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

María Elisa Díaz[1*], Ricardo Figueroa[1], M. Luisa Suárez Alonso[2], M. Rosario Vidal-Abarca[2]

***Corresponding author**: María Elisa Díaz[1*] University of Concepción, Faculty of Environmental Sciences, Concepción, Chile, telephone number: +56-41-2204077, e-mail: mariaelisdiaz@udec.cl

Authors´ address:

[1] University of Concepción, Faculty of Environmental Sciences, Concepción, Chile

[2] University of Murcia, Regional Campus of International Excellence, Mare Nostrum Campus, Faculty of Biology, Department of Ecology and Hydrology, Murcia, Spain

María Elisa Díaz [1*]	e-mail: mariaelisdiaz@udec.cl
Ricardo Figueroa [1]	e-mail: rfiguero@udec.cl
M. Rosario Vidal-Abarca[2]	e-mail: charyvag@um.es
M. Luisa Suárez Alonso[2]	e-mail: mlsuarez@um.es

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 (i.e. drivers of change) 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.

Highlights:

We used Driver-Pressure-State-Impact-Response to relate river and social systems

A correlation analysis showed that DPSIR components are strongly related

Indirect drivers seem ultimately responsible for Biobío Basin degradation

The DPSIR does not reflect the socio-ecosystem's complexity

Keywords: DPSIR framework, ecosystem services, human well-being, change drivers, Biobío Basin.

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 environment 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-Martin 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 1,160 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-Martin 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.

When searching and selecting the indicators to evaluate ES and HWB, it was not always possible to find the most appropriate ones. Thus for some ES, detecting their positive contributions was more difficult than the negative consequence of having lost those services (Layke et al., 2012). This was especially true for regulating services as it was easier to find physico-chemical parameters to detect water quality degradation than to quantify the river's capacity to regulate water quality. Therefore in order to evaluate some ES, we used indicators whose metrics showed the consequences of loss of services.

Finally, we employed some indicators as proxies to evaluate certain DPSIR components. In order to assess the human health dimension in the HWB DPSIR component, indicators related to diseases of the digestive system were used. Obviously, many digestive diseases derive from food, but the Report of Population Records for Cancer in Chile (Ministerio de Salud, 2012) points out that some chemical components of water may be responsible for some diseases detected in the human population.

The selection, justification and interpretation of the indicators employed for each DPSIR component are presented in the Appendix. They include data sources, measuring units, the analysed period according to availability of databases, their justification, and the graphic evolution of the indicator trend.

3.2. Data analyses

To analyse the relationship among all the DSPIR framework components, every indicator was standardised by subtracting the mean and dividing it by the standard deviation (Santos-Martín et al., 2013). This standardisation allows different data sets to be compared. The direction of each indicator was chosen by considering the component to be assessed (Floridi et al., 2011). The trend following each indicator was considered according to the basis of the slope of the linear regression for the time series of each indicator (see Table 1). This trend was classified into five classes: 1) *considerable improvement* (↑↑), when slope was >0.08; 2) *improvement* (↑), when slope was between 0.08 and 0.04; 3) *stable* (↔), when slope was between 0.04 and -0.04; 4) *decrease* (↓), when slope was between -0.04 and -0.08; 5) *considerable decrease* (↓↓) when the slope was < -0.08 (Santos-Martín et al., 2013; Vidal-Abarca et al., 2014).

To obtain the aggregate indices of each DPSIR framework component, indicators were grouped by using the arithmetic mean because it is a useful method to compensate very disparate low and high values (Floridi et al., 2011). Whenever possible, we used several indicators to evaluate each service or dimension of the different DPSIR components (e.g. we utilised four indicators to assess pressure by pollution). The objective was to reinforce aggregate indices when the selected indicators presented short time series. Thus nine aggregate indices were obtained: biodiversity, ES (provisioning, regulating and cultural), HWB (material and non-material), pressures, drivers and responses. Data variability was represented by ± standard deviation (see the shadow behind the aggregate indices in Fig. 1) and can be interpreted as the unpredictability range for all the aggregated indices and the level of uncertainty to predict future trends.

Cronbach's alpha index (1947) was calculated to test the internal consistency of the aggregate indices. This index computes the average intercorrelation among all the indicators on a scale. A high Cronbach's alpha value indicates good internal data consistency (George and Mallery, 2003), but does not denote that each devised index is unidimensional. To achieve this, the different dimensions of the associations, trade-offs and synergies among the indicators for all the indices were identified by a factor analysis. Both analyses were run for all the indices, except for biodiversity because it is composed of only one indicator. Finally, to explored relationships among the DPSIR components (i.e. biodiversity, ES, human well-being, drivers of change and responses) we used Spearman correlations. The SPSS software (2013) was used to perform all the statistical analyses.

4. Results

4.1. Trend indicators

4.1.1. Biodiversity

Loss of biodiversity was represented by the number of species that fell in a conservation category according to the RSC (Regulation of Species Classification; MMA, 2014). From 2006 to the present-day, nine evaluation processes have evidenced the deterioration of national diversity, and the number of conserved species has considerably increased (Appendix A) as has, in parallel, the number of species in danger of extinction. To date, 109 species have been catalogued, of which only fish represent the diversity of aquatic ecosystems, and many are located in the biodiversity hotspot in the Biobío Region (Figueroa et al., 2013).

4.1.2. Ecosystem services

Thirty indicators were used to assess the ES provided by the Biobío Basin. Of these, 53% showed increasing trends associated mainly with direct uses of resources (Table 1). In relation to provisioning services, fish harvesting from both artisanal fishing and aquaculture centres and extracting raw materials (gravel and sand) have increased (Table 1, Appendix B). Likewise, hydroelectric power generation has strongly increased in recent decades (Appendix B). For regulating services, both the river's self-purification capacity and water regulation have diminished. Although some water quality indicators have improved (e.g. O_2, BOD_5; Appendix B), increasing nitrate concentrations have revealed diffuse pollution problems (Table 1, Appendix B). The deterioration of the Biobío Basin's morphosedimentary regulation capacity is shown by the opposite trend between the native forest surface (decreases) and forest plantations (increase) (Table 1, Appendix B).

