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Multicriteria spatial analysis applied to identifying ecosystem services in mixed-use river catchment areas in south central Chile

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Abstract

Background: The flow of goods and services occurring in catchment areas allows the production of a series of ecosystem services. These have a direct impact on the inhabitants of the territory, who in turn recognise and value ecosystems (social value) as a function of the benefits which they generate. This has a direct impact on public policies that contribute to the development of local economies. The present study therefore sought to identify and recognize the social value of the various ecosystem services provided by a mixed-use catchment area in which different productive activities are concentrated. This study examined the social value of ecosystem services and offers qualitative or quantitative, non-monetary estimates of the relative importance of different benefits for human society derived from the functioning of ecosystems (Laterra et al, Valoración de Servicios Ecosistémicos, Conceptos, herramientas y aplicaciones para el ordenamiento territorial, 2011). The methodology involved the participation of leading actors in the territory, and a panel of experts who defined criteria and weighting which were applied to a multicriteria spatial model. They assigned ordinal scale to the territory representing levels of appreciation based on the various ecosystem services in the ecological, productive, landscape and cultural dimensions. The results showed that the inhabitants of the territory recognise the ecosystem benefit of areas covered by native forest, in particular the species *Nothofagus dombeyi* (Mirb.) Oerst., in contrast to areas used for farm production. The functioning of the ecosystem is recognised, and particularly its contribution to regulating water flows and to water production and quality.

Results: The study results showed that areas covered with secondary forest of *N. dombeyi* provide a variety of ecosystem functions which support the creation of ecosystem services to the population, especially in riparian areas throughout the basin where they are important for water production and quality. ES ponderations for provision, regulation and cultural showed that the native forest and riparian units (HEU 1 and HEU 6) as a very important group in relation to the ES because there are recognized by the local society ($P < 0.05$). The leading actors assigned a low social value to other land-uses, like mixed use and farmland, because of the high degree of anthropisation of these ecosystems; this viewpoint has generated conflicts in the territory. Neither foresters nor farmers recognise or accept the impacts of their activities on the various ecosystem services provided by the territories where they operate, even though they are leading actors for the development of local economies.

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Conclusion: The participation of the leading actors of a territory, represented spatially in a multicriteria analysis model, highlighted the social value of the ecosystems present in a hydrographic catchment area which supports different productive and conservation activities. The model contributed to understanding of the functional processes which generate goods and services present in the physical medium. The study used a hybrid method which included definition of homogeneous environmental units and multicriteria and multivariate statistical analysis. This allowed the information provided by the actors in the territory to be analysed with different spatial scales, levels of perception and elements of territorial planning which contribute to the generation of public policies and the sustainable management and conservation of natural ecosystems.

Keywords: Coihue, Water quality, Goods and services, Sub-catchment areas, Riparian areas

Background

Natural systems provide numerous goods and services to human society, supporting human welfare and economic prosperity (MEA 2005). Among these goods and services are food production, regulation of the climate, water regulation, etc. (de Groot et al. 2002). Broadly speaking, Ecosystem Services (ES) are the conditions and processes through which natural ecosystems help to sustain human life (Daily 1997). Costanza et al. (1997) define them as those benefits which human populations receive directly or indirectly from ecosystem functions, defined as a set of ecological processes in the structure of an ecosystem (de Groot et al. 2002). Therefore the production of an ES will depend on the structure and processes of an ecosystem; any factor which has an impact on the ecosystem will affect its processes as well as the flow of benefits generated by the ecosystem for society (Costanza et al. 1997; Daily 1997; de Groot et al. 2002; Esse et al. 2014).

In Chile, the current conceptual framework defined by the Environment Ministry (MMA) establishes a classification of ES based on Haines-Yong and Potschin (2013) and Haines-Young and Potschin (2018), who divide these services into: 1) support, intermediate and final services provided by the environment, and 2) the goods and benefits of the economic and social system. Thus we may say that ecosystems are the basic functional units of the ecology, in which we can recognise the constant interaction between biotic and abiotic components (Odum 2004). Ecosystem studies concentrate on describing biological phenomena from a systemic perspective. They involve the three variables which allow these ecological units to function, namely energy flows, nutrient cycles and biomass generation (Rees 2018).

Starting from the conceptual framework proposed by the Millennium Ecosystem Assessment (MEA 2005), a more explicit link has been established between how a service is provided and how society benefits from it (ecological and economic integration of ecosystems), relating function and ES with the benefit to society.

MEA (2005) classifies ecosystem goods and services into four categories: (1) Provision: associated with tangible goods or products obtained from ecosystems; (2) Regulation: benefits obtained from the regulation of complex ecosystem processes by which environmental conditions are regulated; (3) Cultural: immaterial benefits obtained from ecosystems; and (4) Support: basic ecological processes to ensure proper ecosystem functioning and the flow of provision, regulation and cultural services. Other classifications exist, such as those proposed by Boyd and Banzhaf (2007), Wallace (2007), Fisher and Turner (2008) and TEEB (2010); they differ in the breadth and complexity of their approaches.

In geographical space, where the processes which generate the various ES occur, the territorial dimension is an integrating element which must be carefully studied (Zasada et al. 2017). Sánchez (2009) stresses the importance of territory, due to the endogenous capacity of actors to establish connections and flows, both material and immaterial; linking those involved who are inserted in different and sometimes distant territorial scales. Thus the spatial representation of ES in the territory allows the public resources and policies for safeguarding these services to be properly directed (Esse et al. 2014). Citizen participation is a key aspect; it must be considered when ES are being identified (Verburg et al. 2016), since the inclusion of local actors allows respect for their identity and other aspects which are unlikely to be recognised. Little attention is usually paid to this aspect in policy planning and drafting (Braat and de Groot 2012), where the tendency all over the world is towards the 'upscaling' model (Larsen et al. 2012), using results as the basis for larger-scale policies, for example at national level. In citizen participation processes, the leading actors in the territory possess more information on the flow of goods and services produced in the environment where they carry on their own productive activities (Costanza and Shuang 2014); their perception does not always coincide with that of specialists and researchers, who seek to understand the flow of goods and services by establishing

a conceptual model (Hermelingmeier and Nicholas 2017) which excludes the knowledge of those who live in the territory. This needs to be corrected to achieve greater accuracy and knowledge about ecosystem production derived from the physical medium (Peterson et al. 2018), as occurs when the functioning of native forest is compared with that of forestry plantations.

