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# Which are, what is their status and what can we expect from ecosystem services provided by Spanish rivers and riparian areas?

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**Concise title**: State and trends of ecosystem services of Spanish rivers

**Abstract**

By applying the framework proposed by MA (Millennium Ecosystem Assessment), we analysed the current state and trends of 20 ecosystem services provided by Spanish rivers and riparian areas using 139 indicators. We compared the obtained results with the Europe and United Kingdom (UK) assessment. It is the first document that attempts to analyse the importance of services provided by Spanish rivers and riparian areas, and it forms part of the evaluation carried out for the Spanish Millennium Ecosystem Assessment. Among the provisioning services, *freshwater*, *hydropower energy* and *genetic resources* were classified as high importance, and *water regulation and self-purification capacity*, and *natural hazard mitigation* are among the regulating services, with *landscape-aesthetic values* and *recreation and ecotourism* featuring among the cultural services. About 61% of the assessed ecosystem services are currently declining or degrading, but are higher than the percentage calculated for Europe (45%) or for the UK (53%). All regulating services are degrading, especially *water regulation*, *natural hazard mitigation*, *soil formation and fertility* and *biological control*, and the cultural services related to rural populations. Likewise, the biodiversity of Spanish aquatic ecosystems is decreasing rapidly. *Land use changes* and *overexploitation of biological and mineral raw materials* have been the main direct drivers of change in Spanish rivers and riparian zones, and relate directly to increase urbanised areas and irrigated agriculture. Finally,

we draw some considerations on alternative models for aquatic ecosystems management which maintain aquatic ecosystem services and their biodiversity.

**Keywords:** Ecosystem Services, Rivers, Spain, Trends, Biodiversity, Direct drivers.

## 1. Introduction

Ecosystem services are the direct and indirect benefits that people derive from ecosystems and their biodiversity, and which contribute to human well-being (de Groot et al. 2010; EME 2011). This concept, which derives from the Millennium Ecosystem Assessment (MA 2005a), links ecosystems to human needs and their well-being, and generates a framework to socio-ecological sciences (Glaser et al. 2008, Martín-López et al. 2009) that aims to understand the complex relationships between nature and society (Montes and Martín-López 2011). Besides drinking water and the development of many economic activities, from aquatic ecosystems we obtain a large number and diversity of services that are less recognised by society. Their ability to provide these services is due to the complex relationships between their physical, chemical and biotic components.

Rivers and their floodplains represent a functional unit that transfer to matter and energy into catchments (Dodds 2002; Naiman et al. 2005). Both rivers and floodplains are an interconnection through water flows, so they are interdependent. Water flows connect headwater with the mouth (longitudinal component), floodplains with channels, and vice versa (horizontal component) and groundwater with channels and floodplains (vertical component) (Gregory et al. 1991; Jones and Mulholland 2000; Ward and Wiens 2001). These connections are basic for providing services that generate these ecosystems. Thus, the longitudinal component functions as corridors for the dispersion of organisms and seeds, and for the distribution of nutrients, salts, dissolved and suspended solids, and other organic and inorganic materials. The vertical component allows the exchange of the materials between the different compartments, and the movement of organisms acting on material processing and organic nutrients recycling (for example, nitrification or denitrification). The horizontal component intercepts lateral flows by limiting the erosion and expansion of some species, filtering nutrients or facilitating recharge water (Allan and Castillo 2007). These components do not always act in time, so the relative importance of each one depends on the dominance and direction of the predominant water flow (Gonzalez del Tánago et al. 2007). For example during floods, the channel and floodplains are connected, which contributes to the soil fertility of floodplains (Junk et al. 1989).

In Spain, rivers and their floodplains are one of the ecosystems that have been more extensively modified by human activities (García de Jalón et al. 2007, Grantham et al. 2012). Throughout history, regulations on Spanish rivers have had one main aim: to provide or supply water for drinking, for agriculture, for hydropower, and to control floods. The vast majority of Spain is included in the Mediterranean climate region, characterised by the seasonality of precipitation patterns and the asynchronous timing when water is available, and when it is necessary to undertake human activities, such as agriculture. Consequently, most Spanish rivers have been severely altered by dams and other hydraulic infrastructures (García de Jalón et al. 2007).

This study forms part of the work carried out for the Spanish Millennium Ecosystem Assessment (EME 2011), which aims to generate interdisciplinary scientific knowledge, relevant for public and private sectors, on the impact that changes in aquatic and terrestrial ecosystems have on human well-being. It is the first document that attempts to analyse the importance of the services provided by Spanish rivers and riparian areas, and to identify trends in their current state and use over time. Our study aims to document the variety and relative magnitude of the services provided by Spanish rivers and riparian areas, trends in their status and human use, and the direct drivers of change that alter functions and capacity to provide ecosystem services and biodiversity.

## 2. Methodology

### 2.1. Study area: biophysical and socio-economic characteristics

The physiognomy of the Spanish territory is characterised by a very rugged relief where mountains occur between relatively narrow valleys. So, drainage basins are small and rivers are short, with high or very high slopes and highly erosive channels. The hydrological functioning and water quality of these rivers depend on lithological materials and geodynamics. Thus, the three major lithological domains in the Spanish Mediterranean region (siliceous, limestone and clay-loamy) shape the networks, channels and different hydrological models. In the limestone domain, drainage networks are generally less dense with narrower channels, and water is "sweeter" than in the clay-loamy domain, where drainage networks are very dense, with wider channels and more saline water. In the siliceous domain, these traits are intermediate (Vidal-Abarca et al. 2004, Gomez et al. 2005).

In Spain, there are currently 20 hydrographic units with different surface areas (between 2,891 $km^2$ of the Basque Basin to 13,539 $km^2$ of the Douro basin, excluding Ceuta and Melilla) (Table 1). The total drainage network is 85,856 km and occupies an area of approximately 5,520 $km^2$;

it represents only 1.1% of the total surface area of Spain. Almost all the Spanish watersheds are located in the Mediterranean climate region, except for the northernmost ones. In most Spanish watersheds, limestone and clay are the dominant geological materials.

Over 26 million people (55.38% of the total population of Spain) live in these basins, but the rest of the population is settled on the coast, but also depends on water to generate these basins. The population density, excluding Ceuta and Melilla, ranges from 611 inhab./km$^2$ in the Basque Basins and 26.6 inhab./km$^2$ in the Guadiana basin, although overall population density is higher in Mediterranean basins (an average of 144.8 inhab./km$^2$) than in the Atlantic (132 inhab./km$^2$) (Table 1). Although agriculture is the largest user of water consumed, it is not usually the dominant economic sector. Conversely, the service sector dominates in most watersheds.

### 2.2. Ecosystem services selected

An adapted version of the ecosystem services framework proposed by the MA (2005a) has been used in this study (EME 2011). The framework adopted by EME (2011) categorises ecosystem services into three different classes: provisioning, regulating and cultural services (Table 2). Each category includes several services. So we selected and assessed seven provisioning, six regulating and seven cultural services. Some services, such as food or mineral raw materials, were further divided.

### 2.3. The ecosystem service indicators used

One hundred and thirty-nine indicators and indices have been used to assess the ecosystem services provided by rivers and riparian areas. We used 51 indicators to assess the provisioning services, 55 for the regulating services and 33 for the cultural services (Table 2). Additional data on the indicators and indices, data sources, years assessed and units employed in this study are given in Online Resource 1.

We followed several criteria to select these indicators. Firstly, we selected the indicators capable of communicating information about ecosystem services clearly and not ambiguously to detect changes in time and for them to become widely accepted. Another criterion was data availability. We selected the indicators which collect data with sufficient regularity, that are normalised and disaggregated, and on a relevant spatial and temporal scale, to detect changes. Whenever it was possible, we used official data sources and we assessed complete or almost complete historical data series dating between 1960 and 2010 (for some indicators, the 2011 data have been included). Because official data sources are presented on a provincial or autonomic scale, assessing Spanish rivers and floodplains services has been carried out at national scale.

However, we must make some considerations about the quality and interpretation of the indicators used. As far as possible, the indicators should focus on obtaining information about the ecosystem service being provided. However, this is often not possible (Layke et al. 2012). Hence some of the indicators used in this study provide information about ecosystem service stock indicators (e.g., *Area occupied by riparian forests)*, whereas others gave information on the ecosystem's capacity to provide a service (e.g., *Wood produced by riparian forests*). For many regulating and cultural services, it was not possible to find flow indicators. In these cases, we used stock indicators as a reasonable proxy. For example, *natural hazard mitigation*, *urbanised land surface* were included because of increased runoff and dangerous floods. Although we made considerable efforts to find the indicators of cultural services, their assessment almost always relies on descriptive information because quantitative data are lacking. Finally for some services, we included the negative consequences of having lost that service because the positive contribution is more difficult to detect. For example, we detected loss of *Water quality regulation* using indicators such as *$BOD_5$* or *Nitrate concentration*.

**2.4. Valuing the importance, trends and direct drivers of change**

To value the relative importance of the services provided by rivers and riparian zones in Spain we ranked into four categories: high, medium-high, medium-low and low importance (Table 3). This ranking is based on the importance of the service for human well-being and does not consider the economic benefits deriving from the service. These categories were supported by evidence from literature, although some of them were based solely on expert opinion (e.g. cultural services). We compared this classification with that proposed by UK National Ecosystem Assessment (2011) for the UK and that by Harrison et al. (2010) for Europe. However, the ranking proposed for European freshwater ecosystems includes the different categories (key contribution, some contribution, no contribution and unknown contribution) which we assimilated with high, medium-high, medium-low, and low importance, respectively.

The trend of each indicator was categorized into seven classes (improving, some improving, no net change, improvement and/or deterioration, some deterioration, deterioration and unknown) (Table 4) taking into account the slope and direction of data series analyzed (between 1960 and 2010). We interpret the "direction" of each indicator, i.e. whether increase or decrease the indicator value, taking into account the component to assess (Floridi et al. 2011). For example, for regulating service, *Emissions of $CO_2$ by wastewater treatment plants*, high values are worse than low one. These trends are compared with Europe and the UK, as reported by Harrison et al. (2010), and with the UK National Ecosystem Assessment (2011), respectively. However, European trends only present three levels: improving, no net change and deterioration.

