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Patterns of ecosystem services supply across farm properties: Implications for ecosystem services-based policy incentives

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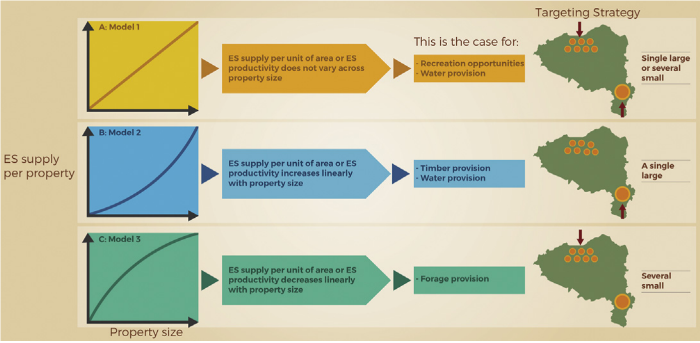
HIGHLIGHTS

- We tested three models of ecosystem service supply-farm area relationships.
- Farm size influenced forage and timber supply more clearly than recreation and water.
- Larger farms were more effective in providing timber.
- Small farms were more effective in providing forage.
- Large and small farms were equality effective in providing recreation opportunities.

GRAPHICAL ABSTRACT



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ABSTRACT

In developing countries, the protection of biodiversity and ecosystem services (ES) rests on the hands of millions of small landowners that coexist with large properties, in a reality of highly unequal land distribution. Guiding the effective allocation of ES-based incentives in such contexts requires researchers and practitioners to tackle a largely overlooked question: for a given targeted area, will single large farms or several small ones provide the most ES supply? The answer to this question has important implications for conservation planning and rural development alike, which transcend efficiency to involve equity issues. We address this question by proposing and testing ES supply-area relations (ESSARs) around three basic hypothesized models, characterized by constant (model 1), increasing (model 2), and decreasing increments (model 3) of ES supply per unit of area or ES "productivity". Data to explore ESSARs came from 3384 private landholdings located in southern Chile ranging from 0.5 ha to over 30,000 ha and indicators of four ES (forage, timber, recreation opportunities, and water supply). Forage provision best fit model 3, which suggests that targeting several small farms to provide this ES should be a preferred choice, as compared to a single large farm. Timber provision best fit model 2, suggesting that in this case targeting a single large farm would be a more effective choice. Recreation opportunities best fit model 1, which indicates that several small or a single large farm of a comparable size would be equally effective

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in delivering this ES. Water provision fit model 1 or model 2 depending on the study site. The results corroborate that ES provision is not independent from property area and therefore understanding ESSARs is a necessary condition for setting conservation incentives that are both efficient (deliver the highest conservation outcome at the least cost) and fair for landowners.

1. Introduction

Around the world, there is increasing recognition that ecosystems in working landscapes deliver ecosystem services (ES henceforth) of enormous value (Kubiszewski et al., 2017). The challenge is to turn this recognition into incentives and institutions that guaranty their protection (Costanza et al., 2017; Daily and Matson, 2008). Institutions (i.e. property rights) along with the features of ES, frame the policy context for the design and implementation of policy incentives for the private and public provision of ES (Guerry et al., 2015). For example, cautiously designed policies, such as payments for ecosystem services (PES), can motivate potential ES suppliers to maintain and enhance ES provision. However, in the context of private lands, guiding the allocation of such payments requires ES researchers and practitioners to address a largely ignored question: for a given targeted area will a single large farm or several small ones provide the most ES supply? The answer to this question has significant connotations for incentive design and allocation, which involve both efficiency and distributional issues.

The allocation ES-based incentives on private lands including agri-environmental schemes has trusted scarcely on the knowledge of ES supply across properties (De Lima et al., 2017; Ferraro et al., 2015; Stoeckli et al., 2017). In absence of this knowledge, the measurement of the efficiency of payments has had to rely on imperfect proxies of ES provision such as avoided deforestation (Ferraro et al., 2015), which impairs the possibility of evaluating the true environmental benefits of payment mechanisms (De Lima et al., 2017). Furthermore, in view of the lack of this information, an increasing number of PES contracts have started to target medium to large properties (Alix-Garcia and Wolff, 2014; Arriagada et al., 2012), which has led to significant critiques on equity and environmental justice grounds (He and Sikor, 2015; Sikor, 2013).

The discussion is particularly relevant in developing countries, keepers of the most threatened biodiversity (Butchart et al., 2015; Montesino Pouzols et al., 2014) and ES worldwide (Turner et al., 2007) and where ES protection rests largely on individual landowners, outside public protected areas or community owned lands and forests (Villamagna et al., 2015). Moreover, most landscapes have been modified by agricultural activities and most natural, unmanaged ecosystems sit in a matrix of agricultural land uses (Power, 2010).

Private lands in these working landscapes comprise millions of individual small landowners that coexist with large operations, in a reality of highly unequal asset distribution that perpetuates and exacerbates inequity and poverty (De Ferranti et al., 2004; OXFAM, 2016; Rodríguez-Pose and Hardy, 2015).

Particularly, Latin America is the world's most unequal region in terms of land distribution. The Gini coefficient for land—an indicator of between 0 and 1, where 1 represents the maximum inequality—is 0.79 for the region as a whole, 0.85 in South America and 0.75 in Central America. These figures indicate much higher levels of land concentration than in Europe (0.57), Africa (0.56) or Asia (0.55). Within Latin America, Chile occupies the second place (after Paraguay) with a Gini coefficient for land of 0.91 (OXFAM, 2016).

In such contexts, land use, biodiversity and ES provision are expected to be highly dependent on property size for several reasons (Coomes et al., 2016; Richards and VanWey, 2015). Small landowners may differ from large owners in their access to credits for replacing native forests by cash crops, or their need for firewood and forage, their interest on and capacity for sustaining non-agricultural land uses (e.g., eco-tourism) (Plieninger et al., 2012), and their access to markets and resource stocks (Miteva et al., 2017). Therefore, different variation patterns of ES supply per unit of area or "ES productivity" can be expected according to ES types and property sizes.

Undeniably, the lack of complete, high-resolution, updated spatial information to obtain ES indicators is a primary restriction to the development of conservation planning assessments in developing countries, including the design of ES-based incentive mechanisms (De Lima et al., 2017). Furthermore, the monitoring of ES at the farm level is not without challenges, ones that are much larger than observing forest cover across time (Cord et al., 2017; Maes et al., 2016).