In the mid-nineteenth century, the forest landscape of Chile underwent a major transformation due to the felling and burning of vast expanses of native forest to clear land for arable and livestock farming (Donoso and Otero 2005; Otero 2006). A hundred years later, the industrial forestry sector was promoted by the passing of the Forest Law and Decree Law No. 701, the object of which was to regulate the felling of native forest and provide incentives for the recovery of degraded soils by installing plantations of fast-growing exotic species (Otero 2006). As a result, there is now growing discussion in south central Chile about the forestry industry and the replacement of large expanses of native forest to promote farming production (Miranda et al. 2015), and the possible impact that this has on ecosystem functioning in river catchment areas, and especially on the services associated with water production and quality (Oyarzún et al. 1997; Soto 2002; Naiman et al. 2005; Richardson et al. 2007; Lara et al. 2009; Little et al. 2009; De los Ríos Escalante et al. 2017). This situation has led the inhabitants of these basins to assert their agreement with criteria for the conservation and preservation of native forest; they are supported by Law 20.283, which regulates the recovery of native forest and promotion of the forestry industry, in order to avoid restrictions on the production of forest goods and services and damage to the potential development of local economies.

In view of the above, our purpose was to assess the social value assigned by important actors in the territory to the production of goods and services by secondary *N. dombeyi* forests in a catchment area with multiple land-use. We expected to find significant recognition by important actors of the production of goods and services by *N. dombeyi* forests as compared to other land-uses. The object of the present study was therefore to identify and analyse the social value of ES, considering different levels of perception in a catchment area which supports a variety of forestry and farming activities. We hope that the results will help in the drafting of public policies to regulate activities in the territory, contributing an easily-applied methodology for including the perceptions of the territory's inhabitants and leading actors.

Materials and methods

Study area

The study catchment area is part of the upper Quepe River basin, located in the precordillera zone of south

central Chile (38°40' S – 71°45' W). The annual precipitation in the area varies between 2300 and 2400 mm (Di Castri and Hajek 1976; Luebert and Plissock 2006). The climate is wet warm-temperate with mediterranean influence lower down, and wet cold-temperate with mediterranean influence on the high ground; temperatures are relatively low throughout the year (Luebert and Plissock 2006). The soil is deep, well-drained silt-loam with nil to slight erosion over the whole area (CIREN 2002). The basin presents sectors under various types of land-use (Fig. 1) including: (1) commercial forest consisting mainly of secondary forests of *N. dombeyi* at the top of the basin; (2) mixed use in the middle sector, consisting of forestry plantations, native forest and pasture; and (3) farm use in the lower sector, in areas used almost exclusively for agricultural production.

Definition of homogeneous environmental units (HEUs)

This methodology is an adaptation of the method proposed by Esse et al. (2014). It was applied in the study area to identify ES provided by the catchment area in general, and to validate the application of the method. The HEUs in which land-uses occur over continuous areas were identified, considering them as territorial units with uniform behaviour in situations of various possibilities dictated by the ecological, cultural, productive and landscape dimensions of the territory (Gómez-Orea 1999). The HEUs were defined through classification by a panel of experts, which was then corrected and validated by leading actors in the territory. This allowed the social perception of the inhabitants to be incorporated, generating spaces for participation and giving the territory an identity. The second stage, once the HEUs had been defined, was the identification of ecosystem services. We used the list of services proposed by the MMA, which is based on Haines-Yong and Potschin (2013) and recognises the different services associated with provision, regulation and culture, the groups which explain the ecosystem functioning of the territory (Table 1). The present study, unlike Esse et al. (2014), included riparian areas as an important HEU; it also included multivariate analysis, a larger number of participants in the workshops, and analysis of the specific ES for different land-uses present in the catchment area, especially areas covered by *N. dombeyi* secondary forest.

The leading actors for the territory were selected by analysis of social networks following Delgado-Aguilar et al. (2017). The technique used was participative mapping, in the following stages: (a) formation of random groups of three or four people; (b) assignation of a map of the study area to each group; (c) giving a list of coded ES to each member of the groups; (d) receiving the reply form in order to draw up a table of frequencies with five classes, which was then analysed by multivalent statistical