In accordance with the MA (2005c), we have assessed six direct drivers of change that are altering the functions and capacity to provide ecosystem services and biodiversity. Direct drivers are relatively easy to detect and to monitor because they cause physical change to the structure and processes of ecosystems. The intensity of direct drivers on each service delivery since the 1960s was categorized into four classes (very high, high, moderate and low) taking into account evidences from literature as well as expert opinion (Table 5). The trend of direct drivers has been obtained after assessing the indicators and indices of each ecosystem service and indicates the current and ongoing trend in the impact of the driver on each service. Change in trends can be positive (very rapid increase of the impact, increasing impact, continuing impact) or negative (decreasing impact, very rapid decrease of the impact) (Table 5).

## 3. Results

### 3.1. The current state of rivers and floodplains services

Table 3 compares the relative importance of the services provided by rivers and floodplains in Europe, the UK and Spain.

#### **3.1.1. Provisioning services**.

Evidently, *freshwater* is the principal service delivered by rivers in Europe, the UK and Spain (Table 3). Spanish rivers annually provide 110,473 $hm^3$ of water supply and the annual recharge to aquifers is estimated at about 30,000 $hm^3$, although this quantity is apparently underestimated (Custodio et al. 2009). However, there is a high spatio-temporal variability in water availability in Spain given the seasonality of the typical precipitation patterns of the Mediterranean climate. Spanish inhabitants used 11% of the total water generated in the watershed. In the last 10 years, the amount of water extracted from Spanish river ecosystems has dropped by 23%. However, extraction of groundwater has increased from 2,000 $hm^3$ in 1960 to 1,213,000 $hm^3$ in 2008 (INE 2010), which was used to irrigate approximately 1 million hectares (30% of the total irrigation of Spain) and supplied a population of 14 million inhabitants (35% of the Spanish population). According to the 2007 data (the Spanish National Statistics Institute (INE) 2010), 12.7% of available water was used in households and over 81% went to agriculture. However, the share of this sector, including forestry and fishing in the GDP, was only 2.6% in 2009 (MAGRAMA 2011b).

Rivers also provide energy such as *hydropower*. This provisioning service was ranked as high importance in both Spain and Europe. In Spain, annual hydropower is highly variable and depends largely on the annual precipitation regime. In the last 20 years, hydropower has, on average, contributed 27% of all the electric energy produced in Spain. Currently, small hydropower systems are promoted in Spain. In 2009, the power produced by small hydropower systems (<10 MW and 10-50 MW) was of 4,997 MW, representing nearly 37% of the total hydropower produced in Spain (http://www.renovablesmadeinspain.es/tecnologia/pagid/20/titulo/Minihidr%C3%A1ulica/. Accessed 12 February 2013).

Rivers are important *sources of food,* such as freshwater fish, crayfish and molluscs. However in Spain, unlike Europe and the UK, this provision of food is only important to local populations for their own consumption. In 2009, all the inland water fishes consumed in Spain amounted to 19,010.7 tonnes (29.5% of the total fishes consumed), but they were produced in constructed ponds (Fundación Observatorio Español de Acuicultura 2010).

The provision of *biological materials* as fibres provided by rivers and riparian areas is not that important in Spain (Table 3). However, riparian forests provide timber and wood. In Spain, 1.25% (346,806.9 hectares) of the total forested area is covered by riparian trees and shrubs (IFN3 1997-2007). Poplars occupy over 97,000 hectares (28% of all riparian forests), although nearly 51,000 hectares are poplar plantations. The amount of timber removed from riparian species was 5,117 tonnes, of which over 94% were the poplars.

Rivers and riparian zones are a source of *mineral materials,* such as gravel and sand, salts or mineral water. Sand and gravel have long since been used as aggregates for the construction of roads and buildings. No reliable data on the extraction of gravel and sand from river terraces and riverbeds in Spain are available (Regueiro 2007). According to ANEFA (2013), the sand and gravel consumption in 2011 dropped in Spain by almost half the consumption for 2007.

In Spain, there is a large number of rivers, streams, wetlands and saline aquifers that have been exploited since Roman times to extract salt. Unlike most industrialised sea salt, these inland saline areas are handmade and are an exclusively Iberian phenomenon in the European continent (Hueso Kortekaas and Carrasco 2008). Of the 271 inland saline areas which existed in Spain before 1900, only 18 are currently exploited (IGME 2010).

According to the International Bottled Water Association, Spain is the fourth country in the European Union in mineral water production. Mineral water is natural water that contains no less than 250 parts per million of total dissolved solids and is provided by natural springs. According to the study of Espejo (2001), Spain has about 2,000 springs and 115 bottled water marketing companies. In 2008, 171 different trademarks of mineral water were marketed in Spain, whose production in 2011 came to 5,027 million litres (IDEPA 2012).

Rivers and riparian areas also provide *genetic resources*, but their extent and importance are still poorly known. However, we ranked as high importance, as the UK does (Table 3), because they are not only rich in species, but are also rich in endemic species. The total number of vertebrates from Spanish rivers and riparian areas is 106 (Inventario Nacional de Biodiversidad (http://www.magrama.gob.es/es/biodiversidad/temas/inventarios-nacionales/inventario-especies-terrestres/inventario-nacional-de-biodiversidad/). Freshwater fishes are the group with highest number of species (46.2%) (Doadrio and Aldeguer 2007). The total number of vertebrate endemics is 74 (almost 70% of all species). Freshwater fishes and amphibians are the groups with the highest number of endemic species (37 and 26, respectively). The level of knowledge of aquatic invertebrates is low, but 20% of aquatic beetles species currently described are endemic (Ribera 2000). Geographic isolation and the environmental characteristics of Spanish rivers justify the high endemicity detected (Morales and Lizana 2011).

The contribution of rivers and floodplains to provide *natural medicines* is poorly studied in both Europe and Spain (Harrison et al. 2010). So our medium-low importance ranking was based on expert opinions. However in Spain, there is a good popular knowledge of medicinal plants, many of which are provided by rivers and riparian areas. The studies of Benitez et al. (2010) indicate, however, that we are losing this traditional knowledge and that only to a few species are being promoted to extract active ingredients for their use in pharmacology, cosmetics, etc. Even so, the use of many medicinal plants persists, which are offered to the public in traditional markets and herbal shops.

### 3.1.2. Regulating services

Among the regulating services, *water regulation and purification* and *natural hazard regulation* were ranked as high importance in Europe, the UK and Spain (Table 3). Groundwater, snow accumulated in mountains and soil moisture, are the water reservoirs and natural mechanisms regulating the hydrological cycle.

Groundwater, especially in the Mediterranean region, plays a role in regulating the water cycle and can buffer reduced surface during drought phases which are typical of the Mediterranean environment. It is estimated that the amount of water stored in Spanish aquifers ranges from 150,000 to 300,000 million $m^3$, and that the amount of water renewed annually through the hydrological cycle is around 30,000 million $m^3$/year (Custodio et al. 2009). According to the EU Water Framework Directive (WFD), 744 units hydrogeological units have been identified in Spain, of which 174 are overexploited and at risk of not achieving a good quantitative status, and 269 are at risk of not achieving a good chemical status (MAGRAMA 2012a).

The highlands of basins store water in glaciers and snowpacks, and they regulate water flow by modulating the run-off regime. In Spain, snow is important in the Ebro, Duero, Miño-Sil and Cantabrico basins. According to Arenillas et al. (2008), there are 3 times less glaciers from the Pyrenees than there were 200 years ago, and their surface has decreased by 136 times.

Water regulation is also carried out in the soil. The capacity of soil to store water plays a critical role in regulating water run-off and water retention in soils. The average soil moisture value in Spanish basins is 51.34 $l/m^2$, although the Mediterranean basin present lower values (e.g., the Segura basin = 17.84 $l/m^2$) (MMARM 2010a).

Dams have been the basic structures used by humans to control the flow of rivers. Spain has the largest number of dams per km of channel. Indeed there are currently 1,300 dams in Spain which store 54,380 $hm^3$, which is over 50% of the mean annual basin run-off (MAGRAMA 2011a).

According to the studies carried out in Spanish watersheds to implement the WFD, 74% of Spanish water bodies present pollution problems. So, the *self-purification capacity* of Spanish rivers has drastically dropped and this regulating service is currently being carried out by sewage treatment plants. In Spain, there are 1,710 treatment plants which treat almost 100 $m^3$/inhabitant/year. In 2008, the total volume of wastewater discharged to rivers was 10,291.5 $hm^3$, of which 5,138.5 $hm^3$ were treated by sewage treatment plants (MMARM 2010a). However in many rivers in Spanish Mediterranean basins, treated water does not return to the rivers, but is used for irrigation agriculture, which further diminishes the self-purification capacity of rivers.

The extensive eutrophication of rivers originating from agricultural practices is regulated by their floodplains and by riparian plants, which are basic to buffer sediments, pollutants and nutrients from adjacent areas. When floodplains are reduced by human building and riparian forests are altered, diffuse pollution is detected in rivers. The diffuse pollution affecting all Spanish basins is due primarily to the use of fertilizers and pesticides in agriculture. In 2010, the total fertilizer consumption in Spain was 111.2 kg/ha (MAGRAMA 2011b). Moreover, discharge sewage treatment plant effluents and agricultural practices on silt loam soils, as in some Mediterranean basins, are some causes of river salinisation. For example, during a 15-year period (1983-1998), the salinity of the River Segura doubled (Espinosa et al. 2001), which was due in part to the irrigation of large areas of loam soils (285,000 hectares, according to Corine Land Cover) (Martínez Fernández and Esteve 2009).

In relation to the *natural hazard* regulating service, floods and droughts are the most important natural phenomena causing disruptions to people's lives (Benito et al. 2005). Both flood and drought periods are normal and natural hydrological phenomena. From the beginning of the 14$^{th}$ century to the first half of the 20th century the following have been recorded in Spain: 410 extraordinary floods in Ramblas of Catalonia, 117 in the River Ter, 109 in the River Llobregat, 103 in the River Guadalquivir and 98 in the River Segura (Barriendos and Rodrigo 2006), and there are records of at least 10 drought periods during the 20$^{th}$ Century, (MMARM 2008). Floods and droughts are natural risks with a huge economic-social impact: between 1995 and 2009, 268 people died in Spain through floods and 102 people perished from heat stroke. These statistics derive from the Insurance Compensation Consortium (http://www.consorseguros.es/web/guest/ad_re_ere Accessed 10 February 2013), and indicate that from 1971 to 2008, total compensation due to loss of property amounted to more than 3,886 million euros and 3,885,987 euros through human victims. Floodwater storage on floodplains is one of the mechanisms that reduces flood magnitude and its danger downstream. Moreover, functioning floodplains also help the area to balance the hydrograph, even under low flow conditions (drought periods). Of the 1.5 million hectares occupied by Spanish rivers and their floodplains, which should potentially be forested (Rivas-Martinez 1987), there are currently only some 346,806.91 hectares (http://www.magrama.gob.es/es/biodiversidad/temas/montes-y-politica-forestal/estadisticas-forestales/default.aspx. Accessed 10 February 2013), including poplar plantations.

