized that the 'willingness to pay' indicator measures people's attitudes and preferences (Kahneman and Ritov, 1999) and that its results are partially motivated by non-economic reasons such as people's moral issues or individuals' previous experiences (Kahneman and Knetsch, 1992; Martín-López et al., 2007b; Spash, 2006; Tisdell et al., 2008). In fact, willingness to pay should be partially understood as an indicator of socio-cultural preferences rather than exclusively a market value per se (Chan et al., 2012). This fact can be the reason that the 'paradox of valuation' (Simpson, 2011) takes place in our study. While the Neoclassical Economic Theory predicts a high monetary value when the supply of an ecosystem service is deteriorated or scarce and its demand is high, we found that water quality and the existence value of biodiversity have less monetary value than the other ecosystem services (Fig. 3C) in spite of they were highly demanded by society (Fig. 3B) and their delivery was deteriorated (Fig. 3A).

On the other hand, the dominance of monetary valuation in scientific literature also entails a privileged position in the environmental decision-making process because the cost–benefit analysis is often the favoured technique to guide the choice among different policies that affect ecosystem services (Carpenter et al., 2009; Daily et al., 2009; Wegner and Pascual, 2011). This has significant consequences to achieve the environmental sustainability challenge because if the decision-making is mostly based on the cost–benefit analysis, then the environmental policies would promote monetary valuation studies in order to have enough information for taking decisions, ignoring or downplaying the other value-domains of ecosystem services.

Consequently, rather than conducting all scientific efforts for converting biophysical and socio-cultural properties into monetary values, we call for a multi-dimensional and pluralistic methodological framework that engender multi-metric information about irreducible and incommensurable value dimensions (Martínez-Alier et al., 1998; Kumar and Kumar, 2008; Gómez-Baggethun and de Groot, 2010; Wegner and Pascual, 2011; Busch et al., 2012). All applied scientific research is political to the extent that it articulates the decision-making process. Acknowledging that service assessment methods are value-articulating institutions, invite us to rethink how to design a comprehensive approach that deals with the complexity of ecosystem services values. Following the institutional framework developed by Ostrom (1998) in the context of the governance of complex systems, which also refers to the 'Law

of Requisite Variety' (Ashby, 1960), we argue that the ecosystem service research needs as much variety of methods as complexity and value plurality exists in the system we want to analyze. Consequently, scientists should be cautioned to incorporate multiple values (from biophysical to monetary values) and multiple forms of knowledge (which includes different disciplines, from biophysical, to sociological, to economic science) in their research of ecosystem services in order to improve transparency in the environmental decision-making process (Luck et al., 2012). As Ludwig (2001) stated the era of atomized disciplines is over in environmental management. If we recognize the complexity of ecosystem services (from the supply to the demand-sides), then a dialogue between biophysical and social scientists, as well as between academics and policy-makers becomes fundamental.

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