In general, cultural services have improved in recent years, with populations showing more preference for and/or appreciation of ecosystems (Table 1, Appendix B). However, the cultural services related to cultural identity and local ecological knowledge have deteriorated.

4.1.3. Human well-being

Eleven indicators were selected to assess four of the five HWB dimensions (health, freedom of choice and action, security and material well-being) proposed by the MEA (2005). The fifth HWB dimension (i.e. social relationships) was not assessed as adequate indicators were lacking. The indicators of most dimensions showed increasing trends (Table 1, Appendix C). The number of digestive diseases (e.g. stomach tumours, digestive diseases) in relation to health indicators has increased in recent years. The opposite can be stated of freedom of choice and action, which have declined as the construction works of hydroelectric power stations have displaced people (Table 1). Loss of security shows an increasing trend, which is associated with more naturally-occurring hazards. In particular, very uncertain flood events have taken place (Table 1). Finally, the material dimension measured by the population's access to drinking water and agricultural production has contributed to the well-being of the basin's population (Table 1).

4.1.4. Pressures (direct drivers of change)

All the indicators used to assess the pressures to which the Biobío Basin is subjected generally showed intensity and an increasing tendency. Declining rainfall and a rise in temperatures were proxy indicators of the pressure exerted by climate change. Land use change (increased sown surface) and pollution produced using pesticides (Appendix D) came over as the most important pressures on the Biobío Basin.

4.1.5. Drivers (indirect drivers of change)

Demographic indicators revealed an increased population density at the Biobío Basin. In parallel, there was a cultural ageing process with more people aged over 60 years (Table 1, Appendix E). Rural populations have undergone depopulation processes or have displaced to urban areas in search of better opportunities. Economic indicators revealed the efforts made by public administrations in water conservation terms because the indicators showed growing public investments in water (Table 1, Appendix E), or more investments in wastewater treatment being maintained. Nonetheless, demand was virtually covered (99.9%) in all urbanised places, but remained unsolved in rural and remote locations. The socio-political indicators indicated that more females occupied public positions. However, we were unable to evaluate this influence on the management of the Biobío Basin's aquatic resources as no more specific data were available.

4.1.6. Responses

Most of the indicators used to assess responses have increased in recent years (Table 1, Appendix F). Chilean Governmental Institutions have made huge efforts to improve both water quality (e.g. treatment plants) and human access to drinking water (e.g. water coverage). Regarding water governance issues, the creation of the Environmental Courts of Law in Chile (Act 20.600/2012) has generated instances that favour the development of protection actions and environmental responsibility through environmental complaints. Their solutions in compliance plans can redirect the investments made, ranging from environmental fines to objective solutions (e.g. environmental complaints; Table 1). However, there is still much to be done with social responses to promote environmental market initiatives, such as organic agriculture (Table 1, Appendix F), which uses less water and phytosanitary products.

4.2. Consistency of aggregate indices and associations among indicators

In most of the aggregate indices constructed for the DPSIR model, Cronbach's alpha indicated good internal consistency because most were above > 0.5, except for provisioning services (α: 0.49) (Fig. 1). For all the aggregated indices, the eigenvalues of the first two factor analysis were higher than 1.0 (except for the second factor in the non-basic material of HWB). This demonstrated that all the indicators contributed to explain the aggregated indices through a bi-dimensional structure. Hence the first two factors in all the indices explained more than 50% of variance (Appendix G). Finally, we calculated Cronbach's alpha for all the indicators to evidence the association of the set of indicators. The high value found (α: 0.653) indicated that the global DPSIR analysis was most consistent.

4.3. Tendency of aggregate indices

Loss of biodiversity, represented by the number of species in some conservation categories, has increased since 2010 (Fig. 1a). No complete freshwater biodiversity evolution record (save some fish species) exists for the Biobío Basin.

Despite aggregate index fluctuations, provisioning services have shown a slightly increasing trend with time (Fig. 1b). On the contrary, the aggregate index for regulating services has shown a declining trend. The sharp peak in 1997 corresponded to the forest fires that devastated the region, with the consequent loss of capacity to regulate climate control and morfosedimentary services (Fig. 1c). The aggregate index of cultural services displayed an increasing tendency (Fig. 1d).

With the aggregate indices for HWB, we detected an opposite trend when comparing the material and non-material dimensions (Fig. 1e and f). Here access to water or increased agricultural production contributed to the well-being of the population living near the basin (Fig. 1e). However, the deterioration of other services (e.g. water quality) had a negative impact, as shown by the aggregate index of the non-material dimension (Fig. 1f). The larger number of digestive diseases, possibly linked to water, and violated freedom of action, particularly in 2013 from forced eviction actions applied to rural populations to construct engineering works (e.g. hydroelectric stations), have made the quality of life of the population living near the Biobío Basin worse.

Although aggregate index fluctuations due to pressures (direct drivers of change) have accounted for the continuous impacts that have deteriorated river systems, a drop in pressure has been detected in the last 10 years (Fig. 1g). On the contrary, the trend of drivers (indirect drivers of change) presented a steadily increasing slope (Fig. 1h). The sharp peak detected in 2010 for the aggregate index of drivers corresponded to the year of the earthquake (27 February), when important economic resources were diverted to mitigate its effects. Despite some institutional responses having been associated with certain environmental topics (positive trend) (Fig. 1i), they have not been constant with time.

The shaded area of each DPSIR aggregate index (Fig. 1) responds to the variability of the used data, and can be interpreted as the degree of uncertainty of the indicators employed herein.

4.4. Exploring the relationships among DPSIR model components

According to the Spearman correlations, significant correlations between some DPSIR model components were observed (Fig. 1, Appendix H). Biodiversity loss was positively associated with pressures, cultural services and the basic material HWB dimension. These associations suggest that not only pressures, but acquisition of material goods, influenced the state of the Biobío Basin rivers, as measured by biodiversity loss. The positive correlations between cultural services with both biodiversity loss and pressures were probably due to most indicators evidencing the urban population's use of, and preference for, enjoying landscapes with water mirrors, regardless of their ecological quality (e.g. artificial lagoons, dams).

