Biodiversity and Conservation

Silvopastoralism, local ecological knowledge and forest trajectories in a Category V-type management area

--Manuscript Draft--

Manuscript Number:	BIOC-D-20-00263R1
Full Title:	Silvopastoralism, local ecological knowledge and forest trajectories in a Category V-type management area
Article Type:	Original Paper
Keywords:	Agriculture; smallholders; silvopastoralism; disturbance; conservation; ILK; Ethnobiology
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Funding Information:	FP7 People: Marie-Curie Actions (Agreenskills +) — Dr. Meredith Root-Bernstein
	CONICYT, Chile (CONICYT PIA/BASAL FB000) — Not applicable
	Fondecyt Iniciación (11160672) — Dr. Francisco Zorondo-Rodríguez
	FONDECYT Regular (No. 1140598) — Not applicable
Abstract:	Preserving landscape heritage elements and indigenous and local knowledge is an increasingly popular approach in conservation. We focus on a globally very contentious practice, silvopastoral livestock raising, which along with other peasant practices, is slated for elimination according to projected Chilean conservation policy. We used ecological surveys to ask how central Chilean semi-arid woodlands in the locality of Alhué have responded to past human livelihoods practices, including silvopastoralism. Using interviews, we examined local ecological knowledge and uses of forest plants. We also conducted surveys on current agricultural practices. Many residents maintain a diversified, smallholder subsistence agricultural strategy. Residents identified 113 plants with 73 uses. They also demonstrated a good knowledge of woodland regulations. We found that woodlands recover well from historical disturbances over 50-100 year time scales. In fact, the presence of cattle

	year-round in the woodlands was associated with greater tree regeneration. We find that despite the conservation discourse, there is no evidence of a degradation problem, and we hypothesize based on our findings that eradicating peasants' silvopastoralism and other practices could increase degradation. We recommend that the Conservation Landscape programme be used to save key traditional practices, which should be studied further to determine optimal management. We show how conflicts and misalignments within and between ILK, data, and environmental discourse can signal complex socio-ecological issues where a closer look at how the evidence fits together is necessary.
Response to Reviewers:	Dear Dr. Hawksworth, We have taken your advice and combined the two papers into one. I hope you will now consider it for review. Regards, Meredith Root-Bernstein

Silvopastoralism, local ecological knowledge and woodland trajectories in a Category V- type management area

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Words total: 9800 (without abstract) 9200 (without abstract & tables)

Abstract

Preserving landscape heritage elements and indigenous and local knowledge is an increasingly popular approach in conservation. We focus on a globally very contentious practice, silvopastoral livestock raising, which along with other peasant practices, is slated for elimination according to projected Chilean conservation policy. We used ecological surveys to ask how central Chilean semi-arid woodlands in the locality of Alhué have responded to past human livelihoods practices, including silvopastoralism. Using interviews, we examined local ecological knowledge and uses of forest plants. We also conducted surveys on current agricultural practices. Many residents maintain a diversified, smallholder subsistence agricultural strategy. Residents identified 113 plants with 73 uses. They also demonstrated a good knowledge of woodland regulations. We found that woodlands recover well from historical disturbances over 50-100 year time scales. In fact, the presence of cattle year-round in the woodlands was associated with greater tree regeneration. We find that despite the conservation discourse, there is no evidence of a degradation problem, and we hypothesize based on our findings that eradicating peasants' silvopastoralism and other practices could increase degradation. We recommend that the Conservation Landscape programme be used to save key traditional practices, which should be studied further to determine optimal management. We show how conflicts and misalignments within and between ILK, data, and environmental discourse can signal complex socio-ecological issues where a closer look at how the evidence fits together is necessary.

Words: 229

Keywords: landscape, ethnobiology, ILK, conservation, succession, forest, livestock

Introduction

The valorisation of heritage elements related to exploitation of resources, climate adaptation, and other relations to the environment, such as indigenous and local knowledge (ILK), is increasingly integrated with conservation (Reser & Bentrupperbaumer 2005; Hill et al. 2011; Xu et al. 2009; Valencia et al. 2015; Assandri et al. 2018). While it is relatively easy to recognise the importance of things like sacred groves and sites of geological interest, other ILK and heritage elements are more slippery, due to incomplete information, multiple interepretations, or controversies.

Globally, interest in incorporating ILK into both ecological research and environmental management is growing (Gómez-Baggetun & Reyes-García 2013; Danielsen et al. 2014; Fernández-Llamazares et al. 2015; Mistry & Berardi 2016; Benyei et al. 2019). In the context of environmental management, inclusion of ILK can be part of participative mechanisms, which can add legitimacy to co-management with communities (Walker et al. 1995; Danielson et al. 2009). ILK can also be a key aspect of adaptive management (Mistry & Berardi 2016). However, ILK tends to have a less dynamic role in the conception of ecological research outside an adaptive management context. Questions around ILK in ecological research mainly revolve around demonstrating its reliability as a data source (Cámara-Leret et al. 2019; Paniagua-Zambrana et al. 2019). It is less common to view ILK as a source of independent hypotheses or models that may be further explored with scientific methods.

The interplay between scientific inattention and attention, and the interpretation and valorization not only of ILK, but also of traditional practices and the landscapes they produce, has a long and complex history. For example, silvopastoral systems have benefited from ecological and conservation research, leading to the contemporary creation and adoption of many new versions of silvopastoralism now applied throughout Latin America and the world (Peri et al. 2016). This interest and valuation is not uniform across silvopastoral systems of the world. A specific example of complex social and scientific valuations of silvopastoralism is in Central Chile. Central Chile, composed largely of shrubland, open woodlands, and closed woodlands, as a whole has long been seen, locally, as a wasteland-in-the-making, emptied of value (Root-Bernstein 2014). This area currently lacks self-identified indigenous populations, and the livelihoods practices of mestizo peasants have long been considered non-adaptive and environmentally destructive (Aronson et al. 1998). The accepted view has been that silvopastoral *Acacia caven* woodlands ("*espinal*"), where cattle and horses are grazed at low densities, are unproductive degradations of native sclerophyllous woodlands (Aronson et al. 1993; Schulz et al. 2010, van de Wouw et al. 2011; Rojas et al. 2016). Only recently has a new understanding of espinal emerged, repositioning it as a resilient pioneer habitat that establishes after disturbance and is the first stage in succession towards sclerophyllous forest (Hernández et al. 2016; Root-Bernstein et al. 2017). A large body of agronomical research has also shown that silvopastoralism in espinal can be efficient and productive (Olivares 2016). Chilean conservation officials remain strongly opposed to any kind of livestock pasturing in sclerophyllous or other native woodlands (pers. comm. C. Ravanal 2019), despite there being no research evaluating it.

This anti-livesock view, despite the lack of evidence, takes its cue from the international conservation discourse about livestock, which generally ranges from negative to doubtful. On average globally, livestock and especially cattle have been shown to contribute to global warming, to require a large amount of water, and to cause erosion and degradation of forests and grassland habitats (Henríquez & Simonetti 2001; Stedfast et al. 2009; Herrero et al. 2013; Mekonnen & Hoekstra 2012; Ripple et al. 2014). Thus, some researchers call for the eradication of livestock production (e.g. Smith 2013). However, there are many counter-examples where livestock have a range of positive environmental impacts, including fire reduction, maintenance of habitat mosaics, and seed dispersal, especially where wild large herbivores have disappeared (Mazzini et al. 2018; Gregory et al. 2010; Lasanta et al. 2009; Fuhlendorf & Engle 2004; Bruun & Fritzbøger, 2002; Brown & Archer 1988). Pastoralism may be resilient and adapted to marginal habitats where water is scarce (Oteros-Rozas et al. 2013; Scholz et al. 2013). Intensified ranching is only one form of livestock raising: there is a large diversity of livestock husbandry conceptions and forms (e.g.