During floods, rivers transport sediments, and organic and inorganic materials, which contribute to *soil formation* and their fertilisation when deposited on floodplains. In such areas, intensive agriculture has been traditionally carried out. According to Corine Europe Soil (database version 2, The European Environment Agency), fluvial soils in Spain cover some 303,222 hectares (about 6% of the surface area in Spain), which supports only one part of agricultural irrigation, which reached 3.41 million hectares in 2010 (MAGRAMA 2011b). Loss of agricultural soil fertility is partly offset by the addition of sludge from treatment plants. This sludge applied to agricultural land not only provides nutrients and organic matter, but also often incorporates heavy metals to alter soil quality and agricultural products. The quantity of sludge produced by treatment plants in 2009 was 1,205.1 thousands of tonnes of dry matter, of which 83% (over one million tons of dry matter) were incorporated into Spanish agricultural soils (MAGRAMA 2012a).

The riparian vegetation is key to buffering sediments from adjacent areas which provide *erosion regulation*. There are major differences in the erosion rates of different Spanish watersheds (from 8 to 2,000 tonnes/km$^2$/year). According to Avendaño and Cobos (1997), Mediterranean basins are those that exhibit higher erosion rates, mainly due to heavy rains, move large amounts of solids that run on easily erodible lithology, and are extensively deforested, and have a long-standing history of soils transformation, and a topography that favours a rapid run-off concentration (García Ruiz and López Bermúdez 2009). However, information to obtain reliable data on sediment budgets in different Spanish basins is lacking.

The regulating service *biological control* was ranked as medium-high importance in both the UK and Spain, unlike the classification proposed by Harrison et al. (2010) for European rivers (Table 3). River ecosystems are an important pathway for the dispersion of plants and animals, but may also act as migration pathways for non-native species. Of all the vertebrates living in Spanish rivers, 32% are non-native species. Fishes are the largest number of alien species presents (27 species) (Elvira and Almodovar 2001). It is not yet known how many non-native invertebrate species there are, although there is information available about damaging species (e.g., zebra mussel: *Dreissena polymorpha*, Asian clam: *Corbicula fluminea*, signal crayfish: *Pacifastacus leniusculus* or American crayfish: *Procambarus clarkii* ) (Geiger et al. 2005). Furthermore, there is no sound knowledge available of introduced riparian and aquatic flora species into rivers and Spanish riparian areas. According to Doadrio and Aldeguer (2007), the total plant species introduced into Spanish riparian areas is 120. Grasses include the largest number (62 species). Non-native species have severe, and even dramatic, consequences for rivers and riparian vegetation as they alter the life cycles of native species with which they co-exist, and can even cause them to disappear (Vila et al. 2008).

In global terms, freshwater ecosystems contribute very little to *carbon uptake*. As small territories occupied by rivers, they are not considered in carbon cycles. Only until recently have freshwaters been identified as important quantitative components of the carbon cycle on the regional scale (e.g., Cole et al. 2007; Aufdenkampe et al. 2011). However, forested floodplains and fluvial soils are carbon sinks. Spanish riparian forests store 496.2 Giga-grams of $CO_2$ /ha/year, which represents 0.14% of all the $CO_2$ emissions emitted in Spain in 2010 (MMA 2007b; MMARM 2010b). Moreover, the calculations made in accordance with the data obtained by Díaz-Hernández et al. (2003) in fluvial soils of south Spain reveal that Spanish fluvisols accumulate over 159,230 tonnes of organic carbon. Conversely, greenhouse gases deriving from wastewater and sewage sludge are considerably increasing in Spain. In 2010, the $CO_2$-eq emissions from wastewater accounted for 1% of all the $CO_2$ emitted in Spain, and 24.1% of all $CO_2$ residues (including municipal solid waste, waste incineration, sludge treatment and compost) (MAGRAMA 2012b).

Freshwater ecosystems can moderate extreme temperatures by contributing to *regulating the local climate*, especially riparian forests. The supply of water to the atmosphere is also an essential contribution to fundamental climate control on all scales, but can be especially marked at the local level. According to the data provided by the National Geographic Institute (http://www.ign.es/ign/es/IGN/ane_tablaDatos.jsp. Accessed 19 January 2011) and MMA (1998), evaporation of 139 selected reservoirs in Spain is 2,202.5 $hm^3$ per year, which is more than 2% of the water provided annually by Spanish rivers.

### 3.1.3. Cultural services

Among the cultural services provided by rivers and riparian areas, *landscape-aesthetic values* and *recreation and ecotourism* were ranked as high importance in Europe, the UK and Spain. Rivers play a key role in various kinds of recreational activities, such as bathing, fishing and ecotourism activities like photography, hiking and wildlife viewing. Moreover, many freshwater ecosystems are valued for their beauty or for providing a sense of well-being. In Spain, water landscapes are increasingly valued and are required especially by urban people. There are currently 14 declared national parks that cover a total surface area of 347,030 hectares. Eight of them include river ecosystems, with an area of 295,748 ha (85.22% of total). In 2010, over 4.3 million visitors came to enjoy their spectacular landscapes and rich cultural heritage.

Recreational activities are also increasingly being demanded by urban citizens. Spain has 1,714 reaches of rivers and reservoirs for recreational fishing practices (IFN3 1997-2007). Of these, it is possible to practice "fishing without death" in only 446 (26% of the total). Fishing licences in 2007 generated over 4.7 million euros. The total number of river beaches in Spain is 206 (133 are located in rivers and 73 in reservoirs). According to CEDEX data (http://hispagua.cedex.es/datos.php?c=result_busqueda&pg=0&localizacion=Balnearios%20espa%F1oles. Accessed 01 November 2010), in Spain 199 natural spas are cataloged, including hot springs which are increasingly used by urban dwellers.

*Cultural identity and sense of belonging* and *Spiritual and religious values* were ranged as high importance in the UK and as medium-high importance in both Spain and Europe. In Spain, people's experience with water and aquatic ecosystems forms part of popular knowledge through proverbs, rituals, words, festivals, etc., and in particular ways of organising water uses. “Spanish proverbs”, collected sayings, aphorisms and adages that have been generated over time form popular knowledge. Of the 40,000 collected sayings in Spanish proverbs (http://www.refranerocastellano.com/. Accessed 10 February 2013), more than 2% include references to the various phases of the water cycle (rain, snow rain, floods, etc.), types of aquatic ecosystems (rivers, streams, springs, etc.), the services they provide (sand, riparian plants, etc.), occupations (water carriers, watermen), or hydraulic systems and devices for water use (wheels, watermills, irrigation channels, etc.). In Spain, there are two of Europe’s oldest organisations whose laws regulate water uses: the Tribunal de las Aguas (Valencia) and the Consejo de los Hombre Buenos de la Huerta de Murcia, both in E Spain. Both are Islamic in origin and have recently been declared Intangible Cultural World Heritage (http://www.consejodehombresbuenos.es/. Accessed 10 February 2013).

Many villages located in surrounding aquatic ecosystems, rivers, springs, streams, etc., have developed deep spiritual and religious values around water. These values are manifested in rituals and beliefs, which do not always respond to knowledge learned through experience. The benefactors of these values are generally small rural populations. The sacredness assigned to many of these small aquatic ecosystems continues and is preserved for future generations.

The cultural service *Scientific knowledge* is not assessed in neither the UK nor Europe. In Spain, knowledge about the structure and function of aquatic ecosystems is increasing available. In 2011, 355 references were found by ISI web knowledge using three words (“ecosystem services”, “Spain” and “water”). From 1984 to 2009, the Journal of the Iberian Association of Limnology (Limnética) has published 261 scientific papers relating to rivers and riparian areas, and the data from the databases of CEDEX (http://www.cedex.es/castellano/eventos/formacion.html. 10 February 2013), DIALNET (http://dialnet.unirioja.es/. 10 February 2013) and Spanish Ministry of Education, show that the number of scientific congresses attended by Spanish scientists, from master’s, PhD programmes and doctoral theses in Spain relating to water and aquatic ecosystems has increased.

The *Environmental education* service was ranged as key importance in Europe and of medium-high importance in Spain where environmental education programmes are promoted and financed by public and private entities, which are useful for raising awareness among urban citizens.

The *Local ecological knowledge* service is not assessed in the UK or in Europe (Table 3). Popular knowledge based on experience in the use and enjoyment of many ecosystem services, is a now disused legacy. However, it forms a part of the cultural heritage of local people who knew how to use the services provided rivers and riparian areas for their well-being. The manners and customs of using these services were coupled to rhythms about nature, thus they remain today. Spain has a rich heritage in hydraulic systems. These hydraulic systems were the most important manifestation of mankind's ability to harness water and/or energy in the different water cycle stages. For example, cisterns accumulated rainwater for human supply, the so-called “boqueras” used run-off and flood water. Crankshafts, mines, watermills and especially qanats were used to mine groundwater. Fulling mills, windmills and waterwheels used water power to grind or raise water levels, which increased irrigable areas in floodplains.

Many ancient professions depended directly on the services provided by rivers and floodplains, such as water, gravel, sand, fishes, plants, etc. Moreover, many plants from rivers and riparian areas are still used by rural dwellers for their culinary (e.g., hackberry, celery, watercress, mint) and therapeutic value (e.g,. maidenhair, rosehips, horsetail, wild rose), building materials (e.g., bulrushes, reed, ash, elm), in basketry (e.g., reed, wicker), dye-making (e.g., bramble) or rituals (e.g., bramble, cane, oleander, poplar) (Andreu et al. 2001). In addition to plants, animals were, and are currently, used in alternative medicine, like leeches, which are used today to reduce bruising or as activators of blood flow after skin operations (Andreu et al. 2001). Similarly, certain properties of water and sediments from rivers were, and still are, used for therapeutic purposes.

