This is a post-peer-review, pre-copyedit version of an article published in Environmental Management*. The final authenticated version is available online at:* https://link.springer.com/article/10.1007/s00267-016-0674-6

Understanding complex links between fluvial ecosystems and social indicators in Spain: an ecosystem services approach

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Abstract

Fluvial systems have been considered from a holistic perspective as one of the most important ecosystems given their capacity to provide ecosystem services that directly affect human well-being. To our knowledge, there are no previous national studies that link the complex ecological and social components of fluvial systems, and that analyze their current capacity to supply services, the direct and indirect causes that affect their integrity, and the policy response options taken. We used the Driver-Pressure-State-Impact-Response (DPSIR) framework to explore the complex interlinkages between fluvial ecosystems and social systems in Spain. We selected 58 national-scale indicators that provide long-term information and allowed us to explore the trends and associations among DPSIR components. The trend analysis showed progressive aquatic biodiversity loss and deterioration of regulating services, and an increasing linear trend of direct pressures and indirect drivers, and of institutional responses, to correct negative impacts. Although we were unable to establish the causalities among the DPSIR components with the correlations analysis, we show that most are strongly related; e.g., biodiversity loss and regulating services are negatively associated with the supply of provisioning services and institutional responses, respectively. This indicates that current water management policies do not deal with the underlying causes of ecosystems deterioration. These results suggest that the second Water Framework Directive (WFD) phase could include the ecosystem service concept in its reporting system to better assess aquatic biodiversity conservation and the supply of services delivered by fluvial ecosystems to human well-being.

Keywords: DPSIR framework; drivers of change; ecosystem services; indicators; human well-being; trade-offs

1. Introduction

Since the Millennium Ecosystem Assessment (MA, 2005) introduced a new framework to analyze the links between ecosystems and social systems, many studies have addressed the relationships between ecosystem services and human well-being (e.g., Maskell et al., 2013, Santos-Martín et al., 2013, Smith et al., 2013). Most of them have centered on assessing terrestrial ecosystems services (e.g., heathlands: Morán-Ordóñez et al., 2013; forests: Delgado, Sepúlveda and Marín, 2013, Quine et al., 2013; agroecosystems: Macfadyen et al., 2012) and much less attention has been paid to aquatic ecosystems (e.g., rivers: Keeler et al., 2012; wetlands: Faulkner et al., 2011; and coastal: Brenner et al., 2010).

Rivers have been identified as one of the most important ecosystems related to human well-being as they deliver a wide spectrum of ecosystem services (De Groot et al., 2010). Yet fluvial ecosystems have been recognized as one of the most deteriorated ecosystems globally (Naiman and Dudgeon, 2011), in Europe (Harrison et al., 2010), and in Spain (Spanish Millennium Ecosystem Assessment, 2011; Vidal-Abarca and Suárez, 2013). For decades, many initiatives have been taken to sustainably manage fluvial ecosystems (e.g., GWP, 2000; Bernhardt, et al., 2006), but most attempts made have focused on solving the effects of pollution and overexploitation as direct pressures. Nowadays however, fluvial ecosystems are considered from a holistic perspective (e.g., as providers of ecosystem services) because it helps us understand how their deterioration affects human well-being (Naiman and Dudgeon, 2011; Keeler et al., 2012). Recent efforts have also been made to relate the effect of direct drivers of change on the ecosystem services delivered by fluvial ecosystems (Holland et al., 2011; Garmendia et al., 2012; Keeler et al., 2012; Vidal-Abarca and Suarez, 2013). To our knowledge, there are no national studies that link the ecological and social components of the ecosystem services delivered by fluvial ecosystems, and which consider not only the state of this ecosystem and its capacity to supply services, but also the direct and indirect causes (i.e., drivers of change) responsible for its state, and the policy response options taken.

Since 2000, the most important guideline in EU legislation to influence water management in Spain has been the Water Framework Directive (WFD, European Commission, 2000), which includes, among others, protection of all aquatic ecosystems. Although it proposes a more holistic vision of aquatic ecosystems (whose principal goal is to achieve the *good ecological status* of all water bodies) than previous legislation, it does not include the assessment of biodiversity and the ecosystem services provided by aquatic ecosystems. In Spain, the implementation of the WFD has helped to improve the integration of management actions, the implementation of monitoring and reporting programs, and has enhanced institutional capacity for basin-scale management (Grantham et al., 2012).

This study aims to explore the existing links among drivers of change (both direct and indirect), the aquatic biodiversity state, the status of the ecosystem services provided to society and how they affect human well-being, as well as the institutional responses made to preserve these ecosystems. To achieve this objective, we used different data sets and indicators that identify the long-term (1960-2010) dynamics and interrelations between different components of natural and social systems in Spanish fluvial systems. More specifically, we aimed to analyze: (1) the trends and exchange rates of the different indicators related to the social and ecological components of fluvial ecosystems; i.e., aquatic biodiversity, ecosystem services, human well-being, institutional responses, and the direct and indirect drivers of change to it; (2) the interlinkages between components by identifying the possible synergies and trade-offs between ecosystem service categories, and also the connections between social and ecological components.

2. Material and methods

2.1. Conceptual framework

We adopted the Driver-Pressure-State-Impact-Response (DPSIR) framework (EEA, 1999), which provides an organized structure to analyze the causes, consequences and responses to changes in ecosystems (Ness et al., 2010, Rounsevell et al., 2010). According to this framework, the demographic, economic and natural conditions driving human activities (**D**river) exert **P**ressure on ecosystems and, consequently, its **S**tate change. **I**mpacts are the effects on environment, health human and materials, which may induce a social and/or government **R**esponse that feeds back on all the other components.