Ingold 1988; Ferguson 1985). Livestock production practices are integral parts of many cultures, serving as a medium for social relations, systems of value, and relationships to the environment (Manzano Baena & Casas 2010; Scheele 2010; Barragan López & Linck 1994; Fairhead & Leach 1996). Over the years, pastoralism and transhumance have gained temporary waves of policy support as it becomes clear that their ecological effects are context- and practice-dependent (Hoffman & Boerma 2014; FAO 2011; Hemme & Otte 2010; FAO 2001; Seré et al. 1995; Krätli et al. 2013; Bosire et al. 2015). Studies of the livestock raising practices of non-indigenous peoples living in arid, semi-arid or seasonally dry forest environments of the Americas have been neglected (Barragan Lopez & Linck 1994).

As part of an effort to contribute research to understanding how contextual environmental and socio-economic factors affect the environmental impacts of traditional livestock raising, here we focus on ILK and traditional livelihoods practices related to the silvopastoral and schlerophyllous woodlands of central Chile, and their impacts on woodland degradation, restoration and succession. Central Chile has a long history of anthropogenic impacts. An increase in woodcutting and possibly fire following the Spanish conquest led to the decline of *Prosopis chilensis*, a native acacia that is now threatened and rare (Fuentes et al. 1989; Westphal et al. 2015; Rojas et al. 2016; McRostie et al. 2017). Shifts in agricultural strategies, from large *fundos* owned by a family and worked by their tenants, to smallholdings and cooperatives created during the agricultural reform of the mid-20th century, to partial reversal of agricultural reform and development of industrial export agriculture, altered the scales, distributions and intensities of land use change and agriculture (Wright 1982; Kurtz 2001; Murray 2003). While large industrial vineyards and orchards have a clear negative ongoing impact on woodland cover (Armesto et al. 2010), it is less clear whether or how the transition from *fundos* to smallholdings in the mid-century period impacted anthropogenic disturbance patterns in woodlands. This has now been followed by partial agricultural abandonment, and economic and development pressures to adopt more intensified and lucrative modes of agriculture.

Plans being considered by the Chilean government to meet their obligations under the Convention on Biological Diversity and the United Nations Framework Convention on Climate Change propose to eradicate remaining traditional peasant livelihood and cultural activities in forests and other habitats, by paying rural people to give up some practices and folklorize others for tourism (personal comm. C. Ravanal 2019). This project is in apparent conflict with a project that developed the "Conservation Landscape" concept in Chile. A "Conservation Landscape" here refers to a land-use planning framework for municipalities designed by a GEF (Global Environment Fund) project to improve the conservation of heritage elements and the environment (e.g. PLADECO Alhué 2014). In theory, Conservation Landscapes could help to preserve any ILK and traditional practices that may have currently unrecognised environmental benefits—such as silvopastoralism.

We combine various research methods to identify which elements of traditional livelihoods practices may be harmful or helpful to promoting woodland regeneration and conservation. We combine an ecological study of tree regeneration following anthropogenic disturbances, with a study of ethnobiological knowledge of woodlands and threats to them, and an assessment of local agricultural livelihood strategies. We ask how locals believe that agricultural and forest-use practices should change, compared to data on their current state and its impacts, and compare this to our data and the dominant conservation discourse.

Methods

Study site. A map is shown in Figure 1. Alhué is an interesting area with a rich cultural and ecological heritage due to its relative isolation within the valleys of the Cordillera de Cantillana in the Coastal Mountain Range of central Chile. The Alhué municipality has a population of 6,444 inhabitants and a rural population of 3,660 inhabitants (56,8%) (INE 2017). The main socioeconomic activities are agriculture, livestock production and mining (CED, 2013), with both an important gold mine and the tailings dam from the largest underground copper mine in world within the district. Alhué municipality, with a total area of 88.476 ha, contains a number of well-conserved native sclerophyllous forests and woodlands (3.091 ha of mature native forest and 52.378 ha of secondary native forest), including those in San Juan de Pichi Natural Sanctuary (1,614 ha), and El Membrillo (16.000 ha), the compensation site for the gold mine. Most forests and woodlands in the area are private property and consist of former *fundos*, or latifundia. Alhué contains part of the Roblería Cobre de Loncha National Reserve, the only public protected area in the district. There are also woodlands that are owned by smallholders, as well as a woodland owned and managed by a cooperative. Local smallholders have traditional use rights in many former *fundos*, which their families, former tenants on the *fundos*, retain from before the agrarian reform in the mid twentieth century.

Fieldwork. Our sampled area was the entire Alhué municipality, which is characterized by matorral shrublands especially on north-facing hillslopes (Badano et al. 2005), espinal woodlands—a kind of silvopastoral woodland dominated by *Acacia caven* (Donoso 1982)—and sclerophyllous woodlands containing many Chilean endemic species (Donoso 1982). Fieldwork was carried out in austral spring 2017. We repeated the methods of Root-Bernstein et al. (2017). We made transects consisting of 15 trees (> 40 cm) each (thus, of variable length), and 4 m wide. This sampling approach captures an equal number tree-tree associations (or non-associations) regardless of tree density. Transect locations were chosen in order to gain a representative sample of both typical woodland habitats with typical anthropogenic histories, and unique habitat formations or sites with unique anthropogenic histories. Unique formations included, for example, areas with rare endemic Chilean palms (*Jubaea chilensis*). This representative sample was created according to the advice of locals using snowballing, in the sense that at each site we asked locals (woodland users, managers, or owners) where else we should sample that was either typical of the area, or unusual. Permission to enter property and collect data was obtained from site managers or owners as relevant.

We sampled 42 transects, including one double transect (30 trees) (see Figure 1). The double transect (no. 35) occurred at a site where the tree density was much higher than anticipated, due to a large number of trees being nursed by a single tree, which prevented sampling the formation. A double transect seemed more transparent than deleting the original sample and resampling: we correct for the doubled number of data points where it can affect statistics. At each site where we placed a transect, we oriented the transect in an arbitrary direction that allowed walking access and that crossed the vegetation type we wanted to sample. In each transect, we recorded the position of each of the 15 trees with a GPS device, as well as the species, tree height, trunk base diameter (since many trees are multi-stemmed following resprouting from the base), canopy area, and tree-tree facilitation (nurse tree) interactions, as in Root-Bernstein et al. (2017). We also recorded environmental variables, including presence of cattle or horses (using their feces as a proxy), presence of *Oryctolagus cuniculus* (using their feces as a proxy), presence of irrigation, and presence of a natural water source (e.g. a river or gully adjacent to the transect). Altitude data was collected by inputting the GPS position of each transect into Geoplaner.com (accessed 2018). We also recorded an oral history of anthropogenic uses of the site covering approximately the past 50 years (being the period over which most people had a detailed memory), obtained from a local user, manager or owner depending on the site. These uses or anthropogenic disturbances included house gardens, agricultural fields, livestock grazing, restoration planting and fire. Following Root-Bernstein et al. (2017), we coded the oral history, description and observation of current land-uses, along with environmental data, to create a set of explanatory variables (Table 1).

