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ORIGINAL ARTICLE

"Listen to us": small-scale farmers' understandings of social-ecological changes and their drivers in Important Agricultural Heritage Systems

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Abstract

Current social-ecological changes affect territories and people's livelihoods worldwide. Many of these changes have detrimental effects on small-scale agricultural systems, with concomitant negative consequences on global and local food security and sovereignty. The objectives of this study were to explore (i) local knowledge on social-ecological changes and (ii) the perceived drivers of those changes occurring in a mountainscape and an islandscape in two Important Agricultural Heritage Systems of southern South America, both located within a Global Biodiversity Hotspot. This was done by conducting in-depth semi-structured interviews with local campesinos, whose livelihoods are based on the use and management of agrosilvopastoral systems. We found that local communities experience a wide range of globally and locally induced social-ecological changes acting in their territories. Campesinos mentioned 79 different observations of social-ecological changes and identified drivers for 77% of them. Changes in the atmospheric system, specifically regarding changes in precipitation, drought, and temperatures, were commonly observed by campesinos in both sites. Participants also observed complex interrelations between these changes and the drivers influencing them, climatic drivers being the most important. Even though general changes in climatic patterns were identified as drivers of changes by campesinos, other situated changes derived from the site's biophysical, social, and economic conditions were also important. Our results highlight the importance of considering local knowledge to understand social-ecological changes and to support the development and implementation of public policies that promote contextualized adaptation measures to global changes that affect local livelihoods.

Keywords Global change · Climate change · Globally Important Agricultural Heritage Systems · Local knowledge · Campesinos · Chile

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Introduction

Current social-ecological changes such as climate change, biodiversity loss, land use shifts, and resource overexploitation affect all territories and people's livelihoods worldwide (Trenberth et al. 2014; FAO and UNEP 2020; Scheidel et al. 2020; Pörtner et al. 2021; IPCC 2022). Many of these changes have detrimental effects on agricultural systems (e.g., decrease in crop productivity and soil quality, invasion of new pests, agrobiodiversity loss) with negative consequences for global and local food security and sovereignty (Blair et al. 2018; Díaz et al. 2011; Mukhopadhyay et al. 2021; Skendžić et al. 2021; Wheeler & von Braun 2013). The increase in global temperature in the last decades, for example, has decreased yields of wheat, rice, maize, and soybean worldwide, crops which together provide two-thirds of human caloric intake (Zhao et al. 2017). In 2016, a 3-year drought in the dry Pacific region of Central America resulted in 3.5 million people demanding humanitarian assistance and almost two million being food insecure (FAO 2016). In Chile, a significant mega-drought over the last decade has resulted in a decline in crop productivity with concomitant negative consequences for the country's food security (Gruère et al. 2020).

Small-scale farmers—responsible for producing at least one-third of the world's food (Lowder et al. 2021)—are some of the most vulnerable groups to these social-ecological changes, given their direct dependence on their local ecosystems, their structural disadvantages, and their historical marginalization (Morton 2007; Pelletier et al. 2016; Hagen et al. 2022). Indeed, previous studies have shown how different social-ecological changes interact and affect rural communities and agricultural-dependent livelihoods worldwide (Morton 2007; Stevanović et al. 2016; Hagen et al. 2022). For example, in the Amazon region, deforestation caused by large-scale intensive agriculture altered local climatic patterns by increasing surface temperature and reducing convective rainfall, with negative impacts on small-scale farms (Maeda et al. 2021). In mountain ecosystems of Nepal, changes in land use practices and technological advancements (e.g., use of chemical pesticides and fertilizers) are contributing to agrobiodiversity loss (Upreti and Upreti 2002). Furthermore, resource overexploitation in the islandscapes of Timor-Leste is triggering an abandonment of small-scale farming and threatening the island's food security (Bambrick 2018). The complexity and pervasiveness of social-ecological impacts on small-scale farming hamper rural communities' ability to adequately respond to these rapid changes.