## 4. Trends in Spanish ecosystem services provided by rivers and floodplains

Trends in the status of the ecosystem services provided by river and floodplains in Spain are shown in Table 4. These trends are compared with Europe and the UK, as reported by Harrison et al. (2010), and with the UK National Ecosystem Assessment (2011), respectively.

Around 61% of the services assessed in Spain are currently in a declining or degrading state. This percentage is higher than that calculated for Europe (45%) or the UK (53%). All regulating services are degrading, especially *water regulation*, *natural hazard mitigation*, *soil formation and fertility* and *biological control*, as are the cultural services relating to *local ecological knowledge*, *cultural identity and sense of belonging*, and some provisioning services like *food*, *freshwater* and *genetic resources*. Conversely, the cultural services demanded by urban populations (e.g., *ecotourism*, *recreation*) and some provisioning services are now on the increase.

A key element to understanding the trends in the services provided by Spanish rivers and floodplains is the extraordinary growth that irrigated agriculture has undergone in Spain in the last century. From the early twentieth century to today, the irrigated area has doubled (from 1.2 million hectares to over 3.4 million hectares in 2011) (MAGRAMA 2012b). This intensive and industrialised agricultural is sustained by machines, and by inputs such as fertilizers, pesticides and seeds and, of course, by water and soil. Unlike traditional agriculture, industrial agriculture is decoupled from the territory's productive and biophysical characteristics, which have had serious impacts on Spanish rivers and riparian areas and have reduced many ecosystem services.

### 4.1. Provisioning services

Water demand to maintain irrigated agriculture is so high that its renewal fee in many Spanish rivers has been exceeded. This situation occurs mainly in Spanish Mediterranean basins, where large irrigated areas demand more water because of high evapotranspiration. To meet this water deficit, technology is resorted to; firstly through the construction of dams, and later by inter-basin water transfers and desalination. From the 1990s, Spanish reservoirs do not fulfil their river flow regulating role (Fig. 1A). The amount of water stored directly responds to annual rainfall, so now reservoirs only slightly retard the amount of rainwater. The increase of human water consumption and reduced rainfall due to climate change has led its regulatory function to collapse. Hence it is pointless to build more reservoir regulators.

In Spain, several inter-basin transfers have been performed, of which the Tagus-Segura transfer is the most important (WWF 2007). The average water transfer from the Tagus River to the Segura River between 1978 and 2011 was 320 $Hm^3$, twice the average annual amount of water stored in reservoirs in the Segura basin and 6.6% of the average amount accumulated in the Tagus River reservoirs. Over 61% of the transferred water is used in irrigated agriculture and the rest (about 196 $Hm^3$) is employed for public supply (CHS, http://www.chsegura.es/chs/cuenca/resumendedatosbasicos/recursoshidricos/trasvaseTajoSegura.html. 29 January 2013). In some south-eastern Spanish basins, the demand of water for agriculture is so high that part of the public supply must be maintained by desalination (Fig.

1B). Yet actual water consumption in Spain is much higher if we incorporate green water and virtual water (Aldaya and Llamas 2013). Spain imports about 20,000 $hm^3$ of water as agricultural products (Rodríguez Casado et al. 2008), more than the amount used in Spanish agriculture (about 17,300 $hm^3$ in 2008). In 2007, Spanish inhabitants consumed an average of 157 litres of water. However, if this is added to the water used to produce food, paper and clothes, this value increases from 10 to 20 times. The situation is that Spain is among the European countries with the highest water footprint (2,544 $m^3$/capita for 2008) (Camarero et al. 2011), which makes it especially responsible for the environmental deterioration of aquatic ecosystems of other countries, mainly southern ones.

The trends in almost all the provisioning services provided by Spanish rivers and riparian areas are decreasing. By way of example, and in relation to the food service, since the 1980s, fluvial fish catches have significantly decreased. Salmon fishing in Spanish rivers has dropped by over 76% in the last 30 years (Fig. 1C) and in 29 salmon rivers of the 43 there were in Spain, salmon is extinct (WWF 2001). According to Almodovar et al. (2011), the habitat of brown trout (*Salmo trutta*) in the Iberian Peninsula will have virtually disappeared before the year 2100. In contrast, continental aquaculture production has almost doubled in the past 20 years, although this production has also declined in recent years (Fig. 1C), which means that it is not a good alternative to maintain the loss of the food provisioning service provided by Spanish rivers. Something similar happens with the mineral raw materials service, such as the inland saline, whose production in 2010 has reduced by almost 50% since the 1990s despite its market value have almost doubled during the same period (IGME 2010). The exploitation of all the inland saline during today's economic crisis has contributed to the well-being of the Spanish people. Conversely, the mineral water production recorded in 2011 is almost triple that of 1970, whose market value reached 900 million euros (IDEPA 2012). It is a good example of how many natural springs have been capitalised from springs for marketing purposes by the packaged water industry.

**4.2. Regulating services**

Regulating services not usually perceived by people, so they are the ones which most intensely and rapidly deteriorate. So, the self-purification capacity of Spanish rivers has significantly decreased despite the major economic efforts made to enhance water quality. In the last 20 years, the number of urban effluents has increased by 66% and 82% of industrial effluents (Fig. 2B). Government investments to maintain the water quality of Spanish rivers increased by 224% from 1996 to 2009, but have lowered over the last two years (Fig. 2C). Similarly, the cost in purification has increased by 415%, although the volume of treated water was maintained

(Fig. 2D). In 2009, the Spanish Ministry of the Environmental, Rural and Marine Domains spent almost 500 million euros (41.7% of this Ministry's total investment) in infrastructures to improve water quality, and treating wastewater is costing the Spanish €0.59/$m^3$ (Fig. 2C). However, the major problem of maintaining the self-purification capacity of Spanish rivers is diffuse pollution, caused by the application of fertilizers and pesticides to croplands, whose consumption has increased in recent years (Fig. 2A). Fertilizer consumption in 2010 increased by 35.6% as compared with the previous year, and phytosanitary products (mainly fungicides, insecticides and herbicides) increased by 12%. Moreover, the self-purification capacity of rivers diminishes with decreasing water flows. It is estimated that there are more than 50,000 artificial ponds in Spain (Gonzalez et al. 2009) (although other authors have reported estimates of between 80,000 and 100,000) which withdraw water from natural aquatic ecosystems to supply irrigated land which use the drip irrigation technique. According to MAGRAMA (2012a), 47.5 % of the total irrigated surface corresponds to this technology.

Loss of the soil formation and fertility regulating service is also evident. Disruption to sediment transport from dams has contributed to soil degradation. In all the 47 reservoirs located in most Spanish basins from which data have been obtained (De Antonio et al. 1995; Sanz Montero et al. 1998; Bodoque et al. 2001; Sanz Montero 2002; Palau 2004), it is observed that more than 50% of the reservoirs (24 of them) were silted and that the sediment volume accounted for 20% of initial capacity. Moreover, the disruption of sediment transport in the Ebro River from dams, estimated at 99%, is reducing the Ebro delta surface, one of the most important rice-producing areas of Spain. It is estimated that 45% of the current delta surface will lie under the sea by 2100 (Rovira and Ibañez 2007).

Another highly altered regulating service is natural hazard mitigation capacity. Floods are one the most habitual hazards in Mediterranean basins and their dangerousness relates directly to changes in use land and to loss of traditional territory management models. For instance, in the Segura River Basin, the increase in the number of floods with time is related to important historical changes that have affected land use and have favoured the deforestation of large areas of land to promote agriculture (Fig. 3A). In general, the proposed solutions to mitigate the catastrophic effects of floods are technological (dams, channelling, rectification of channels, disconnection of floodplains, meander cuts, etc.) and they rarely seek more adaptive solutions to minimise their catastrophic impacts.

### 4.3. Cultural services

The depopulation of Spanish rural areas is the main reason that the cultural services related to local ecological knowledge, sense of belonging and spiritual and religious values are decreasing very rapidly in Spain (Table 4). Thus, the traditional models of water use from rivers have allowed the maintenance of environmental flows, thus the conservation of aquatic biodiversity. Although some gadgets and devices that were models of water use still remain, many have disappeared. Indeed of the 22,000 water mills, sawmills hydraulic and batanes registered in the nineteenth century, only one tenth (about 2,000) are preserved today (http://molinosacem.com/. Accessed 2 February 2013).The good conservation state of many natural springs or small aquatic ecosystems is due to the spiritual or religious character that rural populations assigned them. Today, however, many religious traditions and events relating to aquatic ecosystems (e.g., pilgrimages, water festivals, etc.) are being contaminated by the attendance of urban people who do not understand or know the traditions.

In contrast, the cultural services demanded by urban populations are increasing (ecotourism, recreation and environmental education). By way of example, the number of visitors to Spanish Natural Parks with riparian landscapes and aquatic ecosystems is increasing (Fig. 3B). Similarly, the number of fluvial beaches included in the European Environment Agency (http://dd.eionet.europa.eu/ Accessed 2 February 2013) is increasing, although the number of these that comply with the mandatory value of Directive 76/160/EEC for *Escherichia coli* and the more stringent guide values for *Escherichia coli* and intestinal enterococci, is decreasing (Fig. 3C). Once more, excessive extractions of water from rivers and diffuse pollution problems are negatively impacting these cultural services.

### 4.4. Biodiversity trends

Biodiversity is the key element in the ecosystem given its capacity to provide ecosystem services (Diaz et al. 2006; Rands et al. 2012; Cardinale 2012; Naeem et al. 2012). Many biogeophysical processes in aquatic ecosystems are carried out by organisms. For instance, microbial communities (bacteria and fungi) are involved in denitrification and nitrification processes (Palmer et al. 1997; Bernot and Dodds 2005), and they are the main processors of organic sewage and contribute to water self-purification (Lowrance et al. 1997). Riparian vegetation is key for buffering nutrients and pollutants from agricultural areas and helps control diffuse pollution (e.g., Pinay et al. 1992). Moreover, riverine plants contribute to regulate local climate by lowering temperature through evapotranspiration (Nagler et al. 2005) and to air quality regulation as they are net carbon sinks (Wantzen et al. 2012).

