Land Use Policy 82 (2019) 247–257

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

A trilogy of inequalities: Land ownership, forest cover and ecosystem services distribution

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ARTICLE INFO

Keywords:
Green grabbing
Distributional justice
Ecosystem services supply inequality
Payments for ecosystem services
Inequality traps
Ecosystem services curse

ABSTRACT

A main challenge in sustainability sciences is to incorporate distributional aspects into ecosystem management and conservation. We explored and contrasted land ownership, forest cover and ecosystem services supply (ES) distribution in two municipalities of southern Chile (Panguipulli and Ancud), comprising 5,584 private properties. We relied on farm typologies data and ES indicators for forage, water regulation, and recreation opportunities. We calculated Lorenz curves and Gini coefficients to establish concentration ratios, and performed a hotspot analysis to determine ES supply distribution across properties. In both municipalities land ownership was highly concentrated: large properties (> 1,000–30,000 ha) represented less than 1% of total and comprised 74.5% and 20.7% of farm area, in Panguipulli and Ancud respectively. Forest cover distribution followed the same pattern (80.5% and 58.2%, respectively). As a result, water regulation and recreation opportunities concentrated in medium and large properties, whereas forage concentrated in small and medium ones. Gini coefficients ranged from relatively equal to relatively unequal for land ownership, forests cover and ES in both study areas. These inequalities reflect a historical land ownership concentration in private lands since colonial times, a structural condition that challenges both nature conservation and development and, therefore, it should be brought to the forefront of policy design in developing countries.

1. Introduction

Developing countries are keepers of the greatest biodiversity (Butchart et al., 2015; Montesino Pouzols et al., 2014) and ecosystem services (ES hereafter) worldwide (Turner et al., 2007). In the majority of these countries, nature conservation and ES supply rest on millions of individual small properties that coexist with large operations, in a reality of highly unequal land ownership distribution, which perpetuates unfairness and poverty (De Ferranti et al., 2004; OXFAM, 2016). It is no coincidence then, that a more equal access and better distribution of land tenure are included in at least three SDGs 2030: end poverty (goal 1), end hunger (goal 2), and achieve gender equality (goal 5). In turn, access to ES by women, indigenous and local communities and the poor and vulnerable, is the focus of Aichi Target 14.

Latin America (comprising México, Central America and South America) is the world's most unequal region in terms of land ownership distribution, with important consequences for natural capital, ES supply, and social stability (Alston et al., 1999; Fearnside, 2001; Sant'Anna, 2017). The Gini coefficient[1] for land ownership (Gini, 1909; Zheng et al., 2013) is 0.79 for the Latin American region as a whole, 0.85 for South America, and 0.75 for Central America. Within Latin America, Chile occupies the second place (after Paraguay) with a Gini coefficient of 0.91, representing near perfect inequality (OXFAM, 2016).

Despite the increasing relevance of inequality in environmental and development agendas, distributional issues are largely absent in sustainability research and policy (Coomes et al., 2016; Pascual et al., 2014), including the mounting investigation on ES and ES-based incentives conducted in developing countries (McDonough et al., 2017).

Recent studies show that ES-based incentives in the developing

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[1] The Gini coefficient measures the inequality among values of a frequency distribution (for example, levels of income or land sizes). A Gini coefficient of zero expresses perfect equality, where all values are the same (e.g., everyone has the same amount of land). A Gini coefficient of 1 (or 100%) expresses maximal inequality among values (e.g., one person holds all income or land and all others have nothing).

https://doi.org/10.1016/j.landusepol.2018.12.020
Received 6 March 2018; Received in revised form 10 December 2018; Accepted 10 December 2018
Available online 17 December 2018
0264-8377/

world, such as Payments for Ecosystem Services (PES) and REDD + are increasingly being allocated to larger properties capable to ensure ES supply at lower costs (Corbera and Brown, 2010; Lansing, 2014; Markova-Nenova and Wätzold, 2017; McDermott et al., 2013), which has set off important criticisms. Among them is the observation that these mechanisms can lead to the so-called "green grabs" (Jiao et al., 2015; Sikor, 2013; Tura, 2018), involving the privatization or appropriation of land and the exclusion of local people from natural resources on the basis of "green" qualifications (Fairhead et al., 2012). In turn, Kronenberg and Hubacek, 2016 (2016, 2013) have put forward the "ecosystem service curse" hypothesis to refer to the counterintuitive negative socio-economic consequences of PES, which they link, among others, to problems of unequal bargaining power between large and small landowners. PES are tied to land ownership, and therefore those owning larger properties and concentrating forest cover are entitled to an "elite capture" through the monopolization of access to natural resources (Andersson et al., 2018; Xuan To et al., 2012). Selecting only the least-cost larger suppliers of ES for payments may result in unfair outcomes, every time that efficiency considerations allow a few, powerful land users to secure most of the payments (Börner et al., 2017; Corbera et al., 2007; Jindal et al., 2013). There is growing consensus that fair outcomes have a fundamental role in determining the political and social legitimacy of conservation incentives and thus the longer-term success and sustainability of such programs (Corbera and Pascual, 2012; Landell-Mills, 2002; Muradian et al., 2013; Narloch et al., 2013).

Land ownership distribution, and farm size in particular, can condition farm capacities and rural livelihoods in three main ways (Coomes et al., 2016).Firstly, it determines how people use their resources. For example, farmers with less land might use it more intensively, leading to resource degradation (Michalski et al., 2010) and reduced capacity to provide ES. Secondly, a larger amount of land can generate more income, which in turn can be invested in improving access to other resources (e.g., irrigation infrastructure) and thus increase wealth (Ellis, 2000; Tole, 2004). Lastly, since more land correlates to wealth, farmers holding larger tracks of land can more easily diversify production, including the supply of ES, and consequently reduce risk (Ray, 1998; Vosti and Reardon, 1995). It is therefore likely that concentration of land ownership and forest area equate to a greater capacity of large properties to supply ES, which is the hypothesis underlying this research. As a result, large properties would be better endowed to benefit from ES transactions in existing markets (e.g. timber; food) and from PES mechanisms focused on regulating and cultural ES (Locatelli et al., 2008; Pagiola et al., 2010), which can lead to further inequalities, as observed in recent studies (Lansing, 2017, 2014).