The positive correlation found between provisioning services and cultural services and basic HWB materials suggested that an increase in the former would not imply better quality of life, but a higher standard of living. The negative relation noted between the non-material HWB dimension and drivers (Fig. 1) revealed how the deterioration of the Biobío Basin's river ecosystems could affect HWB in quality of life terms. The regulating services associated with drivers indicated how indirect drivers of change negatively affected regulation services.

The negative correlations between drivers with both cultural services and pressures (Fig. 1) indicated that direct drivers (pressures) affect the supply of ES, and how other indirect factors (e.g. demographic, ageing rural population, economic) could also affect those that basically sustain most of the population's well-being. It is noteworthy that responses (e.g., solutions provided by public administrations to mitigate impacts on the Biobío Basin) were not related to any DPSIR framework component. This suggests that the public administrations' efforts have not managed to stop loss of diversity or to maintain the ES and HWB at the Biobío Basin.

5. Discussion

5.1. What can the DPSIR framework explain?

The DPSIR model has been proposed as a useful framework to explore and explain the complex relationships among the indicators that describe how human impacts alter the state of ecosystems, and their capacity to provide ES to society. According to Santos-Martín et al. (2013), the ability of the DPSIR model to explain these relations depends firstly on the quality of the used indicators. Smith et al. (2013) indicate that many objective and subjective variables are not always available in official databases, but are no less important if they show relevant trends and associations. In our study, 65 indicators were selected according to the availability and adequacy of the data for the study area. Santos-Martín et al., (2013) used 53 high quality indicators to establish relationships between HWB and ecosystems in Spain, and obtained many highly significant correlations for all DPSIR components. Vidal-Abarca et al. (2014) selected 58 indicators to analyse these relationships between river ecosystems in Spain and social indicators, and obtained fewer significant correlations. Although our study obtained a few very significant correlations for DPSIR components (Fig. 1, Appendix H), we used them as a purely exploratory analysis. Moreover, the relationships detected among all the DPSIR components were not always linear paths. Yet despite both the indicators and aggregated indices used in this study having their limitations (see Section 3.1), we detected good internal consistency for them all. This study is the first step to understand the complex relationship between the ecological and social systems applied to a fluvial basin: the Biobío River Basin.

It is well accepted worldwide that aquatic ecosystems are the most damaged and impacted ecosystems (e.g. Naiman and Dudgeon, 2011), with the consequent loss of biodiversity and the ability to supply ES to society (e.g. Cardinale et al., 2012). The Biobío Basin's aquatic biodiversity status has significantly worsened, as indicated by the growing number of threatened species encountered in recent years (See Fig. 1a). The current plans and programmes developed for biodiversity conservation in Chile (National Strategy for Biological Diversity) focus on the priority conservation of terrestrial areas. This fact, together with economic resources being scarce (Bovarnick et al., 2010; CEPAL/OCDE, 2016) and many institutions being responsible for conservation issues, make public administrations' responses to preserve aquatic biodiversity difficult and inefficient.

Our results show that most provisioning and regulating services have deteriorated in recent years (see Fig. 1b and c), as described in other studies (e.g., MEA, 2005, UK-NEA, 2011, S-NEA, 2014). In all cases, it is stressed that the responses offered by public administrations attempt to resolve the pressures (i.e. direct drivers of change) that alter the state of ecosystems and biodiversity loss, but not other underlying causes, which probably favour their effects (i.e. indirect drivers of change). However, the DPSIR framework does not incorporate any other actions and/or relationships to explain the deterioration of ecosystems: e.g., power relations between stakeholders, who provide the service and are beneficiaries of it; their interpretation of ES use (e.g. paying for environmental services); scale issues associated with ES management, where not all ES can be supplied at the same time (Barnaud and Antona, 2014). Despite us detecting reduced pressures (i.e. direct drivers) at the Biobío Basin in the last 10 years, regulating services will not stop their diminishing trend. In fact quite the opposite can be stated: indirect drivers show an increasing trend which has been broken only by the 2010 earthquake (Fig. 1h). This situation seems to indicate that indirect drivers are responsible for loss of regulatory services. Indeed the Biobío Basin has undergone significant demographic and socio-political changes in the last 45 years. Since the 1970s, a change in the economic and production system has taken place in Chile for it to join globalisation (Rodriguez and González, 2006). These changes involve the regionalisation of both the industry that concentrates near metropolitan areas and private investments in the primary sector (e.g. mining, forestry, agriculture and fisheries) (Rojas, 2015). At the Biobío Basin, these changes have implied major migration from rural areas to Concepción (the capital of the Biobío Region), boosted by forest industry development (Frêne and Nuñez, 2010). This migration has led to the productive activity of native Biobío Basin forests being abandoned, and the timber industry has expanded; between 1975 and 2000, native forest has reduced by 67% (Echeverria et al., 2006). One effect has been the basin's reduced natural mechanisms to regulate water flows (e.g. Lara et al., 2009, Little et al., 2009). Consequently, some ES have deteriorated (e.g. water regulation, erosion control and natural disturbances like floods), but also the survival of the native populations, who co-exist in harmony and cooperation with their environment, has also been jeopardised (according to Diaz et al., 2015).

We detected a strong increase in cultural services (Fig. 1d), probably due to the bias of the used indicators which were related more to urban populations (e.g. recreation activities, scientific knowledge) than to rural ones (e.g. cultural identity, local ecological knowledge).