There is an increasing body of evidence demonstrating the contributions of Indigenous and Local Knowledge (ILK) to the understanding of the effects on local communities of the interrelations between climatic, ecological, and social changes (Reyes-García et al. 2019, 2022; Junqueira et al. 2021). Indigenous Peoples and Local Communities (IP&LC), including small-scale farmers, have their own ways of observing and interpreting the changes in the environment, based on which they make everyday decisions and shape their agricultural systems and livelihoods (Adger et al. 2013; Schlingmann et al. 2021). For example, Beyerl et al. (2018) reported that local farmers in three Pacific islands increased tree and crop planting in response to the perceived drought and soil erosion to ensure their food security. In the alpine zones of the Sikkim Himalaya, observations of changes in rain and snowfall patterns, and seasonality by Indigenous communities, resulted in the diversification of livestock by replacing sheep with yaks (Ingty 2017). Paradoxically, ILK regarding climate change has rarely been considered by academics and politicians in environmental negotiations or the proposal and implementation of adaptation measures (Reyes-García and Benyei 2019).

The Food and Agriculture Organization of the United Nations (FAO), along with individual States, has designated both Globally Important Agricultural Heritage Systems (GIAHS) and Nationally Important Agricultural Heritage Systems (NIAHS), defined as "outstanding landscapes of aesthetic beauty that combine agricultural biodiversity, resilient ecosystems, and a valuable cultural heritage. Located in specific sites around the world, they provide multiple goods and services, food, and livelihood security for millions of small-scale farmers" (FAO 2018:4), FAO has designated 67 GIAHS in 22 countries since 2005. Small-scale farming systems as part of mountainscapes in the southern Andes were identified by the Chilean State as a NIAHS in 2018 (MINAGRI 2020), while small-scale farming systems in the islandscapes of the Chiloé archipelago, in the South Pacific Ocean, were recognized as a GIAHS by FAO in 2011. Both sites are also located within the "Chilean Winter Rainfall-Valdivian Forests," one of the 36 Global Biodiversity Hotspots (Myers et al. 2000). Despite their global and local importance, ecosystems and livelihoods in these areas are experiencing rapid social-ecological changes particularly in the last decades, with a strong reduction in their native forest area (Echeverría et al. 2006), changes in snow patterns affecting the availability of water in Andean mountainscapes (Parraguez-Vergara et al. 2016), and the irruption of large-scale marine and terrestrial extractive activities in the islandscapes of Chiloé (Bustos-Gallardo et al. 2021). In this context, it is crucial to identify and understand the impacts of social-ecological changes in Important Agricultural Heritage Systems (IAHS) to enhance their resilience. In doing so, we rely on self-reported information by campesinos to investigate (i) the observed social-ecological changes and (ii) the perceived drivers of those changes occurring in a mountainscape and an islandscape in two IAHS of southern South America. Finally, we discuss the threats to small-scale farming livelihoods derived from the identified social-ecological changes and the importance of considering local knowledge (LK) in the design and implementation of public policies regarding adaptation to climate change.

Methods

Study area

The study was conducted in the Andean zone of the La Araucanía Region, specifically in the Municipality of Pucón (38–39°S), and in the Los Lagos Region in the Chiloé archipelago (41–43°S), southern Chile (Fig. 1), both recognized as IAHS by FAO and the Chilean Government. Pucón has historically been inhabited by Mapuche Indigenous People while Chiloé has been historically inhabited by Huilliche and Chono Indigenous Peoples (Gray 2016; Naqill Gómez 2021). Nowadays, both sites are inhabited by Indigenous communities, but also by non-Indigenous campesino families, long-term settlers, and, recently, by a growing number of lifestyle migrants from diverse cultures (Zunino and Hidalgo 2010). Small-scale farming, fishing, and harvesting of seafood and non-timber forest products have historically been the pillar of food sovereignty for Indigenous Peoples inhabiting the southern cone of South America (Coña and de Moesbach 2010). Encompassed by the Valdivian rainforest ecoregion, both sites have a temperate climate with a relatively short dry and warm season during summer months (December to February), and a cold and long wet season (April to November), with mean annual precipitations above 2.000 mm and mean annual temperatures of 10–12 °C (http://explorador.cr2.cl/).