We address the question of ES supply distribution across farms by proposing and exploring ES supply-area relationships (ESSARs hereafter) around three basic hypothesized models, characterized by constant (model 1), increasing (model 2), and decreasing increments (model 3) of ES supply per unit of area (or ES "productivity"). Model 1 supports the equal effectiveness of targeting a single large or several small properties of the same area in order to ensure an ES supply goal. Model 2 advocates for the greater effectiveness of a single large property instead of several small ones. Model 3 supports the selection of several small properties over a large one. We assert that understanding ESSARs is a necessary condition for setting conservation payments that are both efficient (deliver the highest conservation outcome at the least cost) and fair for landowners.

We are not aware of any research that has set to explore such relations and hence our results provide novel insights into the challenges of mainstreaming ES in decision making in working landscapes with asymmetrical distribution of property sizes.

2. Methods

2.1. Study sites

The two study areas chosen for this inquiry exemplify the distinctive unequal distribution of land that has positioned Latin America as the most unequal region of the world (ECLAC et al., 2015). Ancud municipality, Inner Sea of Chiloé Island (41°50′–42°15′S and 73°15′–74°15′W), is located in the province of Chiloé in Los Lagos Region, southern Chile (Appendix S1). It covers a territory of 1724 km^2 of which <1% is classified as urban. According to the last census of 2002, of the total population (39,946 people) 31.7% is rural (INE, 2003).

Forest degradation has been reported to be a drastic process in Ancud, having as its main immediate cause the unsustainable timber extraction to supply the firewood demand of nearby municipalities (Carmona et al., 2010). Small properties (conventionally those with <60 ha) represent 83.8% of total, whereas medium (60–999 ha) and large properties (>1000 ha) account for 15.7% and 0.5% respectively.

Panguipulli municipality (38°30′–40°5′S and 71°35′–72°35′W) is located in the Andes Range of Los Ríos Region, southern Chile (Appendix S1). It has an area of 3292 km^2 of which <0.5% is classified as urban. The municipality has a total population of 33,273 people, of which 52.2% is considered rural and 25.3% belongs to an indigenous group (Nahuelhual et al., 2016). Forest degradation and exotic tree plantation expansion on previously forested land or pastures, are reported as the main land use changes (Reyes et al., 2016). Small properties represent

74.1% of total, whereas medium and large properties account for 21.4% and 4.3% respectively.

2.2. Ecosystem services supply-area relationships

ESSARs are inspired in the species–area relationships which have had an historical importance in biological conservation, including the Single Large Several Small (SLOSS) debate around the size of conservation reserves (see Rosenzweig, 2004). Species–area relationships are frequently presumed to be power relationships, however many other functional forms can fit as well (see Tjørve, 2003, 2009). For the case at hand and being this a first exploration, we chose the three basic forms for ESSARs that are explained bellow.

In model 1 (Fig. 1A), ES supply per unit of area or ES productivity (the slope of the curve) does not vary across property size. For a given targeted area, a single large or several small properties would provide the same ES supply. In model 2 (Fig. 1B), ES productivity increases linearly with property size, and concomitantly conservation of a given area composed of several small properties would render lesser ES supply than an equivalent area integrated by a single or few large properties. In model 3 (Fig. 1C), ES productivity decreases linearly with property size and concurrently, for a given area, several small properties would render a higher supply than a single farm or few large ones.

We may expect several different factors to affect such models, which are related to property size. Among them there might be biophysical factors such as forest structure and composition (combination of land uses and covers), location factors such as the distance of a property from outstanding landscape attributes (e.g. volcanoes) that determine recreation opportunities, and human factors such as management decisions.

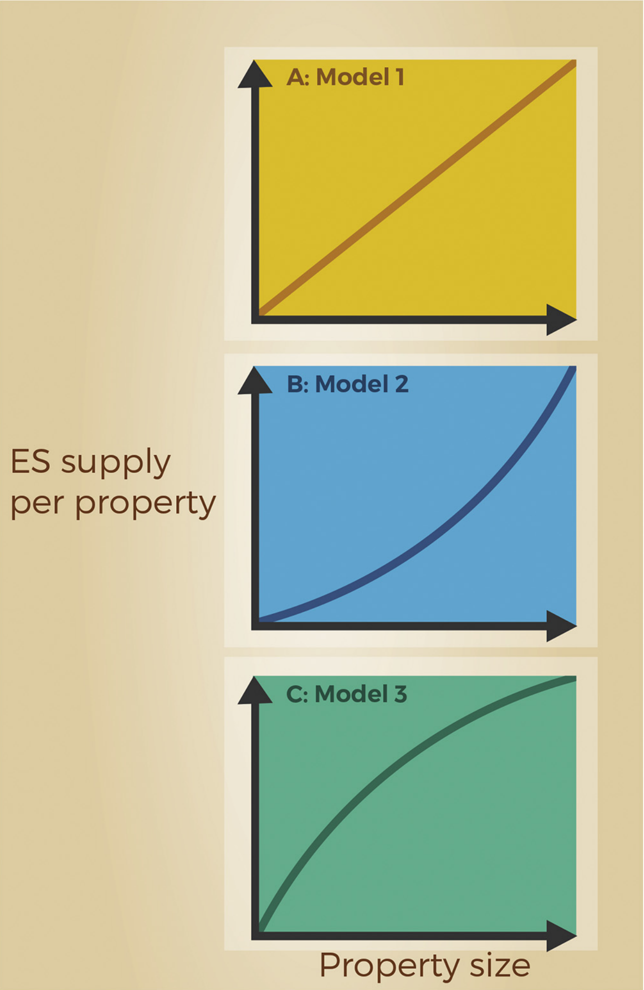

Fig. 1. Potential models of ESSARs.