Our study results also revealed a close positive link between the basic materials provided by the Biobío Basin and biodiversity loss, and a negative relationship between drivers and non-material HWB (Fig. 1). These relationships highlight the links between social and ecological systems, and allowed us to recognise the hydrological basin as a socio-ecosystem according to Ostrom (2009) (McGinnis and Ostrom, 2014). Moreover, the gap that we found between the material and non-material HWB dimensions implies worse quality of life for the Biobío Basin's human population. HWB firstly depends on provisioning services (e.g. water, food, etc.), but also on regulating services (e.g. air quality, water quality, etc.), cultural services (e.g. beautiful landscapes, recreation activities, etc.), and the activities of the different stakeholders that co-exist in the basin, which the model did not detect. There are many examples of the extent of the reciprocal relationship between humans and ecosystems beyond the ES framework's current conceptualisation that involve HWB. (e.g. Shepard and Ramírez 2011, Infante and Infante 2013, Valdés et al. 2014, Comberti et al., 2015). For example in Chile, the "Ingenious World Agricultural Heritage Systems" (SIPAM) are territories proposed for their preservation (e.g. Alto Biobío, Chiloé Archipelago) for their culture and wide-ranging ancestral social practices, beliefs and mythology, many of which are still in use (MMA 2014).

The institutional and legislative framework on water resources management in Chile is widely criticised (e.g. Castro, 2016) because, among other reasons, it has allowed water to be privatised. In fact Chile is the only country in Latin America where water resources management is based on market criteria, which has particularly favoured the hydroelectric sector at the Biobío Basin. This situation reinforces some of the DPSIR model results, which show how indirect drivers of change (economic in our case) are ultimately responsible for the degradation of ES, but also for lost quality of life for humans.

In Chile, the biophysical boundaries where the water cycle is generated (i.e. hydrological basin), the political-administrative jurisdiction that manages aquatic recourses (privatisation of water), and the social system that uses and consumes it, all mismatch (e.g. Fisher & Eastwood 2016). This leads to increasing social inequalities and poverty, and also to diminished cooperation among the beneficiaries of water resources. HWB also depends critically on the institutions that govern the relationships between individuals and human groups, and these with ES (Sarkki, 2017). Therefore, efforts to achieve sustainable basin management should focus on: the pressures of direct drivers, which have been incorporated into global development agendas; indirect pressures (Bennett et al., 2015); commitment to society, local ecosystem dynamics, and the plurality of the stakeholders involved in river basin activities. As Sarkki (2017) points out, it is not useful to evaluate only the results of environmental governance on HWB. Likewise, assessing

HWB as a simple result of the flow of services from nature to people would provide an incomplete view of the complex relationships linking governance, ES and HWB.

5.2. Beyond unidirectional nature-human relationships

Although the DPSIR analysis applied herein allowed us to visualise part of the relationships established between the Biobío Basin's social and ecological systems, other complex links are hidden for several reasons. Thus applying this model may be useful in places where the human population's cultural identity is relatively homogeneous (Fisher & Eastwood 2016), but does not incorporate the world view held by indigenous groups and traditional rural communities (i.e. human communities form part of the ecosystem) (Comberti et al., 2015). At the Biobío Basin, different cultural identities co-exist with distinct world views. For example, water for the Mapuche people is not only a vital element for human use, for animals or for irrigating plants (i.e. ES), but is a producer and giver of resources and/or a generator of other productive services and energetics. For the Mapuche world, water is the sap of the earth ("Through water we exist all living beings that are part of it") (Rumián, n.d.). This different world view has led to many social clashes (e.g. Azócar et al. 2002) that continue today, which today's current governance models fail to solve. Therefore, a new institutional framework that is more flexible and receptive to different social realities needs to be developed (Raymond et al., 2013).

We estimate that the DPSIR framework shows a corseted and reductionist vision of greater complexity than the merely unidirectional nature-human relationship (Polanco 2006). We believe that the DPSIR model has three major drawbacks for its generalised application: 1) it excludes the diversity of the human societies involved in the use and value of ES with their different world views and beliefs; 2) many complex relationships are hidden between the pressures suffered by ecosystems and HWB; 3) the reciprocal human and ecosystem relationship recognised by many authors (e.g. Comberti et al., 2015) is ignored.

However, the strength of the DPSIR method lies in its ability to visualise the interdependencies between the stakeholders that did not previously know they were interdependent. This is a necessary step towards collective learning, intercultural respect and coordinated action (Barnaud and Antona, 2014). To introduce other modalities of action into this methodological framework (i.e. responses) based on the market or the intervention of state institutions, and on local capacities to encourage co-production of services (Fisher and Eastwood, 2016), its sustainable management and collective action would help obtain a more realistic vision of the socio-ecosystems' complexity. It is necessary to continue exploring new methodological approaches to allow different socio-ecological dimensions of ecosystems to be included in the sustainable equitable management of natural resources.

Acknowledgements

This work has been subsidised by the FONDAP Project CHRIAM 1513001, CONICYT doctoral scholarship. Special thanks go to Helen Warburton for helping with the English corrections, who is a native English writer who has been registered in Inland Revenue's professional Epigraph 774 in the city of Valencia, since 28 October 2003, as a translator and English language editor). We sincerely thank the anonymous reviewers for their valuable comments.

References

AEMA. 1999. EEA Annual Work Programme. Copenhagen. https://www.eea.europa.eu/publications/corporate_document_1999_1 (accessed 17.04.12)

Azócar, G., Sanhueza, R., Aguayo, M., Valdés, C., 2002. Propiedad y ordenamiento territorial en áreas de desarrollo indígena: el caso del Alto Biobío. Capítulo VI / Ordenamiento Sustentable del territorio regional. Revista Ambiente y Desarrollo, VOL XVIII / Nº 2-3-4. http://cipmachile.com/web/200.75.6.169/RAD/2002/2-3-4_Azocar.pdf. (accessed 17.12.18)

Barnaud, C., Antona, M., 2014. Deconstructing ecosystem services: Uncertainties and controversies around a socially constructed concept. Geoforum. 56, 113-123. https://doi.org/10.1016/j.geoforum.2014.07.003

Bennett, E., Cramer, W., Begossi, A., Cundill, G., Díaz, S., Egoh, B. N., ... & Lebel, L., 2015. Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability. Curr. Opin. Environ. Sustain. 14, 76-85. http://dx.doi.org/10.1016/j.cosust.2015.03.007

