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Research Paper

Effects of land-use change on wetland ecosystem services: A case study in the Doñana marshes (SW Spain)

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HIGHLIGHTS

- 70% of one of the last remaining wetlands in Europe, Doñana marshland, was converted to cropland.
- Land-use change has been a result of a conservation vs. development process.
- Land-use change has fostered high-economic-value provisioning services.
- Land-use change has deteriorated regulating and locally used provisioning and cultural services.
- Ecosystem services evaluation with biophysical and social methods provides complementary information.

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ABSTRACT

Land-use change is a major driver behind the loss of ecosystem services. We assessed changes in ecosystem services from land-use conversions during the period 1918–2006 in the Doñana marshland and estuary in southwestern Spain, one of the largest European wetlands. We contrasted those results with social perceptions of ecosystem services trends using two techniques (expert judgment by a multidisciplinary scientific panel and semi-structured interviews of locals and visitors). The results show that by 2006, (1) 70.5% of the natural or semi-natural land covers had been converted to intensive agriculture and other mono-functional uses, hampering the performance of regulating services and (2) 31% of the wetland area had been strictly protected, affecting cultural and provisioning services. Our results show that land-use changes have led to a polarized territorial matrix exhibiting fundamental trade-offs in ecosystem service supply, where provisioning services produced for exportation and sale in the market, such as cash crops and fiber, have been enhanced at the expense of regulating services, such as hydrological regulation, flood buffering, and habitats for species and specific cultural and provisioning services used traditionally by the locals.

1. Introduction

Despite wetlands being known to be critical to the delivery of ecosystem services, they are among the ecosystems suffering the greatest transformations worldwide (MA, 2005a). During the 20th century, land-use change was a main driver behind the loss of wetlands and associated ecosystem services (De Fries, Foley, & Asner, 2004; Foley et al., 2005; Gagne & Fahrig, 2007; MA, 2005a). The intensification of agriculture in fertile regions and the abandonment of farming in less favorable areas are affecting natural and cultivated ecosystems all over the world, especially in industrialized countries (e.g., Kristensen, 1999; van Doorn & Bakker, 2007). In Spain, land-use change for intensive agriculture and urbanization is a main driver behind biodiversity loss and has led to the conversion of 60% of the original wetland area over the last five decades. According to the Spanish subglobal ecosystem assessment, 62% of the ecosystem services delivered by wetlands have declined over the last fifty years, affecting regulating services in particular (EME, 2011). The decline in ecosystem services results

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not only from land-use intensification but also from abandonment (Braat & ten Brink, 2008; Schneiders, Van Daele, Van Reeth, & Van Landuyt, 2012). This process may be especially important in the context of Mediterranean ecosystems and cultural landscapes (Bugalho, Caldeira, Pereira, Aronson, & Pausas, 2011), where traditional management coupled with ecosystem dynamics has historically contributed to diversifying ecosystem service supply (García-Llorente et al., 2012; Martín-López et al., 2012).

The aim of this study was to assess the effects of land-use change on ecosystem services delivered by wetlands. As a case study, we assessed land-use changes in the Doñana marshes and estuary (in southwestern Spain) during the period 1918–2006 and their impacts on ecosystem service supply. Our specific objectives were to (1) identify the primary drivers and stages of land-use change, (2) provide quantitative measures of land-use changes for each of these stages, and (3) assess the effects of land-use change on ecosystem service delivery.

Our analysis was conducted using a combination of biophysical and social science methodologies. Our research contributes to advancement of the understanding of how wetland conversion affects human well-being through changes in ecosystem service supply. By quantifying social, ecological, and economic impacts of wetland conversion that are not always accounted for in traditional territorial planning, our research can contribute to preventing further wetland transformations involving loss of critical ecosystem services in other areas.

2. Study area

2.1. Site description

Doñana is located at the mouth of the Guadalquivir River on the southwestern coast of Spain. Montes, Borja, Bravo, and Moreira (1998) defined the Greater Fluvial–Littoral Ecosystem of Doñana (2207 km^2) as an ecological unit whose structure and functions are shaped by the interactions of the Guadalquivir River and the Atlantic Ocean (Fig. 1). The Greater Fluvial–Littoral Ecosystem of Doñana consists of four main ecosystem units at the eco-district scale: marshes (72%), sand dunes (23%), coastal systems (2%), and estuary (3%). Our analysis of land-use change includes two Doñana wetland ecosystems: marshes and the estuary, which together cover 1660 km^2. We focused our research on the Doñana marshes and estuary because (1) they constitute one of the largest and most emblematic wetlands in Europe (García Novo & Marín Cabrera, 2006), (2) they are the Doñana ecosystems that have suffered the most intensive land-use transformations (González-Arteaga, 1993), and (3) they are acknowledged as being important in delivering critical ecosystem services (Martín-López, García-Llorente, Palomo, & Montes, 2011).

Part of the Greater Fluvial–Littoral Ecosystem of Doñana was declared a National Park (IUCN Category II) in 1969, and its surroundings were declared a Natural Park (IUCN Category V), intended as a buffer zone, in 1989. Moreover, parts of Doñana were declared a Biosphere Reserve in 1980, a Ramsar Site in 1982, and a UNESCO World Heritage Site in 1995. In 1999, the National and Natural Parks were unified as the "Doñana Natural Protected Area". Fifteen municipalities currently sit on what was once the original Doñana marsh. Altogether, these territories host a total population of 632,000 inhabitants (127 inhab/km^2). The main economic activities are agriculture and tourism.

2.2. Historical background on land-use change

For at least two millennia, the primary land use in the marshes and the estuary was free-range livestock breeding (Butzer, 1988), but the Doñana wetlands were subject to many other uses by the locals, including hunting, snail harvesting, fishing, and grass cropping for soap and glass making (González-Arteaga, 1993). The outstanding ecological values of the Doñana wetlands persisted throughout a long history of human utilization of its ecosystems (Menanteau, 1984; Ojeda, 1987). This long history of co-evolution between humans and nature produced cultural landscapes where multifunctional ecosystems deliver a diverse range of services to society (see García-Llorente, Martín-López, Díaz, & Montes, 2011; Gómez-Baggethun, Mingorría, Reyes-García, Calvet, & Montes, 2010; Martín-López, Montes, & Benayas, 2007).

During the 18th and 19th centuries, several attempts were made to drain the marshes (González-Arteaga, 1993). Within a generalized context of policies to reclaim wetlands across Europe, public bodies promoted conversion of marshes in Doñana for purposes of sanitation (e.g., to fight malaria) and risk reduction (e.g., flood control), while private companies promoted further conversion plans in search of economic profit from agriculture (Ojeda, 1987). These interventions failed due to insufficient capital investment and lack of appropriate technology and infrastructure (González-Arteaga, 1993). Consequently, the attempted engineering works were destroyed by periodic flooding of the marsh (Ojeda & del Moral, 2004). The only stable transformation before the 20th century consisted of a set of engineering works that shortened the Guadalquivir River by 40 km for navigation purposes (Menanteau & Vanney, 1985). Apart from these works, the other durable transformations in the Doñana marsh began only in the 20th century.

3. Methods

3.1. Characterization of drivers of change

Our research covers the period 1918–2006. Following methodological guidelines proposed by Ruiz and Domon (2009), we identified and characterized the main factors driving land-use change from an historical analysis of the primary socio-economic and political changes that have affected the Doñana marshes and estuary. The main stages in the recent history of the Doñana marshes were reconstructed from an in-depth literature review covering more than 70 publications dealing specifically with the Doñana marshes and estuary (see Appendix A). The sources of information included scientific literature (i.e., peer-reviewed papers and books) and "gray literature", including historical documents, ancient maps, technical and management reports, and documents on the history of land use, territorial planning, and ecosystem change in the area. To differentiate the main stages, we relied on four main criteria: (1) the purposes of the changes (i.e., agricultural development, nature conservation, or ecosystem restoration), (2) the magnitudes of the transformations, (3) the stakeholders promoting the transformations (i.e., private companies or public entities), and (4) other underlying drivers of change, such as socio-economic and technological changes (MA, 2005b, chap. 3).