2.3. Property level information

Land property data came from three main public data sources: i) Farm Cadastral Map (Center of Information on Natural Resources and Production Promotion Corporation, CIREN-CORFO): digital cartography of rural properties at scale 1:20,000 that provides information on farms' area and contour; ii) Service of Internal Affairs data base: digital cartography of land properties at scale1:10,000 for the year 2016, which provides information about the property and the land owner; iii) National Cadaster of Native Vegetation: GIS-based data set of thematic land cover maps (1:10,000) derived from aerial photographs and satellite imagery between 1994 and 1997, which is Chile's most comprehensive cartographic study of natural vegetation. It was published by CONAF (National Forestry Corporation) in 1998, with actualizations in 2006 and 2014. For the case of Ancud, property and Cadaster data could be overlaid for 100% of properties, which amount to 2853 private landholdings, whereas in Panguipulli this was possible for 531 properties, which represent only 21% of the total.

2.4. Indicators of ES supply

For the case of Ancud we relied on indicators constructed in the context of prior research projects and published in scientific papers (Laterra et al., 2016; Nahuelhual et al., 2013), thesis, and technical reports. For the case of Panguipulli, the indicators were created in the context of this study using the most updated information and following near the same basis (variables and procedures) underlying Ancud's indicators, as long as the data permitted. A brief explanation of each indicator is provided in this section while construction details are presented in Appendix S2.

Indicators of ES usually need to be adjusted to local realities and availability of data at that scale (Dick et al., 2014; Feld et al., 2010). But we believe that the slight differences in indicators' construction does not present a limitation but rather an opportunity to show that distributional patterns are influenced by farm size independently of the indicators composition.

2.4.1. Timber provision

Timber provision (supply) is defined here as the amount of timber that can be potentially or currently extracted from a forest stand using forest management criteria. As such timber provision is part of the stock or entire forest biomass and it depends on natural attributes as well as management specifications. For the case of Ancud, the indicator relied on inventory data from previous field work of the research team. For the case of Panguipulli, the indicator was constructed using the same type of data, which was made available to us by CONAF office. In the case of Ancud, the indicator represents the potential amount of timber that can be sustainably extracted in a given year under particular management conditions. For the case of Panguipulli, the indicator is the average of timber actually extracted in a period of 18 years (1998–2016) by each landowner under a formal management plan. In both cases the indicator is expressed AS annual cubic meters of timber per hectare.

2.4.2. Forage provision

Forage provision (or supply) is defined as the amount of biomass that can be potentially or currently extracted from a pasture, which depends on biophysical attributes as well as managerial conditions, such as fertilization and irrigation. The construction of this indicator relied on Multiple Criteria Analysis. The structure is a linear combination of agro-ecological and managerial variables selected and weighted by means of expert opinion. The Saaty matrix methodology and Analytic Hierarchy Process (Saaty, 1990) assisted the weighting of the variables. Data on biophysical variables came from CIREN CORFO (2003) and managerial data was provided by the National Institute for Agricultural Development (INDAP). Experts comprised both academics from Universidad Austral de Chile and professionals from INDAP in Ancud and Panguipulli offices. In both cases, the final indicator is expressed as potential annual tons of dry matter per hectare.

2.4.3. Water provision

Water provision (or supply) is defined here as the surface water available for direct or indirect use, which requires a constant stream flow, generated by a joint effect between surface and groundwater flows (quickflow and baseflow) (Le Maitre et al., 2014). For the case of Ancud the indicator was obtained from a spatially explicit model built on Soil and Water Assessment Tool (SWAT), which allows the computation of hydrological flows for long-term analysis following a semi-distributed approach (Arnold and Fohrer, 2005). Main model inputs are: digital elevation model (DEM; 30 m); soil types (1:50,000); land uses (30 × 30 m) (Echeverria et al., 2006; Carmona et al., 2010); hydrological records (daily data 1985–2011 from meteorological stations); and streamflow data (monthly data 1985–2011 from hydrological stations).

For the case of Panguipulli the construction of the indicator was carried out through the application of the ECOSER protocol (Laterra et al., 2016) for the evaluation of ES and socioecological vulnerability (www.eco-ser.com.ar) through Arcgis 10.1 and its tool retention of excess precipitation by vegetation cover, which uses the empirical index Curve Number developed by the United States Department of Agriculture (USDA, 1986). To obtain the indicator, geo-spatial data were generated (Curve Number values, precipitation, annual storm number) based on land use and cover data at 1:50,000 scale (CONAF, 2014), soil series at 1:0,000 scale (CIREN CORFO, 2003), and expert knowledge.

2.4.4. Recreation opportunities

This ES is defined as the potential for recreation sustained by a particular mixture of natural setting attributes (the physical landscape) and recreation activities that rely upon the physical as well as the built landscape (e.g. roads) (Chan et al., 2011). The core of the construction of the indicator was based on Multiple Criteria Analysis. For the Ancud case, the indicator corresponds to that reported by Nahuelhual et al. (2013) based on five attributes, namely, singular natural resources, scenic beauty, accessibility, tourism attraction capacity, and tourism use aptitude. For the case of Panguipulli the indicator was simplified to scenic beauty, accessibility, and tourism use aptitude, using similar procedures to those presented in Nahuelhual et al. (2013). Both indicators are adjusted by carrying capacity to express ES supply in terms of persons per hectare.

2.5. Data analysis

Data analysis was concerned with the testing of ESSARs models and the relations between patterns of concentration of ES supply and land. We first explored ESSARs by comparing their fitting to linear (model 1) and quadratic models (models 2 or 3) (Fig. 1) using least square regression procedures available in Infostat®. We considered that quadratic models represented a better fit than linear models when: a) the quadratic term of multiple regressions was significant ($p < 0.05$); and b) the multiple regressions R^2 was at least 5% higher for the quadratic than for the linear model. Cumulative analysis was based on Quinn and Harrison (1988) and consisted in a graphical comparison of the cumulative area to cumulative ES supply relationships based on small to large and large to small ranked properties.

3. Results

3.1. Natural capital distribution

The two study areas embody the distinctive unequal distribution of land that characterizes Latin American countries as the most unequal in the world and Chile as the second most unequal in the continent. In Ancud, 37% of private land (excluding national protected areas and public lands) is owned by 1% of largest properties (28 out of 2853) whereas in Panguipulli the same 1% of properties (5 out of 531 properties) comprises 54.3% of land. The concentration of native forest mirrors that of land with 50.4% and 57.1% of the forest area owned by 1% of the largest properties in Ancud and Panguipulli, respectively. On the contrary, grasslands are more equally distributed with 1% of largest properties concentrating 22.3% and 6.23% of grassland area in Ancud and Panguipulli, respectively.