Bizikova, L., 2011. Understanding the contribution of the environment to human well-being: a review of literature. International Institute for Sustainable Development, Winnipeg, Manitoba, Canada. http://www.iisd.org/pdf/2012/understanding_contribution_environment.pdf (accessed 17.04.02)

Bonet-García, F., Pérez-Luque, A., Moreno-Llorca, R., Pérez-Pérez, R., Puerta Piñero, C., Zamora, R., 2015. Protected areas as elicitors of human well-being in a developed region: a new synthetic (socioeconomic) approach. Biol. Conserv. 187, 221-229. https://doi.org/10.1016/j.biocon.2015.04.027

Bovarnick, A., Fernández-Baca, J., Galindo, J., Negret, H., 2010. Financial Sustainability of Protected Areas in Latin America and the Caribbean: Investment Policy Guidance. UNDP and TNC. http://bibliotecavirtual.minam.gob.pe/biam/bitstream/handle/minam/1308/BIV01080.pdf?sequence=5 (accessed 17.03.15)

Butler, C., Oluoch-Kosura, W., 2006. Linking Future Ecosystem Services and Future Human Well-being. Ecol. Soc. 11 (1), 30. http://www.ecologyandsociety.org/vol11/iss1/art30/

Cardinale, B., Emmett Duffy, J., Gonzalez, A., Hooper, D.U., Perrings, C., Venail, P., Narwani, A., Mace, G.M., Tilman, D., Wardle, D. A., Kinzig, A., Daily, G.C., Loreau, M., Grace, J.B., Larigauderie, A., Srivastava, D., Naeem, S., 2012. Loss of biodiversity and its impact on humanity. Nature 486, 59-67. http://dx.doi.org/10.1038/nature11148

Castro, C., 2016. Análisis de la incorporación de la gestión integrada de recursos hídricos en la legislación de aguas. Universidad de Chile, Facultad de Derecho. Tesis para optar al grado de Magister en Derecho Ambiental. 98 pp. http://repositorio.uchile.cl/bitstream/handle/2250/138812/An%C3%A1lisis-de-la-incorporaci%C3%B3n-de-la-gesti%C3%B3n-integrada-de-recursos-h%C3%ADbricos.pdf?sequence=1 (accessed 17.05.12)

CEPAL/OCDE. Comisión Económica para América Latina y el Caribe (CEPAL)/Organización para la Cooperación y el Desarrollo Económico (OCDE). 2016. Evaluaciones del desempeño ambiental: Chile 2016, Santiago. http://repositorio.cepal.org/bitstream/handle/11362/40308/S1600413_es.pdf (accessed 17.05.12)

Comberti, C., Thornton, T.F., Wyllie de Echeverria, V., Patterson, T., 2015. Ecosystem services or services to ecosystems? Valuing cultivation and reciprocal relationships between humans and ecosystems. Global Environ. Chang. 34, 247-262. http://dx.doi.org/10.1016/j.gloenvcha.2015.07.007

Cook, G., Fletcher, P., Kelble, C., 2013. Towards marine ecosystem based management in South Florida: Investigating the connections among ecosystem pressures, states, and services in a complex coastal system. Ecol. Indic. 44, 26-39. https://doi.org/10.1016/j.ecolind.2013.10.026

Cronbach, L.J., 1947. Test reliability: its meaning and determination. Psychometrika, 12, 1-16.

De Juan S., Gelcich, S., Ospina-Álvarez, A., Pérez-Matus, A., Fernández, M., 2015. Applying an ecosystem service approach to unravel links between ecosystems and society in the coast of central Chile. Sci. Total Environ. 533, 122-132. http://dx.doi.org/10.1016/j.scitotenv.2015.06.094

Delgado, L., Marin, V.H., 2016. Well-being and the use of ecosystem services by rural households of the Río Cruces watershed, southern Chile. Ecosyst. Serv. 21, 81-91. https://doi.org/10.1016/j.ecoser.2016.07.017

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., Larigauderie, A., et al., 2015. The IPBES Conceptual Framework — connecting nature and people. Curr. Opin. Environ. Sustainable 14, 1-16. http://dx.doi.org/10.1016/j.cosust.2014.11.002

Echeverría C., David, C., Salas, J., 2006. Rapid deforestation and fragmentation of Chilean Temperate Forests. Biol. Conserv. 130, 481-494.

EEA, 1995. Europe’s Environment: The Dobris Assessment. European Environment Agency, Copenhagen, pp. 293.

Felipe-Lucía, M., Comín, F.A., Escalera-Reyes, J., 2014. A framework for the social valuation of ecosystem services. Ambio 44(4), 308-318. http://dx.doi.org/10.1007/s13280-014-0555-2.

Figueroa, R., Bonada, N., Guevara, M., Pedreros, P., Correa-Araneda, F., Díaz, M.E., Ruiz, V.H., 2013. Freshwater biodiversity and conservation in Mediterranean climate streams of Chile. Hydrobiologia, 719, 269-289. http://dx.doi.org/10.1007/s10750-013-1685-4

Fischer, A., Eastwood, A., 2016. Coproduction of ecosystem services as human–nature interactions—An analytical framework. Land Use Policy 52, 41-50. http://dx.doi.org/10.1016/j.landusepol.2015.12.004

Floridi, M., Pagni, S., Falorni, S., Luzzati, T., 2011. An exercise in composite indicators construction: assessing the sustainability of Italian regions. Ecol. Econ. 70, 1440–1447. https://doi.org/10.1016/j.ecolecon.2011.03.003

Frêne, C., Núñez, M., 2010. Hacia un nuevo Modelo Forestal en Chile. REVISTA Bosque Nativo 47, 25-35.

George, D., Mallery, P., 2003. SPSS for Windows Step by Step: A Simple Guide and Reference. 11.0 Update. 4th Edition, Allyn & Bacon, Boston.