Most examples of successful implementation of ES-based incentive mechanisms such as the one in Mexico (Arriagada et al., 2018; Ezzine-De-Blas et al., 2016; Rodríguez-Robayo and Merino-Perez, 2017) have taken into account distributional issues in order to avoid elite capture and marginalization of smaller landowners.

In this study we explore and contrast land ownership, forest cover and ES supply distribution in two municipalities of southern Chile, Panguipulli in the Andes range and Ancud in Chiloé Island in the coastal range, based on information from 5554 private properties. We expect to find similar results in both areas despite the different environmental settings, since both municipalities share similar past legacies since colonial times. Natural resources concentration in private lands in Chile is a structural condition that challenges both nature conservation and development, and therefore, it should be brought to the forefront of sustainability research and policy design.

2. Study areas

The two selected areas are located in the Temperate Rainforest Ecoregion of Chile (Fig. 1). They both correspond to long-term research areas (over 5 years), from which relevant spatial, economic and social information was collected, that represents the basis for the present study. Both are dominated by peasant agricultural systems characteristic of Latin American countries. In Chile there are no public forest lands or community held forest such as in other Latin American countries. Instead a private regime dominates. Given the purpose of our analysis we only included private protected areas and not public protected areas as National Parks.

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 (Fig. 1a). It has an area of 3292 km^2 of which less than 0.5% is classified as urban land. The latest census reported a total population of 33,273 people (INE, 2018). Table 1 summarizes some key features of both study areas.

In turn, Ancud municipality, Inner Sea of Chiloé Island (41°50′ - 42°15′S and 73°15′-74°15′W), is situated in the province of Chiloé in Los Lagos Region, southern Chile (Fig. 1b). It covers a territory of 1724 km^2 of which less than 1% is urban land. According to the population and housing census released in January 2018, the total population of Ancud reaches 39,946 people (INE, 2018).

3. Methods and data

3.1. Farm types and size ranges

Chile does not have a unifying farm size classification. For agrarian governmental agencies, small farms are those with less than 12 ha of basic irrigation. This unit of measurement depends on land productivity and therefore one basic irrigation hectare can range from one physical hectare in the most productive soils of the country, to 500 ha or more in the least productive soils. In turn, forestry governmental agencies consider small properties as those with a size up to 200 ha, which contain mostly forest cover (Law 20,283 of 2008), whereas there are no clear size limits for medium and large farms. Thus, we relied on previous studies, census data, and expert opinion to define three farm categories representative of and common to both study areas: small properties, holding less than 60 ha, medium properties comprising between 61 and 1000 ha, and large properties holding above 1000 ha.

In Ancud, small properties are multifunctional peasant farms, combining cattle farming (average of 6 cows and 14 sheep) based on natural pastures, usually degraded, native timber extraction and potato crop (Carmona et al., 2010). In Panguipulli, they are also multifunctional farms, combining subsistence forestry, including small non-native tree plantations (Gerding, 1991; Salas et al., 2016) used as firewood source; vegetable and cereal production usually for self-consumption; and livestock (4 cows and 6 sheep in average) for milk and meat production in natural pastures (only 19% of pastures are managed or improved).

In Ancud, medium properties develop mostly agricultural activities, such as livestock rising, obtaining dairy products and meat, with an average of 34 cows and 10 sheep. They hold near equal proportions of agricultural land and forest cover, including increasing areas of non-native tree plantations which compensate for native forest degradation (Carmona and Nahuelhual, 2012). In Panguipulli, medium properties tend to be more specialized in cattle rising (average of 116 cows) based on managed pastures (80% of total) but they have also established expanding areas of non-native tree plantations.

In Ancud, large properties are mostly dedicated to timber extraction from native forest and exhibit high rates of forest degradation (Carmona and Nahuelhual, 2012); they also hold non-native tree plantations for industrial purposes. In Panguipulli large properties combine forestry (native forest and non-native tree plantations) and nature-based tourism on a large scale (e.g., a single private protected area received more than 40,000 visitors in 2015 (SERNATUR, 2015)).

Spatial property data was obtained from three main public data sources: i) Farm Cadastral Map (CIREN CORFO, 1999): digital cartography of rural properties at scale 1:20,000 that provides information on farms' area and contour; ii) Internal Revenue Service data base: digital cartography of properties at scale 1:10,000 for the year 2016,

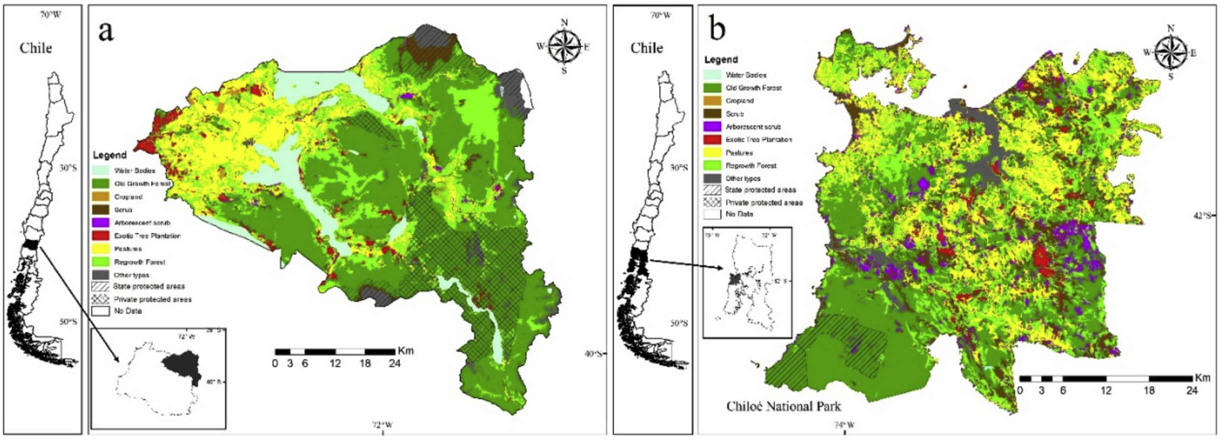

Fig. 1. Location of study areas in Panguipulli municipality in Los Ríos Region (a) and Ancud municipality in Los Lagos Region (b), southern Chile. The legend indicates the main land use and land cover types in each case study and the location of public and private protected areas.