3.2. Quantitative analysis of land-use change

A spatially explicit temporal land-use database was developed from historical maps (see Appendix A), aerial photographs, satellite images, and field work. As in previous published research (Lambin et al., 2001), land use is defined here as the way people use the land rather than to the physical state of the surface of the earth or land cover. Land-use categories were classified and assessed at a 1:5000 scale for five different years, based on various sources of information: 1918 (historical cartography and bibliography), 1955 (aerial photography of 1956), 1978 (Landsat image and aerial photography of 1977), 1998 (aerial photography of 1998, 1995 Landsat

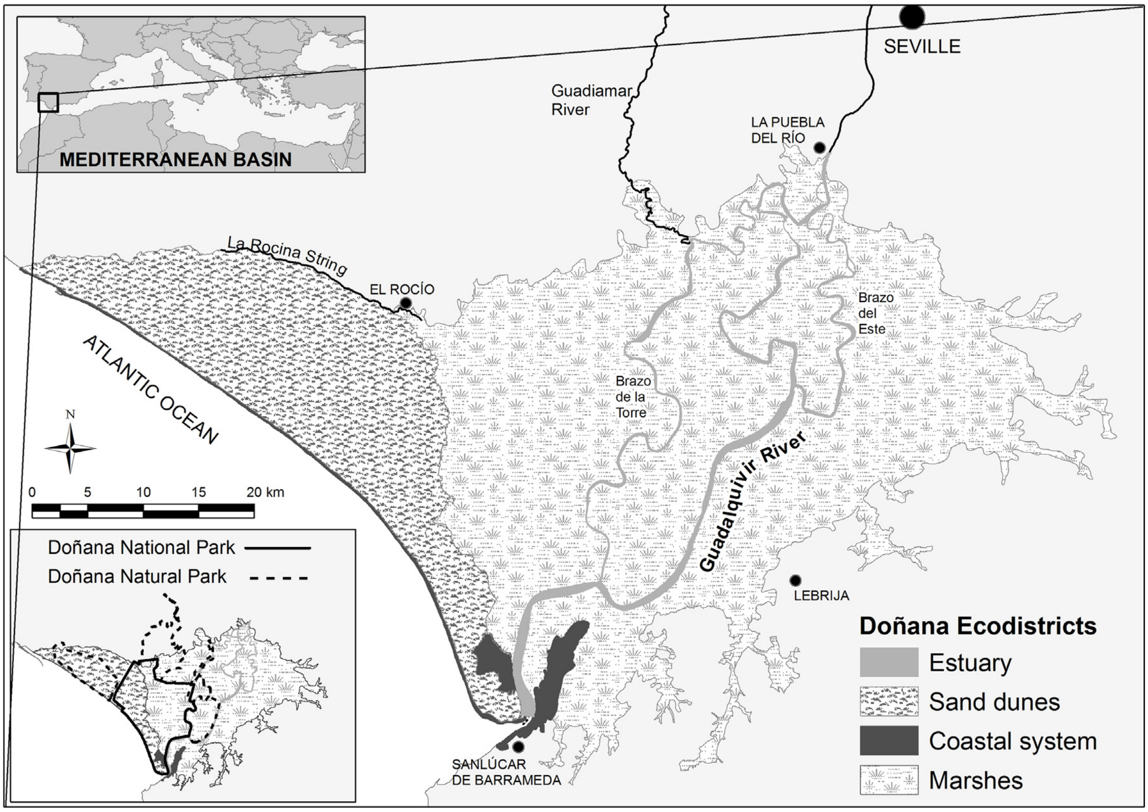

Fig. 1. Map of Doñana's Fluvial–Littoral Great Ecosystem, protected areas and its location in the Mediterranean Basin. The marshes eco-district shown in the map is a reconstruction of its original extent.

image, and the Andalusia Land-Use Study, years 1995 and 1999), and 2006 (aerial photography of 2002, 2003 Landsat image, the Andalusia Land-Use Study of 2001, the Spanish National Agricultural Parcel GIS (SIGPAC), and field work in 2006). The field work conducted for the development of the 2006 land-use map consisted of 15 days of field surveys conducted between February and May of that year. In the field surveys, we verified the land-use changes relative to the map for 2003, and we updated all polygons that had experienced changes in the previous three years to produce the map for 2006.

In total, we identified 12 land-use types that were clustered into three main categories: natural, semi-natural and restored ecosystems, cultivated systems, and artificial areas (Table 1). Land-use change analysis was assessed by comparing the areas occupied by each land use in each period using the ArcGIS software. For each study period (1918–1954, 1955–1977, 1978–1997, and 1998–2006), we calculated the total area lost or gained by each land-use type and the land-use dynamic index (% change per year) (Hao et al., 2012) and land-use dynamic degree (Jiyuan et al., 2010), using Eqs. (1) and (2):

$$K = \frac{S_b - S_a}{S_a} * \frac{1}{t} * 100\,(\%) \qquad (1)$$

where K refers to the dynamic index of a given land-use category, S is the area (in ha) for a certain land-use category, "a" and "b" are the initial and final areas, respectively, and "t" is the study period. If "t" is one year, then K is the annual rate of change of a certain land-use category.

$$S = \left\{ \sum_{ij}^{n} \left(\frac{\Delta S_{i-j}}{S_i} \right) \right\} * \frac{1}{t} * 100(\%) \qquad (2)$$

where S_i is the area of land-use type i at the beginning of the period, ΔS_{i-j} is the total area of land type i converted into other land-use types, t is the study period, and S is the land-use dynamic degree in the period of t.

3.3. *Effects of land-use change on ecosystem service delivery*

Previous studies have acknowledged the challenges of assessing the effects of land-use change on ecosystem services (van Oudenhoven, Petz, Alkemade, Hein, & de Groot, 2012) and taking them into consideration in landscape planning (de Groot, Alkemade, Braat, Hein, & Willemen, 2010). Our assessment of the effects of land-use change in ecosystem service delivery was based on a literature review conducted to define which ecosystem services are associated with different land uses and on the perceptions of beneficiaries. Ecosystem services are defined here as direct and indirect contributions from ecosystems to human well-being (TEEB, 2010) and are usually classified into the broader categories of regulating, provisioning, and cultural services. The ecosystem services evaluated were selected from classifications identified in previous research about the area (e.g., García-Llorente et al., 2011; Martín-López et al., 2011; Palomo et al., 2011).

First, we identified the land-use categories delivering the main ecosystem services (as done before by Burkhard et al., 2012; Hao et al., 2012; Troy & Wilson, 2006; and Vihervaara, Kumpula, Tanskanen, & Burkhard, 2010). Specifically, we gathered and synthesized information on land-use categories as providers of specific ecosystem service types through a systematic literature review in the Web of Science (https://apps.webofknowledge.com). Keywords used in the search included the following: "marsh*" OR "wetland" AND "ecosystem servic*" OR "environmental servic*" OR "benefit" AND "land use" OR "land cover". Besides "marsh*" OR "wetland",

Table 1
Land-use categories and associated ecosystem services. References: (a) Burkhard, Kroll, Müller, & Windhorst, 2009, Burkhard, Kroll, Nedkov, & Müller, 2012; (b) Hao et al. (2012); (c) Scolozzi, Morri, & Santolini, 2012; (d) Vihervaara et al., 2010; (e) Troy & Wilson, 2006; (f) Zhao et al., 2004; (g) Pinto, Patricio, Neto, Salas, & Marques, 2010.