Recently, this conceptual framework has been proposed and used to assess ecosystem services (e.g., Grant et al., 2008; Kandziora et al., 2013; Cook et al., 2013; Santos-Martín et al., 2013; Pinto et al., 2014). In our work we adopted this methodology to specifically explore the associations between fluvial ecosystems and social systems in Spain from an integrative perspective.

Within this framework, *drivers* are interpreted as the factors that induce environmental change (e.g., demographic, economic, cultural, sociopolitical or technological) (Nelson et al., 2006). Thus, this concept matches those indirect drivers of change conceptualized by the Millennium Ecosystem Assessment (MA, 2005). These drivers are the underlying factors that promote the *pressures* affecting fluvial ecosystems (e.g., land-use change, climate change, pollution, overexploitation and invasive alien species), which the Millennium Ecosystem Assessment (MA, 2005) considers to be direct drivers of change. These pressures alter the *state* of fluvial ecosystems and their biodiversity, and affect the ecosystem services provided to society. Therefore, *impacts* are understood as changes in both the supply of ecosystem services and human well-being. Finally, *responses* are the institutional actions made to preserve fluvial ecosystems or to counteract the effect of drivers of change.

Although the methodological framework of this study is similar to those provided by Santos-Martín et al. (2013), its originality lies in its application to fluvial ecosystems, which requires searching and using different indicators to those used by these authors. For more details about the methodological framework, see Santos-Martín et al. (2013).

2.2. Data sources

In order to apply the DPSIR framework to Spanish fluvial ecosystems, we selected 58 national-scale indicators that provide information about each component. In a recent study, Vidal-Abarca and Suarez (2013) used 139 indicators to assess the status and trends of ecosystem services and Spanish fluvial ecosystems, some of which were used in this study. Indicators were selected according to the following criteria: (1) indicators capable of communicating information clearly, not ambiguously, to detect changes in other DPSIR framework components; (2) widely accepted by the multiple stakeholder types involved in the Spanish National Ecosystem Assessment (2011); (3) temporally explicit, e.g., trends can be measured over time; scalable, e.g., can be aggregated to different scale levels; quantifiable, e.g., the information obtained can be easily compared; (4) data availability during the last five decades (from 1960); (5) credibility, e.g., obtained from official statistical data sets (Layke et al., 2012).

Two of the 58 selected indicators are related with aquatic biodiversity, 26 with ecosystem services (9 provisioning, 10 regulating and 7 cultural indicators), 7 are indicators of human well-being, 9 are indicators with policy responses, 5 are indicators with drivers (indirect drivers of change), and 9 are indicators with pressures (direct drivers of change). The selection of these indicators is a compromise between the theoretical interplay of previous criteria and data availability. So we selected those indicators from official sources with long enough data series to obtain reliable results. The selection, interpretation and justification of the indicators selected for each DPSIR component is specified in Appendix A (Annexes A-F), and include the following information: data source, measurement unit, timeline used on an available data basis, rationale and graphical evolution of the trend indicators.

It is quite often more difficult to find indicators of ecosystem services provided by fluvial ecosystems showing the positive contribution of the service than the negative consequences of its loss (Layke et al., 2012). This is especially true for regulating services. For example, it is easier to detect degradation of water quality of rivers through, for example, the physical-chemical parameters that quantify the river's ability to regulate water quality.

2.3. Data analysis

To analyze the relationship between the different DPSIR components in Spanish fluvial ecosystems, we standardized all the indicators by subtracting the mean of each value and dividing by the standard deviation. We chose the "direction" of each indicator; e.g., whether to increase or decrease the indicator value after considering the component to be assessed (Floridi et al., 2011). For instance, for the "atmospheric regulation" regulating service, when the "CO_2 emissions by wastewater treatment plants" indicator displays increasing trends, it means that the atmospheric regulation service is deteriorating. Therefore we calculated the trend on the basis of the slope from the linear regression for the time series of each indicator. The trend of each indicator was categorized into five classes following the signs of Santos-Martín et al. (2013): (1) *highly improve* (↑↑), when the slope of the regression models was higher than 0.08; (2) *improve* (↑), when the slope of the regression models was between 0.08 and 0.04; (3) *stable* (↔), when the slope of the regression models was between 0.04 and -0.04; (4) *decline* (↓), when the slope of the regressions was negative and between the values of -0.04 and -0.08; and (5) *highly decline* (↓↓), when the slope of the regressions was lower than -0.08.

To obtain indices for each DPSIR framework component, we aggregated the indicators of each component using the arithmetic mean because it is a useful benchmarking method that reduces the compensability of poor performance in specific indicators for high values in others (Floridi et al., 2011). In this way, we obtained nine aggregated indices (Fig. 1): biodiversity, ecosystem services including provisioning, regulating and cultural services, human well-being including material and nonmaterial dimensions, responses, pressures and drivers of change. The aim of the separation between the material and nonmaterial dimensions of the human well-being indicators was to show the differences between the welfare (e.g., livelihood, access to goods) and quality of life (e.g., health, security, social relationships) indicators.