Table 1
General description of study areas within the country's context.

	Chile	Panguipulli	Ancud
Number of properties[a]	476,475	2,828	2,756
Native forest area (ha)[b]	14,316,822 (18.9%)	177,559 (54%)	123,150 (71.4%)
Rural population (%)	13.4%	55.8%	27.5%
Small properties (conventionally < 60 ha)[c]	423,278 (90.9%)	2512 (88.8%)	2310 (83.8%)
Annual rate of native forest loss (1998-2006) (%)	2.9[d]; 3.28[e]	0.5[f]	6.1[g]

[a] and c: Based on CIREN-CORFO (1999). Total number of farms excludes the regions of Arica and Parinacota, Antofagasta, and Atacama as well as high Andean zones, for which farm cadastral information is not available.
[b] Forest area includes state (parks, reserves and monuments) owned and privately owned native forests.
[d] Miranda et al. (2015).
[e] Armenteras et al. (2017).
[f] Own calculations based on FAO (2002).
[g] Own calculations based on Carmona and Nahuelhual (2012).

which provides information about the property and the landowner; 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 updates in 2006 and 2013–2014 (for the study regions).

3.2. Assessment of ecosystem services supply at farm level

The selected ES were identified as important for local stakeholders during workshops and expert consultations held in previous years (see Laterra et al., 2016; Nahuelhual et al., 2018; Tapia, 2015). Indicators of these ES were developed during the coming years (see Jullian et al., 2018; Nahuelhual et al., 2018, 2017, 2013) using secondary information, combined with expert consultation and public perception questionnaires. These indicators are briefly described below (Fig. 2), whereas details are provided in SI.1.

Forage supply is the amount of biomass that can be potentially or currently extracted from a pasture in a year, 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. In the case of Ancud the final function is the following (Equation 1):

$$Q = 0.04\,pH + 0.27\,sd + 0.09st + 0.3fz + 0.3li \quad (1)$$

where Q is the amount (tons) of dry matter per hectare, pH is the hydrogen potential of soil; sd is the mean soil depth of a given soil series; st is the soil type (clay or volcanic ash soil); fz is the dose of phosphorous fertilizer; and li is the dose of lime applied to pastures (to correct acidification). The indicator was spatialized in a 30 x 30 m raster map generated with ArcGIS 10.3.

In the case of Panguipulli, the indicator equation is the following (Equation 2):

$$Q = 0.15\,pH + 0.08\,sd + 0.04st + 0.22fz + 0.22li + 0.26ir + 0.03alt \quad (2)$$

where two aditonal variables are added given the geographic and managerial conditions of the study area, namely ir which is the irrigation applied to an area, and alt, the altitude. The differences between Equations 1 and 2 are due to the fact that experts in each study area identified diffent variables to explain forage supply and gave diffent weights to each variable.

In the case of water regulation, the construction of the indicator relied on the application of ECOSER protocol (Laterra et al., 2015) (www.eco-ser.com.ar) through Arcgis 10.3 and its tool "retention of excess precipitation through vegetation cover" measured in cubic meters per hectare, considering ranges of occurrence of storms in a 24 h period and return periods of two years (Jullian et al., 2018). ECOSER relies on an empirical index called Curve Number (CN), developed by United States Department of Agriculture (USDA, 1986). The procedure estimates the ability to regulate the rainfall considering the type of vegetation and the physical characteristics of the soil (Jullian et al., 2018). Water regulation must be understood here as the capacity of regulate surplus after a storm. More water surplus then would imply that the specific land cover has less capacity to regulate water acting as an inverse indicator (Qiu et al., 2018) (more water per ha in this case means less water regulation).

Recreation opportunities indicators also differ across study areas for the same reasons as forage. 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, which were represented by specific spatial criteria validated and weighted by tourism planners and eco-tourists during focus groups. In Panguipulli instead, the indicator is composed of three variables: 1) tourism use aptitude, scenic beauty, and accessibility. The variables were weighted by individual preferences obtained through an online survey applied to 278 people between May and September of 2016. Both indicators are expressed in the number of people that a given hectare can sustainably hold.

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). We

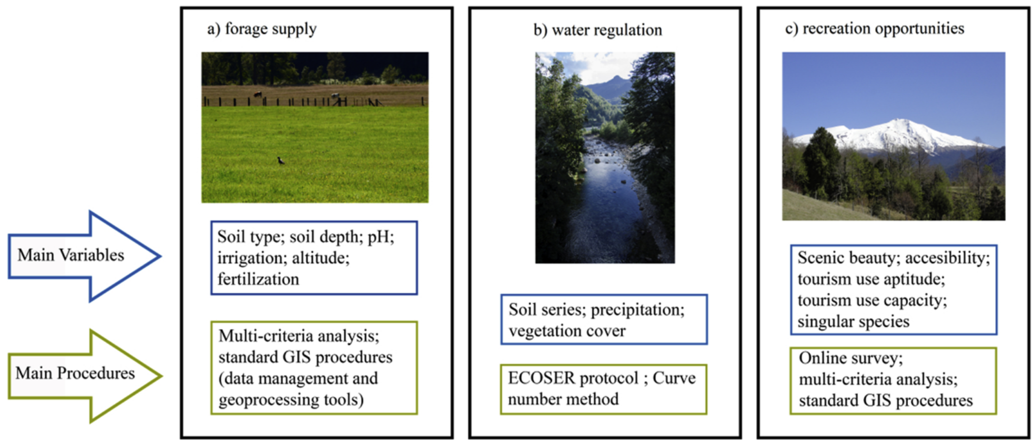

Fig. 2. Main variables and procedures used in the construction of indicators of forage supply (a), water regulation (b), and recreation opportunities (c).

believe that the slight differences in indicators' construction does not present a limitation but rather an opportunity to show that distributional ES supply patterns are influenced by property size independently of the indicators structure. The three indicators are widely replicable as they rely mostly on secondary data sources that are typically available in developing countries.

