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Exploring the complex relations between water resources and social indicators: The Biobío Basin (Chile)

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ABSTRACT

Basins are one of the bio-geo-physical areas where the ecological processes that generate the ecosystem services (ES) and contribute to human well-being (HWB) are more evident. They are also the physical scenario where the nature-human interaction is more intense. The explicit relationships that link biodiversity, ES and HWB, and the direct and indirect causes responsible for their degradation, have been rarely explored. We used the Driver-Pressure-State-Impact-Response (DPSIR) framework to explore the relationships between the river ecosystem and the Biobío Basin's social system. We selected 65 basin and regional-scale indicators to analyse the existing trends and associations among the different DPSIR components. The trend analysis results showed major biodiversity loss and how the regulating services and non-material goods of the HWB component deteriorated, while cultural services, direct and indirect pressures and institutional responses increased. The relationships among the different DPSIR components revealed biodiversity loss to be positively associated with cultural services, the material goods of the HWB component and pressures. Indirect drivers were negatively associated with regulating and cultural services, non-material goods and pressures. Institutional responses did not correlate with any DPSIR component. However, these results do not reflect the complexity of the Biobío Basin's socio-ecosystem. We estimate that the DPSIR framework shows a corseted and reductionist vision of a greater complexity than merely a unidirectional nature-human relationship.

1. Introduction

The importance of relationships between people and nature is increasingly recognized given evidence for health and well-being benefits from the human interaction with nature (e.g., Bizikova, 2011; Martín-López and Montes, 2011; Bonet-García et al., 2015; Ives et al., 2017). The ecosystem services (ES) concept, defined by the Millennium Ecosystem Assessment (MEA, 2005) as the benefits that humans obtain from nature, has emerged as a promising approach for making the connection between ecosystems and human well-being (HWB). Indeed since the MEA proposed this new framework to explore the links between ecosystems and social systems, a growing body of literature has addressed the relationship between ES and HWB (e.g., Butler and Oluoch-Kosura, 2006; Liu et al., 2007; Ostrom, 2009; Martín-López et al., 2009, 2012). According to Liu et al. (2007), human systems and ecosystems are linked by forming socio-ecological systems in which social and biogeophysical components interact on multiple spatial and temporal scales. However, studies that have explored the relationships among all the socio-ecological system's components (i.e., state of biodiversity and the ecosystem, and their capacity to supply ES, direct and indirect causes responsible for their state, and response options) are still scarce (e.g., Santos-Martín et al., 2013; Felipe-Lucia et al., 2014; Pinto et al., 2014; Vidal-Abarca et al., 2014; Hossain et al., 2017).

Despite criticism about the concept, and the interpretation that the ES approach has received and its application (e.g., Raymond et al., 2013; Barnaud and Antona, 2014; Kull et al., 2015; Tadaki et al., 2015), it is one of the most widely used conceptual frameworks to integrate both ecological and social dimensions (MEA, 2005; Butler and Oluoch-Kosura, 2006; Martín-López et al., 2009, 2012). In methodological terms, it is necessary to explore models that allow relationships between ecosystem and social systems to be established from a more holistic perspective (Kelble et al., 2013). The DPSIR approach (Driver-Pressure-State-Impact-Response), a conceptual model that derives from social sciences (Rapport and Friend, 1979), has been widely applied to environ-

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ment sciences (EEA, 1995; AEMA, 1999) to explain the cause-effect relations among indicators, and to improve communication among policymakers, stakeholders and scientists (e.g., Song and Frostell, 2012, Cook et al., 2013; Kelble et al., 2013, Bonet-García et al., 2015). According to this methodological framework, demographic, economic and human activities, among others (drivers), exert pressures on biodiversity and natural ecosystems, which change their state. Impacts include effects on the environment and HWB, which usually induce society and/or government agencies' responses to control the effect of drivers or to preserve the ecosystem's capacity to supply ES.

This framework has been recently adapted and used to evaluate the relationships between ES, and also between DPSIR framework components (e.g., Grant et al., 2008; Santos-Martín et al., 2013; Pinto et al., 2014; Vidal-Abarca et al., 2014, De Juan et al., 2015; Malekmohammadi and Jahanishakib, 2017). For example, Santos-Martín et al. (2013) applied this framework to analyse the complex relationships between ecosystems and human systems in Spain. Vidal-Abarca et al. (2014) applied it to explore the relationships between the ecological and social components of Spanish fluvial ecosystems. In these studies, this methodological framework was applied to territories occupied by human societies that are relatively homogenous in cultural terms, but we do not know the validity of this methodology when applied to more complex social contexts. So we applied the DPSIR framework to the Biobío River Basin, one of the watersheds with the largest surface and of much economic importance in Chile, where different ethnic groups persist. We selected the watershed scale because its represents appropriate units to study ES (Delgado and Marín, 2016). Indeed watersheds are one of the bio-geo-physical areas where the ecological processes that generate ES are more evident (e.g., Pert et al., 2010), but they are also the physical scenario where the nature-human interaction becomes more intense. However for managers and the human population in general, it is not always obvious which (and how) human activities can alter the structure and functioning of aquatic ecosystems, and can induce loss of biodiversity to affect HWB.