The mountainscapes of Pucón are located in the Andes mountain range and within the Araucarias Biosphere Reserve (UNESCO 2016), comprising a mosaic of old-growth and secondary native temperate forests, National Parks and Reserves, the town of Pucón and small settlements, small-scale farms, lakes, rivers, non-native tree monocultures, pastures, and the Andes mountains and volcanoes, the Rukapillan volcano being the highest peak with 2.860 m.a.s.l. (Caviedes and Ibarra 2017). The region is considered an in situ reservoir of agrobiodiversity, where hundreds of crop species and ethnovarieties are grown by local campesinos (Ibarra et al. In Press).

The Chiloé archipelago is located in the southern Pacific Ocean, being the islandscape composed of one bigger island (Isla Grande) and around 40 smaller islands, small cities (the largest one with 45,000 inhabitants) and towns, beaches and coast, mussel and salmon farms, small ports, National Parks and Reserves, small-scale farms, old-growth and secondary native rainforest, non-native tree monocultures, peatlands, and pastures (Nahuelhual et al. 2014). The region is

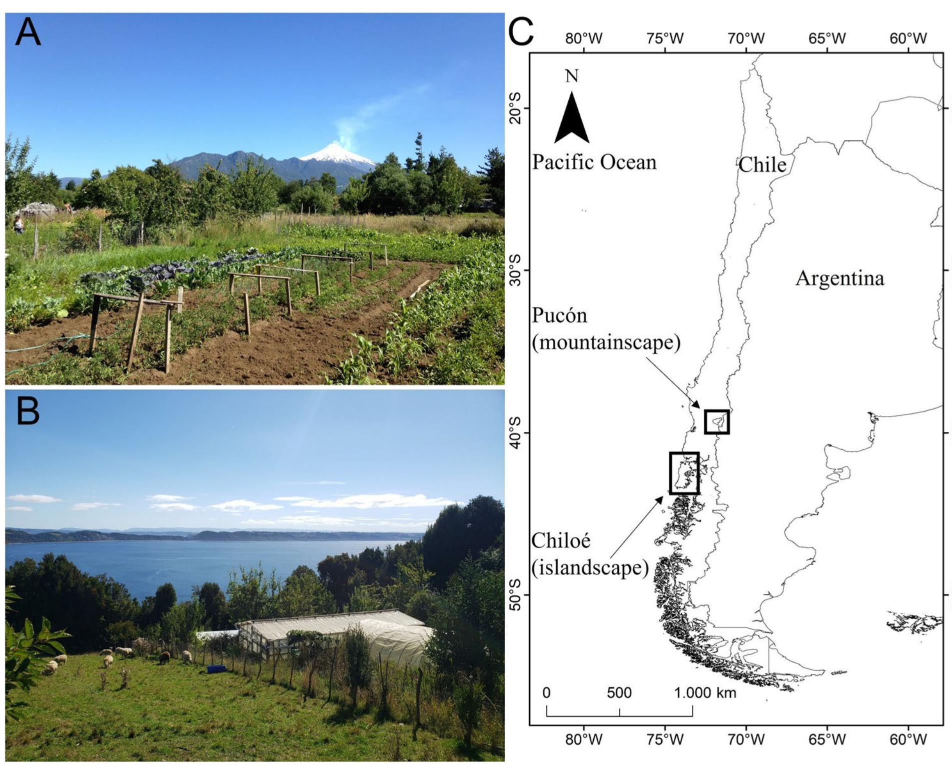

Fig. 1 Agrosilvopastoral systems from the mountainscapes of Pucón (**A**) and the islandscapes of Chiloé (**B**), and a map showing the location of the study sites in southern Chile (**C**)

worldwide recognized for its small-scale agriculture, with more than 300 native varieties of potatoes (*Solanum tuberosum*) cultivated on the archipelago, it is identified as a sub-center of origin of the potato (Solano 2019).