3.3. Gini coefficients calculation

We adapted a version of the land Gini coefficient developed by Sun et al. (2010) and applied it to the assessment of land ownership, forest cover and ES supply concentration. The standard Gini coefficient (Gini, 1909) is mathematically defined based on the Lorenz curve, which plots the cumulative proportions of a variable, sorted in an increasing order (y axis), against corresponding cumulative proportions of a second variable (x axis). The 45° line represents perfect equality. The area between the Lorenz curve and the line of perfect equality represents the degree of concentration. This, in fact, is the basis for Gini's concentration ratio.

The formula used is the following:

$$G = 1 - \sum_{k=1}^{k=n-1} (X_{k+1} - X_k)(Y_{k+1} - Y_k) \tag{3}$$

Where G is the final Gini coefficient value, X_k is the cumulative number of properties and Y_k is either the cumulative percentage of the supply of a particular ES or the land or forest area of each property. When $k = 1$, $Xi - 1$ and $Yi - 1$ are both equal to 0.

For interpretation of the Gini coefficients we used the ranges proposed by Zheng et al. (2013): < 0.2 is "absolutely equal"; 0.2 to 0.3 is "relatively equal"; 0.3 to 0.4 is "reasonable"; 0.4 to 0.5 is "relatively unequal"; and > 0.5 is "absolutely unequal". In the calculations, we only included property owners and excluded people who were not formal title holders.

3.4. Ecosystem service hotspot analysis

To determine the spatial concentration of ES supply we performed a hotspot analysis. In ES research, applications and techniques to evaluate hotspots vary widely, from summing ES maps to obtain "perceived supply" (Willemen et al., 2017) to the optimization of single biophysical maps of ES (hotspot areas of one specific ES), which is the approach followed here. We used ArcGis 10.3 optimized hotspot analysis tool, which creates a map of statistically significant hotspots and coldspots using the Getis-Ord Gi* statistic. The Getis-Ord Gi* statistic (see De Vreese et al., 2016) identifies where high or low values tend to cluster, compared with random distributions. The output of the Gi* statistic is a z-score for each grid cell (Fagerholm and Kayhko, 2009; Zhu et al., 2010). The Gi* characteristic is calculated according to Getis and Ord (1992) and automatically aggregates incident data, identifies an appropriate scale of analysis, and corrects for both multiple testing and spatial dependence. In this case, incident data are either total values of land and forest cover (in hectares), or average supply per hectare of the three different ES.

4. Results

4.1. Property area, forest cover and ES supply concentration

In Panguipulli large properties hold 80.6% and 19.4% of old growth and secondary forests, respectively, which are almost identical to the proportions in Ancud (80.2% and 20.8%). In Panguipulli and Ancud, medium properties hold similar proportions of old growth and secondary forests. In turn, small farmers hold mostly secondary forests (78.2% in Panguipulli and 68.6% in Ancud), which are often degraded as the result of forest logging without proper management criteria. According to Reyes et al. (2016), in Panguipulli municipality about 67% of landowners extracts timber without authorization (without a management plan), of which 48% commercializes firewood.

Small farmers in both study areas generally comprise indigenous owners, whereas there are no indigenous landowners in the segment of large properties and very few in medium properties.

The results in Fig. 3 show that water regulation and recreation opportunities are clearly concentrated in large properties in Panguipulli, and in medium and large properties in Ancud, which coincides with the concentration of native forest area in these properties (Table 2). On the contrary, forage supply is concentrated in small and medium properties, which hold proportionally more pasture area. In terms of ES supply per ha, large properties exhibit the highest averages for all ES in both study areas, with the sole exception of annual forage/ha in Panguipulli and Ancud, which is lower in large farms.

Gini coefficients for land ownership present similar values in both study areas (Fig. 4). According to Zheng et al. (2013) (see methods section), the Gini coefficient for land ownership in Panguipulli falls within the "relatively unequal" category, while for Ancud it falls within the "relatively equal" category. In turn, Gini coefficients for forest cover reveal that Panguipulli has a more unequal distribution of forest area across property sizes, while this value falls within the "relatively equal" category in the case of Ancud.

Among ES, forage supply falls within the "relatively equal" and "reasonable" categories in Panguipulli and Ancud, respectively. This can be attributed to the fact that pasture, unlike forest cover, are more equally distributed across properties and proportionally dominate in small and medium properties.