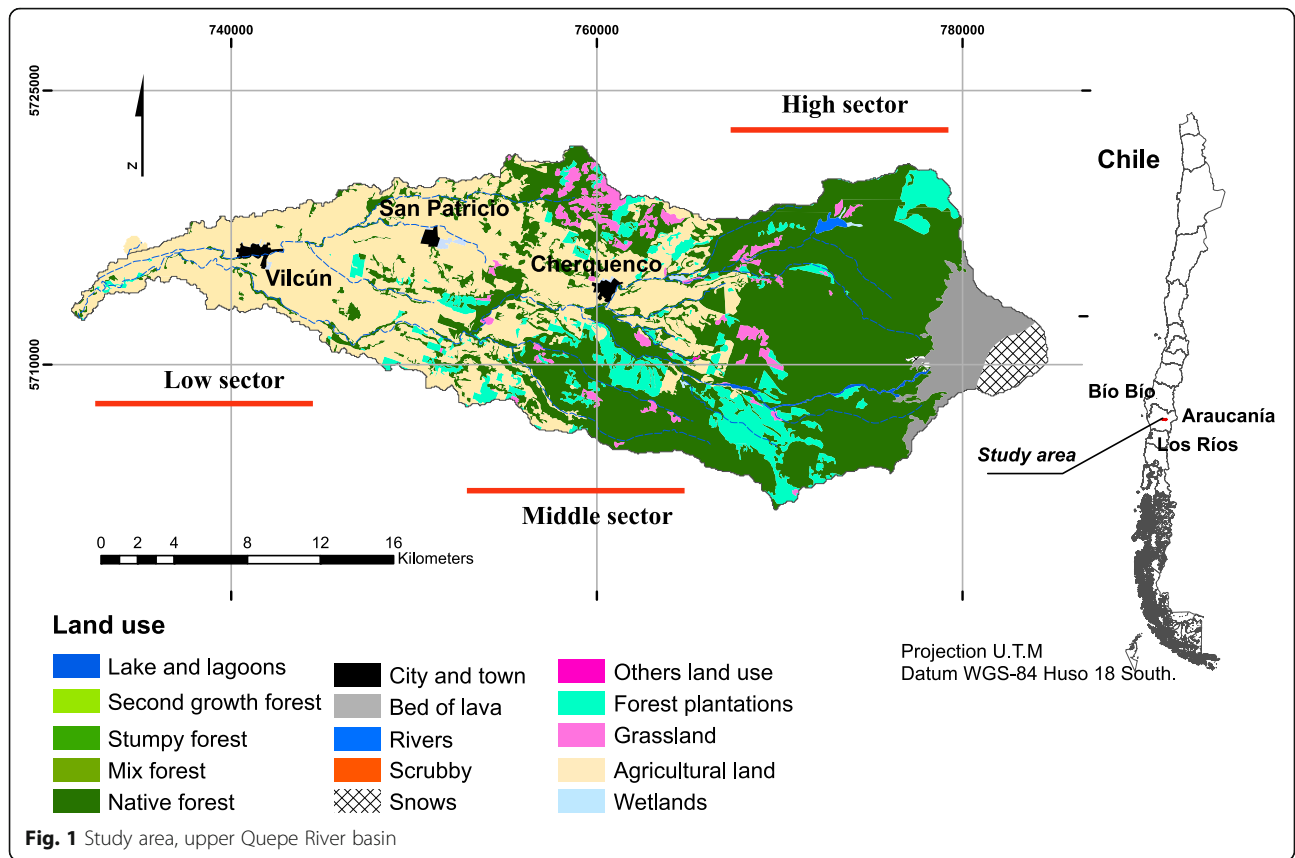


Fig. 1 Study area, upper Quepe River basin

methods. The actors assigned ES to different HEUs individually to avoid bias in the replies.

Construction of the multicriteria spatial model (MSM)

The frequency table was subjected to multivariate principal component analysis (Quinn and Keough 2002). This allowed the most important variables to be selected and the number of variables reduced. Selection of the variables was based on the 70 percentile applied to the contributions of the weighted observations on the factorial axes selected. The object of this was to provide an objective weighting rule based on the recorded frequency, generating a spatial expression of the perception of the leading actors for each of the ecosystem service groups. The model used was a weighted linear equation for each group of services (1).

$$MSM-G_{SE} = \sum_{i=1}^n SE_i \times P_i \tag{1}$$

where $MSM-G_{SE}$ corresponds to the social value or level of importance of the ES according to the assessment of the important actors in the territory; SE_i is the ES selected from the 70 percentile; and P_i is the value of

the contributions of the weighted observations on the factorial axes (2).

$$P_i = \sum_{i=1}^n (f_i \times 100 / f_i) \tag{2}$$

where f_i is the frequency value of the ES on the 70 percentile validated by the panel of experts.

Non-metric multidimensional scaling (nMDS) was used to distinguish similar groups of HEUs. In addition, a hierarchical agglomerative clustering analysis was performed applying Single linkage and using Euclidean distance. To identify the groupings objectively, the SIMPROF test was carried out (Clarke et al. 2014). It was established whether the ecosystem services in a study unit, as a whole, differ between sites (ANOSIM). The services which contributed to the differences in HEU composition between study units were analysed by similarity percentage analysis (SIMPER).

ArcGIS v10.6 software was used for the spatial analysis, and the cartographical bases in vector and raster format were taken from Catastro de los Recursos Vegetacionales de Chile [Register of the Native Vegetation Resources of Chile] (CONAF 2013). The statistical analyses were done using the R software in the *factoextra* (Kassambara and Mundt 2017) and *ggplot2* (Wickham 2009) packages.

Table 1 Groups of ecosystem services defined by the Environment Ministry (MMA), Chile

Code	Provision Ecosystem Services
APR	Rural Drinking Water
APU	Urban Drinking Water
RIE	Irrigation
PRI	Industrial processes
PDV	Sport fishing
PAR	Artisanal fishing
PIN	Industrial fishing
ACUI	Aquaculture
HCU	Hydrocultures
JAN	Energy (hydroelectric, biomass and geothermal - in process)
ARD	Sand and gravel
PLM	Medicinal plants
TRA	Transport
APS	Pasture, livestock (watering points, summer grazing, dairies)
MAD	Wood
ALG	Algae (micro and macro)
AMI	Mineral water (in process)
FLO	Flora (except algae)
FAU	Fauna
ABA	Hot mineral water and mud
PSE	Seed production
AMA	Management areas (natural banks)
HAT	Hatcheries (in process)
ART	Handicrafts and weaving
PFNM	Non wood forest products
PURI	Slurry and dung
Code	Regulation Ecosystem Services
DDC	Elimination of dilution with non-organic pollutants
RCO	Regulation of organic pollution
RCT	Regulation of thermal pollution
RCL	Climate regulation (micro and macro)
RSE	Sediment retention
RIN	Flood regulation
RGE	Erosion regulation
RPS	Regulation of primary /secondary productivity
RCN	Nutrient cycle regulation
CES	Surface run-off control
CCO	CO2 sequestration
ANH	Natural attenuation - hydrological/hydrogeological variability
DCC	Degradation of pollutant loads
CRE	Resilience
ATS	Tsunami attenuation.
Code	Cultural Ecosystem Services

Table 1 Groups of ecosystem services defined by the Environment Ministry (MMA), Chile (*Continued*)

CTT	Thermal centres
EXC	Excursions (without accomodation) (EXC)
BAL	Bathing resorts (resolution by DIRECTEMAR)
CRE	Recreation centres (CR)
TUR	Tourism (with accomodation) (TUR)
BEE	Natural beauty (BES)
VET	Ethnic value (VET)
DNA	Watersports
CEI	Science and research (CIN)
EDU	Education (EDU)
SCE	Ceremonial sites
CPE	Fishing quays
NAV	Navigation (with or without motor)
VCE	Cultural value of particular species
MNC	Non-conventional medicine (MECON)
PFN	PFNM products (clothes dyes, handicrafts, bee-keeping)
SIG	Quiet enjoyment (legal term)

XLSTAT version 4.03, Statgraphics plus 5.1 and PRIMER version 6 programmes were also used.