To test the internal consistency of the aggregated indices, we estimated Cronbach's alpha, which computes the average intercorrelation between all the indicators on a scale. While a high Cronbach's alpha value indicates good internal consistency, it does not mean that each constructed index is uni-dimensional. Therefore, we identified the different dimensions, trade-offs and synergies among the indicators in all the indices with a factorial analysis. We performed these two analyses for all the indices and indicators, except for biodiversity as this integrated index is comprised only by two indicators.

3. Results

3.1. Trends of indicators

3.1.1. Biodiversity

Aquatic biodiversity, represented by evolution in the Red List Index (RLI) for fish, amphibians and reptiles, has declined continuously from 1985 to 2000. Yet we detected a slight recovery of aquatic vertebrates in the last decade (Table 1, Annex A). Conversely according to the RLI, the aquatic invertebrates included in the threat category have increased to 57% in the last 5 years (Annex A, Table 1).

3.1.2. Ecosystem services

Overall, 14 of the 26 indicators selected for this category to analyze the ecosystem services provided by fluvial ecosystems exhibited declining trends (Table 2). For provisioning services, the opposite trend observed between reduced fish catches in

Spanish rivers and increased annual production in aquaculture was quite remarkable (see Annex B). The decreasing tendency in the amount of water harvested to supply agriculture was offset by increased groundwater extraction (Annex B). Finally, the increased production of bottled water for human consumption was extraordinary (Annex B).

Regulating services were the most affected group with eight indicators depicting a losing trend. All the indicators related to atmospheric regulation, and also to both quality and flow water regulation, showing marked declining trends. The increased volume of treated wastewater did not seem harmless given the rise in greenhouse gas emissions (see Table 2, Annex B) detected in wastewater treatment plants, which will undoubtedly affect climatic regulation. However, the biological control regulating service showed an improved trend. Almost all the cultural services have improved in recent decades, except for number of rural inhabitants, which decreased, indicating that the cultural identity service has deteriorated (Table 2, Annex B).

3.1.3. Human well-being

We selected seven indicators to analyze the five dimensions of human well-being (material, health, security, freedom of choice and actions) and social relations following the MA (2005) classification. Each dimension showed different trends with time (Table 3, Annex C). All the indicators relating to the material dimension presented a positive trend, although it has been negative in the last 5 years (Annex C, Table 3). The two analyzed indicators of health showed an opposite trend. The water-related diseases in natural aquatic ecosystems (e.g., typhus) dramatically declined as compared to those related to artificial water accumulation and transport systems in industrialized countries (e.g., legionellosis), which has increased exponentially in recent years (Annex C, Table 3).

The indicator used to assess security is closely related to catastrophic events, e.g., floods, which occur with much uncertainty. This indicator showed an increasing tendency for material damage caused by these natural hazards (Table 3, Annex C). Freedom of choice and actions were assessed using the number of displaced persons by big dams (Annex C), whose trend remained stable (Table 3). Finally, social relations gave a clear tendency to associationism for different purposes (recreation activities, water sports, protection of nature, etc.) (Annex C).

3.1.4. Response options

All the assessed response options indicators have increased rapidly in recent years (Table 4, Annex D). Indeed in the last 20 years, Spain has made huge efforts to improve the water quality of fluvial ecosystems (e.g., low BOD_5 values) by controlling organic discharges (e.g., population connected to wastewater treatment plants), reusing treated water and incorporating standards into water governance (e.g., water use and management guidelines). Civilian and public institutions have been involved in developing and implementing aquatic biodiversity conservation policies (e.g., environmental protection associations; projects of the LIFE-Nature and Biodiversity

Program on aquatic species and ecosystems), and in promoting environmental market initiatives, such as organic agriculture production, which consumes less water and phytosanitary products are no longer incorporated into soil.

3.1.5. Drivers

Economic driver indicators depict the huge efforts made by Public Administrations to restore the environmental quality of Spanish fluvial ecosystems and by the civilian population to pay for sanitation and water purification plants. Whereas public investment for monitoring water quality has declined in recent years due to the current economic crisis, pressure on the civilian population to maintain water purification has increased (Table 5, Annex E). This increase, as seen in knowledge on Spanish fluvial ecosystems and its application to improve water management plans, comes over clearly from scientific and technological indicators. The demographic and cultural indicators indicate a constantly increasing population density (e.g., human population density in the Tagus River basin). In parallel, the human population has undergone an aging process (e.g., people aged over 65 years), and rural areas have undergone a depopulation process. Finally, sociopolitical indicators clearly revealed the strong positive impact of European policies on water governance in Spain (Table 5, Annex E).

3.1.6. Pressures

All the pressure indicators revealed the amount and intensity of the impacts which Spanish fluvial ecosystems have been subjected to (Table 5, Annex F). Among these, land-use change (e.g., increased irrigated area), excessive water extraction of natural systems (e.g., groundwater extracted) and diffuse pollution (e.g., river sampling sites with > 25 mg NO_3 l^{-1}) came over as the most important pressures on fluvial ecosystems in Spain (Table 5, Annex F).

3.2. Internal consistency of aggregated indices and associations among indicators.

Cronbach's alpha indicated good internal consistency for all the constructed indices of the DPSIR model because most were above 0.6, except for the constructed indices of drivers, pressures and regulating services, which were above 0.5 (Table 6). In fact for all the constructed indices, the eigenvalue of the first two factors was higher than 0.9 (except for the second factor in the responses index). This fact demonstrated that all the indicators highly contributed to the explanation of the integrated indices through a bi-dimensional structure. Thus, the first two factors in all the indices explained at least 62% of total variance (Table 6). For the specific associations among the indicators in the first two factors for each constructed index, see Appendix B.