3.2. Ecosystem service supply-property area relations (ESSARs)

In the case of Ancud, the three different ESSARs posed in Fig. 1 were represented by different ES types. Recreation opportunities adjusted to model 1 (Fig. 2D), timber and water supply adjusted to model 2 (Fig. 2A and C), whereas forage provision best fit model 3 (Fig. 2B). Table 1 summarizes the statistical results.

Underlying ESSARs, there are patterns of cumulative ES supply and cumulative property area which are portrayed in Fig. 3 from large to small properties (red dotted line) and from small to large properties (blue dotted line). These curves depict the implications of targeting a single large property or several small ones for achieving a certain ES supply level. Both curves converge at the origin since cero accumulated area implies cero accumulated supply. They also converge at the opposite extreme since the maximum accumulated supply and area are the same whether the properties are arranged from small to large or from large to small sizes. In the middle section, the curves generally diverge because: a) the group of properties that comprise a given area from large to small is not composed by the same group of properties ordered from small to large; and b) ES productivity is not independent from size as suggested by models 2 or 3; model 1 instead would be consistent with more proximate curves.

For example, if 10% of the private property area in Ancud (14,768 ha) were to be hypothetically conserved (comprising those properties that deliver timber) (Fig. 3A), large differences in timber supply would occur by targeting large versus small properties. Specifically, four large properties would render near four times more timber than the equivalent area composed by 1562 small properties (157,306 m^3 versus 40,039 m^3 of timber, respectively). If 50% of the area were hypothetically targeted (72,597 ha) the difference in supply between few large and several small would get much larger (496,284 m^3 versus 275,388 m^3).

In the case of forage however and accordingly with model 3 (the blue dotted line rests on top of the red one), Fig. 3B suggests that if 10% of the private area were targeted (13,909 ha), 1469 small properties would render more than twice the supply of forage than four large properties (51,110 versus 20,587 tons of dry matter).

In the case of water (Fig. 3C), targeting 10% of the area (14,505 ha) of those properties that deliver this ES, would involve four large properties supplying 1,201,256 m^3 as compared to 1462 small properties rendering 756,678 m^3. For recreation opportunities (Fig. 3D) and despite the fact that this ES fit model 1 better, the accumulated curves suggest that targeting 10% of the area (14,320 ha) would imply four large properties rendering 53.4% more supply than an equivalent area comprised by 1334 small ones (94,912 versus 50,771 persons).

In the case of Panguipulli, supply of different ES types also illustrated the three different ESSARs models posed in Fig. 1. Water supply (Fig. 4C) and recreation opportunities (Fig. 4D) adjusted to model 1, timber

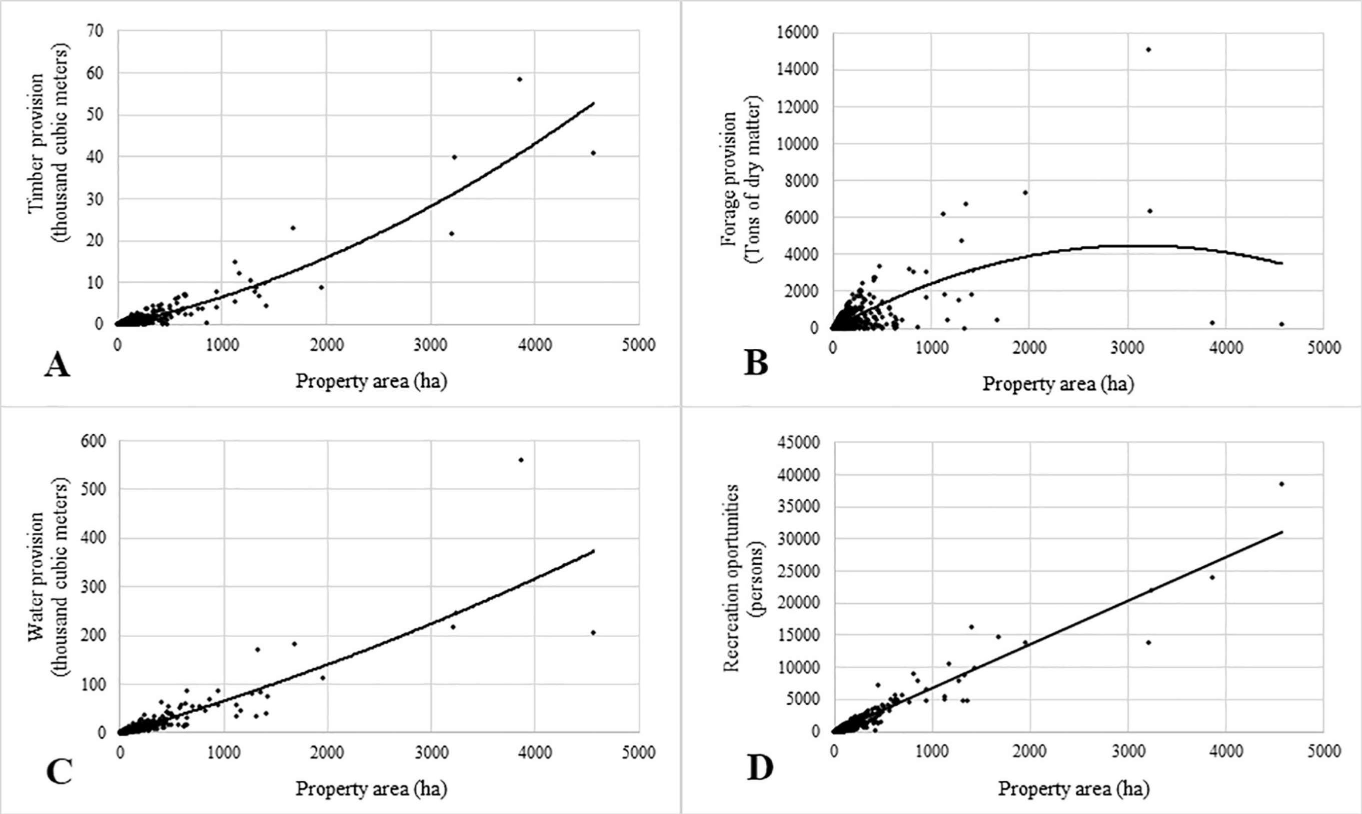

Fig. 2. Best fitting ESSARs models for timber (A), forage (B), water (C), and recreation opportunities (D) in Ancud municipality.

supply (Fig. 4A) adjusted to model 2, whereas forage (Fig. 4B) best fit model 3. Table 2 summarizes the statistical results.