We selected sites based on local perceptions and knowledge of variation in woodland formations. While we assert that local environmental knowledge about local woodland formations is reliable and replicable, we make no assumptions about whether local perceptions correspond to scientifically and statistically assessed habitat formations. We used statistical tests to scientifically characterize the structures and compositions of our woodland sample (following Root-Bernstein et al. 2017). To assess habitat structuring, we used the Wald–Wolfowitz test. It was implemented with the 'wawotest' command in the adehabitat package in R version 3.1.0. This is a non-parametric categorical test that assesses the significance of "runs" or series of the same category (Siegel 1956). Each species was treated as a category, and tree number along the transect was treated as series order. Significance occurs when a given species of tree is more likely to be followed by a tree of the same species than by a tree of another species. As in Root-Bernstein et al. (2017), we defined "patchy" as runs of trees where the species were mixed in small clusters or alternating, and "gradients" as runs of trees that switched from one species at the beginning of the transect to another species at the end. These terms do not refer to spacing of the trees. We sorted transects into three habitat structures: random or "unstructured" series of tree species (including monospecfic transects), patchy habitats, and gradients. To determine whether the transects could be categorized into different habitat types in terms of species composition, we used NMDS (Non-metric Multi Dimensional Scaling) analysis. We used the Dist, metaMDS, Tree, and Group commands in the vegan package in R version 3.1.0. We used Jaccard distances since they are suitable for analysis of species composition, and the "average" command for forming clusters. We chose a height cutoff for the cluster dendrogram based on visual analysis of the tree. Both structure and species composition categories were incorporated in the set of explanatory variables.

To assess current woodland conservation status and successional capacity to overcome disturbances, we created a regeneration index for each sampled site. There are two processes that allow tree regeneration and thus woodland resilience to disturbances: tree establishment with, and without, facilitation. Tree establishment occurs in pulses in this region, following rain events (Gutiérrez et al. 2007; Holmgren et al. 2006). Tree-tree facilitation is a mechanism for habitat composition change or succession (facilitation occurs between species) (Miranda et al. 2019; Soliveres et al. 2011; Root-Bernstein et al. 2017). Where the overall index is low, the woodland is neither reproducing itself, nor changing in composition, and therefore shows no evidence that it could recover (or is recovering) from a disturbance. Where the overall index is high, mechanisms for woodland regeneration are functioning. The regeneration index was defined as the sum of tree seedlings < 40 cm and trees > 40 cm being facilitated by a nurse tree, in each transect. For the double-length transect, we corrected the regeneration index by dividing it by 2.

We then used a zero-inflated regression model to assess whether disturbance and environmental factors explain the regeneration index. We used a zero-inflated regression because many transects (15 transects, or 36%) had regeneration indices of 0. A zero-inflated regression produces two models. The first, the count model, uses a Poisson distribution with log link. The second, the zero-inflation model, uses a binomial distribution with log link. The count model explains what happens in sites with non-zero data, while the zero inflation model gives the odds of having 0s. We then further explored patterns in the data using χ^2 tests. All statistical tests were run in Rstudio version 1.1.453.

Ethnobiology methods. The ethnobiological study was focused on the Pichi community within Alhué (see Figure 1), which is locally reputed to have maintained considerable traditional botanical knowledge. The profile for the sample was adults over 18 years old who lived in Pichi and had experience in the woodlands, possessed knowledge about plants, and were influential in the community. Participants were found first by consulting a list of "key actors" in environmental issues compiled by a community group ("junta de vecinos") and the PRODESAL smallholder outreach office; further individuals were found using snowballing. Snowballing is a common method used in social sciences to obtain a sample of people to interview, in which participants comprising an initial target or convenience sample recommend other people to be interviewed, which continues until no new contacts or no new information is obtained (Mendieta 2015; Rust et al. 2017). The sample included 31 adults, of which 15 were men and 16 women, were interviewed between February and March 2017. Participants were interviewed in their homes, or while carrying out agricultural tasks. Participants were given a written explanation of the study and signed an informed consent form. Each participant was given a questionnaire of closed questions focussing on socio-demographic information. Each participant was then interviewed to determine knowledge of sclerophyllous woodland plants and their uses. Participants were then asked open questions about the problems affecting the woodlands in Pichi in the context of the Conservation Landscape initiative. Uses of plants were assorted by similarity and coded. Finally, a participative mapping workshop including a subset of available participants (3 women and 1 man) was carried out to understand the changes over time in the environment and landscape of Pichi.

Agricultural livelihoods surveys. Agricultural models in central Chile have shifted considerably during the 20th century—for a more detailed account for this field site, see Root-Bernstein et al. (2020). The pattern of agricultural strategies is thus the outcome of several different political and economic processes. We set out to capture the diversity of existing agricultural strategies in Alhué with a survey instrument. The survey instrument was integrated into a larger questionnaire and project, which is described in Root-Bernstein et al. (2020). Here, we report only the data relevant to this study and from Alhué. The questionnaire was applied to farmers, including both smallholders and large landowners, who were located through snowballing and with the support of the Alhué Smallholder Development Program PRODESAL. Our sample was stratified by farm size, using three categories: < 10 ha, 10-100 ha, > 100 ha. Interviews were carried out in Alhué between February- August 2017. Farmers were interviewed at their homes. They were orally informed that their participation was voluntary and anonymous, consent to participate was obtained orally, and they were given a printed form of the contact information of the research team member carrying out the survey. Here we report survey data from closed and open questions and Likert scale questions about farm production, livelihoods, environmental values, knowledge of forest regulations put in place by CONAF (the National Forestry Service), and socio-demographic questions. The surveys were read aloud to participants, and answers were recorded by a research team member.

We created indices to summarize farmers' agricultural and livelihood strategies, socioeconomic profiles and knowledge about forest regulations. The ranges of values that went into the indices were set by the total dataset from the larger study that included farmers in two other municipalities to the north and south of the Cordillera de Cantillana (see Root-Bernstein et al. 2020), Pintué and Doñihue (see Figure 1). The indices thus implicitly provide a view of how Alhuino farmers compare to the observed range of regional farming strategies, socioeconomic conditions and knowledge. The formulas for these indices are given in Table 2. In order to detect trends in the studied population, we tested each index against normality using the Kolmogorov-Smirnov test as implemented by the command "lillie.test" in the nortest package in Rstudio version 1.1.453.

Ethical note: The ethnographic study, carried out by B.H., obtained approval from the ethics committee of the University Alberto Hurtado, because it was designed within the framework of the "Anthropology of the Forest" project led by Dr. Juan Carlos Skewes of that university. The agricultural questionnaire, carried out by A.B. with assistance from M.G.G. under the supervision of M.R.-B. who worked at INRA, was not required to be submitted to an ethics committee. At

INRA, the ethics committee does not pronounce on particular research projects. Researchers are guided by a "Deontological Charter".

Results

Ecological results. Across the 42 transects combined, 33 tree species were recorded, of which 23 are endemic to central Chile. Of a total of 626 trees > 40 cm sampled, *L. caustica* was the most common (117 trees), followed by *P. boldo, A. caven*, *C. alba*), tebo/ trevo (*Retanillo trinervia*) and *Q. saponaria*, all endemic or native trees typical of early to intermediate successional-stage woodlands (Root-Bernstein et al. 2017). A rare but notable species present in the sample was the endangered endemic Chilean palm (*Jubaea chilensis*), in both natural and planted populations. According to ILK, various populations of this species have persisted in Alhué at least in part because their seeds are dispersed by cattle (see Fleury et al. 2015). In the La Linea sector of Alhué there is also an *A. caven* thought to be around 500 years old. In general, all areas of Alhué have experienced extensive anthropogenic disturbance in the form of charcoal production, collection of leaf litter, bark and leaves, and agriculture. Our use of local ecological knowledge helped us to observe a typical landscape formation throughout Alhué that is an outcome of a historical pattern of clearing mountain slopes with fire, followed by a rotation of wheat, beans or potatoes, and fallows grazed by livestock, followed by agricultural abandonment (Figure 2).

The MDS analysis of tree co-occurrence in transects, with a cut-off of h=0.65, yielded 8 distinct clusters. These corresponded to two groups of silvopastoral espinals, espinals entirely dominated by *A. caven* (suggesting chronic heavy disturbance), gully habitat, reforested areas near a river, another set of reforested areas including planted *J. chilensis*, an abandoned site of human habitation, and dense sclerophyllous forest at high elevation. The remaining sites, including sclerophyllous forest sites with a mix of several species corresponding to early and later successional stages, formed the largest group (Figure 3). This grouping does not correspond exactly to how locals identified woodland habitats. Locals did not spontaneously distinguish between different forms of espinal, and they were more likely to distinguish different schlerophyllous formations based on site history or the presence of particular species, although these sites form a single group according to our MDS analysis.