We computed Cronbach's alpha for all the indicators to find that they were highly associated as Cronbach's alpha was higher than the Cronbach's alpha coefficients per each index (Cronbach's alpha = 0.808). This means that the global DPSIR analysis was highly consistent.

3.3. Trends of aggregated indices

The aggregated indices prepared with the indicators for all the assessed components revealed that aquatic biodiversity loss seems to be slightly recovering despite it being persistent in past decades (Fig. 1a). The regulating services index denoted a declining trend in two different phases (Fig. 1b); a very sharp trend from 1960 to 1980; and from 2000 to the present-day. In contrast, the cultural services index showed a clearly increasing tendency. Finally, the provisioning services index represented a complex evolution as a positive trend that has been maintained until 2000, but has clearly declined since (Fig. 1b).

The aggregated indices for human well-being exhibited opposite trends between the material and nonmaterial dimensions (Fig. 1c). Undoubtedly, access to material goods from fluvial ecosystems (e.g., water for agriculture, or population's access to drinking water) has contributed to the Spanish population's welfare. Yet as some regulating services linked to water and fluvial ecosystems are decreasing, the nonmaterial dimension of well-being has deteriorated (e.g., health: "registered cases of legionellosis", or security: "damage by floods paid by insurance companies").

The trend of the aggregated index for pressures (direct drivers) was not easy to interpret (Fig. 1f) from the oscillations observed given the multitude of impacts and pressures which Spanish fluvial ecosystems (water withdrawals, wastewaters, dams, channelizations, etc.) have withstood throughout history. On the contrary, trends of drivers (indirect drivers) and response options (Fig. 1e and 1d) presented a steadily increasing slope, especially in the last decade. A slightly lowering aggregated index trend for drivers was detected in the last year. The strong aggregated index for trend the responses was remarkable given the increasing public economic resources used to maintain water quality, incentives for water research and water governance guidelines.

Data variability, represented by the shadow behind the indices (Fig. 1), can be interpreted as the unpredictability range for all the aggregated indices and the level of uncertainty to predict future trends. It is interesting to note that the highest uncertainty level was seen for the regulating services index (Fig. 1b).

3.4. Looking for relationships among the DPSIR framework components

Spearman's correlation test showed the significant relationships among the DPSIR components in Spanish fluvial ecosystems (Table 7). We found significant correlations between aquatic biodiversity loss (measured by the RLI) and provisioning services (Table 7). We also detected an association between provisioning services and two human well-being dimensions (negative with the nonmaterial dimension, positive with the material dimension). These correlations suggest that an increase in provisioning services does not necessarily imply improved quality of life, but a better standard of living. Regulating services associated negatively with cultural services, the nonmaterial human well-being dimension, and with pressures and responses options, indicating strong relationships between the maintenance of regulating services and human well-being (in quality of life terms), and also between drivers of change and deterioration of regulating services.

Cultural services correlated with most aggregate indices, probably because the indicators used to obtain them referred mainly to the urban population, which uses interchangeably natural fluvial ecosystems (e.g., natural parks with fluvial ecosystems, fluvial beaches) and water infrastructures (e.g., dams) to carry out leisure and recreational activities (e.g., fishing, bathing, walking).

The negative correlation between the nonmaterial human well-being dimension and drivers (indirect drivers of change) should be noted, which seems to indicate how the factors inducing changes in fluvial ecosystems (e.g., demographic: aging rural population; economic: money spent by Public Administrations on water quality) relate negatively with the Spanish human population's quality of life.

Finally, the correlation test showed that pressures, drivers and response options were positively related (Table 7), but not so with aquatic biodiversity loss. This indicates that many efforts have been made in recent decades to response drivers and pressures, but not to stop biodiversity loss.

4. Discussion

4.1. Some considerations of indicators, indices and the DPSIR framework

The DPSIR model's ability to explain associations among the indicators describing how human society impacts the various states comprising an ecosystem and its ability to supply ecosystem services first depend on the type and quality of the indicators used.

To explore linkages between Spanish fluvial ecosystems and the social system, we selected 58 indicators. This selection was based on a compromise between the most adequate and/or representative of the DPSIR components and official data availability for the last **50** years. Other indicators are possibly more appropriate and tailored to the study objectives; e.g., "undisturbed buffering zones" as a water quality regulation service; "pollutants removed per hectare of floodplain" as an atmospheric regulation service; "water retention capacity of floodplains" as a flow regulation service; "number of people living in the proximity of rivers" as human well-being (freedom of choice). However, as pointed out by Pinto *et al*. (2014), more efforts must be made to find the set of indicators that integrates an ecosystem's socio-ecological conditions, and that collects representative data of indicators able to showing associations between human and nature systems. Accordingly, and based on our results, it is necessary to promote the collection of long-term series on regulating and cultural services, human well-being and indicators of drivers.

As for the goodness of the relationships among the DPSIR components, it is clear that the correlation analysis should be interpreted as merely exploratory. Indeed, the connections detected among the DPSIR components are not always linear causal paths. Nevertheless, we detected good internal consistency for all the constructed indices of the DPSIR model (Table 6).

This study is the first step to understand the complex relationships among the DPSIR components applied to Spanish fluvial ecosystems and to gain a better understanding of the root causes of river degradation by considering the socio-ecological system (Song and Frostell, 2012).