In the case of water regulation, values fall within the "relatively

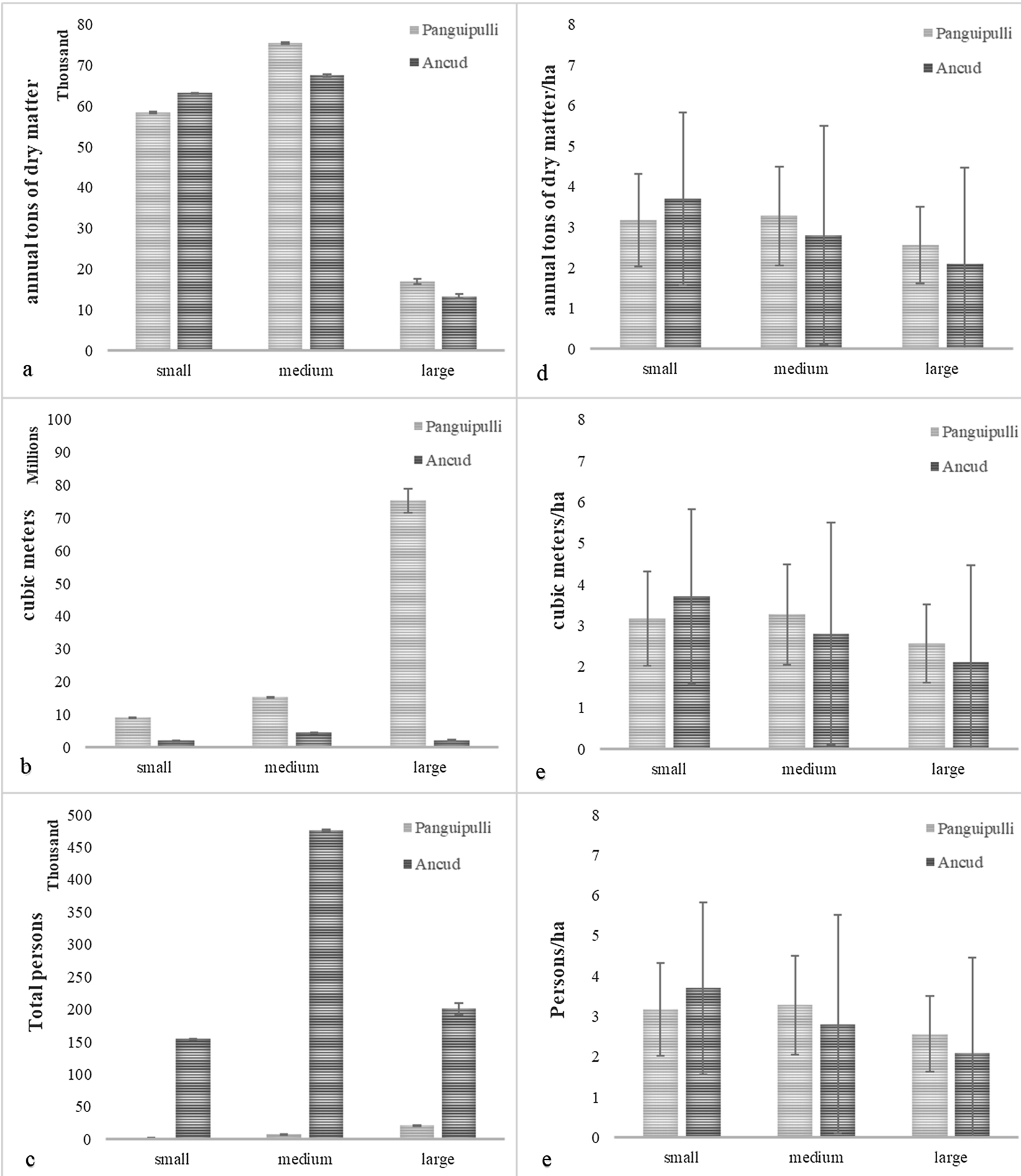

Fig. 3. Ecosystem service total supply (a, b, c) and supply per hectare (d, e, and f) in both study areas (*y* axis) and for each size category (*x*-axis). Error bars represent the standard deviation.

unequal" and "relatively equal" categories in Panguipulli and Ancud, respectively. Recreation opportunities is the most unequally distributed ES, with values of 0.49 and 0.46 for Panguipulli and Ancud, respectively (Fig. 4).

4.2. Spatial patterns of ES distribution

Hotspot analysis corroborates the concentration of ES supply in small properties in the case of forage, and in medium to large properties in the case of water regulation and recreation opportunities.

4.2.1. Forage distribution

In Panguipulli, forage supply hotspots represent 67.8% of the total pasture area and 73.1% of total forage supply. About 40% of hotspots and 37.4% of coldspots are located in small properties. Medium size properties concentrate 58% of hotspots and 18.4% of coldspots. In turn, large properties comprise only 2.4% of the hotspots, but the majority of coldspots (44.2%) (Table 3).

In the case of Ancud, forage supply hotspots represent 13.3% of the pasture area and 19.6% of total ES supply, which are considerable lower percentages than in Panguipulli. Both hotspots (54.7%) and coldspots (57.1%) concentrate in medium farms. However, mean supply values within hotspots are higher in large properties in both municipalities.

Table 2
Main features of properties across size ranges.

	Panguipulli			Ancud		
	< = 60 ha	61-1000 ha	> 1000 ha	< = 60 ha	61-1000 ha	> 1000 ha
Number of properties	2512 (88.7%)	289 (10.2%)	30 (1.1%)	2310 (83.8%)	431 (15.7%)	15 (0.5%)
Average property size (ha)	12	185	1,163	17	174	2,002
Total land area (ha)	30,032 (9.2%)	53,318 (16.3%)	243,793 (74.5%)	39,335 (27.1%)	75,672 (52.2%)	30,023 (20.7%)
Forest area (ha)	10,125 (5.7%)	24,484 (13.8%)	142,950 (80.5%)	14,185 (11.5%)	37,320 (30.3%)	71,645 (58.2%)
Old-growth forest (ha)	2208 (21.8%)	10,787 (44.1%)	115,259 (80.6%)	4451 (31.4%)	18,426 (49.4%)	34,151 (80.2%)
Secondary forest (ha)	7917 (78.2%)	13,698 (55.9%)	27,691 (19.4%)	9733 (68.6%)	18,894 (50.6%)	8423 (19.8%)
Pasture area (ha)	18,013 (38.8%)	22,160 (47.7%)	6304 (13.6%)	15,706 (44.3%)	16,088 (45.4%)	3646 (10.3%)
Indigenous landowners (%)	35.5%	4.1%	0%	9.8%	3.1%	0%
Average forest area per property (%)	41.7%	41.2%	82.3%	34.9%	48.8%	64.1%
Average pasture area per property (%)	71.6%	52.7%	9.4%	44.1%	25%	14.5%