The range of values for the regeneration index was 0-18. In Table 3, the count model explains what happens in sites with regeneration (regeneration index > 0) while the zero inflation model gives the odds of having zero regeneration. We found that among sites with regeneration (count model), both water and cattle presence are the two variables that explain the observed regeneration index; both increase regeneration.   The measure of cattle presence was the only significant variable found for the zero-inflation model: the absence of cattle is associated with an increase in the odds to exp(-1.64) = 0.19, equivalent to a 16% probability, of having a regeneration index of 0.

Because the results that livestock presence is good for woodland regeneration, and its absence leads to lack of regeneration at least a sixth of the time, may be surprising, we examined this result in more detail. Using χ^2 tests, we looked at the relationship between spring-only vs. year-round livestock pasturing on seedling number, rather than the regeneration index. We focus on seedlings because one possibility is that livestock are seed dispersers for certain tree species, in addition to being seedling predators and agents of soil erosion and trampling: they may either increase or decrease seedlings (Brown and Archer 1988; Bruun et al. 2002; Lasanta et al. 2009; Mazzini et al. 2018). There were fewer seedlings in areas with spring-only cattle grazing (χ^2=14.119, df = 7 p = 0.0491), but there was no difference in seedling number between sites with year-round cattle grazing and the rest of the sites (χ^2= 6.4762, df = 7, p = 0.4854).

Ethnobiology results. Of the 31 adults interviewed, 16 were female and 15 male, and 39% were over 60. They represented 24 households out of the 100 in Pichi. 61% had not finished high school, but 19% had a university degree. 64% of participants were born and raised in Pichi, and 70% had lived there for more than 20 years. 45% made a living from agriculture, apiculture or reforestation activities, 19% worked in public administration, and 29% were retired and lived off a pension. However, many pensioners did not have enough money to live on from their pension alone and supplemented it with agricultural production and forest products for their own consumption.

In total, 128 names were given for 113 plant species, 80 of which were native species. The four species most commonly named were the four endemic sclerlophyllous trees boldo (*Peumus boldo*), quillay (*Quillaja saponaria*), peumo (*Cryptocarya alba*) and litre (*Lithrea caustica*), typical of relatively dense woodlands in a successional stage following open espino (*Acacia caven*) woodlands, and of shaded south-facing mountain slopes. The next most commonly named species, patagua (*Crinodendron patagua*), roble (*Nothofagus sp.*), lingue (*Persea lingue*) and canelo (*Drimys winteri*), are endemic trees typical of riverbanks and very moist, shaded, dense woodlands. Canelo is sacred in the indigenous Mapuche culture. Finally, the next most named plant was the espino (*A. caven*), typical of open, early-succession woodlands. 37% of named species were trees, 40% were shrubs, 15% were herbs, and the rest were ferns, creepers, cactus, and bromeliads.

73 uses of plants were recorded, which were grouped into 14 classes (Figure 4). The majority (66%, 73 species) had medicinal uses. 4% (4 spp) were recorded as having no use, and 4 spp had syncretic ceremonial uses. "No use" included one species, *Prosopsis chilensis*, which is endangered and rare and thus reported to be protected by the community (Westphal et al. 2015). The plant species named as having the greatest importance for woodland conservation were the endemic sclerophyllous trees quillay (*Q. saponaria*), boldo (*P. boldus*), and litre (*L. caustica*), because they "produce leaf litter" and grow quickly, and one tree species named because of its association with water, the endemic patagua (*Crinodendron patagua*). There was little agreement

on changes over time in tree species. When naming trees that used to be more numerous in the past, 23% of participants named *C. patagua*, 23% named *Q. saponaria,* and 10% named *C. alba.* However, 10% thought *Q. saponaria* was more numerous today than in the past, and 16% identified *C. alba* as more numerous today than in the past. When thinking of species no longer seen in the forest, 28% of participants identified canelo (*Drimys winteri),* and 21% said the same for *C. patagua*.

Participants identified a set of threats to the woodlands in Pichi. These were classified post-hoc as related to fire, water scarcity, tree felling, poor management and bad behaviours, mining, floods, road construction, and invasive species and plagues. 87% of participants identified wildfires as a princpal threat, while 58% identified a water scarcity factor as a principal threat (threats were not ranked, so percentages do not sum to 100%). While wildfires were blamed on people from outside Pichi (but within Alhué), water scarcity was frequently blamed on climate change and thought to be caused by factors external to Pichi and Alhué. Participants described a clear reduction in rainfall and running water volume in local rivers during their lifetimes. In the past, for example, Pichi was often cut off from the town of Alhué due to flooding. There was also more snow in the mountains, which lasted almost all year. When asked to look to the future of the sclerophyllous forest, the majority of participants expected the forest to diminish in extent, though few thought it would totally disappear (Figure 5). Proposed solutions for woodland conservation during the participatory mapping activity included zonification of the woodlands with fences and exclusion of livestock, education and outreach around forest management and conservation, and training in sustainable agricultural and forest exploitation practices.

Agricultural survey results. We surveyed 34 farmers in Alhué. Alhué has a mixed profile of industrial fruit production and smallholders producing both for their own consumption and for the market. However, the distribution of landowners across farm sizes is highly skewed towards smallholders, with 52% having farms < 10 ha, and 31% with farms 10-100 ha (INE 2007). We attempted to reflect this in our stratification, although we under-sampled farmers with landholdings > 10 ha. We interviewed 33 farmers who held title to < 10 ha, 0 between 10 and 100 ha, and 1 with > 100 ha. The mean farm size, considering land to which the farmer held land title, was 7.6 ± 5.99 ha. This mean farm size includes 6 individuals in the sample who owned woodland or matorral (shrub habitat). These 6 woodland and matorral areas had a mean size of 3.75 ± 2.9 ha. Mean extent of agricultural fields or non-wooded pastures per farm was just 3.9 ± 2.9 ha. Only five of the 34 sampled individuals rented land in addition to the land to which they held title, ranging from 0.05 ha to 3000 ha. We recorded 70 distinct crops and 16 animals being raised. Livestock, which included cattle, horses and sheep, are raised in a free-range, low-input manner on private lands, communally managed lands, or on former fundos via traditional access rights. Generally livestock production is not market-oriented but used for subsistence and as a form of savings or capital.

In Figure 6 we show the data from the indices of agricultural diversity, agricultural model, agricultural capital and lifestyle. The Lifestyle index, the Agricultural Diversity index, the Agricultural Model index and the Knowledge of Forest Regulations index were all significantly different from normal in distribution (K-S test: Life-style index, $D = 0.17003$, p-value = 0.01394; Agricultural Diversity, $D = 0.32247$, p-value = 8.663e-10; Agricultural Model, $D = 0.21299$, p-value = 0.0005716; Knowledge of Forest Regulations, $D = 0.33184$, p-value = 2.113e-10). Only the Agricultural Capital index was not significantly different from a normal distribution ($D = 0.12757$, p-value = 0.1727). A non-normal distribution suggests that a non-random process, here for example some structural features of the socio-economic context, has biased the distribution. The large number of non-normal distributions among the indices illustrates the socio-economic inequality in this region (Figure 6).