4.2. Moving beyond ecological status in water policy: toward an integrated management strategy

Inland aquatic ecosystems are subjected to far greater biodiversity loss globally than actually noted in the most impacted terrestrial ecosystems (Collen et al., 2013; Loh et al., 2005; MA, 2005). In Spain, it is evident that fluvial ecosystems are currently undergoing a major degradation process (Spanish Millennium Ecosystem Assessment, 2011; Suárez and Vidal-Abarca, 2012; Vidal-Abarca and Suárez, 2013) because of: (1) the long-term history of water flow control (e.g., some 1300 dams exist in Spain); (2) high freshwater demand by agricultural and industrial sectors (e.g., hydropower); (3) untreated sewage from growing urban populations; (4) weak water governance by the Water Administration, whose aim is to satisfy all human demands (Grantham et al., 2012; Vidal-Abarca and Suárez, 2013). The pressure on Spanish fluvial ecosystems has been so strong that they are currently unable to provide many ecosystem services, save some cultural services, demanded mostly by urban people; e.g., recreation activities, scientific knowledge and environmental education (Table 2).

However, the aquatic biodiversity state has improved in the last decade (see Fig. 1a), probably because of the institutional response by the European Union through the WFD (2000/60/EC). In fact, the WFD is currently considered the institutional response that has more repercussions on water and aquatic ecosystem management in Europe (European Communities, 2000). Its main objective is to achieve a *good ecological status* for all water bodies. In addition, it intends to improve the quality of water by identifying and controlling the activities that negatively affect the condition of surface and groundwater to secure future community water supply (Howe and White, 2002). The WFD promotes integrated water resources management to environmentally support sound development and to reduce some pressures associated with excessive water abstraction, pollution, floods and droughts. Hence, the WFD can be considered holistic environmental legislation of fluvial ecosystems because, to a certain extent, it compiles other directives; e.g., the Drinking Water (80/778/EEC), Urban Wastewater Treatment (91/271/EEC), Nitrates ((91/676/EEC) , Bathing Water (76/160/EEC), Sewage Sludge Directive (86/278/EEC) or Fisheries Common (2008/56/EC) Policies.

In order to achieve a good status for all water bodies, we need to ask if it is sufficient to preserve aquatic biodiversity and to counteract the effect of direct pressures. To accomplish this, it seems that the good status sites should harbor a high level of beta- and gamma biodiversity, which is not guaranteed by either the framework or the methodology used by the WFD (Hering et al., 2010). Moreover, although the WFD is more complete in ecological structure and ecological assessment terms (Borja et al., 2008), it neither incorporates the assessment of the ecosystem services delivered by inland aquatic ecosystems nor focuses on the underlying causes that impair biodiversity loss. In fact, our results show that despite the biodiversity state having improved in the last decade, most ecosystem services (save some cultural services demanded by urban areas) have deteriorated in the last decade. Indeed, Spanish society is aware of the degradation of fluvial ecosystems and its consequences on ecosystem services because this ecosystem is recognized by people as being capable of providing services (Martín-López et al., 2012). Fundamentally, regulating services are the most affected, which is a general trend demonstrated for other ecosystem types (e.g., Gordon et al., 2010; Harrison et al., 2010; MA, 2005) and on different spatial scales (e.g., MA, 2005; Martín-López and Montes, 2011). This may come into play because the WFD aims to address some pressures (e.g., direct drivers of change), but not the underlying causes that likely favor the effect of them (e.g., indirect drivers of change). For instance, we detected two different phases associated with the delivery of regulating services (Fig. 1b), which are apparently related to demographic and socio-political changes that have occurred in Spain in the last 50 years. Thus from the 1960s to the 1980s, a major migration of rural citizens to cities has been observed. Abandonment of crops and forest areas has decoupled natural water regulation mechanisms, which support these rural populations (see Fig. 1b). From the late 1970s to the year 2000, many large hydraulic works were launched (e.g., dams, channelization, etc.) (Table 5), which have favored increased agricultural productivity, supplying industrial energy demands and municipal waters for cities, and flood control. Thus, loss of the natural water regulation ability by well-conserved, well-managed watersheds has been replaced with hydraulic technology. It seems that the positive effects have lasted a short time as a strongly declining trend from 1990 has been detected.

Therefore pressures on fluvial ecosystems (e.g., water pollution, channelization, construction of dams and water abstraction; Freyhof and Brooks, 2011) have not only an immediate effect on biodiversity and ecosystem services, but are also indirect drivers of change, which seems to reinforce the previous one (Table 7).

4.3. Links between fluvial ecosystems and human well-being: toward understanding fluvial systems as social-ecological systems

Our study results show the close positive links between the material goods provided by fluvial ecosystems and the pressures impairing fluvial ecosystems, which face loss of regulating services, thus diminished nonmaterial human well-being (Table 7). In fact, the gap emerging between the material and nonmaterial human well-being dimensions is obvious (Fig. 1c) and highlights loss of quality of life in relation to benefitting from well-preserved fluvial ecosystems, access to good quality water, protection from flood or drought damage, or the ability to decide on actions of general interest; e.g., building large dams. Our results help explain the Environmentalist's paradox (human well-being has paradoxically increased despite the deterioration in ecosystem services; Raudssep-Hearne et al., 2010) as we demonstrate by the increasing rates of specific provisioning and cultural services delivery, which relate negatively with the nonmaterial well-being dimensions (Table 7). Therefore, we conclude that well-being is dependent on ecosystem services delivery from two viewpoints: (1) human welfare depends partially on certain provisioning services (e.g., food), but not on others (Raudssep-Hearne et al., 2010); (2) the nonmaterial human well-being dimensions associate negatively with the increasing supply of specific provisioning (e.g., food and water consumption) and the cultural services demanded by the urban population (e.g., recreation activities). Hence this study and that of Santos-Martín et al., 2013 are innovative as they analyze the complex relationships between ecosystem services and human well-being since both explicitly disaggregate human well-being in material and nonmaterial components, and they reach similar conclusions.