For Panguipulli, the patterns of cumulative ES supply and area (Fig. 5) were discernably different from those of Ancud. In the case of timber, curves overlay or depart depending on the segment of the curve. Thus if 10% of the area is targeted, comprising properties that deliver timber (19,337 ha), Fig. 5A suggest that the target would be met by 425 small to medium properties rendering near twice the supply of one single large property (45,692 m^3 versus 25,699 m^3 of timber, respectively).

For forage (Fig. 5B) the differences are the most substantial and conserving 10% of the land (17,752 ha), would involve 371 small to medium properties supplying near 16 times the amount of a single large property (22,914 versus 137 tons of dry matter, respectively).

In the case of water (Fig. 5C), targeting 10% of the area comprising properties that deliver this ES (19,767 ha) would involve a single large property rendering a supply of 11,235,257 m^3 as compared to 487 small to medium properties delivering 6,612,338 m^3. For recreation opportunities (Fig. 5D) the cumulative curves suggest that conserving the 10% of the area (17,898 ha) would involve a single large property providing a supply similar to that delivered by 248 small properties (2224 versus 2894 persons).

4. Discussion

As expected, ESSARs varied across ES but were more homogeneous across sites. In synthesis, timber provision best fit model 2, suggesting that in this case targeting a single large farm would be more effective than targeting several small ones. Forage provision best fit model 3, which suggests that targeting several small farms should be a preferred choice as compared to a single large farm. Recreation opportunities best fit model 1, which indicates that several small or a single large farm of a comparable size would be equally effective. Only for water provision ESSARs changed from model 2 in Ancud (Fig. 2A) to model 1 in Panguipulli (Fig. 4A), which corroborates that local landscape conditions also influence ES productivity.

In turn cumulative patterns largely corroborated the intuition of the models, with discrepancies that could be attributed to the dispersion of

Table 1
Multiple regression analysis of ESSARs in Ancud.

Dependent variable	Model	Multiple R^2	X parameter	X^2 parameter	Whole model
Timber	Quadratic	0.876	5.1656 (<0.001)	0.0014 (<0.001)	(<0.01)
Forage	Quadratic	0.510	2.8729 (<0.001)	−0.0005 (<0.001)	(<0.01)
Water	Quadratic	0.800	60.3997 (<0.01)	0.0047 (<0.001)	(<0.01)
Recreation opportunities	Linear	0.920	44.0811 (<0.01)	–	(<0.01)

*Numbers between brackets are the significance of estimated parameters (X or $\times^2$ parameters) or the whole model. Only the model with highest multiple R^2 is shown for each dependent variable. No intercept term is consigned since all models were forced through the origin.

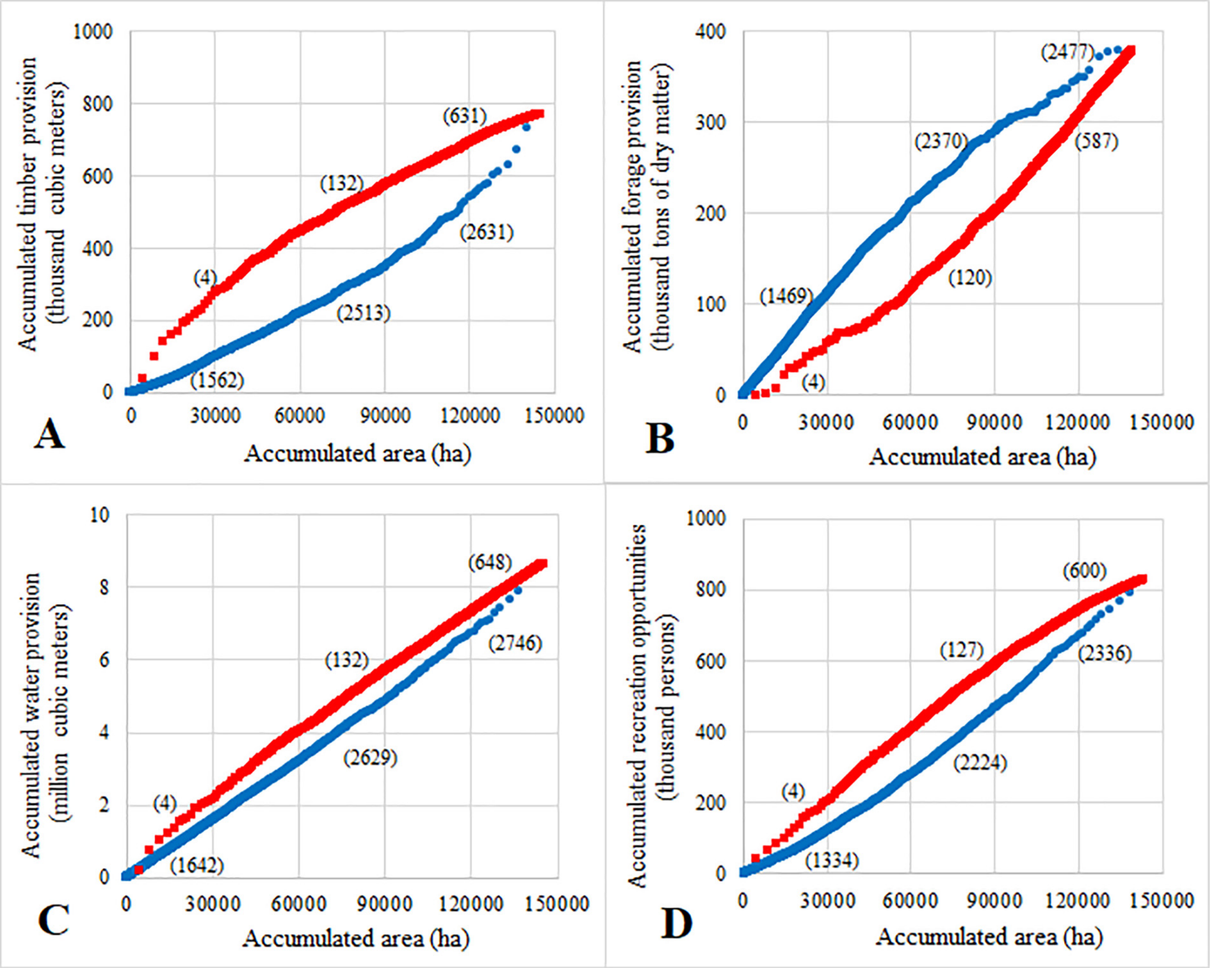

Fig. 3. Patterns of cumulative ES supply and area from small to large (blue dots) and from large to small (red dots) property sizes for timber (A), forage (B), water (C) and recreation opportunities (D) in Ancud municipality. Numbers in brackets along the dotted lines indicate the properties involved in targeting 10%, 50% or 80% of the area for conservation, in cumulative terms. The numbers change since only properties that deliver the particular ES are considered. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