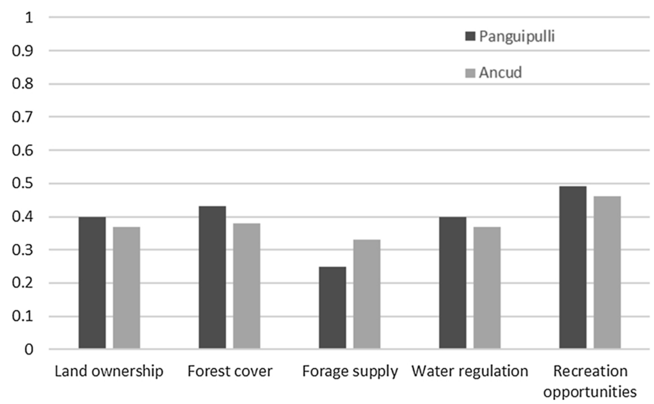

Fig. 4. Gini coefficients for land ownership, forest cover and ES supply in Panguipulli and Ancud municipalities, where 0 represents perfect equality and 1 perfect inequality.

4.2.2. Water regulation distribution

In Panguipulli, hotspots represent 22% of the total area sustaining the ES and 32% of total water regulation. Hotspots are mostly located in large properties (92%), while coldspots are located mostly in medium properties (52.1%) and large properties comprise more supply (32,664,515.7 m^3) than small and medium ones combined. However, mean supply values within hotspots are relatively similar across property sizes, ranging from 480.8 (m^3/ha) in small properties, to 571.5 (m^3/ha) in large ones (Table 4).

In the case of Ancud, water regulation hotspots represent 46% of the total areas sustaining this ES and 44.4% of total supply. On the other hand, coldspots represent 23.1% of the area and 21.8% of the total supply. Non-significant areas comprise the majority of the area sustaining this ES. Regarding distribution across property sizes, hotspots are spread rather evenly, with 14.7%, 55.7% and 29.6% located in small, medium and large properties, respectively.

4.2.3. Recreation opportunities distribution

In Panguipulli, recreation opportunities hotspots represent about 7.2% of the total area that sustains this ES and 53.8% of the total supply of it (Table 5). Recreation opportunities clearly concentrate in large properties (73.4%), however, mean provision values are fairly similar across property sizes, ranging from 0.6 and 0.8 persons. Large properties comprise more supply (14,205 persons) than the other two ranges combined (4005 persons).

In Ancud, hotspots represent 40.2% of the total area sustaining this ES and 53% of total supply. Medium farms concentrate the hotspots (46.2%) and also exhibit the highest supply per unit of area (8 persons/ha) (Table 5).

Table 3
Results from hotspot analysis for forage supply in both study areas.

	Panguipulli			Ancud		
Size range (ha)	< = 60 ha	61-1000 ha	> 1000 ha	< = 60 ha	61-1000 ha	> 1000 ha
Total area within hotspots (ha)	12,537 (39.8%)	18,242 (57.9%)	741 (2.4%)	4988 (16.6%)	10,476 (19.6%)	3672 (1.5%)
Total area within coldspots (ha)	638 (37.4%)	314 (18.4%)	753 (44.2%)	5841 (32.5%)	10,256 (57.1%)	1879 (10.5%)
Total supply within hotspots (annual tons of dry matter)	43,115 (39.1%)	64,500 (58.6%)	2516 (2.3%)	26,209 (32.3%)	42,830 (52.8%)	12,028 (14.8%)
Mean supply within hotspots (annual tons of dry matter/ha)	3.8	3.9	4.2	5.9	6.4	8.1

Table 4
Results from hotspot analysis for water regulation in both study areas.

	Panguipulli			Ancud		
Size range (ha)	< = 60 ha	61-1000 ha	> 1000 ha	< = 60 ha	61-1000 ha	> 1000 ha
Total area within hotspots (ha)	2389 (4%)	2349 (3.9%)	55,537 (92.1%)	10,481 (14.7%)	39,714 (55.7%)	21,058 (29.6%)
Total area within coldspots (ha)	24,374 (30.8%)	41,204 (48.2%)	13,467 (20.3%)	19,462 (52.5%)	13,154 (35.7%)	4395 (11.7%)
Total supply within hotspots (m^3)	1.17. E + 06 (3.3%)	1.23. E + 06 (3.5%)	3.27. E + 07 (93.1%)	2.21. E + 06 (14.4%)	8.52. E + 06 (55.6%)	4.59. E + 06 (30%)
Mean supply within hotspots (m^3/ha)	481	494	572	210	214	217

Table 5
Results from hotspot analysis for recreation opportunities in both study areas.

	Panguipulli			Ancud		
Size range (ha)	< = 60 ha	61-1000 ha	> 1000 ha	< = 60 ha	61-1000 ha	> 1000 ha
Total area within hotspots (ha)	1043 (6.3%)	3333 (20.2%)	12,089 (73.4%)	8667 (13.2%)	30,347 (46.2%)	26,743 (40.7%)
Total area within coldspots (ha)	6045 (15.5%)	9036 (23.2%)	23,645 (61.4%)	16,197 (29.7%)	22,900 (42.8%)	15,433 (28.3%)
Total supply within hotspots (persons)	782	3,123	14,205	56,654	244,420	206,269
Mean supply within hotspots (persons/ha)	0.8	0.9	1.0	6.5	8.0	7.6

Fig. 5 shows the spatial distribution of properties and ES hotspots for each study area. Farm polygons clearly depict the disparate property sizes, particularly in Panguipulli (0.1 to 30,000 ha). Small properties in Panguipulli are generally located on the west side of the municipality, whereas large farms concentrate in the Andes range at the head of important watersheds, in elevations ranging from 80 to more than 2,800 m above sea level. The top 10% of largest properties (28 properties) comprise 76% of water regulation and 63% of recreation opportunities.

In Ancud the spread of property sizes is narrower (0.1–4,568 ha). In this case, the 10% of largest properties (28 farms) comprise 26.8% of water regulation and 32.4% of recreation opportunities.