The biodiversity of Spanish aquatic ecosystems is rapidly decreasing. According to different authors (Doadrio 2001; Pleguezuelos et al. 2002; Palomi et al. 2007), 16 Spanish species of aquatic and riparian vertebrates are classified as critically endangered or extinct, and 51 are listed as vulnerable and threatened (Fig. 4A). That is over 63% of vertebrate species inhabiting Spanish rivers have a worrisome conservation status. In particular, over 73% of freshwater fish (UICN 2009), almost 35% of amphibians, almost 54% of reptiles and 12% of mammals are classified as critically endangered or extinct (Fig. 4A). Freshwater fishes are the species which are most rapidly approaching the endangered category according to the Red List Index (RLI) (55% of species are threatened). Although there is less knowledge of aquatic invertebrate, according to the Atlas of Threatened Invertebrates in Spain (Verdu and Galante 2009), 62% of aquatic invertebrate species are in the same state. These data are even higher than those offered by the MA (2005b) for the species of organisms of inland aquatic ecosystems that have fallen by 50% from 1970 to 2000.

Great biodiversity loss not only implies lack or loss of many ecosystem services, but also loss of economic values. For instance, the native crayfish, which formed part of human diet, is virtually extinct. Currently there are only some 700 populations (probably overestimated data) in their original Spanish habitat (MMA 2007a). Crayfish catches in 1962 represented a market value of 306,516.17 euros (Gutiérrez-Yurrita et al. 1997). Today the native crayfish is protected.

In general, the policies adopted to recover and conserve biodiversity have not proven that successful despite the considerable economic resources spent. Moreover, the financial effort to conserve biodiversity has been mainly invested in the most charismatic species or habitats they occupy. Since 1999, the LIFE programme has financed seven projects in Spain relating to the conservation of species or fluvial ecosystems, and have amounted to €6,651,967, four of which went to species conservation and only two have been destined to habitat conservation (http://ec.europa.eu/environment/life/countries/documents/spain_es_nov06.pdf http://ec.europa.eu/environment/life/countries/documents/spain_es_2010.pdf).

**5. Direct drivers of change**

Table 5 shows the impact that direct drivers have on the ecosystem services provided by Spanish rivers and riparian zones, and also summarises the intensity of direct drivers and trends of the impact of drivers on both Spanish rivers and riparian areas and on aquatic ecosystems in the UK. It is important to note that direct drivers of change do not act in isolation. So the pressure of one exacerbates the impacts of another (SCDB 2010). Quite often, a synergistic effect occurs between several drivers, which must be taken into account to understand future directions of change (MA 2005c).

Both in Spain and the UK, *land use changes* have been the main direct driver of change in aquatic ecosystems (Table 5). In Spain, the trend on the impact is rapidly on the increase and is affecting virtually all the services, while it remains constant in the UK. Two processes are implied in land use change. Firstly, an increase in urbanised areas and irrigated agriculture; secondly, abandonment of rural areas (EME 2011). According to OSE (2011), 2.1% of land in Spain (50,598,500 hectares) is covered by urbanised areas. In the UK, the urban habitat (built-up areas and gardens) is greatly affecting 6.7% of the land area (Winn and Tierney 2011). However in Spain, an increase in urbanised land has taken place very quickly (between 1987 and 2006, the increase of artificial soil was 52%). Soil waterproofing, associated with these urbanised areas, has negative impacts on the run-off and infiltration capacity, and alters the water regulation service, self-purification capacity and floods mitigation.

In relation to agriculture areas, according to CORINE land cover (http://www.ign.es/ign/layoutIn/corineLandCover.do), 50.1% of Spanish territory is occupied by agricultural areas, of which 1.5% corresponds to irrigated agriculture. Despite a 0.19% decrease in agriculture areas having been detected since 2009, irrigated areas increased by 1.4% in 2012 (OSE 2012). In the UK, agriculture areas occupy 47% of territory (Land Cover Map-2000), although its decrease is more marked than in Spain (between 1998 and 2007, arable and horticultural lands decreased by 9.1%). Traditionally, agriculture areas have been associated with more fertile soils. However with the development of chemical fertilizers and mechanised farming practices, agriculture has expanded on infertile land and agricultural products have been simplified. This management and agricultural land use are affecting soil fertility, the self-purification capacity of Spanish rivers and the erosion regulating service. Moreover, abandonment of rural areas by human populations is heightening these impacts. Many varieties of local agricultural products and traditional landscapes are being lost (Cubero 2002; Egea and Egea 2006).

In both Spain and the UK (be it with less intensity), the second most important direct driver of change of fluvial ecosystems is *overexploitation of biological and mineral raw materials* (Table 5). The rates of consumption and/or exploitation of biotic resources have major impacts on biodiversity and ecosystems. A good example is the overexploitation of Spanish fluvial fishes, as was shown in the section above. However, the levels of abstracted water have all been responsible for directly driving changes in ecosystems and for loss of biodiversity. Diverting water has caused modifications in the water regimes of Spanish fluvial ecosystems (Lorenzo-Cruz et al. 2012), which affect aquatic biodiversity and riparian vegetation composition, and provided access to exotic species (Garcia de Jalón et al. 2007). Water abstraction also implies physical modifications of river courses, drainage and devastation of floodplains, resulting in disconnecting rivers from their floodplains, thus increasing the likelihood and severity of floods, and disrupting links with groundwater systems (Nilsson et al. 2005; Sawyer et al. 2009). Moreover water abstraction from fluvial ecosystems degrades the self-purification capacity of rivers.

*Invasive species and biogeochemical cycle change* are direct drivers with a severe impact on river ecosystems and biodiversity. Invasive species in Spanish rivers and riparian areas are affecting all groups of organisms (Fig. 4B) (Cobo et al. 2010). About 32% of all aquatic vertebrate species have been introduced and fishes are the group with largest number of alien species (27 species) (Leunda 2010). In the UK, invasive species are not considered a major driver of change in ecosystem services (Table 5), perhaps because the effects of introducing non-native species can be benign, or even valued (Winn and Tierney 2011). These species are usually introduced into recreational fisheries for pest control, or to release ornamental animals and plants that have been bred in captivity, resulting from interbasin water transfers (Doadrio and Aldeguer 2007; Vila et al. 2008).

The human impact severely acts on *global biogeochemical cycles*. One of the most drastic interventions of humans in global elemental cycles has been caused by the fixation of atmospheric nitrogen for the purpose of fertilizing agricultural crops (Erisman et al. 2008; Canfield et al. 2010). Excess N affects aquatic ecosystems (e.g., eutrophication and degradation of drinking water quality); the atmospheric environment (e.g., increased greenhouse gas emissions, air particulate matter and acid rain); and the soil ecosystem (e.g., altering biologically-mediated carbon and N cycles) (Vitousek et al. 1997). In Spain, the acceleration of many biogeochemical cycles is due to human activities and river ecosystems management. Increased nutrient surplus due to application of fertilizers in agriculture, together with an increase in effluents sewage and decreasing river flow, are altering the major nutrient cycles on the regional scale.

*Pollution* is also an important direct driver, although its impact varies within and between services. In general, the implementation of the Water Framework Directive (European Commision 2000), which aims to achieve a good water bodies status, has positively affected all the aquatic ecosystems in Europe (Bouraoui et al. 2011; Schinegger et al. 2011). Currently the major pollution problems that are difficult to solve are those related to diffuse pollution, which affects both surface water and groundwater. In Spain, fertilizers and pesticides are increasingly used in agricultural areas (see above, 4.2). These products can greatly persist and their degradation can lead to other more toxic products than the original ones. Moreover, it is very difficult to know the exact synergistic effect of the combination of these products on the environment, and which their short- and mid-term impacts will be on biodiversity and biochemical processes. Recently, new contaminants have been found in aquatic ecosystems and drinking water. Treatment plants do not remove these emerging contaminants (organic contaminants such as pharmaceuticals and hormones) and they are discharged into rivers or they remain in sludges, which are applied to cropland (Fatta-Kassinos et al. 2011; Martin et al. 2012). Moreover, these compounds have been detected in bottled mineral water (Gonzalez et al. 2012) obtained from underground aquifers. Pollution of these sources may not only pose a serious human health risk, but can also warn us about the quality of water in Spanish aquifers, which are essential for future water supply (Jurado et al. 2012).

Finally, *climate change* has been identified as the least important of the drivers in both Spain and the UK. However, climate change is predicted to be a major driver in the future. Spain is probably one of the European countries that is most affected by climate change (IPCC 2007). It is expected that climate change will have significant effect on biodiversity and will affect ecosystem functions. The ecosystems that are expected to have greater climatic change impact effects are inland waters. Indeed, the studies of Lorenzo-Lacruz et al. (2012) show a decrease in water flow in Spanish basins as a result of reduced precipitation (Gonzalez-Hidalgo et al. 2010) and increased evapotranspiration with increasing temperature (Erol and Randhir 2012), whose most important impact will be the increased seasonality of Spanish rivers. The effects of climate change on stream water quality in Spain have been revised by Alvarez-Cobelas et al. (2005) and by Benítez-Gilabert et al. (2010), and the water level fluctuations induced by climate change can negatively affect fish habitat structures, and changes in their community composition, abundance and health (Sabater and Barcelo 2010). Today there is strong evidence for changes in the earth's climate which are linked to the greenhouse gases emitted as a result of human activities (e.g., Prentice et al. 2001). In Spain, methane emissions from wastewater treatments have doubled in 15 years and $N_2O$ emissions have increased by more than 20.

## 6. Discussion and conclusions

The ecosystem services approach helps explain how humans benefit from, and depend on, ecosystems via the multiple services they provide (Haslett et al. 2010; Keys, et al. 2012). Despite their functional importance and the ecological values and diversity of the ecosystem services provided, aquatic ecosystems have been extensively modified worldwide (Strayer and Dudgeon 2010, Naiman and Dudgeon 2011). However, dependence on the human health and welfare services provided by ecosystems is becoming more evident (Klugman 2011, Mount and Bielak 2011; The Royal Society, 2012).