Data collection

We conducted 30 in-depth semi-structured interviews (15 in each site) during December 2020 and January 2021 in Pucón, and December 2021 and January 2022 in Chiloé with local campesinos, whose main livelihood strategy relied on agrosilvopastoral systems. We considered local campesinos as non-Indigenous small-scale farmers who were born, lived, and worked in the territory for at least two generations (Ibarra et al. 2021). Even though Indigenous and non-Indigenous cultures are intertwined after cohabiting both areas for decades, most of the participants identified themselves as non-Indigenous. To select participants, we used successive-referral sampling (Newing 2011), asking participants to indicate other people who managed agrosilvopastoral systems and who were locally recognized as experienced and knowledgeable about these systems. In Pucón, we interviewed 10 women and five men with ages ranging from 28 to 70 years old (Mean ± SD = 57 ± 12), while in Chiloé we interviewed 11 women and four men with ages ranging from 42 to 82 years old (Mean ± SD = 59 ± 12). At each site, we conducted interviews in three different localities (i.e., five interviews in each locality) that were distanced by at least 5 km from each other. Interviews were conducted by the first author, a 34 years old, Chilean male researcher, and lasted between 1 and 2 h. The study received approval from the Universitat Autònoma de Barcelona Ethics Committee (CEEAH-3367 and CEEAH-CA02), and we obtained the free, prior, and informed consent from all participants.

This study followed a Data Collection Protocol (Reyes-García et al. 2023) developed under the "Local Indicators of Climate Change Impacts" project (LICCI; 771056-LICCI-ERC-2017-COG; https://licci.eu/). The semi-structured interviews, initially without reference to climate, were aimed at obtaining information on (i) the social-ecological changes observed by campesinos in their territory and (ii) the perceived drivers that were influencing those changes. To do so, we started by asking each participant "Which changes in the environment have you observed during your lifetime?" Each time a participant mentioned an observed change, we asked for the underlying driver(s) of that specific change: "Why do you think this [mentioned change] has occurred?" If a driver was also an observed change, we wrote it down as both, change and driver, and kept asking. The word "environment" (*ambiente* in Spanish) was familiar and understood by the people that participated in the study. Hence, from each interview, we obtained a list of the observed social-ecological changes and the perceived drivers of each of the mentioned changes. Further description of this methodology can be found in Reyes-García et al. (2023).

Data processing and analysis

All the individual mentions of changes (hereafter "citations") quoted by the participants were grouped into observations of social-ecological changes (hereafter "observations of change"). Citations expressing similar changes were grouped together, for example, the citations "It is hotter nowadays," "It used to be colder in the past," and "Nowadays, temperatures are higher" were all grouped under the observation of change "Nowadays, temperatures are higher." Observations of change were then classified following a hierarchical classification of social-ecological changes based on Reyes-García et al. (2023), in which changes are grouped into four different "systems": Atmospheric (e.g., changes in temperatures, rain), Physical (e.g., changes in lakes, rivers), Biological (e.g., changes in flora, fauna), and Human (e.g., changes in agricultural systems, human health) and related subsystems (e.g., system: Atmospheric – subsystem: Precipitation, Physical – Freshwater, Biological – Terrestrial wild fauna, Human – Cultivated plants). Based on the number of times that the observations of change and citations were mentioned by the interviewees, we calculated the absolute and relative frequency of observations of change and citations at the system and subsystem levels for each site and for both sites together. A list with all the systems and subsystems can be found at https://licci.eu/licci-tree/.

Regarding drivers influencing the observations of change, we used a similar approach, in which individual mentions of drivers (hereafter "drivers' citations") were grouped into driver categories (hereafter "drivers"). For example, the drivers' citations' "It rains less now" (Atmospheric – Precipitation), "Droughts are more intense now" (Atmospheric – Precipitation), and "It snows less now" (Atmospheric – Precipitation) were grouped under the driver category "Climatic." The following 10 driver categories were considered, and inductively developed during the analysis: (i) Biophysical (e.g., "Rivers are drier now"), (ii) Climatic (e.g., "It rains less now"), (iii) Demographic (e.g., "There are more and new people now"), (iv) Infrastructure (e.g., "There are more houses now"), (v) Land use change (e.g., "There is less forest now"), (vi) Overexploitation (e.g., "Peat was all extracted"), (vii) Sea use change (e.g., "There are more mussel farms now"), (viii) Species introduction (e.g., "There are more wasps now"), (ix) Technological (e.g., "People use more pesticides nowadays"), and (x) Others (e.g., "There was a change in the diet"). We then calculated the number of drivers and drivers' citations influencing each observation of change, the number of observations influenced by each driver, and the frequency of drivers' citations associated with each category. We used alluvial plots to visually represent the connections between drivers influencing different observations of change. All analyses and visual representations were conducted using the packages "ggplot2" and "ggalluvial" of the R software version 4.2.0 (R Core Team 2021).