Grant, F., Young, J., Harrison, P., Sykes, M., Skourtos, M., Rounsevell, M., Kluva Nkova-Oravska, T., Settele, J., Musche, M., Anton, C., Watt, A., 2008. Ecosystem Services and Drivers of Biodiversity Change. Report of the RUBICODE. Chapter: Approaches to ecosystem service assessment in forest ecosystems (Sandra Luque), Publisher: Funded under the European Commission Sixth Framework Programme https://www.researchgate.net/publication/235972929_Ecosystem_Services_and_Drivers_of_Biodiversity_Change (accessed 17.05.13)

Hossain, M.S., Pogue, S.J., Trenchard, L., Van Oudenhoven, A.P.E., Washbourne, C.-L., Muiruri, E.W., Tomczyk, A.M., García-Llorente, M., Hale, R., Hevia, V., Adams, T., Tavallali, L., De Bell, S.,

Infante, A., Infante, F., 2013. Percepciones y estrategias de los campesinos del secano para mitigar el deterioro ambiental y los efectos del cambio climático en Chile. Agroecología 8(1), 71-78.

Ives, C.D., Giusti, M., Fischer, J., Abson, D.J., Klaniecki, K., Dorninger, C., Laudan, J., Barthel, S., Abernethy, P., Martín-López, B., Raymond, C.M., Kendal, D., von Wehrden, H., 2017. Human–nature connection: a multidisciplinary review. Curr. Opin. Environ. Sustainability, 26–27, 106-113. http://dx.doi.org/10.1016/j.cosust.2017.05.005

Kelble, C.R., Loomis, D.K., Lovelace, S., Nuttle, W.K., Ortner, P.B., Fletcher, P., Cook, G., Lorenz, J., Boyer, J., 2013. The EBM-DPSER Conceptual Model: Integrating Ecosystem Services into the DPSIR Framework. PLoS ONE 8(8), e70766. https://doi.org/10.1371/journal.pone.0070766

Kull, C.A., Arnauld de Sartre, X., Castro-Larrañaga, M., 2015. The political ecology of ecosystem services. Geoforum, 61, 122-134. https://doi.org/10.1016/j.geoforum.2015.03.004

Lara, A., Little, C., Urrutia, R., McPhee, J., Alvarez-Garreton, C., Oyarzun, C., Soto, D., Donoso, P., Nahuelhual, L., Pino, M., Arismendi, I., 2009. Assessment of ecosystem services as an opportunity for the conservation and management of native forests in Chile. Forest Ecol. Manag. 258, 415-424. https://doi.org/10.1016/j.foreco.2009.01.004

Layke, C., Mapendembeb, A., Brown, C., Walpole, M., Winnb, J., 2012. Indicators from the global and sub-global Millennium ecosystem assessments: an analysis and next steps. Ecol. Indic. 17, 77–87. https://doi.org/10.1016/j.ecolind.2011.04.025

Little, C., Lara, A., McPhee, J., Urrutia, R., 2009. Revealing the impact of forest exotic plantations on water yield in large scale watersheds in South-Central Chile. J. Hydrol. 374, 162-170. https://doi.org/10.1016/j.jhydrol.2009.06.011

Liu, J., Dietz, T., Carpenter, S.R., Alberti, M., Folke, C., Moran, E., Pell, A.N., Deadman, P., Kratz, T., Lubchenco, J., Ostrom, E., Ouyang, Z., Provencher, W., Redman, C.L., Schneider, S.H., Taylor, W.W., 2007. Complexity of coupled human and natural systems. Science 317, 1513–1516. https://doi.org/10.1126/science.1144004

Malekmohammadi, B., Jahanishakib, F., 2017. Vulnerability assessment of wetland landscape ecosystem services using driver-pressure-state-impact-response (DPSIR) model. Ecol. Indic. 82, 293–303. http://dx.doi.org/10.1016/j.ecolind.2017.06.060

Martín-López, B., Gómez-Baggethun, E., Lomas, P.l., Montes, C., 2009. Effects of spatial and temporal scales on cultural services valuation. J. Environ. Manage. 90, 1050–1059. https://doi.org/10.1016/j.jenvman.2008.03.013

Martín-López, B., Montes, C., 2011. Los sistemas socio-ecológicos: entendiendo las relaciones entre la biodiversidad y el bienestar humano. Biodiversidad y servicios de los ecosistemas. Biodiversidad en España: base de la sostenibilidad ante el cambio global. Observatorio de la Sostenibilidad en España (OSE) 6 (1), 444-465. https://www.uam.es/gruposinv/socioeco/documentos/Martin-Lopez%20y%20Montes_OSE.pdf. (accessed 17.05.12)

Martín-López, B., Iniesta-Arandia, I., García-Llorente, M… Montes, C., 2012. Uncovering Ecosystem Service Bundles through Social Preferences. PLoS ONE **7**, e38970. https://doi.org/10.1371/journal.pone.0038970

McGinnis, M. D., and E. Ostrom. 2014. Social-ecological system framework: initial changes and continuing challenges. Ecol. Soc. 19(2), 30. http://dx.doi.org/10.5751/ES-06387-190230

MEA, Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-Being: Our Human Planet: Summary for Decision Makers. Island Press. http://www.millenniumassessment.org/documents/document.356.aspx.pdf (accessed 17.04.12)

Ministerio de Desarrollo Social. 2017. Encuesta de caracterización socioeconómica nacional. Pueblos indígenas. Síntesis de resultados. Casen-2915. http://observatorio.ministeriodesarrollosocial.gob.cl/casen-multidimensional/casen/docs/CASEN_2015_Resultados_pueblos_indigenas.pdf (accessed 17.12.03)

Ministerio de Salud. 2012. Primer Informe de registros poblacionales de cáncer de Chile. Quinquenio 2003-2007. http://www.paho.org/chi/index.php?option=com_docman&view=download&alias=174-informe-rpc-chile-2003-2007&category_slug=cancer&Itemid=1145. (accessed 17.09.19).

Mittermeier, R., Gil, P., Hoffmann, M., Pilgrim, J., Brooks, T., Mittermeier, C.G., Lamoreux, J., Fonseca, G., 2004. Hotspots revisited: Earth's biologically wealthiest and most threatened ecosystems. CEMEX, México DF, México.