Discussion

The ecological evidence suggests that the Alhué area has a diverse set of endemic woodland tree species, which as we show here, mainly assort into a single habitat type characterized by a mix of species typical of different stages of woodland succession, as found at other sites in central Chile (Root-Bernstein et al. 2017). Unsurprisingly in this semi-arid habitat (Holmgren et al. 2006; Gutiérrez et al. 2007), the regeneration index was highest where there was water available in the form of a river or gully. The presence of irrigation, in planted woodland restoration sites, was not associated with natural regeneration. Restoration sites may differ from other sites in that they generally lack adult trees that provide shade, which is important for tree-tree facilitation in this region (Root-Bernstein et al. 2017). Currently, it is illegal in Chile to use plant-plant facilitation in restoration projects. Adult trees' shade and branches are also important for attracting livestock and perching birds, which are dispersers for several native trees (Olivares 2016; Miranda et al. 2019). Irrigation alone appears inadequate to jumpstart natural regeneration processes.

Perhaps more surprisingly, the regeneration index was also highest in the presence of extensively grazed livestock. When we looked closer just at abundance of tree seedlings under 40 cm, we found that year-round cattle presence by itself did not explain seedling presence. This suggests either that cattle neither benefit (e.g. through seed dispersal) nor harm (e.g. through seedling herbivory or trampling) tree regeneration, or that these two effects balance out. The general benefit of extensive livestock grazing must be via a mechanism or interaction that does not directly affect seedling abundance. Rather, livestock might affect, for example, the spatial distribution of those seedlings, and thus their ability to benefit from tree-tree facilitation (Root-Bernstein et al. 2017), or their competitive advantage (see below). However, spring-only cattle pasturing was harmful to tree seedlings: there were more seedlings in areas with no cattle and with year-round cattle, compared to areas with spring-only cattle. One mechanism that may explain this would be selective foraging of grasses and herbs but not tree seedlings by experienced livestock, as opposed to unselective foraging by naïve livestock. Under this hypothesis, which was suggested to us by a local farmer during a session where we presented our study results, keeping cattle out of woodlands during most of the year prevents livestock from learning to forage selectively. Tree seedlings are generally lacking in sugars, and so may be non-preferred as food sources (Wohlleben 2015). Effects of social learning and experience on cattle foraging preferences have indeed been reported in rangelands research (Provenza and Ralph 1988). As suggested by another interlocutor, cattle and horses may also selectively eat the grass under tree canopies at the end of winter, which could reduce tree seedling-grass competition and facilitate seedling establishment if they emerge after winter grass grazing (Smit et al. 2015; see also Kraj & Ward 2006). Spring-only pasturing, starting after grasses and herbs have been allowed to accumulate biomass, may occur too late to provide an opening for trees to germinate under canopies.

There were some areas where reported ILK corresponds well to the scientific literature and our ecological results. The four trees most cited in the ethnographic interviews were also four of the five most common tree species in the local ecological transects (*Q. saponaria*, *P. boldus*, *C. alba*, and *L. caustica*). Local ecological knowledge confirmed the importance of water to woodland conservation. Reports of a reduction in rainfall and water volume, and the risks of drought and fire, are echoed in research demonstrating that a long mega-drought has taken place in central Chile, and that drought-facilitated anthropogenic fires are increasing (Garreaud et al. 2017; Bowman et al. 2018; Gómez-González et al. 2019). Although a study in Chile (Alfonso et al. 2017) suggests that rural people are not conscious of the magnitudes of climate change impacts, our results demonstrate that climate change is percieved and understood as a threat. Such awareness has been demonstrated among smallholders globally (e.g. Burnham et al. 2016; Lasco et al. 2016; Ayanlade et al. 2017).

By contrast, another set of issues was more ambiguous and points to areas where further research is needed to clarify socio-ecological dynamics. These include reported beliefs about cattle management, leaf litter collection, and agricultural training for development. These are all highly pertinent and unresolved local issues that draw on global discourses about best practices.

The ethnobiological results show that local residents believe that cattle should be zoned out of forests in order to conserve forests better. Exclusionary zoning of different kinds is a globally common conservation intervention (e.g. Cotroneo et al. 2018), which, however, is increasingly questioned in different contexts due to the socio-ecological impacts it can have (e.g. Brown & McDonald 1995; Evans et al. 2006). The idea of keeping livestock out of woodlands was also contested by other local individuals, outside the ethnographic study. Local farmers claimed that the cattle are good for the forest because they eat all the grass that will otherwise dry up and feed wildfires (pers. comms. to MG-G, MR-B; see also discussion of leaf litter and forest fires below). It is difficult to assess whether the claim that cattle should be excluded from forests represents Alhuinos' ILK, or whether it represents an attempt to position themselves as "environmentalist" (as they believe themselves to be, see Root-Bernstein et al. 2020) by aligning with CONAF and PRODESAL, which in turn are aligned with the dominant global discourse against livestock. Alternatively, by "zonation" they may be refering to traditional local practices of community-managed rotational harvest of bark, leaves, and leaf litter, and transhumance and the spring-only pasturing discussed above. Rotational zonation and transhumance can lead to landscape-level ecological connections (e.g. Dominguez et al. 2010), but timing issues may be important.

The ethnobiological results also highlight a claim that leaf litter/ humus formation is important to maintain the forest. Our knowledge of decomposition rates of schlerophyllous hardwood litter, and their interaction with mediterranean or South American habitat weather and climate patterns, is incomplete (Bani et al. 2018). The interactions between leaf litter, soil, and nutrient cycling are complex, and it is not necessarily the case that a greater accumulation of leaf litter points to richer soil, if the rate of decomposition is particularly slow under drought or species composition change, for example (Hobbie 2015; Krishna & Mohan 2017; Bani et al. 2018). Leaf litter traps soil moisture, and can improve the germination rate of species such as the endangered endemic *Bielschmiedia miersii* (Becerra et al. 2004), and probably other species as well. However, leaf litter might also prevent the germination of trees with other requirements. During fieldwork we also encountered a view held by local *arrieros* (cowboys) that woodlands should be kept "clean" through a combination of livestock grazing and leaf litter collection. This is a view held across rural Chile (Di Giminiani & Fonck 2018) and, historically, in Europe (Gimmi et al. 2013; Mathews 2018). Leaf litter collection presumably removes nutrients from the system, although the traditional 10-year rotations should allow some nutrient leaching (Krishna & Mohan 2017; Bani et al. 2018). Livestock grazing of the understory should relatively increase nutrient cycling rates, especially as wild herbivores that might have done so in the past are absent (Schmitz 2008). Critically, a 'clean' forest may have a lower risk of intense forest fires (Gómez-González & Cavieres 2009). We predict that the timing and patchiness of leaf litter collection and cattle grazing will modulate between possible benefits to fire control vs. tree establishment.

Finally, some local residents expressed the view that training in sustainable agricultural and woodland exploitation practices would secure forest conservation. With this claim, local residents are clearly aligned with global best practice in adaptive and community-based conservation (Kristjanson et al. 2009; Klerkx & Leeuwis 2010; Staiger-Rivas et al. 2012; Geertsema et al. 2016). However, if we take this alignment as proof that their opinion is justified, we would be ignoring our empirical evidence. The agricultural results point to a set of agricultural and exploitative practices with notable diversity and apparent flexibility, related to past and current rural poverty, as suggested by our Agricultural Capital and Lifestyle indices. Our data shows that Alhuino smallholders tend to have an independent, isolated lifestyle that is moderately integrated with services and infrastructures. This lack of integration can act to maintain dependency on woodland resources (e.g. firewood) and to maintain ILK and management knowledge, while also representing a lack of integration with the logics and capitals that allow intensified agricultural exploitation. Residents also showed good knowledge of forest regulations. Our own evidence indicates that the historical and current traditional anthropogenic disturbances throughout the valley of Alhué have not resulted in widespread degradation. The patchy legacies of historical and present land uses in Alhue (e.g. Figure 2) may allow the preservation of seed sources for woodland regeneration, as elsewhere (Armesto et al. 1991; Debussche and Insenmann 1994; van de Leemput et al. 2018). Small-scale, rotational and diversified agricultural livelihoods produce patchy disturbances, and are globally associated with better forest conservation outcomes than alternative agricultural strategies (Allen et al. 2014; Biazi et al. 2015; Kahane et al. 2013; McNicol et al. 2015; Perz 2004).