Using the DPSIR framework, our objectives were to: firstly, evaluate the direct and indirect effects that the loss of biodiversity and ES have on HWB in the Biobío River Basin; secondly, explore the validity of this methodology when applied to a more complex social context. Specifically, we analysed the trends and exchange rates of the different indicators that compose the Biobío River Basin's socio-ecosystem; the relationships between natural and social systems by exploring the links between (direct and indirect) change drivers and the biodiversity status, ES, and how they affect HWB; the responses to preserve the water resources in the Biobío River Basin. Finally, we discussed the suitability of the DPSIR model to visualise the complexity of the Biobío River Basin's socio-ecosystem.

2. Study area

The Biobío River Basin extends between 36° and 39° S. It covers an area of 24,260 km^2 which is one of the basins with the largest surface and flow in Chile. The Biobío River is born in the Galletué Lake at 1160 m asl and runs 380 km in a SE–NW direction. Its hydrological regime is pluvio-nival, with a mean monthly maximum flow of approximately 2,200 m^3/s (Valdovinos and Parra, 2006). Roughly 53.7% of the basin area is occupied by forest formations. Native forests concentrate in the middle and upper parts of the Andean Cordillera and cover 317,500 ha (13% of the total basin area). A large portion (100,334 ha) of the Biobío River Basin belongs to the State National System of Protected Wild Areas (SNASPE). The Biobío Basin provides water to 1.2 million people. The Biobío Basin's social system is complex because more than 5% (80,870 people) of the human population are indigenous as they belong mainly to the Mapuche ethnic group (Ministerio de Desarrollo Social, 2017). On a national scale, this basin is an important centre of economic development. Its productive sectors are related to forestry, agriculture, industry (pulp and paper, metallurgic, chemical and oil refinery industries) and the hydroelectric sector, and it is the main source of energy supply in this country (Parra et al., 2013). The Biobío River also has an exceptional mosaic of habitats and biological diversity, which are sustained by the geographical and environmental characteristics provided by all the rivers that are tributaries of its channel (Mittermeier et al., 2004; Figueroa et al., 2013).

3. Methodology

According to Santos-Martín et al. (2013), we adapted the DPSIR framework to analyse the links among biodiversity loss, ES, HWB and society's responses to conserve and/or restore the ES flow. So **drivers** are the factors (i.e., demographic, economic, social-political and cultural) that trigger environmental change (Nelson et al., 2006), and they coincide with the indirect drivers of change that are conceptualised in the MEA (2005). These drivers promote the **pressures** that affect the integrity of ecosystems, which are recognised by the MEA (2005) as direct drivers of change. We considered four direct drivers of change: change in land use, climate change, pollution and overexploitation. Although the MEA (2005) also includes invasive species, we found that no indicators met this requirement. Pressures alter the **state** of ecosystems and their biodiversity by affecting the ES that provide society. So **impacts** can be understood as changes in the supply of both ES and HWB. We considered 14 ES (5 provisioning services, 4 regulating services and 5 cultural services) and four HWB dimensions (access to goods, health, freedom of choice and security). We separately analysed the material and non-material HWB dimensions to indicate the differences between well-being (access to goods) and quality of life (health, freedom of choice and security) (e.g., Russell et al., 2013). Finally, depending on the social perception of well-being, institutions or groups as politicians, managers and consensus groups, perform actions (i.e., **responses**) to conserve ecosystems and/or to counteract the effect of change factors.

3.1. Data source

To apply the DPSIR to the Biobío Basin's river ecosystems, 65 indicators on regional and basin levels were selected. These indicators provided relevant information about spatial and temporal scales for each DPSIR framework component. Information was selected from diverse official publicly available governmental and scientific sources and private sources, and covered an approximate 35-year period (1980–2015). The selection criteria for these indicators were those proposed by Layke et al. (2012). Of the 65 selected indicators, six were related with drivers (indirect drivers of change), 11 with pressures (direct drivers of change), one with biodiversity, 30 with ES (8 provisioning, 14 regulating and 8 cultural), 11 with HWB, and six were indicators of responses.

To select these indicators, we had to compromise between complying with the criteria proposed by Layke et al. (2012) and data availability. Despite our efforts to find indicators to assess all the DPSIR components on the basin scale, it was not always possible because the government agency responsible for water management does not use the hydrographic watershed as a management unit, and many official available data are generated only on a regional scale. Although our objective was to assess an approximate 35-year time series, we found very few indicators that covered it.