Land-use category	Class description	Main ecosystem service associated **P** (provisioning), **R** (regulating), **C** (cultural)
Artificial areas		
	Includes city centers, large infrastructures, and other types of large construction.	
Cultivated systems		
Aquaculture ponds	Areas of the marshes that had been transformed to control water levels for fish or seafood breeding.	**P**: Food from fish (aquaculture) (f)
Drained marshes	Land that is being drained or land that has been already drained where cultivation has been abandoned.	**P**: Livestock (a, d) **R**: Soil fertility (a, b, d, e), Pollination (d)
Greenhouses	These have existed since the 1970s in small plots between the irrigated fields. Although greenhouses account for a small percentage of area, this category is important because regulating and cultural services were affected by policies aimed at increasing provisioning services. Additionally, they require great amounts of fossil fuel energy.	**P**: Food from agriculture (a, d)
Irrigated fields	Common crops include corn, potatoes, cotton, pepper, and beans.	**P**: Food from agriculture (a, b)
Rain-fed fields	Crop fields without irrigation. This category underwent an important change between 1918 and 2006: at the beginning of the period, its cultivation was labor-intensive, whereas at the end, it was very intensive in consumption of fossil fuel exosomatic energy. Presently, its cultivation is very dependent on subsidies from the European Common Agriculture Policy, and some fields are being abandoned.	**P**: Food from agriculture (a, b), Livestock (a, d) **R**: Pollination (d)
Rice fields	Areas of the marshes with drainage and irrigation mechanisms for water level control and rice cultivation.	**P**: Food from agriculture (a, b)
Salines	Until the middle of the 20th century (ref. point 1955), salt exploitation was conducted by traditional methods. More recently, it has become an industrial process, and now, tourist routes visit the facilities.	**P**: Salt production (g)
Natural, semi-natural and restored ecosystems		
Lucios	Shallow-water areas of the marshes that maintain water for longer periods and that have higher salinity.	**P**: Freshwater consumption (b, c, d, e), Harvesting (d), Medicinal plants (d) **R**: Air quality (b, c, d), Climate regulation (b, c, d), Flood buffering (a, c, d, e), Habitat for species (b, c, d), Hydrological regulation (c, e), Pollination (d), Soil fertility (b, d), Water depuration (b, c, e) **C**: Aesthetic value (a, b, c, d), Local ecological knowledge (b, d), Local identity (d), Nature tourism and recreation (a, b, c, d, e)
Non-modified marshes	Parts of the marshes that have never been drained, canalized or cultivated.	
Restored marshes	Areas that have been restored by different projects. The restoration has consisted of filling the canals that drain the marshes with soil, elimination of crops, and use of former crop fields as pastures for livestock.	
River, branches and river beaches	Bed of the Guadalquivir River and its branches. The latter have been separated from the main bed by different transformation events. This category also includes meadows in the banks of the Guadalquivir River.	**P**: Food from fish (fishing) (a, d), Freshwater consumption (a, b, c, d, e), Harvesting (a) **R**: Flood buffering (a, d), Habitat for species (a, b, d, e), Hydrological regulation (c, e), Soil fertility (c, e), Water depuration (a, b, c) **C**: Aesthetic value (a, b, c, d), Local ecological knowledge (b, d), Local identity (d), Nature tourism and recreation (a, b, c, d, e)
Other land uses		
	Various land uses of very small extents.	–

we also searched for other specific land-uses such as "aquaculture" or "saline", when the first search did not provide results regarding these specific land uses. We found 144 articles, from among which we selected those that allowed us to identify the main ecosystem service provided by each land-use category. The articles selected provide information on the capacity of each land cover types to provide each ecosystem service. We assumed that a given land use delivers a specific ecosystem service when that association had been identified in at least one previous publication. To filter the main ecosystem services supplied by land use, we only considered ecosystem services with score above the average value in the ranking given by the authors of each article. To enhance the stringency of our criteria and improve the accuracy of the identified associations, when an ecosystem service was mentioned by more than one author with respect to different land uses, we selected only the ecosystem service/land-use associations that were mentioned by more than one author. Finally, we selected only the relations between land use and ecosystem services applicable to the Doñana marshes and the Guadalquivir estuary. For example, although Vihervaara et al. (2010) identifies the "local cultures/agricultural areas" association, we did not consider this association applicable to the specific case of Doñana because agriculture in the Doñana marshes did not start until the 20th century, and therefore agricultural areas have not contributed to the local culture of the marshes or estuary as much as other land uses have.

Because previous studies recommend using different methods to assess social perceptions of ecosystem services (Lynam, de Jong, Sheil, Kusumanto, & Evans, 2007) we assessed perceptions of ecosystem services trends using two techniques: (1) expert judgment by a multidisciplinary scientific panel, and (2) semi-structured interviews of locals and visitors, including face-to-face administration of questionnaires.

The expert panel comprised ten researchers with at least eight years of research experience in the area. Each member of the panel assessed trends in ecosystem services for the period 1955–2006 in the marshes and in the estuary. A Likert scale ranging from 0 to 5 was used to evaluate ecosystem service trends, with (0) meaning strong decline, (1) meaning moderate decline, (2) meaning stability, (3) meaning enhancement, and (4) meaning strong enhancement. We used a Chi-square test to explore which

Table 2
Description of methods used for the three sampling techniques to identify changes in ecosystem services based on expert judgment and perceptions of local stakeholders.

	Expert panel	Interviews	Questionnaires
N	10	14	70
Year of sampling	2006	2009	2009
Duration of each survey	4 h	40–90 min	20–25 min
Stakeholder involved	Scientists	Key respondents	Local population and tourists
Question	What is the trend of ecosystem services in the period 1955–2006?	Which ecosystem services have been declining during the last decades?	
Categorization of answers	Strongly declining, declining, stable, enhancing and strongly enhancing	Participants chose the five ecosystem services from the list that had the greatest decline and ranked them on a Likert 1–5 scale.	
Time frame	1955–2006	No specific time frame (the last two to three decades)	

categories of ecosystem services (i.e., provisioning, regulating, or cultural) enhanced or declined during the period analyzed. Additionally, we used a Mann–Whitney test to determine at which scale beneficiaries enjoyed the services, differentiating between local beneficiaries and broadly oriented (national and the international) beneficiaries. For more details, see Table 2 and Gómez-Baggethun, Martín-López, Lomas, Zorrilla, and Montes (2011).

Secondly, we conducted semi-structured interviews of local key informants ($N = 14$) and administered questionnaires ($N = 70$) to local stakeholders and visitors to assess social perceptions of trends in ecosystem service delivery. A list of the ecosystem services, with associated pictures, was presented to the respondents, who had to select the five ecosystem services they perceived to be declining most severely. As the respondents were non experts, and it could be difficult for them to detect changes in ecosystem services that have taken place specifically between 1955 and 2006, the question referred to “the last decades”. The results from the semi-structured interviews and questionnaires were analyzed through calculation of descriptive statistics. For more details, see Table 2 and Palomo et al. (2011). Further details about the three methodologies used to ascertain trends in ecosystem services are summarized in Table 2.

4. Results

4.1. Drivers of change behind marshes conversion

The conversion of the Doñana marsh and estuary during the period 1918–2006 can be classified into four main stages, each of which was different with respect to the magnitude of change, underlying promoters (public bodies and private entities), motivation (sanitation, security, navigation, agriculture, conservation, restoration), and other drivers of change (technological innovations, market integration, socio-political and economic reforms).

4.1.1. First transformations (1918–1954)

In the first period (1918–1954), the primary interventions to drain the marsh and to convert it to agriculture were promoted by both the Spanish government and foreign private companies (Ojeda, 1987). Between the end of the Spanish Civil War (1936–1939) and 1954, a critical motivation for wetland conversion was the demand for food in the post-war period. Other important drivers in this period included sanitation goals, technological change and financial investment. According to González-Arteaga (1993), mechanization allowed the construction of durable channels to drain the marsh and the construction of levees to contain natural floods, making a difference compared to previous failed attempts to drain the marsh.

4.1.2. Great transformations and emergence of conservation policy (1955–1977)

During the second period (1955–1977), the main motivation behind the transformations was the government’s aim of facilitating investment opportunities to attract foreign capital. In 1955, the National Institute for Colonization declared the transformation of the Doñana marshes into irrigated crops to be of “major national interest”. Subsequently, the Spanish government was a primary actor in promoting the drainage of the marsh and its conversion for agricultural purposes (González de Molina, 1993; Granados, Martín, & García Novo, 1987; Grande Covian, 1978).

During this period, a new driving force, the conservation movement, emerged in Doñana. In 1963, the World Wildlife Fund (WWF) and the Spanish government purchased 6800 ha of land for conservation purposes (Ojeda, 1987) and in 1969 34,625 ha of Doñana were declared a national park.