Results

Homogeneous environmental units (HEUs)

A total of seven organisations, consisting of 42 adults, were identified as leading actors in the territory (Table 2). This group agreed with the HEUs proposed by the panel of experts. The results highlight the high social value attributed to the presence of native forest in the territory, related with water production and regulation of water flows in the basin.

A total of six HEUs were identified in the territory, based on relative importance and area covered (Table 3). The largest HEUs were of native forest (45.43%), followed by farmland (32.07%) and forestry plantations of exotic species. The important actors in the territory lay stress on native forest management and farming,

Table 2 Key actors in the territory for the definition of HEUs and identification of Ecosystem Services (ES)

Organisation	N°	District	Location
NGOs	6	Temuco	Temuco
University	6	Temuco	Temuco
Municipality	4	Vilcún	Vilcún
Neighbourhood association	8	Vilcún	Vilcún-Cherquenco
Environmental committee	4	Vilcún	Cherquenco
Retailers' association	8	Vilcún	Vilcún-San Patricio
CONAF	6	Temuco	Temuco-Los Paraguas

Table 3 Current land-use for the basin and sub-basins presenting different land-uses as a function of their homogeneous environmental unit

HEU	Current use	Area of basin (ha)	Percentage (%)
0	Unclassified	3931.86	7.26
1	Native forest	24,598.91	45.43
2	Lakes-ponds	95.97	0.18
3	Plantations	4639.31	8.57
4	Pasture	1416.00	2.62
5	Farmland	17,366.87	32.07
6	Riparian areas	2096.70	3.87
Total Area		54,145.62	100

stating that these two activities support an important part of the local economy, which relies heavily on construction timber, firewood, tourism, exploitation of Non Wood Forest Products (NWFP) and cereal farming.

The areas covered by native forest are dominated by *N. dombeyi* (Coihue) which forms part of the Roble-Raulí-Coihue and Coihue-Raulí-Tepa forest types (Fig. 1). The upper basin contains a large area of *N. dombeyi* secondary forest, as do the riparian areas where this species forms long river galleries. This species covers a large proportion of the whole catchment area

(50%). The middle sector of the basin presents mixed land-use, with high presence of native forest and a variety of species belonging to the Roble-Raulí-Coihue forest type. The ground is covered with semi-dense and open scrub, clearly showing different degrees of degradation produced by the anthropic pressures of the farming and forestry activities carried on here (Fig. 1). The landscape also contains pasture and intensive farming land belonging to the big producers of this zone. The lower part of the basin is mainly used for arable farming with large areas of highly technified crop production (Fig. 1). The majority of the land is owned by a small number of families. The effects of the high pressure of this land-use are apparent. It is remarkable that in this sector the riparian areas present little native vegetation, since these areas have been taken in for crops (Table 3).

Selection of ecosystem services

The principal component analysis showed, for each ES, that components 1 and 2 explain over 70% of total variability. A total of eight production services were selected (Table 4); they are directly related with the presence of native forest and water bodies. Four regulation services were selected, of which CO₂ sequestration and erosion control are cited as the most important, especially in areas covered by forest and pasture. Five cultural services were identified in the analysis, the most notable being science

Table 4 Provision, regulation and cultural ecosystem services selected

Model	Variables	%	Multicriteria Spatial Model
Production	(1) Rural Drinking Water (APR)	11	$MSM-G_{prod} = APR*0.11 + APU*0.11 + PAR*0.11 + PIN*0.12 + PAS*0.13 + FLO*0.13 + FAU*0.15 + PSE*0.16$
	(2) Urban Drinking Water (APU)	11	
	(3) Artisanal fishing (PAR)	11	
	(4) Industrial fishing (PIN)	12	
	(5) Grazing, livestock (watering points, summer grazing, dairies) (PAS)	13	
	(6) Flora (except algae) (FLO)	13	
	(7) Fauna (FAU)	15	
	(8) Seed Production (PSE)	16	
Regulation	(1) Elimination of dilution with non-organic pollutants (DDC)	22	$MSM-G_{regul} = DDC*0.22 + RGE*0.23 + CCO*0.27 + CES*0.28$
	(2) Erosion Regulation Erosion (RGE)(2) Erosion Regulation Erosion (RGE)	23	
	(3) CO ₂ sequestration (CCO)	27	
	(4) Surface run-off control (CES)	28	
Cultural	(1) Thermal centres (CCT)	21	$MSM-G_{cul} = CCT*0.21 + TUR*0.18 + BEE*0.18 + CPE*0.21 + CEI*0.22$
	(2) Tourism (TUR)	18	
	(3) Natural beauty (BEE)	18	
	(4) Fishing (CPE)	21	
	(5) Science and research (CEI)	22	

and research, tourism, and activities associated with sport fishing. In the provision group, the effect of the factorial axes gave weighting to the ES of flora, fauna and seed production, which received the highest scores. In the regulation group, the highest scores were given to CO₂ sequestration and surface run-off control. In the cultural ES group, the highest weightings were given to science and research, and fishing (Table 4).

The weightings and factorial analysis for provision ES showed on the first plane (Fig. 2a) that the variable which correlated with HEUs consisting of arable farmland, pasture and plantations was grazing; in the case of the native forest HEU, there was a high correlation with flora, medicinal plants and irrigation; the riparian HEU showed a high correlation with urban and rural drinking water. In the case of the regulation ES (Fig. 2b), it was found that the pasture and arable land HEUs were correlated with control of run-off and a high resilience in the ecosystem; the plantations HEU was correlated with control of erosion and flood-risk; the native forest, riparian areas, and lakes and ponds HEUs showed a high correlation with contaminant elimination, carbon sequestration and climate regulation. Finally, for the cultural ES (Fig. 2c), the results showed that the plantations HEUs are correlated with education, while pasture and arable land HEUs in Quadrant I and native forest in Quadrant IV are correlated with non wood forest products and science and research.