In Spain, the situation is similar, and it is currently almost impossible to find pristine aquatic ecosystems that have not been altered by human activities. As in other European countries such as Portugal (Pereira et al. 2009) or the UK (UK National Ecosystem Assessment 2011), policies, technology, market forces and globalisation have increased food, water and raw materials, but have also had severe impacts on ecosystems. According to EME (2011), rivers and riparian zones are the most degraded ecosystems of Spain due to the synergic effects of the six direct drivers of change studied, although two of them (land use change and overexploitation) have had an even greater impact. The effects on the ecosystem services of both direct drivers are the result of a land use model that is based on extracting the highest possible productivity by empowering provisioning services (food, freshwater, energy, etc.) versus the regulation or cultural ones, which are more opaque to the human population. To minimise these impacts, we use technology to try to make up for the loss of many services, especially regulating services (e.g., creation of reservoirs and channelling of rivers to protect from flooding). However, the current economic crisis, which forces austerity, is already affecting public investments in works and projects, and is causing great difficulties to maintain the quantity and quality of water in rivers and riparian areas, to protect fluvial ecosystems of endangered aquatic species, and to remove invasive species as they are all very expensive (Suarez and Vidal-Abarca 2012). This scenario is also accelerated by the uncertainties that the global climate crisis is generating and the perception becomes increasingly evident that the changes that ecosystems are undergoing are not linear, but are, therefore, difficult to prevent. So, now is perhaps a good time to reconsider current aquatic ecosystems management models and to try alternatives models that allow us to maintain aquatic ecosystem services and their biodiversity.

Rivers and their catchments constitute a functional unity; i.e., both are interconnected, although it is sometimes difficult to perceive the complex relationships between them. Water flows connect all the terrestrial ecosystems through water cycle, which operates worldwide, as does the watershed scale (Kravcík, et al. 2009). Today, the food consumed by the vast majority of the world's population is produced with virtual water (water used to produce crops and other raw materials which are exported to other regions of the world). Yet we still do not understand the environmental and social consequences of this global management model (Bernhardt et al. 2006; Alcamo et al. 2008; Hoekstra and Mekonnen 2012). On the watershed scale, hydrological planning is often not based on the recycling water rate through the hydrologic cycle, but on maximising the provision of all the services in each watershed sector. Thus water management decisions are carried out by politicians and private sectors with clear economic interests (WWAP 2009). This management model has led to the overexploitation of water flows, and to breaking up the connectivity of rivers that is essential to ensure the provision of services that these ecosystems offer societies, including (but not limited to) water in rivers. So, an adaptive management process should analyse the biophysical conditions of each catchment sector in order to prioritise the type of ecosystem services that are best suited to provide such services (Holland et al. 2011; Nel et al. 2011) (e.g., uplands of catchments for regulation climate, and water regulation; medium-low catchment for food (agriculture) and mitigation floods, etc.). This proposal is not new, and not until more than 50 years ago, local populations living around rivers sustained many of the services provided by aquatic ecosystems.

We must be aware of the aggregative effects of human activities within a catchment because one of the most important is biodiversity loss. Currently freshwater organisms are among the most threatened ecosystems in biodiversity loss terms (Abell 2002, Strayer and Dudgeon 2010). Species in aquatic ecosystems are involved in lots of ecological processes (e.g., production, decomposition, nutrient cycling, biogeochemical processes, etc.) from which we benefit by consuming clean water, air quality, water self-purification, etc. However, these benefits are hidden for most of the human population, so, it is necessary to transmit more information of better quality in order to bring about a change in the social values for conservation, for which the scientific community is greatly responsible.

New technologies can help us to manage water in both natural and heavily modified catchments (Bernhardt et al. 2006; EEA 2012). Yet we should not underestimate the important knowledge that remains in local rural populations, who have always lived with natural inland waters ecosystems by extracting and managing their resources sustainably. It is not possible to act on the impacts of direct drivers of change, but only with alleviation or eradication actions (e.g., with many exotic species, Garcia-Llorente et al. 2011). In a globalised world where there are no restrictions on human population movements, preventive strategies would be more realistic.

Finally, we must accept that natural systems are dynamic and unpredictable. We do not even know the direction of change whenever there is an impact. Thus an adaptive way would be to learn to live with environmental variability rather than trying to manage stability and predictability (Bernhardt et al. 2006; Montes 2007; WWAP 2012). For freshwater ecosystems, learning to live with rivers from permanent flows to temporal, and even, dry streams is necessary because they all provide ecosystem services for human well-being.


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Table 1.- The biophysical and socio-economic characteristics of Spanish catchments. * The surface data include coastal areas and originate from SIA (integrated water information system, MARM);** The Northern basin was divided into the Miño-Sil and Cantábrico by Royal Decree 266/2008; *** The Atlantic basin of Andalusia was divided into two districts.

| | | **Bio-physical Characteristics** | | | | **Socio-economic Characteristics** | | |
|---|---|---|---|---|---|---|---|---|
| | **Basin** | **Drainage area ($km^2$)*** | **Total length of channels (km)** | **Climate** | **Geology** | **Population (nº inhab)** | **Population density (inhab/$km^2$)** | **Main economic sector** |
| Mediterranean Basins | Catalonia Basin | 18,047 | 2,786 | Mediterranean, Med. high mountain | Siliceous/clay-loamy | 6,730,000 | 373 | Services |
| | Ebro | 85,939 | 12,495 | Continental Mediterranean | Clay-loamy | 3,019,176 | 35.1 | Services |
| | Júcar | 45,118 | 5,386 | Continental Mediterranean | Limestone/clay-loamy | 5,162,163 | 114.4 | Services |
| | Segura | 20,115 | 1,469 | Continental Mediterranean, Semidesertic | Clay-loamy | 1,944,690 | 96.7 | Services |
| | Mediterranean Basin of Andalusia | 18,425 | 2,145 | Mediterranean, Med. high mountain, semidesertic | Siliceous | 2,281,000 | 123.8 | Tourism, Agriculture |
| | Balearic Islands | 8,790 | 442 | Mediterranean | Clay-loamy/limestone | 1,105,000 | 125.7 | Services |
| Atlantic Basins | Galicia-Costa | 16,437 | 2,875 | Oceanic | Siliceous | 1,983,661 | 120.7 | Services |
| | North ** | 37,681 | 9,085 | Oceanic | Siliceous | | | Services |
| | -Cantábrico | 22,452 | 4,699 | Oceanic | Siliceous | 2,076,000 | 92.5 | Services |
| | -Miño-Sil | 17,619 | 4,473 | Oceanic | Siliceous | 835,000 | 47.4 | Services |
| | Basque Basin | 2,891 | 422 | Oceanic | Limestone | 1,766,401 | 611 | Services, Industries |
| | Douro | 78,860 | 13,539 | Continental Mediterranean | Clay-loamy | 2,210,541 | 28 | Agriculture, services |
| | Tagus | 55,764 | 10,130 | Continental Mediterranean | Siliceous/clay-loamy | 6,099,113 | 109.4 | Services |
| | Guadiana | 55,469 | 8,046 | Continental Mediterranean | Siliceous | 1,472,800 | 26.6 | Services |
| | Guadalquivir | 57,726 | 9,701 | Continental Mediterranean | Siliceous/clay-loamy | 4,107,598 | 71.2 | Services |
| | Atlantic basin of Andalusia*** | 11,414 | 2,066 | Southern Mediterranean | | | | Services |
| | -District Guadalete and Barbate | 6,445 | | Southern Mediterranean | Limestone | 1,020,000 | 158.3 | Services |
| | -District Tinto, Odiel and Piedras | 6,871 | | Southern Mediterranean | Siliceous | 388,000 | 56.5 | Services |
| | Canary Islands | 11,920 | 5,182 | Subtropical | | 1,968,280 | 165.1 | Services |
| | Melilla y Ceuta | 31.86 | | Mediterranean | | 80,570 | 4,891.6 | Trading, Services |

Table 2. Classification of the ecosystem services and the number of indicators analysed in this study.

| Ecosystem service | Sub-category | Number of Indicators/indexes |
|---|---|---|
| PROVISIONING | | **51** |
| Food | Capture fisheries | 5 |
| | Aquaculture | 6 |
| Freshwater | | 17 |
| Biological raw materials | | 4 |
| Mineral raw materials | Gravel/sand | 4 |
| | Salts | 4 |
| | Mineral water | 2 |
| Renewable energy | Hydraulic energy | 5 |
| Genetic resources | | 3 |
| Natural medicines | | 1 |
| REGULATING | | **55** |
| Climate regulation | Regional and local climatic regulation | 8 |
| | Carbon storage | 3 |
| Water regulation and water quality regulation | Water regulation | 10 |
| | Water purification and waste treatment | 17 |
| Erosion regulation | | 3 |
| Soil formation and fertility | | 2 |
| Natural hazard mitigation | | 7 |
| Biological control | | 5 |
| CULTURAL | | **33** |
| Scientific knowledge | | 7 |
| Local ecological knowledge | | 5 |
| Cultural identity and sense of belonging | | 5 |
| Spiritual and religious values | | 4 |
| Landscape-aesthetic values | | 4 |
| Recreation and ecotourism | | 7 |
| Environmental education | | 1 |

Table 3.- Relative importance of the services provided by rivers and floodplains in Europe, the UK and Spain.

| Ecosystem service | | High/key contribution | | | Medium-high/ Some contribution | | | Medium-low/No contribution | | | Low/unknown | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Europe | UK | Spain | Europe | UK | Spain | Europe | UK | Spain | Europe | UK | Spain |
| PROVISIONING | | | | | | | | | | | | | |
| Food | | √ | | | | | | | | | | | |
| | Capture fisheries | | | | | √ | | | | | | | √ |
| | Aquaculture | | | | | | | | | √ | | √ | |
| Freshwater | | √ | √ | √ | | | | | | | | | |
| Biological raw materials | | √ | | | | | | | | | | | √ |
| Mineral raw materials | | | | | | | | | | √ | | | |
| Renewable energy (Hydropower) | | √ | | √ | | | | | | | | | |
| Genetic resources | | | √ | √ | √ | | | | | | √ | | |
| Natural medicines | | | | | | | | √ | | √ | √ | | |
| REGULATING | | | | | | | | | | | | | |
| Climate regulation | | | | | √ | | | | | | | | |
| | Regional and local climatic | | | | | | | | √ | | | | √ |
| | Carbon storage | | | | | | | | | | | √ | √ |
| Water regulation and water quality | | √ | √ | √ | | | | | | | | | |
| Erosion regulation | | | | | √ | | √ | | | | | | |
| Soil formation and fertility | | | | | | √ | √ | | | | | | |
| Natural hazard mitigation | | √ | √ | √ | | | | | | | | | |
| Biological control | | | | | | √ | √ | √ | | | | | |
| CULTURAL | | | | | | | | | | | | | |
| Scientific knowledge | | | | | | | √ | | | | | | |
| Local ecological knowledge | | | | | | | | | | √ | | | |
| Cultural identity/sense of belonging | | √ | √ | | √ | | √ | | | | | | |
| Spiritual and religious values | | | √ | | √ | | √ | | | | | | |
| Landscape-aesthetic values | | √ | √ | √ | | | | | | | | | |
| Recreation and ecotourism | | √ | √ | √ | | | | | | | | | |
| Environmental education | | √ | | | | | √ | | | | | | |