Why then do locals ask for training in sustainable agriculture and woodland exploitation? It would be naïve to read this as a real lack of know-how. Some locals may believe that their own knowledge is illegitimate. Capacity building, to promote entrepreneurial values, is also an important feature of the Chilean approach to reducing poverty (Mayol et al. 2013). The rural poor are thus likely to have an expectation that training leads to social mobility and economic development.

There may be forms of sustainable agriculture in which locals could be trained that could lead to economic development while also legitimizing low-imput diversified agricultural models (e.g. Bucher & Huszar 1999, van de Fliert et al. 2007; Ponnusamy & Pachaiyappa 2018; Khwidzhilli & Worth 2019), which might thus conserve local woodlands. In contrast, the currently proposed interventions aimed at altering or removing anthropogenic uses of woodlands may, as we discuss above, reduce tree recruitment and increase fire intensity. These recommendations should be tested before people are trained in them.

Category V-type protected areas and programmes are a kind of normative tool for identifying what is and should be valued about landscapes. We find that in this context, despite the conservation discourse, there is no evidence of a degradation problem that could be fixed by eradicating peasant smallholder livelihoods. We recommend that the Conservation Landscape programme be used to save key traditional practices, which should be studied further to determine optimal management. We show how conflicts and misalignments within and between ILK, data, and environmental discourse can signal complex socio-ecological issues where a closer look at how the evidence fits together is necessary. Using ILK and ecological data, we have demonstrated clear possible mechanisms by which livestock raising in particular, as well as other traditional anthropogenic woodland uses, could play key roles, when managed properly, in woodland maintenace and recovery. If these forms of management can be developed, then land-sharing in heritage landscapes should be sustainable (Bucher & Hazar 1999; Zorondo-Rodríguez et al. 2019).

Acknowledgements

BH thanks Juan Carlos Skewes and Victoria Castro for their supervision and assistance. We are grateful to numerous people who shared their knowledge and provided assistance and support, including the park rangers at the National Reserve Roblería Cobres de Loncha, the San Juan de Pichi Nature Sanctuary, Gerardo Schlack of Fundo El Membrillo, the PRODESAL Alhué office, the municipal staff of Alhué, Bernardita Castro, Benjamín Riveros, Luna Chiang, Ángela Danbach, Marta Bello, Flavia Bustos, and everyone who shared their experience and knowledge with us in the field. We will miss the expertise, boundless curiosity and speculations of Rafael Valenzuela, who died in 2018.

Funding: Marie Curie FP7 COFUND Agreenskills Plus Fellowship; CONICYT PIA/BASAL FB000; Fondecyt-Iniciación 11160672; FONDECYT No. 1140598)

Conflicts of interest/Competing interests none declared

Ethics approval Ethics committee of the University Alberto Hurtado.

Consent to participate For the ethnographic study, this was obtained through a signature. For the agricultural strategies study, this was obtained orally.

Consent for publication Not applicable

Availability of data and material The agricultural data and tree data will be made available on ResearchGate.

Code availability Not applicable

Authors' contributions MR-B conceived of the paper idea with FZ-R, MG-G, AB, and BH. Methods for the different parts were designed respectively by BH and MR-B. BH, AB, MG-G, MR-B, MH, RV, and AVB collected the material and data. RV and AVB made particular contributions to data interpretation. BH, AB and MR-B carried out data analysis. BH and AB wrote masters theses; on the basis of these and the other material MR-B wrote the paper. FZ-R and MG-G provided editorial comments.

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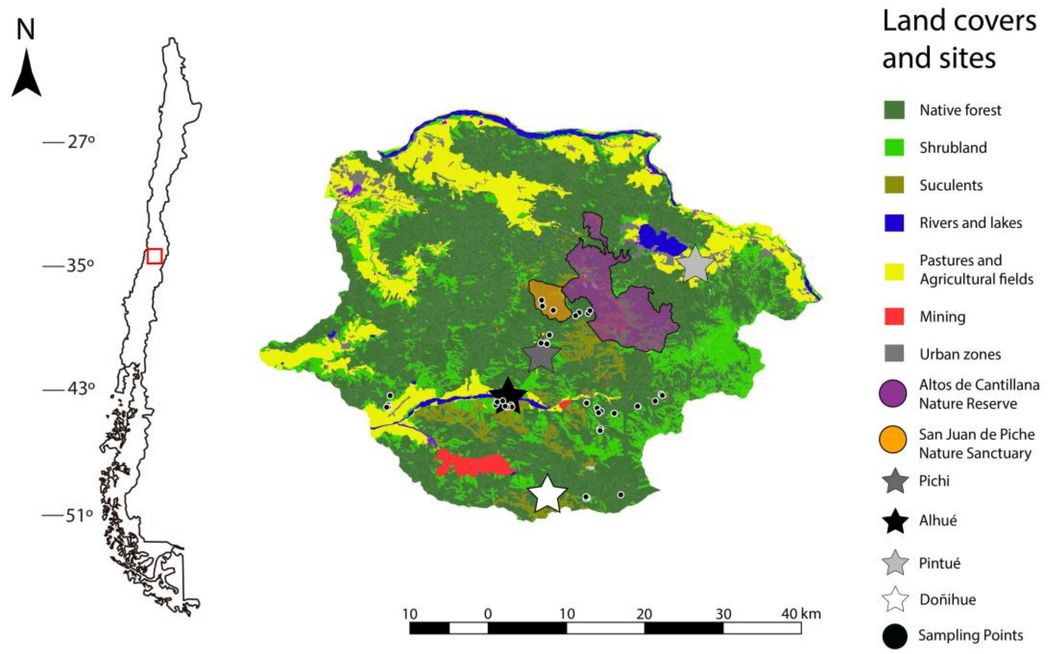

Figure 1. Map of the study sites, with major land cover types, with data from CONAF, 2013. Catastro vegetacional Región Metropolitana. Also shown, the 42 transect sites in Alhué.

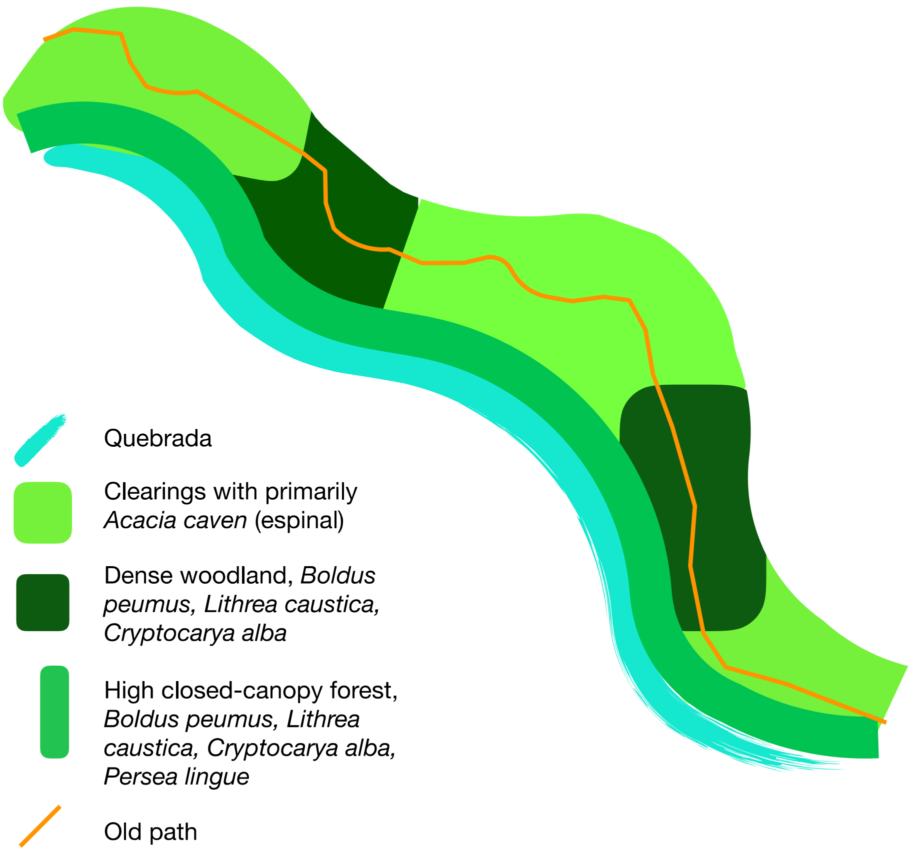

Figure 2. Observed woodland structure along mountainsides in Alhué. The single-trunk *Acacia caven* in espinals in former agricultural fields have never been cut or burned. The "dense woodland" and "high closed-canopy forest" are typical sclerophyllous forest formations.