Our findings also show close relationships between the social and ecological components involved in fluvial ecosystems, which lead us to explicitly recognize fluvial systems as social-ecological systems (as in Ostrom, 2009). The open system nature of fluvial ecosystems, plus their high heterogeneity in space and time terms, suggest that their structure and functions are highly dependent on exchanges with their watersheds (Thorp et al., 2010). So many ecosystems services are dependent on the functional linkage with their riparian areas (e.g., controlling sedimentation, intercepting runoff of nutrients and pesticides from agricultural lands, or reducing flood hazards) (Allan and Castillo, 2007; Naiman et al., 2005). As Gleick (2000) stated, one of the most important failings of 20th-century water management is not understanding the connection between water and ecological processes, and the links between ecosystems and human well-being.

Fluvial ecosystems management should be integrated into the territorial space making up watersheds, and should be coordinated with other policies (i.e., agriculture and forestry policies) that directly affect the integrity of fluvial ecosystems (Vidal-Abarca and Suárez, 2013). So water should be understood and managed in the hydrologic cycle context that operates on a watershed scale (Alcamo et al., 2008; Arthington et al., 2010). Therefore, we must make the relationships among watershed management, fluvial ecosystems and delivered services, human well-being and drivers of change more visible. Recently, some studies conceptualized fluvial aquatic systems as social-ecological systems to help understand the complex relationships between the ecological and social components in the watersheds context (e.g., García-Llorente et al., 2012; Rathwell and Peterson, 2012; Tuvendal and Elmqvist, 2011). The present study contributes to this recent literature by adopting another methodological approach, the DPSIR framework, which unravels complex social-ecological relationships. We believe that the integrated indices developed in this study help us view connections between current Spanish fluvial ecosystems management and human well-being by helping managers and the general public to understand these complex relationships. This approach can provide useful information for the second phase of WFD implementation (2015-2021). It can also help with decision-making processes, whose aim is conservative management of fluvial ecosystems, used by institutions, particularly to guide the implementation of more sustainable frameworks (integrating biodiversity and ecosystem services for human well-being).

Acknowledgments

This work has been conducted within the framework of the Spanish National Ecosystem Assessment (http://www.ecomilenio.es) Project funded by the Biodiversity Foundation of the Spanish Ministry of Agriculture, Food and Environment. Special thanks to Helen Warburton for her assistance in the English corrections. We thank anonymous reviewers for their valuable comments.

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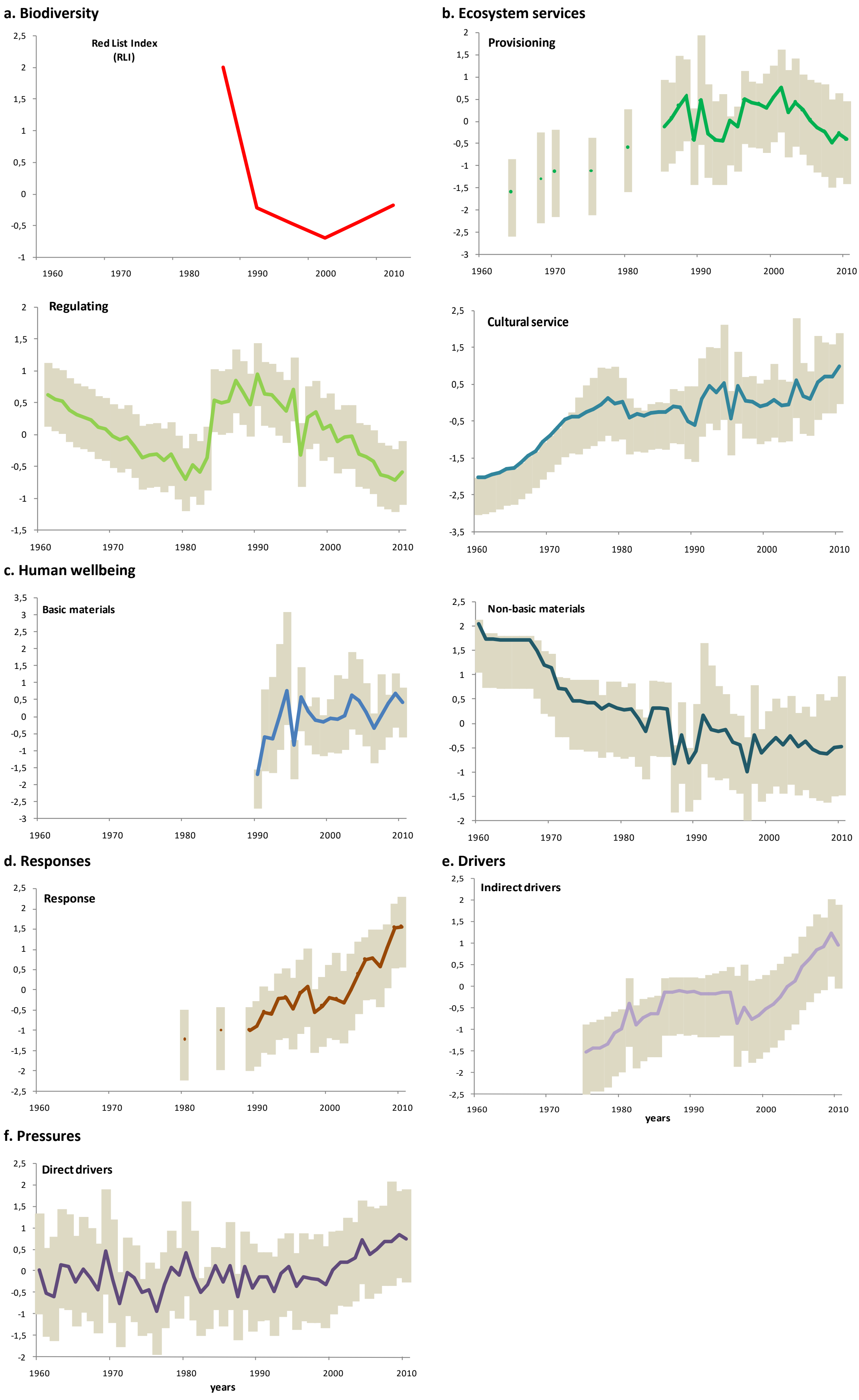
a. Biodiversity
Red List Index
(RLI)
b. Ecosystem services
Provisioning
Regulating
Cultural service
c. Human wellbeing
Basic materials
Non-basic materials
d. Responses
Response
e. Drivers
Indirect drivers
f. Pressures
Direct drivers
1960
1970
1980
1990
2000
2010
years