Table 4. The trends of the ecosystem services provided by rivers and floodplains in Europe, the UK and Spain. (Source: Europe, Harrison et al (2010); United Kingdom, the UK National Ecosystem Assessment (2011), Spain, EME (2011)). (Symbols in parentheses represent that there is less evidence for or confidence in the service flow direction).

| Ecosystem service | Europe | UK | Spain |
|---|---|---|---|
| PROVISIONING | | | |
| Food | | | |
| Capture fisheries | ↓ | (↘) | ↘ |
| Aquaculture | ↓ | ↘ | ↘ |
| Freshwater | ↔ | ↘ | ↘ |
| Biological raw materials | ~ | ↘ | ↑ |
| Mineral raw materials | ~ | ~ | ± |
| Renewable energy ( Hydropower) | ~ | ~ | ↔ |
| Genetic resources | ~ | ↘ | ↘ |
| Natural medicines | ~ | ~ | (↓) |
| REGULATING | | | |
| Climate regulation | | | |
| Regional and local climatic regulation | ↔ | ↔ | ↘ |
| Carbon storage | ~ | ↔ | ↘ |
| Water regulation | ↔ | ~ | ↘ |
| Water quality | ↔ | (±) | ± |
| Erosion regulation | ↓ | ~ | (↘) |
| Soil formation and fertility | ~ | ↘ | ↘ |
| Natural hazard mitigation | ↔ | ↘ | ↘ |
| Biological control | ↓ | ↘ | ↘ |
| CULTURAL | | | |
| Scientific knowledge | ~ | ~ | ↑ |
| Local ecological knowledge | ~ | ~ | ↘ |
| Cultural identity and sense of belonging | ~ | ↗ | ↓ |
| Spiritual and religious values | ~ | ↗ | ± |
| Landscape-aesthetic values | ↓ | ↔ | ↑ |
| Recreation and ecotourism | ↑ | ↗ | ↑ |
| Environmental education | ~ | | ↗ |

| | | | |
|---|---|---|---|
| ↑ | Improving | ↘ | Some deterioration |
| ↗ | Some Improvement | ↓ | Deterioration |
| ± | Improvement and/or deterioration | ~ | Unknow |
| ↔ | No net change | | |

Table 5. Impact of direct drivers on the ecosystem services provided by Spanish rivers and floodplains and a summary of the relative importance and trends on the impact of direct drivers on Spanish rivers and floodplains and on UK aquatic ecosystems. Colour indicates the intensity of the direct driver in the last 50 years. Arrows indicate the ongoing trend in the impact of the driver.

| | Direct Drivers of Change | | | | | |
|---|---|---|---|---|---|---|
| Ecosystem service | Land Use Change | Climate Change | Pollution | Invasive Species | Biogeochemical cycle change | Overexploitation |
| PROVISIONING | | | | | | |
| Food | | | | | | |
| Capture fisheries | √ | | √ | √ | | √ |
| Aquaculture | | | √ | √ | | |
| Freshwater | √ | √ | √ | | √ | √ |
| Biological raw materials | √ | | | | | |
| Mineral raw materials | √ | | √ | | | √ |
| Renewable energy (Hydropower) | √ | | | | | |
| Genetic resources | √ | √ | √ | √ | | √ |
| Natural medicines | √ | | | | | |
| REGULATING | | | | | | |
| Climate regulation | | | | | | |
| Regional and local climatic regulation | √ | √ | | | | |
| Carbon storage | √ | √ | | | √ | |
| Water regulation | √ | √ | | | | √ |
| Water quality | √ | | √ | | √ | √ |
| Erosion regulation | √ | | | | | |
| Soil formation and fertility | √ | | √ | | √ | √ |
| Natural hazard mitigation | √ | √ | | | | |
| Biological control | | | | √ | | √ |
| CULTURAL | | | | | | |
| Scientific knowledge | √ | √ | √ | √ | √ | √ |
| Local ecological knowledge | √ | | √ | √ | | √ |
| Cultural identity and sense of belonging | √ | | √ | √ | | √ |
| Spiritual and religious values | √ | | √ | | | √ |
| Landscape-aesthetic values | √ | | | | | |
| Recreation and ecotourism | √ | | √ | | | |
| Environmental education | | | √ | √ | | √ |
| GLOBAL TRENDS | | | | | | |
| Rivers and Floodplains Spanish | ↑ | ↗ | → | ↑ | ↗ | ↗ |
| Aquatic Ecosystems UK | → | ↗ | ↘ | ↗ | | ↗ |

| Intensity of direct driver | | Trend in the impact of the driver | |
|---|---|---|---|
| (dark red) | Very high | ↑ | Very rapid increase of the impact |
| (light red) | High | ↗ | Increasing impact |
| (orange) | Moderate | → | Continuing impact |
| (yellow) | Low | ↘ | Decreasing impact |
| | | ↓ | Very rapid decrease of the impact |

Figure captions

**Fig 1**. **A**.-A cumulative number of Spanish reservoirs, annual precipitation and water stored in reservoirs from 1920 to 2008. Since the second half of the 1990s, Spanish reservoirs do not fulfil their river flows regulating role. (data from http://www.magrama.gob.es/es/agua/temas/planificacion-hidrologica/sia-/indicadores.aspx and Meteorological Agency). **B**.- Origin of the water consumed by the human population in the Segura River basin (South Spain). Only 16% of the water is supplied by the rivers of this basin (the Taibilla River). The rest comes from the Tagus-Segura transfer and desalination. (data from CHS: http://www.chsegura.es/). **C**.- The trends data of the salmon caught in Spanish rivers and annual trout production in aquaculture from 1960 to 2011. (data from Spanish Ministry of Agriculture, Fisheries and Food).

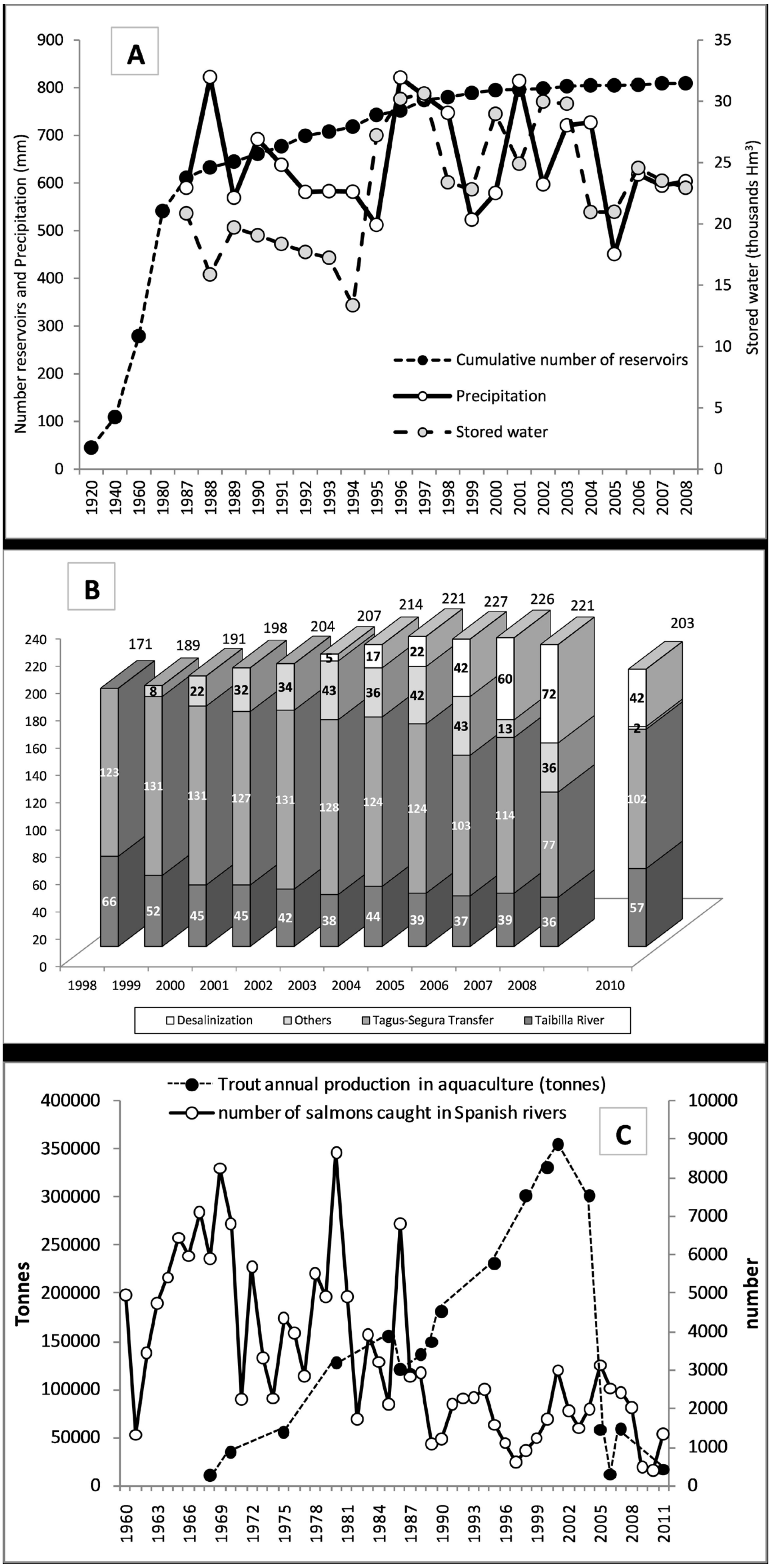
A
Number reservoirs and Precipitation (mm)
Stored water (thousands Hm³)
Cumulative number of reservoirs
Precipitation
Stored water
B
Desalinization
Others
Tagus-Segura Transfer
Taibilla River
C
Trout annual production in aquaculture (tonnes)
number of salmons caught in Spanish rivers
Tonnes
number

**Fig. 2**. Consumption of nitrogenous fertilizers applied to croplands and Spanish rivers sites with nitrate concentrations of up to 25 mg/l (**A**); number of urban and industrial effluents in Spanish rivers (**B**) (data from Spanish National Institute of Statistics: INE); the trends of public investments in water quality and sanitation and purification costs (**C**) and the volume of treated water by wastewater treatment plants from 1996 to 2011(**D**). (data from Spanish National Institute of Statistics: INE and Spanish Ministry of Agriculture, Food and Environment).