MMA, Ministerio del Medio Ambiente. 2014. Quinto Informe Nacional de Biodiversidad de Chile, Elaborado en el marco del Convenio sobre la Diversidad Biológica. http://portal.mma.gob.cl/wp-content/uploads/2015/01/Libro_Convenio_sobre_diversidad_Biologica.pdf (accessed 17.04.12)

Naiman, R., Dudgeon, D., 2011. Global alteration of freshwaters: Influences on human and environmental well-being. Ecol. Res. 26 (5), 865-873. http://dx.doi.org/10.1007/s11284-010-0693-3

Nelson, G.C., Bennett, E., Berhe, A.A., Cassman, K., Defries, R., Dietz, T., Dobermann, A., Dobson, A., Janetos, A., Levy, M., Marco, D., Nakicenovic, N., O'neill, B., Norgaard, R., Petschel-Held, G., Ojima, D., Pingali, P., Watson, R., Zurek, M., 2006. Anthropogenic drivers of ecosystem change: an overview. Ecol. Soc. 11, 29. http://www.ecologyandsociety.org/vol11/iss2/art29

Ostrom, E., 2009. A general framework for analyzing sustainability of social– ecological systems. Science 325, 419–422. http://dx.doi.org/10.1126/science.1172133

Parra, O., Figueroa, R., Valdovinos, C., Habit, E., Díaz, M.E., 2013. Programa de monitoreo de la calidad del agua del sistema Río Biobío 1994-2012: Aplicación del Anteproyecto de Norma Secundaria de la Calidad Ambiental (NSCA) del río Biobío. Editorial Universidad de Concepción, Chile.

Pert, P.L., Butler, J.R.A., Brodie, J.E., Bruce, C., Honzák, M., Kroon, F.J., Metcalfe, D., Mitchell, D., Wong, G., 2010.A catchment-based approach to mapping hydrological ecosystem services using riparian habitat: a case study from the Wet Tropics, Australia. Ecol. Complexity 7, 378-388.

Pinto, R., De Jonge, V.N., Marques, J.C., 2014. Linking biodiversity indicators, ecosystem functioning, provision of services and human well-being in estuarine systems: application of a conceptual framework. Ecol. Indic. 36, 644–655, http://dx.doi.org/10.1016/j.ecolind.2013.09.015.

Polanco, C., 2006. Indicadores ambientales y modelos internacionales para la toma de decisiones. Revista Gestión y Ambiente 9, 27-41. http://www.redalyc.org/articulo.oa?id=169420986007

Rapport, D., Friend, A., 1979. Towards a comprehensive framework for environmental statistics: a stress–response approach. In: Statistics Canada Catalogue 11-510. Minister of Supply and Services Canada, Ottawa.

Raymond, C.M., Singh, G.G., Benessaiah, K., Bernhardt, J.R., Levine, J., Nelson, H., Turner, N.J., Norton, B., Tam, J., Chan, K.M., 2013. Ecosystem services and beyond: Using multiple metaphors to understand human–environment relationships. BioScience 63, 536-546. https://doi.org/10.1525/bio.2013.63.7.7

Rodríguez, J., González, D., 2006. Redistribución de la población y migración interna en Chile: continuidad y cambio según los últimos cuatro censos nacionales de población y vivienda. CEPAL-CELADE. Rev. geogr. Norte Gd. N°35, 7-28. http://dx.doi.org/10.4067/S0718-34022006000100002

Rojas, P., 2015. Tendencias migratorias en el Gran Concepción durante la segunda mitad del siglo XX. Memoria para optar al título de Geógrafa. Universidad de Chile. http://repositorio.uchile.cl/bitstream/handle/2250/134313/tendencias-migratorias-en-el-gran-Concepcion.pdf?sequence=1 (Accessed 17.09.25)

Rumián, P., n.d. Desde la cosmovisión Mapuche: el agua de la mapu está en grave peligro. http://www.futawillimapu.org/pub/NgenKo.pdf (Accessed 17.12.03)

Russell, R., Guerry, A.D., Balvanera, P., Gould, R.K., Basurto, X., Chan, K.M.A., Klain, S., Levine, J., Tam, J., 2013. Humans and nature: how knowing and experiencing nature affect well-being. Ann. Rev. Environ. Res. 38, 473-502. https://doi.org/10.1146/annurev-environ-012312-110838

Santos-Martín, F., Martín-López, B., García-Llorente, M., Aguado, M., Benayas, J., Montes, C., 2013. Unraveling the relationships between ecosystems and human wellbeing in Spain. PLOS ONE 8 (9), e73249, http://dx.doi.org/10.1371/journal.-pone.0073249.

Sarkki, S., 2017. Governance services: Co-producing human well-being with ecosystem services. Ecosyst. Serv. 27, 82-91. http://dx.doi.org/10.1016/j.ecoser.2017.08.003

Shepard Jr, G.H., Ramirez, H., 2011. Made in Brazil: human dispersal of the Brazil nut (*Bertholletia excelsa*, Lecythidaceae) in Ancient Amazonia. Econ. Bot. 65 (1), 44-65.

Smith, L., Case, J., Smith, H., Harwell, L., Summers, J., 2013. Relating ecosystem services to domains of human well-being: foundation for a US. Ecol. Indic. 28, 79–90. http://dx.doi.org/10.1016/j.ecolind. 2012.02.032

S-NEA (Spanish National Ecosystem Assessment), 2014. Ecosystems and Biodiversity for Human Wellbeing. Synthesis of the Key Findings. Spanish Ministry of Agriculture, Food and Environment, Madrid. Available at: http://www.ecomilenio.es

Song, X., Frostell, B., 2012. The DPSIR Framework and a Pressure-Oriented Wated Quality Monitoring Approach to Ecological River Restoration. Water 4, 670-682. http://dx.doi.org/10.3390/w4030670

SPSS IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp. https://www-01.ibm.com/support/docview.wss?uid=swg21646821 (accessed 17.02.10)

Tadaki, M., Allen, W., Sinner, J., 2015. Revealing ecological processes or imposing social rationalities? The politics of bounding and measuring ecosystem services. Ecol. Econ. 118, 168-176. https://doi.org/10.1016/j.ecolecon.2015.07.015

UK NEA, 2011. The UK National Ecosystem Assessment Technical Report. UNEP-WCMC, Cambridge.