Legend to the Figure

Figure 1. Aggregated indices for all the DPSIR components assessed. The y-axis represents the arithmetic mean corresponding to the time series from 1960 to 2010 of all the standardized indicators used for each component. The data variability (± standard deviation) represented by the shadow behind the indices, can be interpreted as the unpredictability range for all the aggregated indices and the level of uncertainty to predict future trends. (a) **Biodiversity** is based on the Red List Index of vertebrates; (b) **For the ecosystem services,** nine indicators were used for provisioning services, ten for regulating services and seven for cultural services; (c) **For human well-being,** seven indicators were used (two and five for the material and nonmaterial dimensions, respectively); (d) **For the responses options,** nine indicators of biological and environmental conservation strategies, social participation and market initiatives were used; (e) **Drivers** (indirect drivers of change) were based on five indicators of the demographic, economic, sociopolitical and scientific aspects; (f) **Pressures** (direct drivers of change) were based on nine indicators relating to land use, climate change, over-exploitation, pollution and invasive alien species. For further details and information on individual indicators, see Appendix A.

Table 1. Aquatic biodiversity status trends (vertebrates and invertebrates) on the basis of the Red List Index (Bubb, et al., 2009). (IUCN= International Union for Conservation of Nature).

Taxonomic group		**Indicator**	**Trend**
Vertebrates	Fish, amphibians and reptiles	The Red List Index of freshwater vertebrates	↓
Invertebrates	Aquatic invertebrates	Aquatic invertebrates that underwent category changes according to the IUCN Red List	↓↓

Division	Group	Class	Indicator	Trend

Table 2. Ecosystem services trends provided by Spanish fluvial ecosystems (BOD_5 = 5-day Biological Oxygen Demand).

Provisioning				
Nutrition	Animals for food	Fish	Total fish caught in Spanish rivers	↓↓
		Aquiculture	Total annual production in aquiculture	↑
Water supply	Water for human consumption	Domestic water use	Surface water harvesting for human use	↓↓
		Agriculture water use	Surface water harvesting for agriculture	↓↓
			Groundwater harvesting for agriculture	↑↑
		Industry water use	Water harvesting for industry use	↓↓
Materials	Abiotic materials	Mineral water	Water harvesting of natural springs for drinking	↑
		Inland salt	Inland salt production	↔
Energy	Renewable abiotic	Hydropower production	Total production of hydropower	↔
Regulating				
Regulation of physico-chemical environment	Atmospheric regulation	Local and Regional climate regulation	Emissions of CO_2 by wastewater treatment plants	↓↓
			Emissions of CH_4 by wastewater treatment plants	↓↓
			Emissions of N_2O by wastewater treatment plants	↓↓
	Water quality regulation	Water purification and oxygenation	Volume of wastewater treated	↓↓
	Pedogenesis and soil quality	Maintenance of soil fertility	Total fertilizer consumption in floodplains	↓
			Sludge produced in wastewater treatment plants used as fertilizer	↓↓
Flow regulation	Water flow regulation	Control of discharge	Water control capability by dams	↓↓
		Attenuation of runoff and discharge rates	Damages to persons by floods	↔
Regulation of biotic environment		Biological control mechanisms	BOD_5	↑↑
Regulation against hazards	Life cycles maintenance		Cumulative number of droughts	↓
Cultural				
Symbolic	Heritage	Cultural identity	Municipalities with less than 2000 inhabitants of Tagus River Basin	↓
Intellectual and experiential	Recreation and community activities	Landscape character for recreational	Number of visitors to National Parks with river ecosystems	↑↑
			Number of freshwater bathing water	↓↓
			Number of freshwater bathing water that compliant with Directive 76/160/EEC	↔
			Number of licenses to fish in Spanish rivers	↑
	Information & knowledge	Scientific	Number of scientific publication on aquatic ecosystems	↑↑
		Environmental education	Number of PhD Theses on water	↑

Table 3. Human well-being indicators trends divided into their five dimensions on the basis of the Millennium Ecosystem Assessment (MA, 2005) and in relation to Spanish fluvial ecosystems.