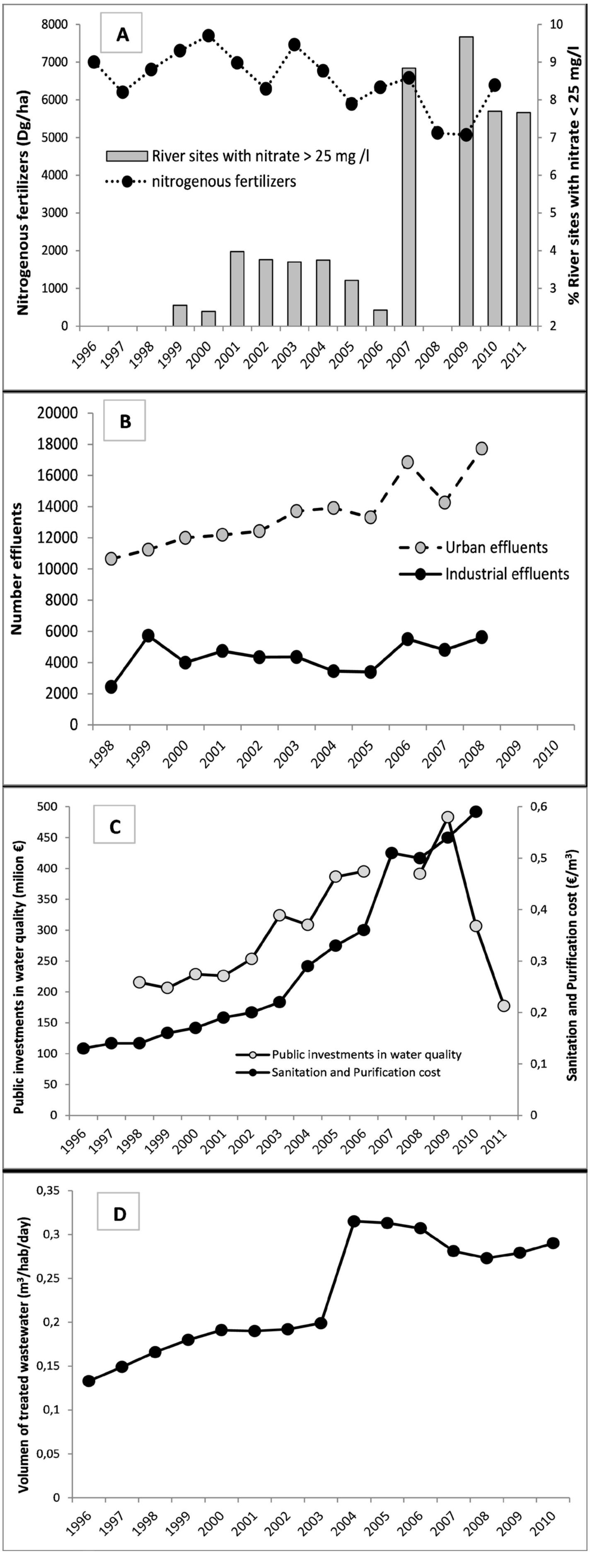
A
Nitrogenous fertilizers (Dg/ha)
% River sites with nitrate < 25 mg/l
River sites with nitrate > 25 mg /l
nitrogenous fertilizers
B
Number effluents
Urban effluents
Industrial effluents
C
Public investments in water quality (milion €)
Sanitation and Purification cost (€/m³)
Public investments in water quality
Sanitation and Purification cost
D
Volumen of treated wastewater (m³/hab/day)

**Fig. 3**. **A**.-Number of floods recorded in the Segura River Basin from before 1000 to the present-day. Note that after each political decision made, the number of floods has increased. Four historical events that affected land use have been identified: I.-Abandonment of farmland after the Spanish Reconquest, II.-The first *desamortización* (ecclesiastical confiscation) which took place in the first half of the seventeenth century, III.- The second *desamortización* between the eighteenth and nineteenth centuries, IV.- Abandonment of large rural areas in the early twentieth century. (data from Bautista (1989) and CHS: http://www.chsegura.es/ ). **B**.- Number of visitors to Spanish National Parks, including aquatic ecosystems, from 1989 to 2011. (*The 2011 data are provisional). (data from Spanish National Institute of Statistics: INE). **C**.- Number of fluvial beaches included in the European Environment Agency, and number of fluvial beaches that are compliant with the mandatory value of Directive 76/160/EEC for *Escherichia coli* and the more stringent guide values for *Escherichia coli* and intestinal enterococci. (data from http://dd.eionet.europa.eu/)

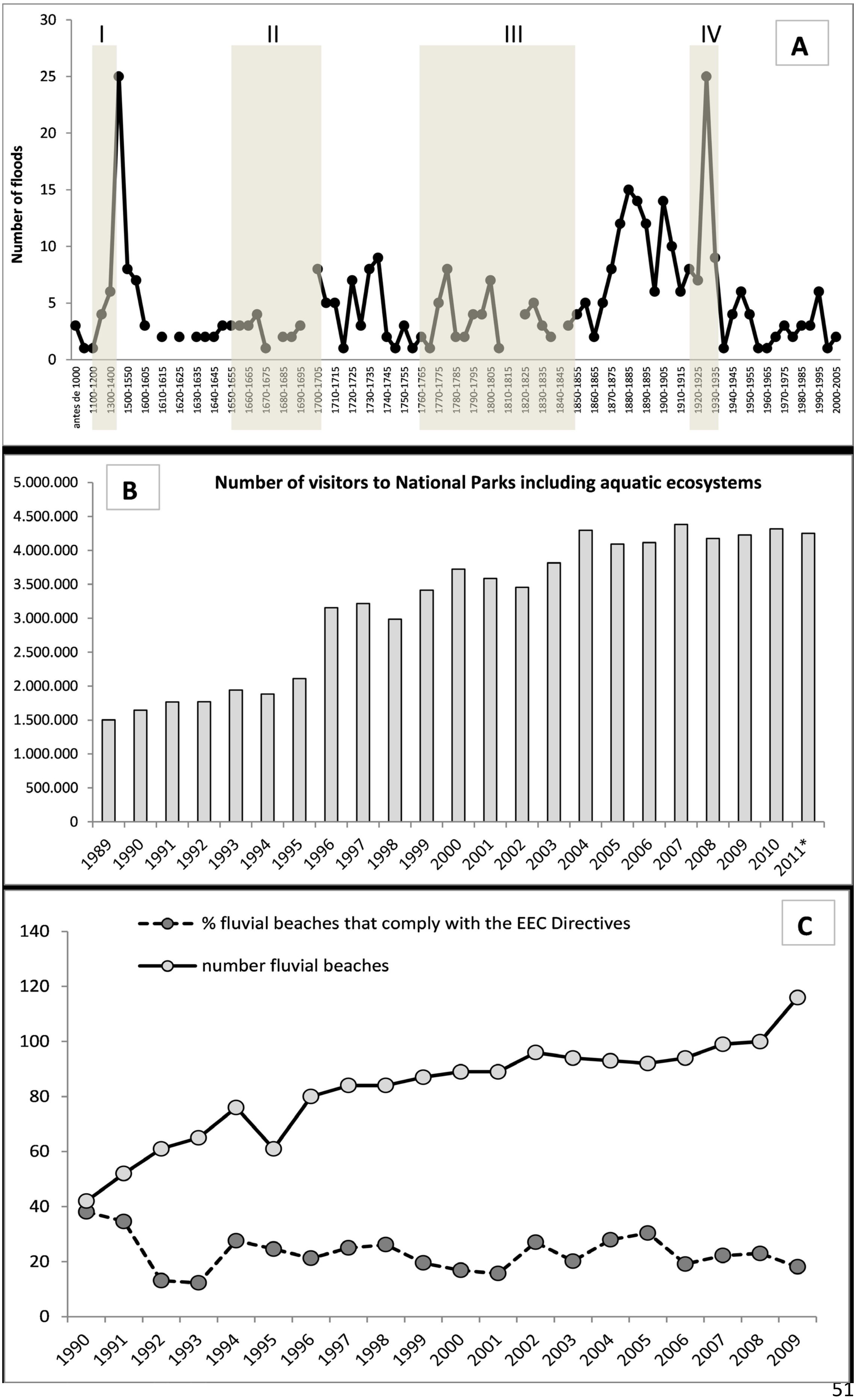
A
Number of floods
I
II
III
IV
antes de 1000
1100-1200
1300-1400
1500-1550
1600-1605
1610-1615
1620-1625
1630-1635
1640-1645
1650-1655
1660-1665
1670-1675
1680-1685
1690-1695
1700-1705
1710-1715
1720-1725
1730-1735
1740-1745
1750-1755
1760-1765
1770-1775
1780-1785
1790-1795
1800-1805
1810-1815
1820-1825
1830-1835
1840-1845
1850-1855
1860-1865
1870-1875
1880-1885
1890-1895
1900-1905
1910-1915
1920-1925
1930-1935
1940-1945
1950-1955
1960-1965
1970-1975
1980-1985
1990-1995
2000-2005
B
Number of visitors to National Parks including aquatic ecosystems
5.000.000
4.500.000
4.000.000
3.500.000
3.000.000
2.500.000
2.000.000
1.500.000
1.000.000
500.000
0
1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011*
C
% fluvial beaches that comply with the EEC Directives
number fluvial beaches
140
120
100
80
60
40
20
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009

**Fig. 4**. **A**.- Total number of aquatic and riparian vertebrate species. Number of endemisms, and number of vulnerable-threatened and endangered species. (data from National Biodiversity Inventory (http://www.magrama.gob.es/es/biodiversidad/temas/inventarios-nacionales/inventario-especies-terrestres/inventario-nacional-de-biodiversidad/). **B**.- The cumulative number of non-indigenous freshwater species (total, invertebrates, vertebrates and macrophytes) recorded in the Iberian Peninsula (data from Cobo et al. (2010)).