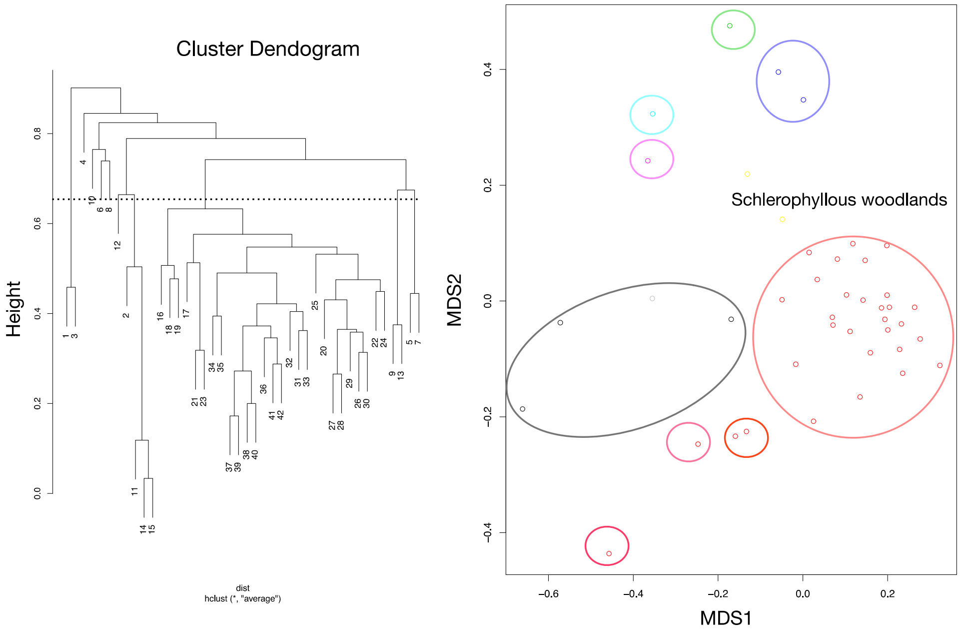

Figure 3. Dendogram and plot of clusters from MDS analysis of tree composition. The dotted line on the cluster dendogram indicates the cluster cutoff of h = 0.65. The main cluster of schleropyllous woodlands is indicated on the cluster plot.

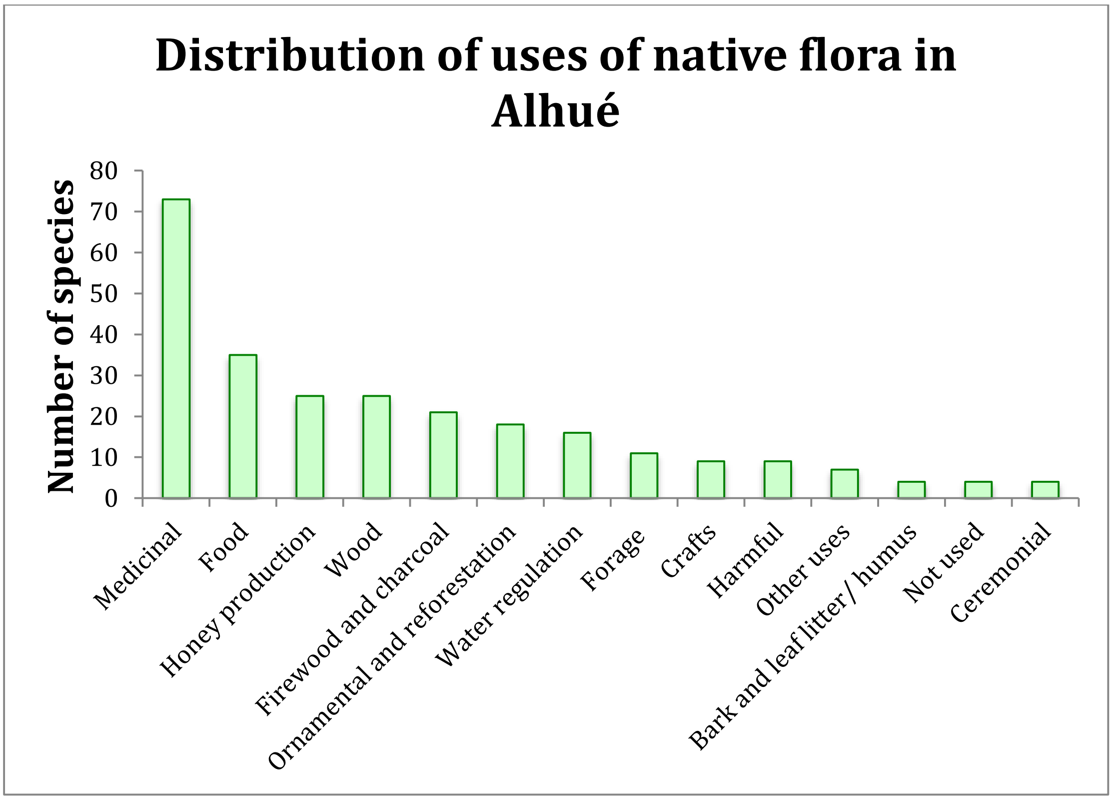

Figure 4. Distribution of recorded uses of native flora in Alhué.

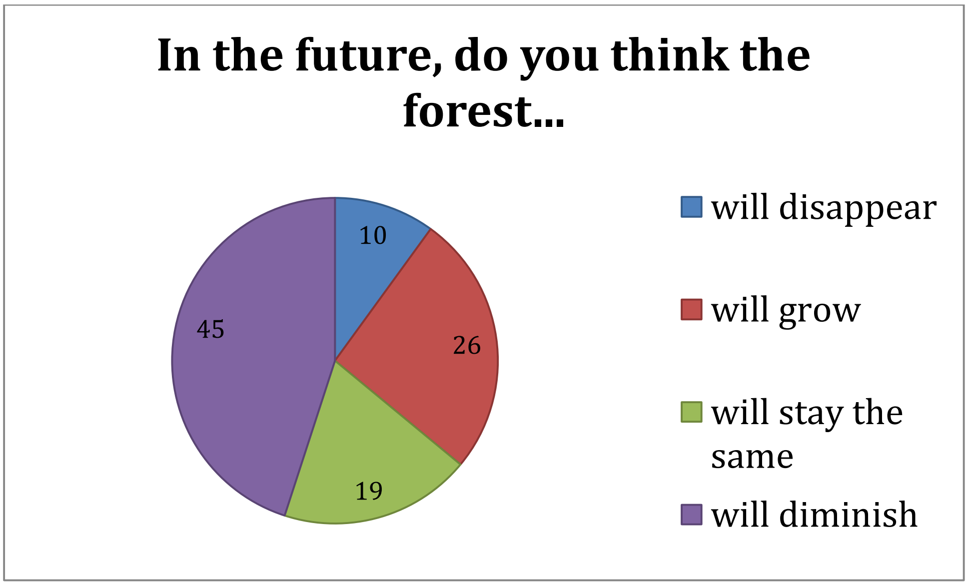

Figure 5. Perceptions of the future extent of the sclerophyllous forest by participants in the participatory mapping exercise. Numbers indicate the illustrated percent agreement with each answer.