Dimension	**Sud-dimension**	**Indicator**	**Trend**
Materials	Livelihoods	Gross value added of Spanish agriculture due to the use of water from Spanish rivers	↑↑
	Access to goods	Water harvesting for human use	↑
Health	Diseases related to water	Registered cases of typhoid	↓↓
		Registered cases of legionellosis	↑↑
Security	Natural hazards	Damages by floods paid by insurance companies	↑
Freedom of choice and actions	Actions forced of general interest	Cumulative number of displaced persons by big dams	↔
Social relations	Professional associations	Number of associations registered at the Ministry of the Interior on agriculture, livestock, hunting and fishing	↑↑

Table 4. Response options indicators trends to detect the efforts made by the Spanish hydraulic institutions for the conservation of fluvial ecosystems (BOD_5 = 5-day Biological Oxygen Demand).

Class	Type	Indicator	Trend
Biological conservation	Biodiversity conservation	Number of projects of Program LIFE+Nature and Biodiversity related to aquatic species and ecosystems	↑↑
Social participation on environmental issues	Environmental engagement	Number of associations for preserving animals and plants	↑↑
		Number of associations on environmental protection	↑↑
		Number of associations on naturism and alternative medicines	↑↑
Water Conservation	Water quality	Population connected to wastewater collection and treatment systems	↑↑
		Number of sampling sites with BOD_5 less than 3 mg O_2 l^{-1}	↑↑
	Water quantity	Reused water	↑↑
Water governance	Guidelines on water	Spanish guidelines about use and water management	↑
Market initiatives	Organic agricultural production	Organic agriculture surface	↑↑

Table 5. Trends of drivers and pressures indicators to determine the main causes and effects on aquatic biodiversity and fluvial ecosystems in Spain.

Class	**Type**	**Indicator**	**Trend**
Drivers			
Economic	Public investments in water quality	Amount of money spent by the public administration on water quality	↑↑
	Sanitation and Purification cost	Money paid by the people for sanitation and water purification	↑↑
Demographic	Population density	Human population density of Tagus River Basin	↑
Sociopolitical	Water governance	European guidelines on use and water management	↑↑
Cultural	Urban population	People over 65 years of the Tagus River Basin	↑↑
Pressures			
Land use change	Surface irrigated area	Total surface of irrigated area	↑↑
Over exploitation	Biotic materials	Capture of salmons (*Salmo salar*) in rivers	↑
	Abiotic materials	Number of dams built	↑
		Groundwater extracted	↑↑
Climatic change	Soil water	Quantity of water contained in the soil	↔
	Potential evapo-transpiration	Moisture loss of the land surface	↔
Invasive alien species	Invasive freshwater species	Number of invasive freshwater species	↑
Pollution	Water pollution	Number of sewage effluents	↑↑
	Diffuse pollution	Number of river sampling sites with nitrates more than 25 mg l^{-1}	↑↑

Table 6. Cronbach's alpha results and factorial analysis results for all the constructed aggregated indices of the DPSIR framework (except state of fluvial biodiversity): drivers, pressures, impact on provisioning services, impact on regulating services, impact on cultural services, impact on human wellbeing, and responses. For the specific factorial scores of each of the indicators in every factor, see Appendix B.

Index	Cronbach's alpha	Eigenvalue F1	Eigenvalue F2	Explained variance F1	Explained variance F2
Drivers	0.513	3.420	1.009	69.622	20.542
Pressures	0.521	2.867	0.913	45.958	14.635
Provisioning services	0.745	1.664	1.443	34.924	29.654
Regulating services	0.565	2.200	1.470	42.046	28.101
Cultural services	0.867	4.179	1.284	62.925	19.336
Human wellbeing	0.655	1.695	0.987	39.667	23.104
Responses	0.639	1.922	0.778	49.549	20.053

Table 7. Spearman correlation analysis showing the associations between aggregated indices. Level of significance at 95% confidence shown in bold. (P.S. = Provisioning services; R.S. = Regulating services; C.S. = Cultural Services; HW-M. = Material dimensions of human well-being; HW-N-M. = Nonmaterial dimensions of human well-being).

Variables	Biodiversity	P.S.	R.S.	C.S.	HW-M.	HW-N-M.	Responses	Pressures
Biodiversity	**-**							
P.S.	**-0.71**	-						
R.S.	-0.09	0.21	-					
C.S.	0.09	0.07	**-0.41**	-				
HW-M.	-0.37	**0.51**	**-0.43**	**0.47**	-			
HW-N-M.	0.37	**-0.47**	0.14	**-0.70**	-0.28	-		
Responses	-0.26	0.03	**-0.65**	**0.73**	**0.60**	-0.34	-	
Pressures	0.09	0.05	**-0.30**	**0.45**	**0.36**	-0.23	**0.73**	-
Drivers	0.0.9	-0.13	0.05	**0.37**	-0.02	**-0.56**	**0.67**	**0.59**