Non-metric multidimensional scaling

The results of the SIMPROF and ANOSIM analysis for the provision ES group (Fig. 3a) showed that HEU 1 and HEU 6 differ significantly from HEU 3, 4 and 5 and from HEU 2 ($P < 0.05$). The services which account for the similarity of 60% are medicinal plants, flora, rural drinking water, aquaculture, sport fishing, artisanal fishing and irrigation. For the regulation ES group (Fig. 3b), HEU 1, HEU 2 and HEU 6 differ significantly from HEU

4 and 5 and HEU 3 ($P < 0.05$). The services that contribute the most to the group formed by HEU 1, 2 and 6 are nutrient cycle regulation, regulation of thermal pollution, climate regulation, flood regulation, CO₂ sequestration and degradation of pollutant loads. For the cultural ES group (Fig. 3c), HEU 1, HEU 2 and HEU 6 differ significantly from HEU 4 and 5 and HEU 3 ($P < 0.05$). The services that contribute the most to the group formed by HEU 1, 2 and 6 were thermal centres, navigation, bathing resorts, quiet enjoyment and water sports. In general, the results of the non-parametric analysis showed that soil covered by secondary forest of *N. dombeyi* support a group of important ecosystem functions, recognised by the important actors of the territory.

Spatial model for ecosystem services

The weightings assigned (P_i) to each ES generated the $MSM-G_{SE}$ for each group (Table 4). The results of each $MSM-G_{SE}$ showed that for provision services especially (Fig. 4a), the greatest value to the territory in the basin is derived from the presence of native forest, coinciding with almost 50.0% of the basin's total area. Secondly, a high value for the territory was assigned to riparian areas, and a lesser value to areas containing pasture and lakes and ponds, which together account for only 2.7% of the area. In the case of regulation services (Fig. 4b), the greatest value to the territory was assigned to areas covered by native forest. Finally, under cultural services (Fig. 4c), the greatest value to the territory was assigned to areas covered with native forest, riparian areas, and lakes and ponds, which coincided with the appreciation for provision services.

Discussion

This study shows that catchment areas are complex systems; they support different ecosystem processes which are usually particular, individual and characteristic, making comparison between them difficult (Esse et al. 2014). These

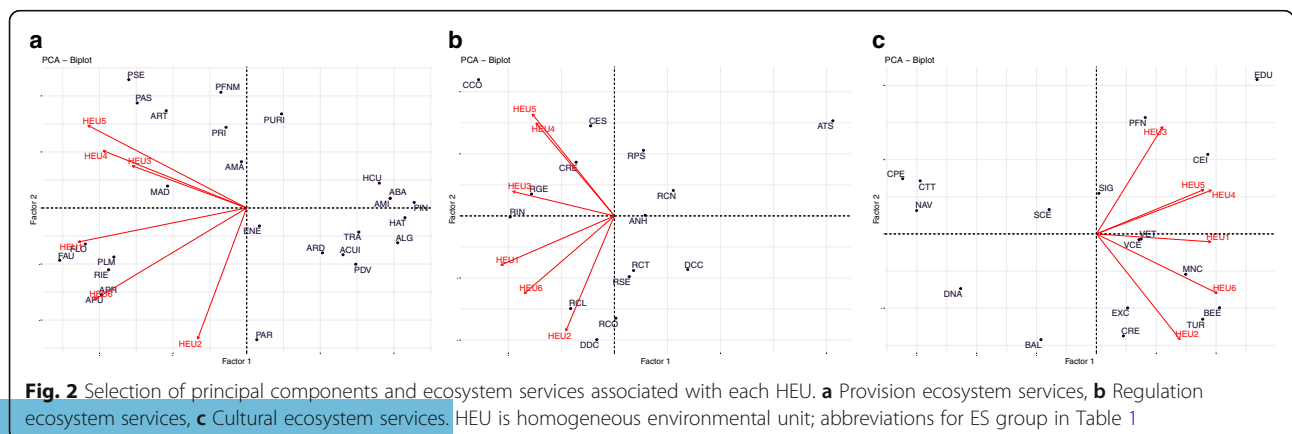


Fig. 2 Selection of principal components and ecosystem services associated with each HEU. **a** Provision ecosystem services, **b** Regulation ecosystem services, **c** Cultural ecosystem services. HEU is homogeneous environmental unit; abbreviations for ES group in Table 1