4.1.3. Development vs. conservation phase (1978–1997)

In 1978, the Doñana Law 91/1978 was approved, marking the beginning of a period of more robust conservation policies. The area of the Doñana National Park was expanded to a total of 50,700 ha. We identified three primary motivations for the expansion of the protected area: (1) research had shown that the non-transformed marshes had high ecological value (Fernández-Delgado, 2005), (2) the economic importance of the Spanish agriculture sector was decreasing in relation to the industrial and services sectors (Naredo, 2004), and (3) the goals that had motivated the initial transformations of the marsh (i.e., increasing land productivity and sanitation) had already been achieved (González-Arteaga, 1993). While a private entity, WWF, took the initiative for nature conservation, authorities of the Spanish government became an increasingly powerful and active stakeholder in promoting conservation in Doñana.

However, even though no new large conversion projects were planned during this period, programs that were already in place were completed between 1978 and 1997, mainly through the initiative of the private sector. In this situation, the primary objective of conservation managers was to halt further transformation of the marshes. In 1989, the Doñana Natural Park was declared to protecting three additional sectors surrounding the National Park (Fig. 2). The National Park has more strict conservation policies than the Natural Park, and therefore, some uses forbidden in the former, such as hunting and specific types of agriculture (e.g., rice fields), were allowed in the latter under the regulation.

Conservation policies were put in place mainly in response to the ecological decline that followed economic development. The tension between these two policies soon became apparent (Gómez-Baggethun et al., 2010; Ojeda-Rivera, 1986) and policy makers realized that some convergence between stakeholders representing development and conservation interests was needed to attenuate rising social conflicts (Aguilar Fernández, 2008). In an attempt to harmonize development and conservation policies, the first Plan for Sustainable Development of Doñana (1993–2000) was approved by the European Commission, with a budget of 372 million Euros. Following this investment, economic development

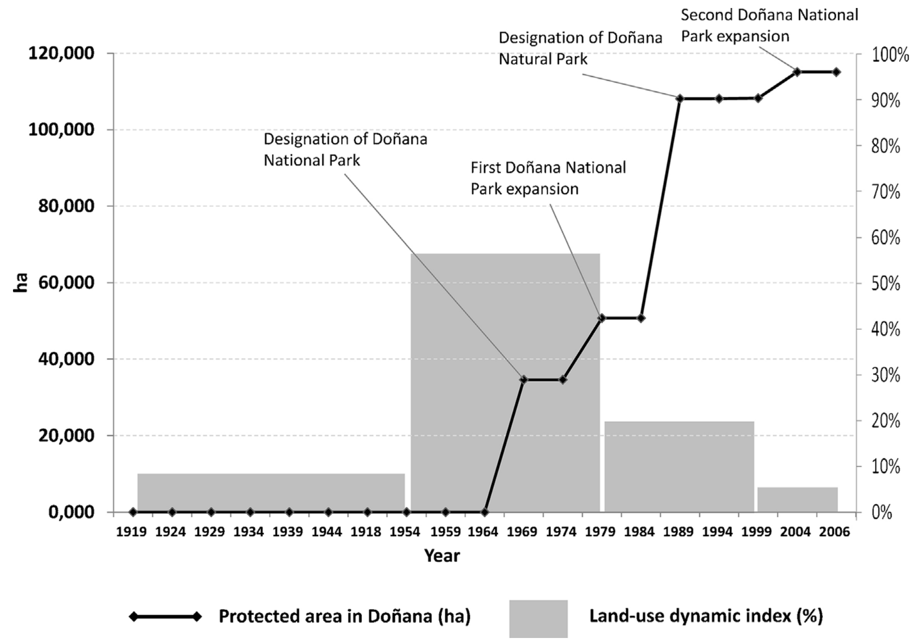

Fig. 2. Protected area in Doñana (ha) and Land-use dynamic index (%) during the studied time period. The creation of the Doñana National and Natural Parks were moments of rapid protected area expansion, after which the rate at which new land was protected stabilized, with small additional increases associated with the restoration phase. As seen in the figure, the designation of protected areas did not occur at the end of a land-use transformation process, but when the intensification of land uses had the highest land-use dynamic index.

promoted through infrastructure for tourism and greenhouse agriculture outside the protected area reduced the opposition of the local population to conservation but also generated new expectations of investment (Oñate, Pereira, & Suárez, 2003).

4.1.4. Ecological restoration (1998–2006)

In 1998, a toxic waste spill from the Boliden pyrite mine in Aznalcóllar (60 km away from the protected area) released 4.5 Mm^3 of water polluted with heavy metals to the Guadiamar River, one of the main tributaries of the marshes of the Doñana National Park (Grimalt, Ferrer, & Macpherson, 1999). The mine spill crossed the Natural Park and reached the border of the National Park, causing an ecological and socio-economic disaster, covering 4634 ha of natural and agricultural lands by toxic spillage (PICOVER, 2003). In response to this event, the national and regional governments launched two major restoration programs, named the "Guadiamar Green Corridor" program (1998–2002) and the "Doñana 2005" program (1998–2006). Another important event during this period was the approval of the Second Sustainable Development Plan of Doñana in 2005, with an emphasis on participation, conflict resolution, and institutional coordination.

4.2. Quantification of land-use changes

According to our calculations, the land-use changes during the four main stages identified above can be summarized as follows:

- In the first stage, 1918–1954, policies promoting agricultural development led to the conversion of 5000 ha of the marshes to rice fields and the conversion of 7700 ha to rain-fed herbaceous crops. Another 55,000 ha of the marshes were drained but not transformed into arable land (Table 3 and Figs. 3 and 4).
- In the second stage, 1955–1977, agricultural policies led to the conversion of an additional 37,000 ha of natural or semi-natural marshes (Corominas, 1995; Reguera, 1983). By the end of this period, a total of 23,000 ha of new rice fields, 23,400 ha of new irrigated fields and 7000 ha of new rain-fed fields had been created (Table 3 and Figs. 3 and 4). At the same time the establishment of the Doñana National Park in 1969 led to the protection of 34,625 ha of natural or semi-natural ecosystems. Approximately 47% of that area (16,274 ha) consisted of marshes, with the rest consisting of sand dunes and beaches.
- In the third stage, 1978–1997 development policies transformed 22,000 ha to new irrigated fields relying on groundwater, and 13,000 ha to new rice fields irrigated with water from the Guadalquivir River (Table 3, Figs. 3 and 4). Additionally, during this period, 3600 ha of marshes were transformed into the largest aquaculture area in Spain (Campos & López, 1998). The new farmland areas occupied 20,000 ha of previously drained marshes and 20,000 ha of natural or semi-natural marshes. Conservation policies implemented during the same period added 53,709 ha of protected land through the declaration of the Doñana Natural Park.
- Finally, during the last period, 1998–2006, the reversal of land-use change from conversion of cultivated systems to conservation was consolidated. By 2006, restoration projects had led to the restoration of 5600 ha of marshes and to the expansion of the National Park into 3532 ha of these restored lands.

Overall, between 1918 and 2006, 70.5% of the Doñana marshes were transformed into cultivated systems (69.5%) and artificial areas (0.7%), whereas 29.5% remained untransformed or had been restored, most of these marshes within the Doñana National Park (Figs. 3 and 4).