observed values of ES supply around model predictions. Whereas the models reflect the trends, the cumulative curves depend on the real cases and therefore reproduce the entire dispersion of the data around the adjusted trend.

For timber, two factors can explain model 2 (which advocates for targeting a single large property) in both sites: i) Large properties hold comparatively greater proportions of native forests, and ii) timber productivity is higher in medium and large properties as compared to small properties, which have usually depleted or degraded their native forests as a result of unsustainable timber logging practices (Carmona et al., 2010). In Ancud, native forests represent 64.1%, 45.8% and 34.9% of total property area in large, medium and small land holdings. Timber productivity is higher in medium (4.3 m^3/ha) and large properties (8.4 m^3/ha) as compared to small ones (2.9 m^3/ha).

In Panguipulli native forest represent 80.5%, 53.3% and 64.8% of total area in large, medium and small landholdings, respectively. However, productivity is lower in larger properties (0.8 m^3/ha) as compared to small and medium size ones (2.8 and 2.3 m^3/ha, respectively). This could be explained by the fact that the timber supply indicator in the case of Panguipulli reflects the amount of timber actually extracted as compared to the Ancud indicator, which reflects the potential supply (Appendix S2). In Panguipulli, small to medium properties extract more timber in relation to their forest area than larger properties, which does not necessarily imply a larger productivity of the former.

For forage, two factors could explain model 3 in both sites: i) smaller properties hold larger proportions of pastures as compared to medium and large properties; and ii) pasture productivity tends to be higher in small to medium properties as compared to large landholdings. This can be explained by fertilization subsidies specifically allocated to small and medium properties, and the specialization of small properties in cattle rising. In small properties in Ancud, pastures represent 51% of total area on average, whereas this percentage lowers to 27% and 14.5% in medium and large properties, respectively. Forage productivity in small properties reaches 3.7 tons of dry matter/ha as compared to 2.9 and 2.1 in medium and large properties, respectively. In Panguipulli, small properties hold an average of 38.5% of pastures respect to total area, whereas in medium and large properties the average proportion is 37.5% and 7.05%, respectively. In turn, forage productivity reaches 3.29 and 3.26 tons of dry matter/ha in small and medium properties, respectively, compared to 2.9 tons of dry matter/ha in large properties.

This result is confirmatory of the tradeoffs within small farms, which sustain food provision at expenses of reducing their capacity to provide other ES such as water. This finding is in line with other studies that support that the conversion of undisturbed natural ecosystems to agriculture can have significant effects on the system's ability to produce important ES (Power, 2010). Furthermore, forage provision and provisioning services in general are not targeted in compensation mechanisms, leaving small farms in a highly disadvantaged position in the context of incentive programs.

