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Original Research Article

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 the best of 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.

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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-Ordoñez et al., 2013; forests: Delgado et al., 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

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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 Suárez, 2013). To the best of 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. Materials 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 Suárez (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