4.3. Effects of land-use changes on ecosystem services

Table 1 includes a description of the land-use categories and associated ecosystem services, as identified from the literature review. We did not find references documenting direct associations between land use and the following ecosystem services: shellfishing, plague and pest control, environmental education, recreational hunting, scientific knowledge, and spiritual value. The literature review showed that ecosystem services associated with cultivated

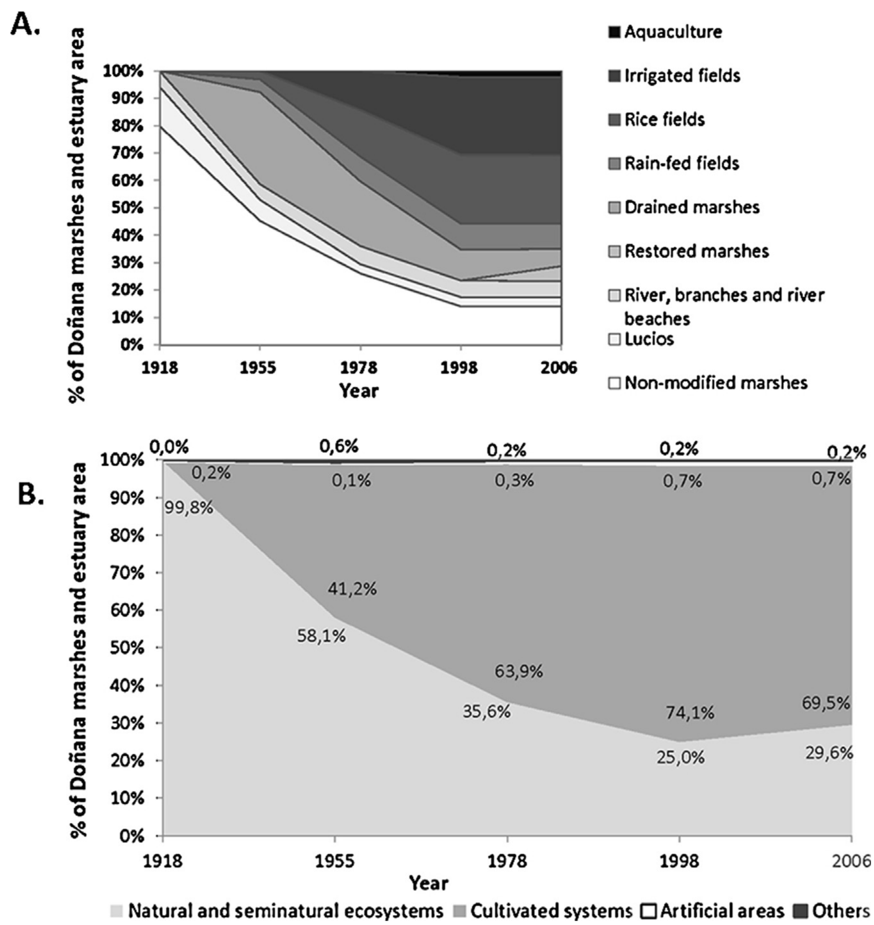

Fig. 3. (A) Evolution of the primary land uses in the Doñana marshes and estuary, expressed in percentages. (B) Transformation of natural ecosystems in the marshes and estuary.

land uses, the area of which increased over the studied period, are mainly provisioning services (i.e., food from agriculture, livestock, and fish—from aquaculture and fishing) (Table 1). Natural and semi-natural land-uses, which have decreased since 1918, are mainly associated with regulating (i.e., flood buffering, habitat for species, and hydrological regulation) and with cultural services (i.e., aesthetic value, local identity, nature tourism and recreation, and local or traditional ecological knowledge).

This picture broadens when compared with the results obtained from the social evaluations. The assessment by the expert panel suggests that most regulating services were either declining or strongly declining, while cultural services were considered to be stable or improving (Table 4 and Fig. 5). There were differences regarding trends in provisioning services depending on the scale at which their benefits accrue. For example, 80% of the provisioning services that were perceived to be declining or strongly declining are consumed at the local scale (i.e., freshwater consumption, medicinal plants, and shellfishing). Meanwhile 60% of the provisioning services that were perceived to be stable or enhancing are directed primarily toward beneficiaries in the national and international markets (i.e., food from agriculture and food from fish—both aquaculture and fishing) ($U = 15.50$; $p = 0.04$).

Finally, consistent results were obtained from the interviews of and questionnaires administered to local stakeholders and tourists. Most respondents considered regulating services to be those that were declining most severely (42% of total responses), with the ecosystem service "habitat for species" perceived to have suffered the largest decline (11% of total responses) (Fig. 6). Provisioning services were perceived to be declining (38% of total responses), as exemplified by declines associated with fishing and shellfishing along the river banks. Finally, only 20% of the responses perceived cultural services to be declining (Fig. 6).

5. Discussions

5.1. Land-use change and loss of wetlands

Our data show a severe loss of wetland area in Doñana due to agricultural intensification during the 20th century (Table 3). These results are consistent with findings obtained in previous research in Doñana (Fernández Alés, Martin Vicente, Ortega, & Ales, 1992), and in many other floodplains around the world (Finlayson, Davidson, Spiers, & Stevenson, 1999; MA, 2005a; Teferi, Uhlenbrook, Bewket, Wenninger, & Simane, 2010). A common policy response to wetland conversion has been the demarcation of protected areas to preserve remaining ecosystems (MA, 2005a), and Doñana is a paradigmatic example of this response (see Table 3 and Fig. 2).

5.2. Drivers of land-use change and ecosystem service trends

Our research showed the interrelated and often synergistic effect of different drivers of land-use change on ecosystem service delivery. There has been a combination of multiple drivers of change, from the earliest sanitary goals and risk reduction purposes, profit motives, technological changes and innovations, market forces, to conservation policies. These drivers played roles in shaping the current "conservation vs. development" dichotomy that characterizes the polarized territorial matrix in