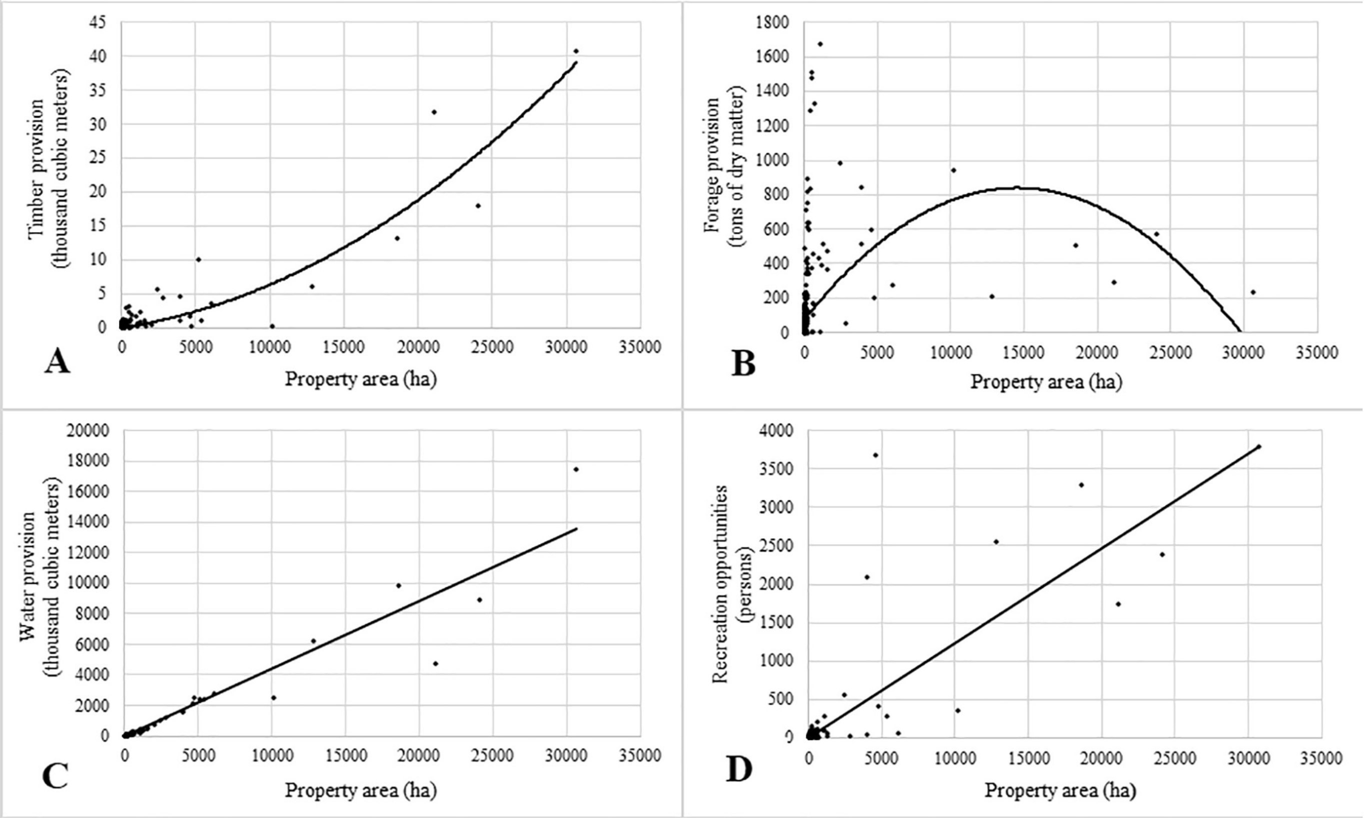

Fig. 4. Best fitting ESSARs models for timber (A), forage (B), water (C) and recreation opportunities (D) in Panguipulli municipality.

In the case of water and recreation opportunities, model 1 could be expected since at least some of the attributes that compose ES indicators (Appendix S2) are independent of property size and forest area. Water supply is the result of complex interactions between soil characteristics, land uses and covers, and precipitations at the watershed scale. In Ancud water supply productivity was fairly comparable across small (53.2 m^3/ha) and medium size properties (55.3 m^3/ha) but higher in larger properties (65.7 m^3/ha) which can explain model 2. In Panguipulli instead, ES productivity was fairly similar across sizes with values of 389.8, 305.2, and 388.8 m^3/ha for small, medium and large properties, respectively, which can explain model 1. This type of result is most relevant for the design of ES based payments since it highlights that water provision might not be so closely linked to forest area. In fact, some of the criticisms to PES mechanisms relate to some of their untested assumptions such as that of the role of vegetation on hydrological services (Ponette-González et al., 2014).

In turn, recreation opportunities depend on biophysical attributes of the landscape, likely to be observed and accessed (Appendix S2). In Ancud, ES productivity varied more notoriously than in Panguipulli, with mean values of the indicator of 3.9 persons/ha in small properties as compared to 5.7 and 6.6 persons/ha in medium and large properties, respectively. In Panguipulli ES productivity was similar across property sizes with mean values of 0.21, 0.17, and 0.16 persons/ha, for small, medium and large properties, respectively, which would explain model 1.

Whereas ESSARs and ES productivity analysis across farm sizes can answer the question of which properties are more effective providers of ES for a given area, the selection of properties presupposes a decision that goes beyond efficiency. ESSARs need to be combined with equity and social justice criteria (Hausknost et al., 2017; Mcgrath et al., 2017; Pascual et al., 2014; Schröter et al., 2017), particularly in countries and territories with pressing social claims (Sikor et al., 2014) that are the focus of significant socio-environmental conflicts around natural resources tenure (Carruthers and Rodriguez, 2009; Serenari et al., 2017). ESSARs patterns are the result of two distinct types of land inequality, namely land size and land use inequality (Coomes et al., 2016; Zilberman et al., 2008). The effect of land size is determined by the extent of the farm itself and by the area of forests held by larger farms, which influence water supply and recreation opportunities. In

Table 2
Multiple regression analysis of ESSARs in Panguipulli.

Dependent variable	Model	Multiple R^2	X parameter	X^2 parameter	Whole model
Timber	Quadratic	0.883	0.3227 (<0.01)	0.000002 (<0.01)	(<0.01)
Forage	Quadratic	0.203	0.1264 (<0.001)	−0.000004 (<0.001)	(<0.01)
Water	Linear	0.9208	441.0811 (<0.01)	–	(<0.01)
Recreation opportunities	Linear	0.709	0.1239 (<0.01)	–	(<0.01)

Numbers between brackets are the significance of estimated parameters (X or X^2 parameters) or the whole model. Only the model with highest multiple R^2 is shown for each dependent variable. No intercept term is consigned since all models were forced through the origin.