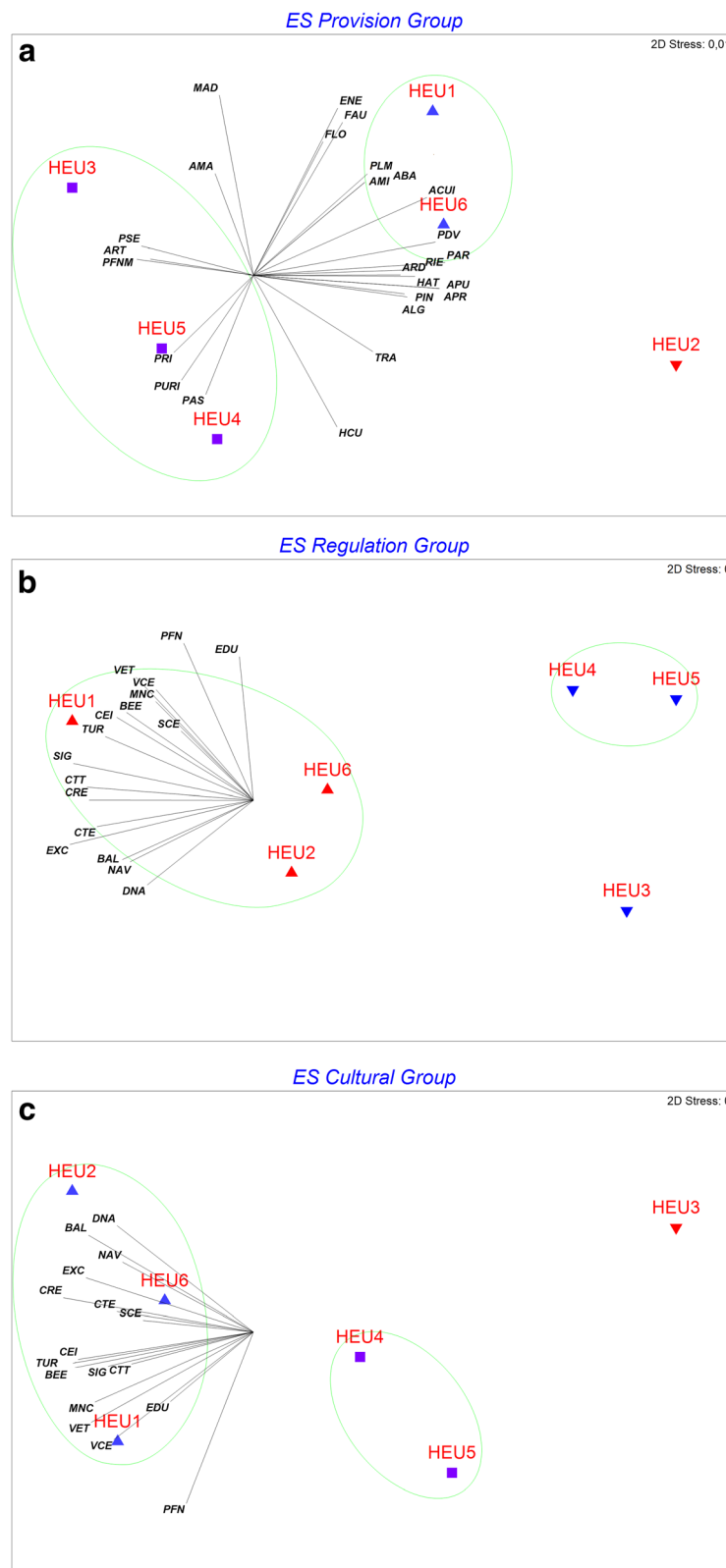


Fig. 3 Non-metric multidimensional scaling. **a** Provision ES group, **b** Regulation ES group, **c** Cultural ES group

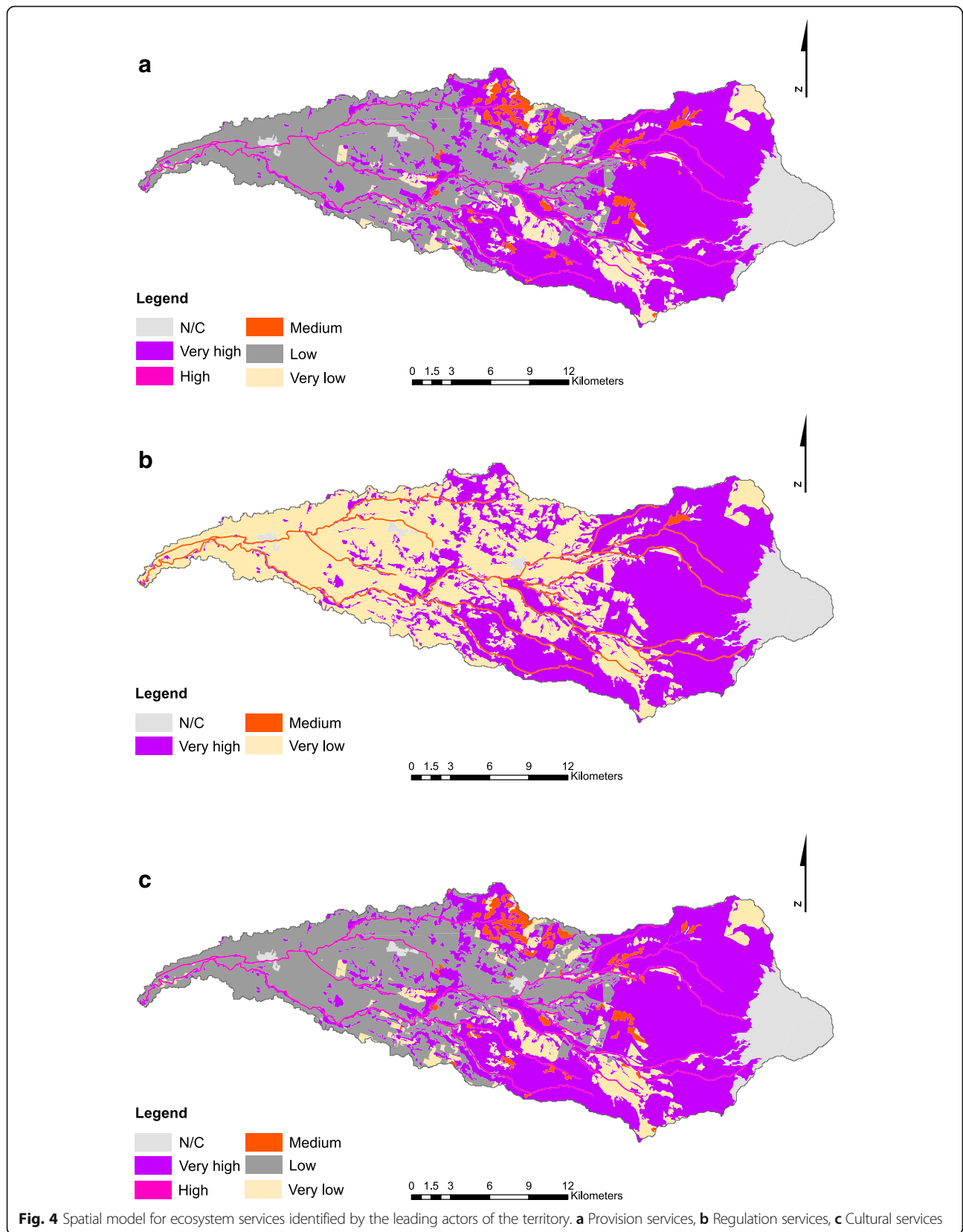


Fig. 4 Spatial model for ecosystem services identified by the leading actors of the territory. **a** Provision services, **b** Regulation services, **c** Cultural services