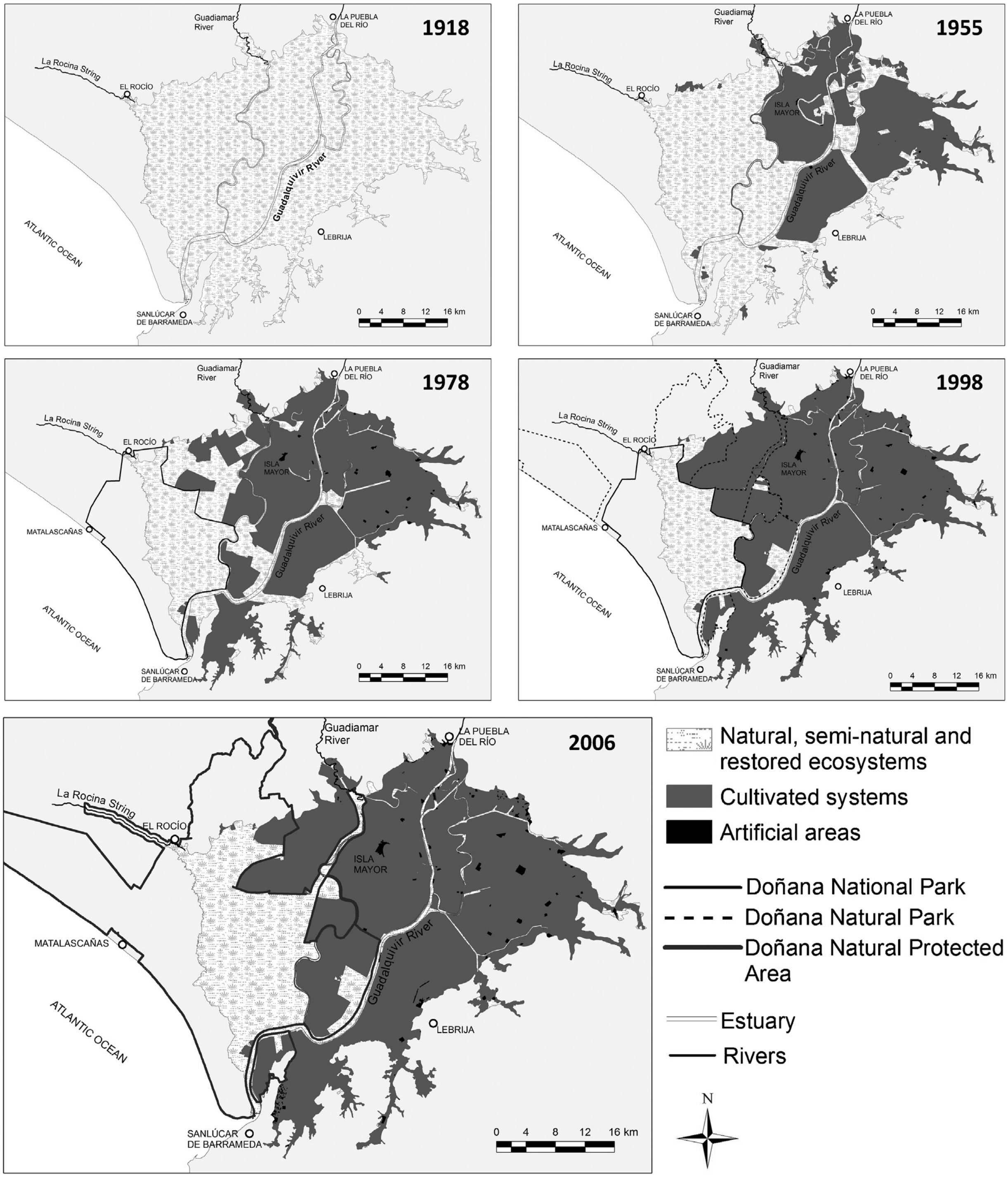

Fig. 4. Maps showing the primary land-use changes during the period 1918–2006 in the Doñana marshes and estuary, clustered into the three main categories of land uses (see Table 1 to see the clusters of individual land-use categories). The northeastern area of the National Park and the area east of the village of El Rocío were restored through the Doñana 2005 project. The Doñana estuary has been included among the natural, semi-natural and restored ecosystems.

Doñana. Outside the Doñana protected area, the transformation of natural and semi-natural ecosystems into intensively managed agricultural lands and artificial areas stem mainly from economic development pressures and global market forces (Fig. 3). These land-use changes result in an increase of provisioning services of high economic value in international and national markets (i.e., food from irrigated agriculture or aquaculture) at the expense of regulating services (Martín-López et al., 2011). As a result, food from agriculture is the main ecosystem service supplied outside the protected area, while regulating and cultural services are mainly delivered inside the protected area (Palomo, Martín-López, Zorrilla-Miras, Del Amo, & Montes, in press).

The results of the literature review linking ecosystem services to land uses (Tables 1 and 3) and social perceptions of ecosystem services trends (Table 4; Figs. 5 and 6) suggest that besides the increase in food production and some cultural services, most regulating services have declined in the Doñana marshes and estuary. The shift toward land uses that provide specific services with market value is also a major driver of land-use change in ecosystems all over the world (Lambin et al., 2001). Thus, our results are consistent with the

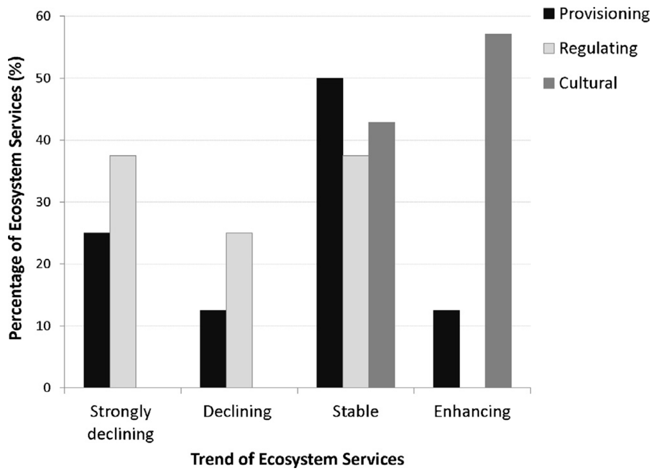

Fig. 5. Percentages of ecosystem services classified by the panel of experts as having strongly declined, declined, been stable, or been enhanced during the period 1955–2006.

results of previous studies on international (MA, 2005a), national (EME, 2011), regional (Su, Xiao, Jiang, & Zhang, 2012), and local scales (García-Llorente et al., 2012; Gómez-Baggethun, Alcorlo, & Montes, 2011).

Surprisingly, the results from our analysis of land-use change regarding agricultural expansion are in contrast with those obtained from the interviews of and questionnaires administered to locals and visitors: 9% of the responses expressed a perception that food production by agriculture declined over the period analyzed (Fig. 6). This result may be related to a methodological limitation, namely, the fact that interviews and questionnaires referred to the last two to three decades, a period of time sufficiently long for stakeholders to evaluate, whereas the greatest increase in agricultural lands occurred between 1918 and 1977 (Fig. 3). Moreover, during the last two decades, conservation forces became more powerful and regulation of the agricultural sector became stricter, increasing the feeling of vulnerability among local farmers engaged in irrigated farming activities. Because respondents were generally quite critical of the restrictions imposed on agricultural practices by conservation authorities, their responses may be biased toward the perception of a negative trend in the food-from-agriculture service. The panel of experts considered the food-from-agriculture service to have had a stable trend. Although the volume and tonnage of crops have increased as a result of agricultural land growth, the panel of experts probably expressed the view that food production from traditional activities had decrease, resulting in an overall assessment of the service as stable.

Another surprising result pertained to the perceived trend in cultural services. From the dramatic decrease in natural and semi-natural ecosystems we would have expected a decline in cultural services (as occurred with regulating services). However, several cultural services were perceived by respondents to have been enhanced over the period analyzed. This result can be explained by uneven trends associated with specific cultural services. For example, cultural services that were more specific to local demands, such as recreational hunting, local ecological knowledge, and local identity, have declined, whereas cultural services demanded by beneficiaries on broader scales, such as tourism, environmental

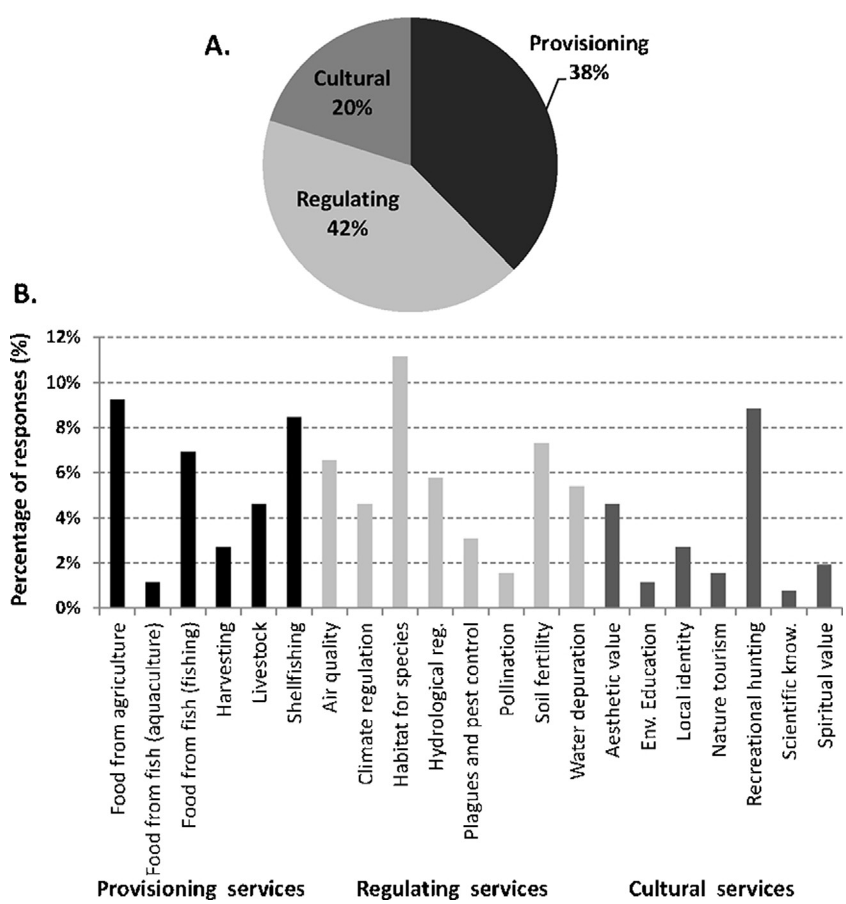

Fig. 6. Percentage of responses to interviews and questionnaires by local stakeholders and tourists perceiving different categories of ecosystem services as having declined in the municipalities of marshes and estuary: (A) for overall ecosystem service categories, i.e., provisioning, regulating, and cultural; (B) for specific ecosystem services.

Table 3
Changes in land uses in the Doñana marshes and estuary.