5. Discussion and conclusions

This study has explored the links between land ownership, forest cover and ES supply distribution across the rural landscape of southern Chile. Two main findings emerge from this research. Firstly, the inequality in land ownership and forest cover distribution unequivocally leads to concentration of water regulation and recreation opportunities in larger farms, which presently use resources less intensively than smaller properties. In turn, small properties depend on intensive firewood extraction to sustain family income and energy needs, which has led to important rates of forest degradation.

Secondly, patterns of ES supply distribution depend on the interaction among property size, ES supply per unit of area, property location, and the total number of properties comprising each size range. Water regulation is concentrated in medium to large properties with two mechanisms explaining this outcome: i) location; and ii) the presence of well-conserved native forests on these properties. In Ancud, water regulation is concentrated in medium size properties located near Chiloé National Park and in elevations higher than the remaining properties, in watershed heads. In Panguipulli, water regulation is concentrated in large properties located in the high Andes range, where precipitations are higher. These properties also comprise the most well-preserved forests, located in a continuous native forest matrix.

In turn, recreation opportunities are concentrated in large properties in both study areas, which can be explained by two mechanisms: i) the concentration of singular natural resources that can occur in larger areas; and ii) the strategic location of large properties near scenic views. In Panguipulli for example, a single private protected area comprises 12.4% of recreation opportunities. This property is located in the highlands of the Andes range and preserves the majority of the remaining old growth forest of the municipality. Within its limits, it contains unique landscape attributes such as water falls, lakes and a volcano.

Conversely, forage supply is concentrated in small and medium size properties, with two mechanisms explaining this outcome: i) small and medium properties have higher proportions of pastures than large properties (see Table 2) as they have historically deforested to open up grassland areas; and ii) pasture productivity tends to be higher in small to medium properties than in larger ones. This difference can be partially explained by fertilization subsidies which are specifically allocated to small and medium properties in order to sustain livestock production.

Thus, ES supply inequality relates to two distinct types of land ownership inequality, namely land size and land use inequality (Zilberman, 2008; Coomes et al., 2016). The effect of property size is determined by the extent of the farm itself and by the area of forests held by larger properties, which influence water regulation and recreation opportunities. Contrarily, both the reduced property size and the limited amount of forest cover (among other natural resources) becomes a limitation for the smallest properties to sustain water regulation and recreation opportunities. It is important to notice that the Gini coefficients tend to soften these disparities (values near 0.5 indicate that inequality is not as high as the raw data suggests). This, nonetheless, finds an explanation in the fact that typical applications of Gini coefficients consider a much larger amplitude of values for the observed variable (e.g., incomes of the entire population) (Gogas et al., 2017; Molero-Simarro, 2017) as compared to the number of properties considered in this study.

Land use inequality in turn, arises from the fact that among large properties either a non-extractive use prevails (some properties are dedicated to ecotourism) or they are used more extensively (they extract timber but from a proportionally smaller area); this allows them to conserve forests, which equates to a better capacity to sustain water regulation and recreation opportunities. In turn, small properties are continuously pressing their remaining and impoverished forests to open grasslands or extract firewood, dynamics that have been observed in other studies (Chomitz et al., 2007; Reyes et al., 2016).

These findings have important implications for the implementation of the Ecosystem Service Approach in developing countries. Firstly, property size and land use inequalities condition small farmers to remain suppliers of low valued provisioning ES (forage, timber) at the expense of their possibility to provide other ES compensated through payments, given the inherent trade-offs that conservation imposes onto these farms (Grossman, 2015; Narloch et al., 2013; Zilberman et al., 2008). Secondly, property size and land use inequalities and the effects of both on the capacity of farms to provide ES, are highly relevant factors when shaping ES-based interventions and PES mechanisms in particular. An efficiency focused ES policy will result in land being allocated to its highest and best use (total benefits to society are maximized, including the amount and value of ES) (Benjamin and Sauer, 2018; Polasky et al., 2014). Under such efficiency criteria, conservation efforts will almost unequivocally favor large properties (Fletcher, 2012; Lakerveld et al., 2015; Lansing, 2014) which already concentrate land property and forest area, thus consolidating a “trilogy of inequalities”. Such results would seem to confirm the worst fears of ES critics: that creating a market-based system of conservation will favor the wealthy and well connected, and ultimately exacerbate land ownership and wealth inequality (e.g. Mcafee and Shapiro, 2010; Wittman and Caron, 2009; Kronenberg and Hubacek, 2013).

Being inequality a complex issue, recommendations from these results are necessarily restricted in scope and limited to potential further actions in ES-based policies. Firstly, it is important 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