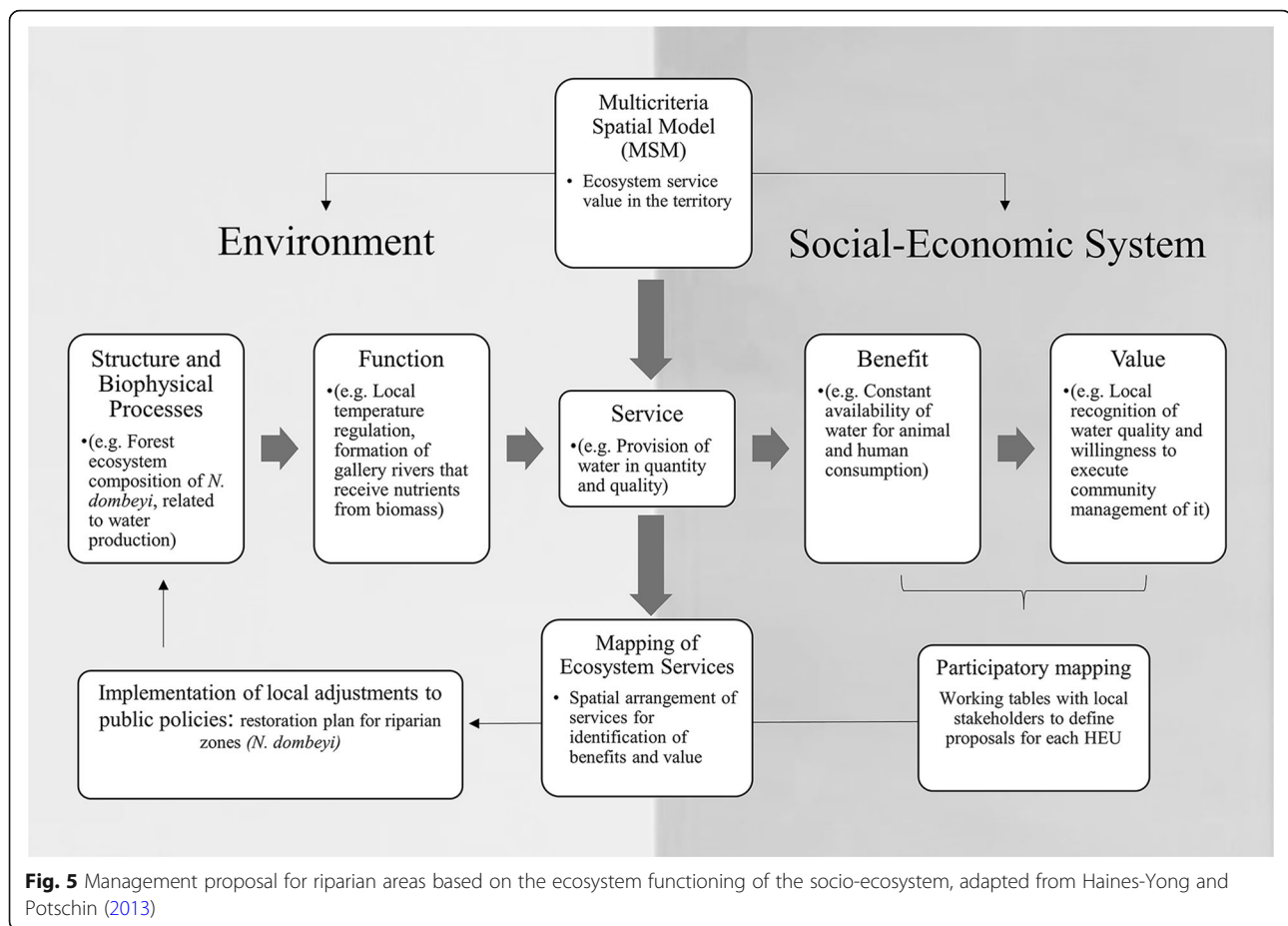
territorial units present different ecosystems throughout their length and breadth, incorporating boundaries which are not merely political or administrative borders, as noted by Rodríguez (2006), Vuscoviuch and Tavares (2011) and Gómez-Orea and Gómez (2014). Proper study requires tools for quantifying and mapping the various components, in order to dimension the flows of goods and services occurring in the basin (Latterra et al. 2011; Esse et al. 2014). The technologies derived from geographical information systems (GIS) and remote detection offer high quality detail and remote observation of the various ecosystems which make up a territory. The results of this study show a methodology that incorporates easy-access technological tools and allows precise information to be obtained on environmental components, similar to Keller et al. (2015); Basco-Carrera et al. (2017); Diaz-Balteiro et al. (2018). The identification of benefits is assisted by the inclusion of leading actors, whose perceptions contribute information on the effects of resource handling and management, and how these relate to conservation plans in the framework of co-management of river catchment areas. Multicriteria analysis methods are a way of discovering the perceptions of the territory's inhabitants while minimising the bias in appreciation. Other researchers have obtained good results using these techniques (Keller et al. 2015; Uhde et al. 2015; Diaz-Balteiro et al. 2018), however the present study proposes a hybrid model which allows spatialisation of the perception of the important actors with respect to ES production, facilitating decision-making for territorial planning and the formulation of public policies. A view of the consequences for land-use of such decisions, incorporating the complexity of the natural environment and its variations in time and space, is indicated by Bateman et al. (2013) as an advantage for decision-making in government policies, demonstrating the advantages of the method applied in this study. Nevertheless, the method presents certain deficiencies such as the scale of the analysis, dependence on territorial cartographic bases and the representativeness of the important actors from the territory who participated in the workshops; all these aspects may affect the quality and accuracy of the model; however, they can be improved as a function of the proposed objects.