Land-use	Surface (ha)					Annual changing rate (ha/year)						Land-use dynamic index (%)					
	1918	1955	1978	1998	2006	1918–54	1955–77	1978–97	1998–2006	1918–2006	1955–2006	1918–54	1955–77	1978–97	1998–2006	1918–2006	1955–2006
Artificial areas	42	138	534	1142	1142	3	18	30	0	**13**	**20**	6.03%	13.03%	5.69%	0.00%	**29.76%**	**14.53%**
Cultivated systems																	
Aquaculture ponds	0	0	0	3608	3608	0	0	180	0	**41**	**72**	–	–	–	0.00%	–	–
Drained marshes	0	55,098	38,612	18,312	10,191	1450	−749	−1015	−1015	**116**	**−898**	–	−1.36%	−2.63%	−5.54%	–	**−1.63%**
Greenhouses	0	0	0	154	154	0	0	8	0	**2**	**3**	–	–	–	0.00%	–	–
Irrigated fields	0	0	23,415	46,185	46,213	0	1064	1139	3	**525**	**924**	–	–	4.86%	0.01%	–	–
Rain-fed fields	0	7678	14,807	15,340	14,912	202	324	27	−53	**169**	**145**	–	4.22%	0.18%	−0.35%	–	**1.88%**
Rice fields	0	5040	27,740	40,751	40,751	133	1032	651	0	**463**	**714**	–	20.47%	2.35%	0.00%	–	**14.17%**
Salines	339	359	1133	1506	1506	1	35	19	0	**13**	**23**	0.15%	9.82%	1.65%	0.00%	**3.92%**	**6.40%**
Natural, semi-natural and restored ecosystems of marshes and estuary																	
Lucios	23,659	12,580	5479	5498	5498	−292	−323	1	0	**−206**	**−142**	−1.23%	−2.57%	0.02%	0.00%	**−0.87%**	**−1.13%**
Non-modified marshes	131,899	74,194	42,637	22,762	22,762	−1519	−1434	−994	0	**−1240**	**−1029**	−1.15%	−1.93%	−2.33%	0.00%	**−0.94%**	**−1.39%**
Restored marshes	0	0	0	0	8925	0	0	0	1116	**101**	**179**	–	–	–	–	–	–
River, branches and river beaches	9586	9404	10,812	9854	9451	−5	64	−48	−50	**−2**	**1**	−0.05%	0.68%	−0.44%	−0.51%	**−0.02%**	**0.01%**
Other land uses	0	1034	355	411	411	27	−31	3	0	**5**	**−12**	–	−2.99%	0.79%	0.00%	–	**−1.21%**
Land-use dynamic degree												8.51%	57.07%	20.05%	5.39%	**35.48%**	**42.35%**

Table 4
Expert panel results indicating the trends in the identified ecosystem services.

Category	Ecosystem service type	Expert panel
Provisioning	Food from agriculture	Stable
	Food from fish (aquaculture)	Enhancing
	Food from fish (fishing)	Stable
	Freshwater consumption	Strongly declining
	Harvesting	Stable
	Livestock	Stable
	Medicinal plants	Declining
	Shellfishing	Strongly declining
Regulating	Climate regulation	Stable
	Flood buffering	Strongly declining
	Habitat for species	Stable
	Hydrological regulation	Declining
	Pollination	Strongly declining
	Soil fertility	Declining
	Water depuration	Stable
Cultural	Aesthetic value	Enhancing
	Environmental education	Enhancing
	Local ecological knowledge	Stable
	Local identity	Stable
	Nature tourism and recreation	Enhancing
	Recreational hunting	Stable
	Scientific knowledge	Enhancing

education, and scientific knowledge, were perceived to have been enhanced over the period analyzed (Table 4 and Fig. 6). These results may be interpreted in terms of shifts in the scales at which the bulk of the benefits from cultural ecosystem services accrue (Gómez-Baggethun, Kelemen, Martín-López, Palomo, Montes, in press). Thus, in line with findings from previous research, our results reflect, on the one hand, a rise of those cultural services demanded by urban people in Spain (Martín-López et al., 2012), and on the other hand, reflect a decline of those cultural services more directly demanded by the locals (Gómez-Baggethun et al., 2010; Gómez-Baggethun, Reyes-García, Olsson, & Montes, 2012).

The bulk of the regulating services were found by the survey and questionnaire respondents and by the panel of experts to be decreasing. This result is consistent with the reduction of natural and semi-natural ecosystems identified from our analysis of land use change. However, when it comes to the water depuration service in particular, contrasting results were obtained from the panel of experts and from the respondents to interviews and questionnaires. The panel of experts perceived the performance of the water depuration service to be stable, while the respondents to surveys and questionnaires considered it to be declining. The perception of the latter seem more consistent with the results from the analysis of land use changes. A possible explanation of the experts' perception is that declines in the performance of water depuration may have been compensated by perceived increases in water quality from new regulations that limit the use of agricultural inputs in the protected areas.

5.3. Effects of territorial polarization on ecosystem service supply

The conservation vs. development model (Folke, 2006) of current territorial planning consists of protected areas preserved through 'fortress conservation policies' embedded in an ecologically degraded matrix devoted to economic development and growth. In Doñana, as a result of development aims that transformed to some extent the landscape, conservation drivers appeared in the area. Conservation in turn also fostered intensification of uses outside the protected area, creating a dialog among conservation and development schemes that has produced the current conservation vs. development landscape. The disparate land uses inside and outside the Doñana National Park have resulted in acute conservation problems due to border effects (Fernández-Delgado, 2005; Palomo, Martín-López, Potschin, Haines-Young, & Montes, 2013). By the end of the conservation period (1978–1997), diverging management policies in different zones of the marshes became more stringent. Outside the protected area, aggressive economic development projects were permitted and even supported by the public sector. In contrast, inside the National Park, only a few traditional uses were permitted (e.g., livestock grazing and beekeeping), whereas some other traditional uses and practices, such as hunting, fishing, and harvesting of wild products, were prohibited or severely constrained. Consequently, the managers of the protected marshes faced two confronting problems. On the one hand, those originated outside the protected area driven by economic and technological forces, including the conversion of wetlands to intensively managed agrosystems and its associated effects on the flooding regime, increased sedimentation rates, and water pollution (Martín-López et al., 2011; Rodríguez Ramírez, Yañez Camacho, Gasco, Clemente Salas, & Antón, 2005). On the other hand, problems originated inside the protected area caused by conservation policies related to restrictions of access to local users, disruption of traditional uses and loss of local knowledge, have affected some provisioning and cultural services, i.e., harvesting, local identity, and recreational hunting (Fig. 6b).

Our results represent a paradigmatic example of the polarized conservation vs. development territorial model that commonly entails a trade-off between the delivery of regulating and provisioning services (Carpenter et al., 2009). The combination of preservation of portions of the landscape under strict conservation with land conversion to intensive land uses outside the protected area is likely to lead to an overall degradation of ecosystem services in the long term. Protected areas can play fundamental roles in protecting regulating services (e.g., Elmqvist, Tuvendal, Krishnaswamy, & Hylander, 2011; Schneiders et al., 2012). However, their long-term maintenance involves a shift in approaches to territorial planning from the present conservation vs. development paradigm toward multi-scale governance systems, aimed at securing broad diversity in delivery of ecosystem services capable of meeting the basic demands of a variety of stakeholders and beneficiaries on the local and larger scales.

6. Conclusions

A combination of economic and technological drivers of change together with conservation interests has shaped the current "conservation vs. development" dichotomy that characterizes the polarized territorial matrix in Doñana. Nowadays 70% of the Doñana marshes are occupied by cultivated systems whereas 29.5% remain untransformed or have been restored, mainly within the Doñana National Park. The land use changes occurred have affected ecosystem service delivery, as the literature review and social perceptions on ecosystem services have shown. We have found a decrease of regulating services and those cultural and provisioning services locally demanded, and an increase of the cultural services demanded by beneficiaries on broader scales and of the provisioning services with market value. Finally, we advocate for combining biophysical and social methodologies for evaluating land use change effects on ecosystem services delivery since, as seen in this research, both approaches can provide complementary information.