Valdés, J., Meza, J., Ortiz, H., 2014. El desarrollo de la agricultura familiar campesina a través de la forestería comunitaria. In: Agricultura Familiar en América Latina y el Caribe: Recomendaciones de Política. 191-214. FAO, Santiago, Chile. http://www.fao.org/docrep/019/i3788s/i3788s.pdf

Valdovinos, C., Parra, O. 2006. La cuenca del río Biobío: Historia Natural de un ecosistema de uso múltiple. Publicaciones Centro-Eula. http://www.eula.cl/images/stories/documentos/3.pdf. (accessed 17.05.20).

Vidal-Abarca, M.R., Suárez Alonso, M.L., Santos-Martín, F., Martín-López, B., Benayas, J., Montes, C., 2014. Understanding complex links between fluvial ecosystems and social indicators in Spain: an ecosystem services approach. Ecol. Complexity, 20, 1–10. https://doi.org/10.1016/j.ecocom.2014.07.002

Legends

Table 1: Trends of the indicators used to analyse the supply of ecosystem services, human well-being, pressures and drivers, and the response indicators developed by institutions for water resource conservation at the Biobío Basin.

SERVICE//CLASS	SUBTYPE	INDICATOR	Slope	TREND
ECOSYSTEM SERVICES				
PROVISIONING SERVICES				
Food	Artisanal fisheries	Harvesting of fish, shellfish and algae by artisanal fishing	0.21	↑↑
	Aquaculture	Harvesting of fish, seafood and algae in aquaculture centers	0.05	↑
Freshwater	Water supply	Water for human consumption	0.004	↔
		Water for industry consumption	-0.29	↓↓
Mineral raw materials	Gravel/sand	Sand and gravel companies	-0.05	↓
		Sand and gravel production	0.08	↑↑
Renewable energy	Hydropower	Total production of hydropower	0.06	↑
Genetic resources		Species in “danger” category	0.16	↑↑
REGULATING SERVICES				
Climate regulation/ Air quality	Carbon storage	Loss of CO_2 from forest fires	0.02	↔
		Forest area burned by fire	0.03	↔
Water regulation	Water regulation	Volume of reservoirs	-0.05	↓
		Flow	-0.02	↔
	Self-purification	Volumes of wastewater generated	0.25	↑↑
		Volumes of treated wastewater	0.80	↑↑
	Water quality	Nitrite concentration in the river	-0.03	↔
		Nitrate concentration in the river	0.20	↑↑
		Phosphorous concentration in the river	0.02	↔
		BOD_5	-0.07	↓
		O_2	0.09	↑↑
Regulation of disturbances		Number of people affected by flood events	-0.02	↔
Morphosedimentary regulation		Native forests	-0.21	↓↓
		Forest plantations	0.20	↑↑
CULTURAL SERVICES				
Landscape aesthetic service		Number of National Reserves	0.21	↑↑
Recreation and ecotourism		Visitors to National Reserves	0.19	↑↑
		Visitors to National Parks	0.21	↑↑
Cultural identity		Evolution Urban population	0.22	↑↑
		Evolution Rural population	-0.18	↓↓
Scientific knowledge		Number of PhD Theses on water	-0.01	↔
		Number of Scientific Projects on water	0.08	↑
Local ecological knowledge		Rural v/s Urban	-0.20	↓↓
HUMAN WELL-BEING				
BASIC MATERALS				
Access to goods		Water consumption	0.14	↑↑
		Agricultural production	0.08	↑
NON-BASIC MATERIALS				
Health	Diseases related to water	Food outbreak reports	0.27	↑↑
		Number of food diseases	-0.41	↓↓
		Nutritional diseases	0.13	↑↑
		Stomach tumor	0.11	↑↑
		Colon tumor	0.22	↑↑
		Other digestive diseases	0.22	↑↑
Freedom of choice and action	Forced actions	Families displaced by dam construction	0.11	↑↑
		People displaced by hydroelectric stations	0.10	↑↑

Security	Natural hazards	Floods victims	0.07	↑
PRESSURES (DIRECT DRIVERS OF CHANGE)				
Climate change		Precipitation	-0.04	↓
		Temperature	0.04	↑
		Nº Floods	0.13	↑↑
Land use change		Sown surface	0.25	↑↑
		Irrigated surface	-0.19	↓↓
Overexploitation		Ground water use	-0.38	↓↓
		Reservoir volume	-0.03	↔
Pollution		Class 4 water quality	-0.28	↓↓
		Wastewater generated	0.29	↑↑
		Sludge production	0.74	↑↑
		Use of pesticides	0.19	↑↑
DRIVERS (INDIRECT DRIVERS OF CHANGE)				
Demographic		Population of the basin	0.14	↑↑
Economic		Investment in potable water	0.21	↑↑
		Investment in sewerage	0.04	↑
		Investment in wastewater treated	0.03	↔
Socio-political		Number of women in public positions	0.60	↑↑
Cultural		Population >60 years of age	0.19	↑↑
RESPONSES				
Biological conservation	Biodiversity conservation	Number of projects on aquatic ecosystems	0.04	↑
		Investment in projects on aquatic ecosystems	-0.08	↓
Water conservation	Water quality	Water coverage	0.27	↑↑
		Treatment plants	0.34	↑↑
Water governance		Environmental complaints	0.95	↑↑
Marketing initiatives	Agricultural production	Organic agriculture	-0.08	↓

Figure 1: Aggregate indices of all the DPSIR model components. The Y-axis represents the arithmetic mean of the temporal series of all the standardised indicators. The colour shade behind the graph corresponds to the variability and level of uncertainty of trends. Arrows represent Spearman correlations and significance ($p < 0.1$ (*); $p < 0.05$ (**) and $p < 0.01$ (***)) among the different DPSIR framework components. For each component, a Cronbach's alpha value is indicated, which corresponds to the consistency level of the indicators for each dimension.