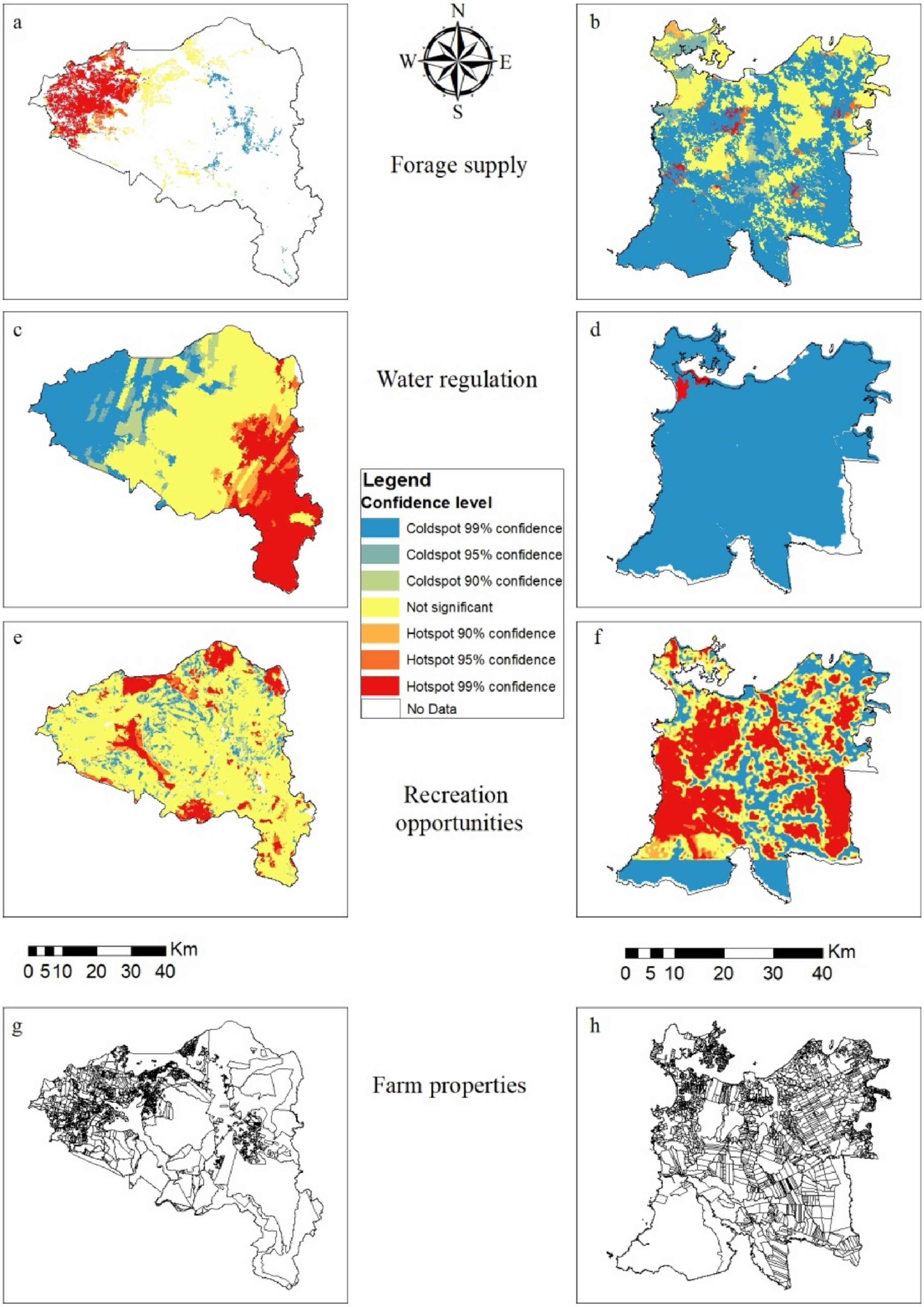

Fig. 5. Hotspot maps for forage supply, water regulation, recreation opportunities and property limits maps, for Panguipulli (a, c, e, g) and Ancud (b, d, f, h), respectively.

inequalities" (Coomes et al., 2016) such as the ones considered here and those that characterize developing countries, targeting hotspots to allocate conservation incentives would benefit a reduced group of landowners. Several studies have shown that a key determinant of acceptability and success of payments mechanisms is the perceived fairness of the intervention (Pascual et al., 2014; Rodríguez de Francisco et al., 2013; Sommerville et al., 2010). Somerville et al. (2010), for example, show that a lack of benefits accruing to those individuals facing high agricultural opportunity costs and evidence of some groups securing excessive benefits, was a barrier to success in some communities.

Secondly, if the Ecosystem Service Approach is to simultaneously deliver conservation and well-being, the disparate capacities of small and large farmers to provide ES and the reasons behind ES supply inequalities cannot be concealed. This omission can reinforce "inequality traps" which serve to keep people poor and deprived (Rao, 2006: p1). Inequality traps refer to strengthening a system of economic, political and social structures that lead to what social scientists have called durable inequality (Tilly, 1998). This situation represents a pattern of access to natural resources more broadly, in which efforts to include the marginalized within an access regime are accompanied by practices of governance that work to exclude the very same groups (Larson and Ribot, 2007; Sandbrook et al., 2010).

Thirdly, it is the need to construct ES baselines at the farm level that truly support accountability, monitoring and evaluation. This would allow, among others, payment differentiation among providers (Ezzine-De-Blas et al., 2016). Undeniably, the lack of complete, high-resolution and updated spatial information on farms and ES indicators is a primary obstacle to achieve these recommendations in developing countries (Di Minin and Toivonen, 2015; Stephenson et al., 2017), one that needs to be overcome as better and more systematic information on ES is available at different scales (Cord et al., 2017).

All the former can only be addressed if conservation and development policies are truly aligned. Whereas tackling ES loss and addressing persistent inequality (and poverty) in developing countries are stated international goals, the convergence to date has been superficial, with few evidence of integrated decision-making or coordination between conservation and development sectors (Roe et al., 2013). A real focus on distributional aspects by ES and conservation researchers and practitioners, which transcends the rhetoric, involves recognizing the importance of i) the context as a factor shaping these inequalities (Rodríguez-Robayo and Merino-Perez, 2017), ii) the relative disempowerment of weaker groups such as small farmers (World Bank, 2017, 2016), and iii) past injustices (Golub et al., 2013; Jerneck et al., 2011), and also extends to the need of designing public action to promote greater "equality of agency" (Rao, 2006: p3) with respect to existing social hierarchies. In this manner, smaller and more disadvantaged landowners may be able to benefit from ES transactions and have the power to influence the market from which they are expected to receive compensation.

Acknowledgements

This work was funded by CONICYT Chile through FONDECYT grant Nº 1151187 and FONDAP grant Nº 15150003 and by the Inter-American Institute for Global Change Research which is supported by the US National Foundation (Grant GEO-1128040).

The authors wish to thank Cristobal Jullian for his assistance in the development of ecosystem services indicators and two anonymous reviewers whose comments helped to improve the manuscript.

Appendix A. Supplementary data

Supplementary data related to this article can be found in the online version, at doi:https://doi.org/10.1016/j.landusepol.2018.12.020.

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