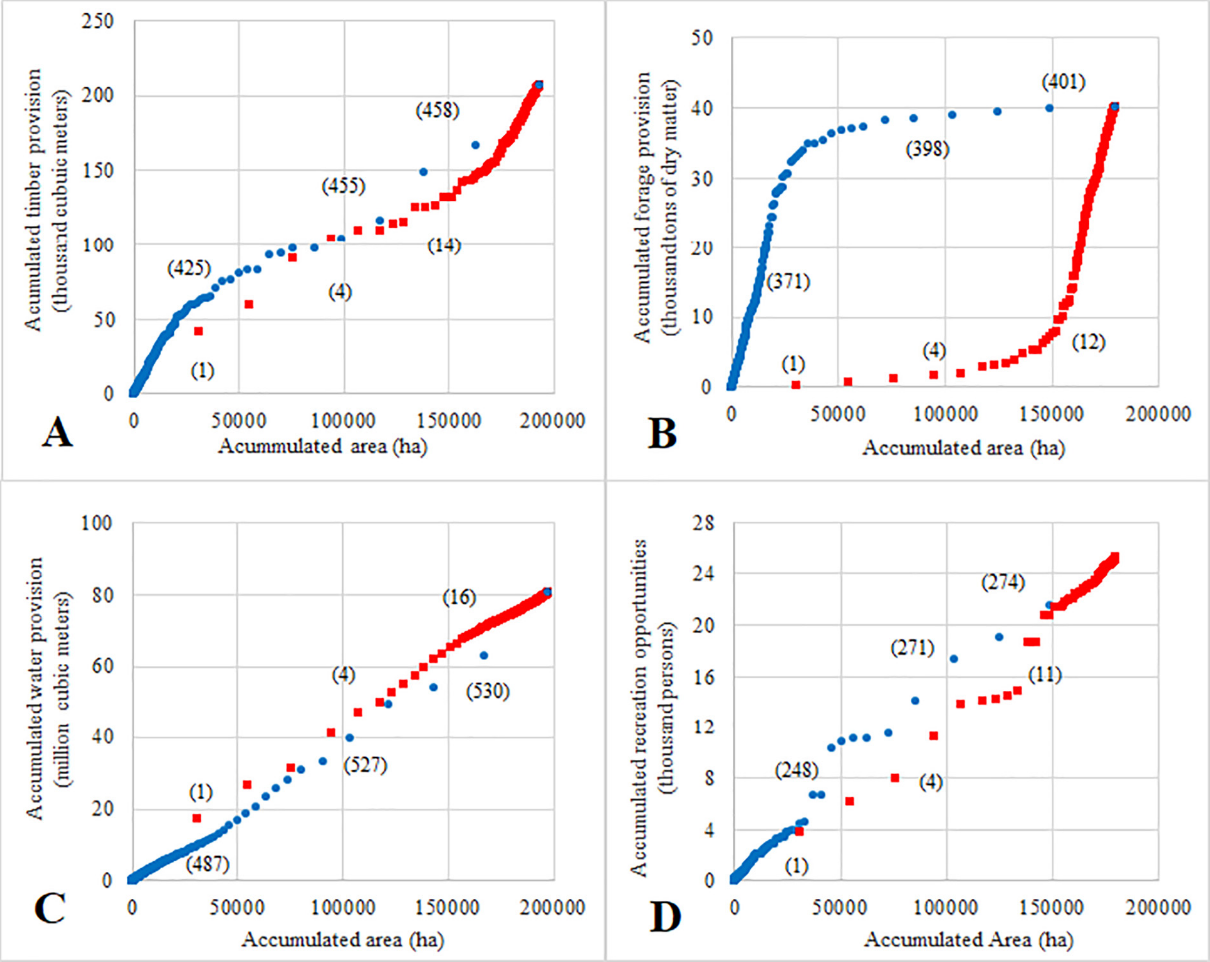

Fig. 5. Patterns of cumulative ES supply and area from small to large (blue dots) and from large to small (red dots) property sizes for timber (A), forage (B), water (C) and recreation opportunities (D) in Panguipulli municipality. Numbers in brackets along the dotted lines indicate the properties involved in targeting 10%, 50% or 80% of the area for conservation, in cumulative terms. The numbers change since only properties that deliver the particular ES are considered. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Panguipulli for example, a single privately owned protected area comprises 12.4% of recreation opportunities. This property is located on the highlands of the Andes range and preserves the majority of the remaining old-growth forest of the municipality and the region. Contrarily, both reduced farm size and the limited amount of forests become a limitation for the smallest properties to sustain such services.

Equity and social justice have come to be translated in "pro-poor" payments positively biased towards disadvantaged stakeholders (Wunder, 2015). Yet, feasibility of delivering ES could be more troublesome in small properties for several reasons. Firstly, too disperse small properties can make the implementation of a payment mechanisms difficult given the costs involved but, on the other hand, a strategic dispersion can provide the opportunity for heterogeneous multifunctional landscapes, which may mediate landscape pressures (land use change and intensification) and enhance ES supply and benefits in some working landscapes (Tuck et al., 2014).

Secondly, it is the question of how small can a small property be in order to secure ES supply. Although ES can be mapped at any desired resolution, this does not imply that the mapping unit is a viable ES providing unit (Luck et al., 2003). Ecosystem services emerge when a minimum scale threshold is met. In the context at hand, it is reasonable to argue that provision of ES from the smallest properties of less than a hectare might be simply too imperceptible for them to be targeted for payment programs.

Thirdly, small land holders are recognized to be more vulnerable to changes in surrounding conditions, such as market fluctuations or climate change (Harvey et al., 2014), which inevitably affects the ES supply at a given moment and its continuance over time. This is combined with high rates of forest loss in the smallest properties of the study areas, which mirrors the general situation of the country.

Finally, transaction costs for the implementing agency can be larger in the case of targeting smaller properties given the difficulty to get a large number of landowners organized for the joint provision of ES. There is explicit acknowledgment that "community-based PES schemes offer a particular challenge, as incentives aimed to influence individual behavior … pass through community institutions" (p. 1263) (Sommerville et al., 2010).

The results of this research strongly support the need for understanding ESSARs in order to evaluate how policy interventions can better promote the provision of certain ES, and avoid undesirable distributional and welfare effects. The results corroborate that when comparing small and large land properties, these are not equally capable to deliver ES and that tradeoffs are a binding constraint to such purpose, particularly in smaller farms which are sustaining provisioning ES at expenses of regulating and cultural ES.

Thus, the results warn about the need to reconsider criteria for targeting conservation efforts based on ES hotspots as promoted by several authors (Kolinjivadi et al., 2015; Wendland et al., 2010; Wünscher et al., 2008; Wünscher and Engel, 2012). In "landscapes of inequalities"

(Coomes et al., 2016) such as the ones studied here, focusing incentives based on supply hotspots contradicts the fundamental notion of the ES approach of reconciling nature conservation and human well-being.

These results come to contribute to a contended issue in ES literature and practice which is the need for ES payments interventions to avoid further inequalities. ES-based initiatives must be designed in ways that recognize the relative disempowerment of weaker groups such as small farmers and to ensure inclusion of the poor, since they are more dependent on common property assets like ES (Farley and Costanza, 2010; World Bank, 2016, 2017). They also need to recognize past injustices (Golub et al., 2013; Jerneck et al., 2011) that reflect today in the natural capital endowment and the capacity to sustain ES by different properties. ESSARs are equally relevant in the context of REDD plus implementation. Recent studies reveal the concentration of benefits associated to REDD plus projects due to historical development of land tenure patterns, involving dispossession and elite capture, which leave local people with little or no land entitlement. As the distributive policy of REDD plus projects maps onto the existing unequal land distribution, it reinforces inequality (Chomba et al., 2016).

The results are also in line with the Heredia Declaration on PES and recently proposed guidelines around payment schemes. Prominent in those principles and guidelines is the need to obtain baseline information to document initial conditions in order to continue to develop better methods to measure and monitor ES at multiple scales (Farley and Costanza, 2010; Naeem et al., 2015) and to support spatial targeting, payment differentiation among providers, and strong conditionality (Ezzine-De-Blas et al., 2016).

The ESSARs proposed and tested here and the results obtained are a contribution to ES research and practices towards answering the question if single large or several small properties should be targeted in ES incentive mechanisms, a question whose answer requires the necessary consideration of efficiency and equity criteria.

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