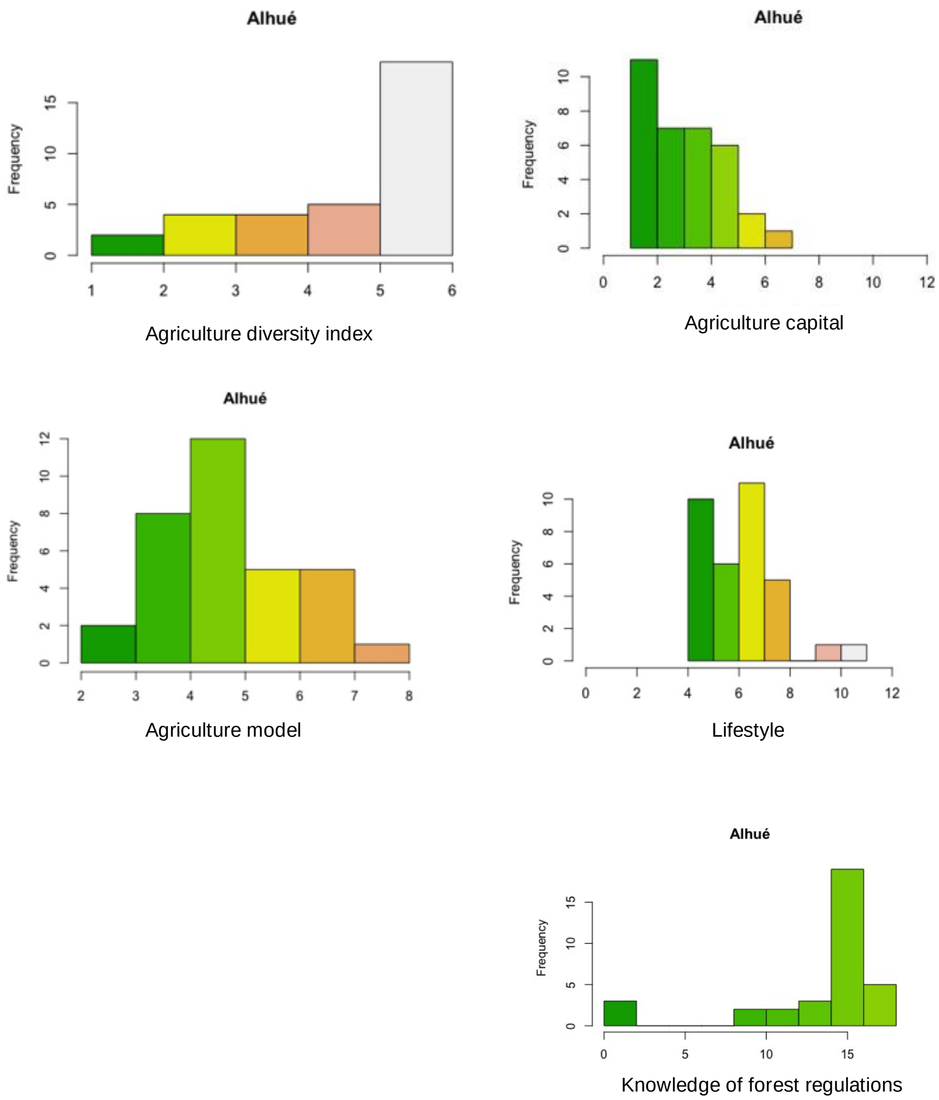

Figure 6. Indices summarizing farmer livelihood profiles and strategies.

Variable	Values	
Number of seedlings < 40 cm	quantity	Sum = regeneration index
Number of under-canopy beneficiary trees	quantity	
Habitat structure	Gradient Random Patchy	
Habitat composition	Espinal 1 Espinal 2 Espinal 3 Gully Schlerophyllous Reforested 1 Reforested 2 Abandoned house Forest	
Livestock in spring only	presence/ absence	
Livestock year-round	presence/ absence	
Wheat-beans rotation in past 50 years	yes/ no	
Charcoal production in past 50 years	yes/ no	
Cattle grazing	presence/ absence	
Horse grazing	presence/ absence	
Sheep grazing	presence/ absence	
Rabbit grazing	presence/ absence	
Burned in wildfire 2016-2017	yes/ no	
Historical wildfire	yes/ no	
Reforested	yes/ no	
Old house or garden	yes/ no	
River nearby	yes/ no	
Gully	yes/ no	
Water	River + gully	
Sector of Alhué	La Linea Cementerio de Piedras Fundo el Membrillo Villa Alhué San Juan de Pichi Señora Amalia Talamí La Gruta Fundo los Lagartos Fundo Lisboa Los Leones Roblería Cobres de Loncha	
Altitude	meters	

Table 1. Variables and their values, used to form or explain the regeneration index for sampled woodlands. Yes/ no and presence/ absence were scored as 1/ 0.

Index	Formula	Interpretation
Lifestyle	For cooking and heating, we order energy sources by level of integration into services/ infrastructure, so that firewood = 1, gas and parafin = 2, electricity = 3. Number of people in household is by quantiles, 1-4, inverted so that 1 is the highest quantile (100%), thus larger families are at the low end of the scale. Index = household (1-4) + cooking (1-3) + heating (1-3) + internet (0,1) x 3.	Higher numbers indicate greater integration in state/ centralized services and infrastructures, lower numbers indicate a more traditional, independent/ isolated lifestyle.
Agricultural model	For own-use diversity, counted the number of plant crops raised for own use (including 'own use and sale'). Own use quantiles collapsed to 3 categories due to many 0s. Added hectares rented and owned, took quantiles and inverted so that lower area goes with higher diversities. Index = production diversity (1-4) + own use diversity (1-3) + hectares in production (1-4) + number of other economic activities (1-3).	Higher numbers indicate a traditional, diversified small-holder strategy, while low numbers indicate a modern, intensified strategy.
Capital	Sum of cattle, horses and mules, in quartiles (0-3) + hectares owned categories < 5, 5-20, > 20 (1-3) + water title (1,0)*3	Higher numbers indicate greater ownership of agricultural resources/ livestock.
Agricultural Diversity	For production diversity, counted the number of plant and animal species raised, calculated quantiles (1-4), + mix livestock & crops (0,1)*2	Diversity of species raised on the farm.
Knowledge of Forest Regulations	Scored answers as correct or incorrect and calculated the sum of correct answers (total: 21)	Knowledge of native forest regulations as set by CONAF = National Forestry Corporation, in charge of forests and conservation.

Table 2. Indices summarizing farmer livelihood profiles, strategies, and knowledge.

Count model	**Estimate**	**Std. Error**	**z value**	**p value**
intercept	0.8561	0.2123	4.032	5.53e-05 ***
water	0.5231	0.2291	2.284	0.0224 ***
cattle	0.6205	0.2271	2.732	0.0063 *
Zero-inflated model				
intercept	0.1582	0.5079	0.312	0.7554
water	-1.7587	1.2882	-1.365	0.1722
cattle	-1.6444	0.8388	-1.960	0.0499 *

Table 3. Summary of results of the zero-inflated regression model explaining the regeneration index. * refers to significant at the $p < 0.05$ level, *** to significant at the $p < 0.001$ level.

Dataset

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data bosques Alhue.xlsx

cover letter

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