The results show that the historical use of the basin has encouraged the growth of arable farming and stock-raising; in fact only 8.6% of the total area consists of plantations of exotic species, while arable farming and stock-raising occupy 34.7%. Both these activities have been responsible for the substitution of native forest, according to Díaz (2006). This may lead to greater contamination of water bodies, species loss, habitat reduction etc. (Habib et al. 2016; Dassou et al. 2017; De los Ríos Escalante et al. 2017), as well as contributing to the impact on the world CO₂ balance by increasing the accumulation of greenhouse gases (GHG) and thus

promoting climate change. This is suggested by the leading actors of the area, who recognise the negative effects of these two activities on the ecosystem, especially on *N. dombeyi* forest and the water production and quality services associated with this species. Consequently the leading actors attribute greater social value to areas covered with *N. dombeyi* forest, making it clear that the forestry industry (monocultures) is a business which benefits very few people and does not contribute significantly to the local economy. At the same time, farming bears the greatest responsibility for the disappearance of native forest in the basin, and for generating water pollution and a reduction in soil productivity.

The transformation of large areas from native forest to land-uses like farming and forestry plantations modifies the water flow and supply significantly; this may affect economic activities, as remarked by Habib et al. (2016). Oyarzún et al. (2005) indicate that economic activities related with the production and consumption of market goods like drinking water may be severely affected. The result may be that changes in the production of market goods are passed on to society through the pricing system, affecting people's welfare. The results showed that although they contain sectors of severely degraded native forest, riparian areas possess a high value, since they have a recognised function in water provision, the regulation of bio-geochemical processes and cultural aspects, particularly natural beauty and tourism. These areas are fundamental in the territorial unit, and must be properly managed by policies to encourage and incentivise their conservation, allowing a balance between use and the production of goods and services. One object of a management proposal (Fig. 5) should be the restoration or bio-remediation of such areas.

Most of the provision services identified refer to tangible goods, including water, wood, NWFP, fibres, etc. Turning to regulation services, the results show that these are closely related to air and water quality regulation, as they help to maintain bio-geochemical cycles. They are also directly associated with the presence of native forest, and they are recognised and valued as vital services for human welfare, in agreement with MEA (2005), Lara et al. (2009) and Little et al. (2009). For cultural services, native forest is the most valuable unit in the territory, since local actors associate its presence with natural beauty, the culture and world-view of the Mapuche people, tourism, education and research; these results agree with Esse et al. (2014). Cultural services offer benefits which depend on the collective perception of society, a fact which reveals the social importance attributed to the spiritual, recreational and educational benefits provided by ecosystems. Thus, the methodology applied, based on MSM, represented efficiently the value of the territory, since it was able to express the perception



of the inhabitants of the study area in the spatial plane. This allows options to be created for socio-ecological management through local decision-making, which can be applied on a regional scale as detailed by Larsen et al. (2012). This scaling can be applied in Chile through the authority of the municipal governments to pass mandatory general standards applicable to the local situation, adapted from laws passed at national level (Santander-Massa 2014).

Forestry activity and the replacement of large areas of native forest have altered the ecosystem functioning of the study catchment area, leading to a critical appreciation of such activities among leading actors in the basin. Earlier studies, such as Lara et al. (2003), Echeverría et al. (2006), Lara et al. (2009), Miranda et al. (2015), indicate that the landscape of south central Chile has undergone a series of transformations in recent decades; drastic changes and intense pressure on land-use have resulted in incompatibility between different goods and services. The factors responsible for these changes have been activities like clearing land for agriculture, use of fire, deforestation and degradation of natural forests in areas of high biodiversity (Habib et al. 2016), and wood production in fast-growing plantations

relying on irrigation. This reflects the historical reality of the study basin.

The results of the present study recognise the social value of a local viewpoint. This is of great importance for the country's economic development, since it highlights the fact that the conflict between forestry producers and farmers is basically economic, and that their respective positions do not recognise the impacts that they have caused on the ES provided by the territories where they carry on their activities. Thus the participation of the leading actors of the territory is fundamental for generating public policies whose final object is to safeguard the ecosystem functioning of such important areas as river catchments.

Conclusions

A number of very varied land-uses may be identified in a river catchment area. For this reason, an ecological approach based on ecosystem functioning will give unique, individual results which are unlikely to be comparable with those of other similar geographical units. Correct identification and value attribution of ES will contribute to correct description of the flow of the goods and services affecting the territory.

The important actors of the territory recognise the importance of native forests, and that they are fundamental for the maintenance of ES related with water production and flow regulation. This is particularly so in the case of *N. dombeyi* forests, which grow in damp conditions associated with watercourses, covering riparian areas. *N. dombeyi* therefore has great potential for use in plans for the restoration of riparian areas.

The methodology used in this study, based on multicriteria spatial analysis, enabled us to represent the territory at landscape scale and to recognise the social value of the different ES of the natural ecosystems and anthropic production systems of which it is composed.

The participation of the leading actors of the territory is fundamental for achieving a proper valuation scale for the different ES; they contribute a broad perspective on territorial management which goes beyond the particular interests of productive sectors such as farming and forestry. Their participation must be reflected in the definition of public policies for the sustainable management and conservation of natural ecosystems.

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Availability of data and materials

All the cartographical data used in this study can be found in the territorial information system of the Chilean National Forest Corporation (CONAF), <http://sit.conaf.cl> and in the Chilean bank of geospatial data, <http://www.ide.cl>. Own databases were also used. The software programmes used were ArcGis v10.6, licensed by ESRI, and R-project, free software <https://www.r-project.org/> with the facto-extra <https://cran.r-project.org/package=factoextra> and ggplot <https://ggplot2.tidyverse.org/> packages. The XLSTAT version 4.03, Statgraphics plus 5.1 and PRIMER version 6 statistical programmes were used.

Authors' contributions

CE, RS, PR, FE were responsible for collecting and analysing the data. The databases were prepared by CE, PS, DF and RS. The manuscript was prepared by CE and RS with contributions by PR and FE. PS reviewed the manuscript and applied the final format, which was agreed by all the authors.

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All the authors are academics involved in environmental management and research. CE is doctor in forest sciences. RS is master in rural development. FE is doctor in environmental sciences, PR is doctor in system sciences and ecology. DF is doctor in agricultural engineering and PS has a degree in natural resource sciences.

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Not applicable.

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Competing interests

The authors declare that they have no competing interests.

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