Acknowledgments

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Appendix A. Selection of main publications considered in the literature review

Publications included in the literature review relating to the evolution of Doñana marsh and its land-use changes.

1. Bajer, F. 1900. "Carta de la Provincia de Sevilla", por don Fernando Bajer, Ingeniero. Cartoteca Histórica del Servicio Geográfico del Ejército.
2. Campos, P., López, J. 1998. Renta y naturaleza en Doñana, a la búsqueda de la conservación con uso. Editorial Icaria. Barcelona.
3. Coello, F. 1869. "Huelva", por don Francisco Coello, Coronel de Ingenieros Militares 1869. Cartoteca Histórica del Servicio Geográfico del Ejército.
4. Coello, F. 1869. "Provincia de Sevilla", por don Francisco Coello, Coronel de Ingenieros. Cartoteca Histórica del Servicio Geográfico del Ejército.
5. Corominas, J. 1995. La agricultura en el entorno de Doñana. Revista de obras públicas, 3.340, año 142:65–74.
6. Cota, H., García-Novo, F. y Pou, A. 1977. Estudio de las marismas del Parque Nacional de Doñana utilizando imágenes del satélite ERTS-1. Boletín de la Estación Central de Ecología. Vol. 6, I. 12:29–40.
7. Cuevas, J. M., y González Alonso, F. 1993. Análisis mediante una imagen Landsat MSS de la diversidad espacial de los usos del suelo en el Parque Nacional de Doñana. Investigación Agraria Producción y Recursos Forestales. 2(1):89–98.
8. Cuevas, J. M., González Alonso, F., y Herrón, M. 1992; Relación entre la respuesta espectral captada por el sensor AVHRR de los satélites NOAA en un área de Pinar del Parque Nacional de Doñana y las condiciones meteorológicas. Ecología (6):3–7.
9. Cuevas J.M., González Alonso, F., y Herrón, M. 1994. Reconocimiento de eucaliptares en el sureste de la provincia de Huelva mediante análisis de una imagen Landsat MSS. Investigación Agraria Producción y Protección Vegetales. 9(3):439–448.
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11. Espelius, J. 1754. Carta Geographica o Mapa General de los Pueblos, Montes y sus Principales Arboledas. . .que comprenden la Provincia de Marina de Sevilla. Biblioteca Nacional, Madrid.
12. Fernández Alés, R., Martín, A., y Merino, J. 1995. Landscape changes in the last 500 y in the Gualdalquivir river Valley with special reference to Doñana National Park. En: BL Turner, A II, Gómez Sal, F. González Bernáldez, F. and di Castri, F., editors. Global land-use change: A perspective from the Columbian Encounter. CSIC, Madrid. pp. 361–378.
13. Fernández Alés, R., Martin Vicente, A.; Ortega, F., and Alés, E. E. 1992. Recent changes in landscape structure and function in a Mediterranean region of SW Spain (1950–1984). Landscape Ecology 7:3–18.
14. Francisco Fernández de Agudo.1870. Plano particular de una porción del Río Guadalquivir con el Baxo del Copero para

Demostración de el y los varios modos de remediarlo. En: Rubiales, J., Menanteau, L., Martín, A., Carasco, D. 1985. El Río, El Bajo Guadalquivir. Ayuntamiento de Sevilla.; página 122.
15. Francisco Fernández de Agudo.1870. Plano General del Río Guadalquivir desde más arriba de la Ciudad de Sevilla hasta su desembocadura en el mar, para inteligencia de su proyecto de rectificación de los medios de evitar sus baxos, sus inundaciones y mejorar y cortar la navegación. En: Rubiales, J., Menanteau, L., Martín, A., Carasco, D. 1985. El Río, El Bajo Guadalquivir. Ayuntamiento de Sevilla.; página 122.
16. García Murillo, P. y Sousa, A. 1997. Vegetation changes in Abalario. Parque Natural del Entorno de Doñana. Lagascalia 19(1–2):737–744.
17. García Murillo, P. y Sousa, A. 1999. El paisaje vegetal de la zona oeste del Parque Natural de Doñana (Huelva). Lagascalia 21(1):111–132.
18. García Otero, J. 1829. Levantado por el arquitecto don Jose García Otero, Capitán retirado de Ingenieros, bajo la dirección del Intendente Honorario de Provincia Agustín de Larramendim Comisario de Caminos y Canales. Sevilla, 20 de Noviembre de 1829. En: Rubiales, J., Menanteau, L., Martín, A., Carasco, D. 1985. El Río, El Bajo Guadalquivir. Ayuntamiento de Sevilla. pp. 123.
19. Gavala y Laborde and J. 1949. Memoria explicativa de la hoja n° 1018 (El Rocío) del mapa geológico de España a escala 1/50.000. IGME, Ministerio de Industria y Energía. Madrid.
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24. Grande Covián, R. 1973. Las Marismas del Guadalquivir. Drenaje subterráneo como medio de saneamiento de suelos salinos y alcalinos. Instituto Nacional de Reforma y Desarrollo Agrario. Ministerio de Agricultura.
25. Grande Covián, R. 1978. El estuario del Guadalquivir y su problemática agrosocial. IRYDA.
26. Instituto de Cartografía de Andalucía. 1998. Mapa-Guía de Doñana. Parques Naturales de Andalucía. 1:75.000.
27. Instituto Geográfico Nacional. 1978. Mapa Topográfico. Hoja 1001, Almonte. 1:50.000.
28. Instituto Geográfico Nacional. 1989. Mapa Topográfico. Hoja 1048, Jerez de la Frontera. 1:50.000.
29. Instituto Geográfico Nacional. 1992. Mapa-Guía Parque Nacional de Doñana. 1:50.000.
30. Instituto Geográfico y Catastral y Servicio Geográfico del Ejército. 1948. Mapa Topográfico. Hoja 1001, Almonte. 1:50.000.
31. Instituto Geográfico y Catastral. 1942. Mapa Topográfico. Hoja 1018, El Rocío. 1:50.000.
32. Instituto Geográfico y Catastral. 1942. Mapa Topográfico. Hoja 1033, Palacio de Doñana. 1:50.000.
33. Instituto Geográfico y Catastral. 1955. Mapa Topográfico. Hoja 1047, Sanlúcar de Barrameda. 1:50.000.
34. Instituto Geográfico y Catastral. 1970. Mapa Topográfico. Hoja 1034, Lebrija. 1:50.000.
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Appendix B.

List of the ecosystem services evaluated in this paper, selected on the basis of previous research in the area (e.g., García-Llorente et al., 2011; Martín-López et al., 2011; Palomo et al., 2011) and fieldwork interviews conducted during 2006 with key respondents. Social samplings (expert panel and interviews and questionnaires) used data from previous ecosystem services assessments conducted by the authors, i.e., Gómez-Baggethun, Martín-López, et al. (2011) and Palomo et al. (2011). Not all ecosystem services were evaluated with both techniques: * means that the ecosystem service was evaluated by that specific method.

Category	Ecosystem service	No.	Expert panel	Interviews and questionnaires	Biophysical assessment
Provisioning	Food from agriculture	1	*	*	*
	Food from fish (aquaculture)	2	*	*	*
	Food from fish (fishing)	3	*	*	*
	Freshwater consumption	4	*		*
	Harvesting	5	*	*	*
	Livestock	6	*	*	*
	Medicinal plants	7	*		*
	Shellfishing	8	*	*	
Regulating	Air quality	9		*	*
	Climate regulation	10	*	*	*
	Flood buffering	11	*		*
	Habitat for species	12	*	*	*
	Hydrological regulation	13	*	*	*
	Plague and pest control	14		*	
	Pollination	15	*	*	*
	Soil fertility	16	*	*	*
	Water depuration	17	*	*	*
Cultural	Aesthetic value	18	*	*	*
	Environmental education	19	*	*	
	Local ecological knowledge	20	*		*
	Local identity	21	*	*	*
	Nature tourism and recreation	22	*	*	*
	Recreational hunting	23	*	*	
	Scientific knowledge	24	*	*	
	Spiritual value	25		*	

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