Results

Observations of social-ecological changes

In the mountainscapes of Pucón, the 15 participants mentioned social-ecological changes 220 times (citations), which were grouped into 56 different observations of change, being the Atmospheric system the most salient (most citations) and the one with most observations (Table 1). The observations "Rivers are drier now" (system: Physical – subsystem: Freshwater), "There is less forest nowadays" (Biological – Land degradation), and "There is less native wildlife nowadays" (Biological – Terrestrial wild fauna) were the most salient observations of change, with 15 citations each (7% of the total citations) the first two, and 13 citations (6%) the last. In the words of one participant "In the past everything was messy, everything was forest. I remember that my father cleaned it [the forest] for his crops and animals. Now there is little forest left and hardly any large trees" (Woman, 73 years old, Pucón). The 56 observations of change were classified into 17 subsystems, being the Precipitation subsystem (Atmospheric system; 21% of the total observations; 23% of the total citations; Supplementary material 1)—and specifically, the changes related to snow and rainfall—the most often referred by campesinos in the mountainscapes of Pucón. For example, one participant pointed out "Nowadays it doesn't fall more than four drops of rain (rain amount). In ancient times the rain was pleasant, it rained all year long, lots of rain, weeks in a row (rain frequency). The rain was intense, not like now (rain intensity). Now it rains just a little in winter (rain distribution)" (Woman, 78 years old, Pucón).

In the islandscapes of Chiloé, the 15 participants mentioned social-ecological changes 243 times (citations), which were grouped into 45 different observations of change. The Biological system was the one with most observations while the Atmospheric system was the most salient in terms of citations (Table 2). The observations "Droughts are more intense now" (Atmospheric – Precipitation), "It rains less now" (Atmospheric – Precipitation), and "Nowadays, temperatures are higher" (Atmospheric – Temperatures) were the most salient observations with 15 citations each (6% of the citations each). Drought is an important and recent phenomenon occurring on the island, as illustrated by one participant "In Chiloé we have never had water problems, never. It's been about five years since we've been dry in the summers, they [municipal government] have to bring us

Table 1 Absolute and relative frequency of observations of change and citations at the system level reported by campesinos in mountainscapes of Pucón. Each observation reported by local campesinos was grouped into one of four different "systems" (i.e., Atmospheric, Human, Physical, or Biological)

System	No of observations	Relative frequency of observations	No of citations	Relative frequency of citations
Atmospheric	21	38%	89	41%
Human	19	34%	58	26%
Physical	9	16%	35	16%
Biological	7	12%	38	17%
Total	56	100%	220	100%

Table 2 Absolute and relative frequency of observations of change and citations at the system level reported by campesinos in islandscapes of Chiloé. Each observation reported by local campesinos was grouped into one of four different "systems" (i.e., Atmospheric, Human, Physical, or Biological)

System	No of observations	Relative frequency of observations	No of citations	Relative frequency of citations
Atmospheric	10	22%	81	33%
Human	15	33%	70	28%
Physical	4	9%	16	7%
Biological	16	36%	76	31%
Total	45	100%	243	100%

water in cistern trucks" (Woman, 53 years old, Chiloé). The 45 observations of change were classified into 19 different subsystems, being "Marine biological system" (Biological system; 16% of the total observations; 18% of the total citations; Supplementary material 1) the one that encompassed more observations. A 68-year-old woman in Chiloé told us "At first, salmon farms were fine because they provided work. But later the sea got contaminated, fishes and seafood disappeared. Now it would be better if they left [the salmon farms]." The second most important changes at the subsystem level were those related to "Precipitation" (13% of the total observations; 21% of the total citations).

When analyzing mountain and islandscapes data together, participants mentioned social-ecological changes a total of 463 times (citations), which were grouped in 79 different observations of change. Of the 79 observations of change, 26 observations (33% of the total observations), corresponding to 128 citations (28% of the citations), were classified into the Human system, 22 (28%), corresponding to 170 citations (37%), into the Atmospheric system, 21 (27%), corresponding to 114 citations (25%), into the Biological system, and 10 (13%), corresponding to 51 citations (11%), in the Physical system. Different observations were shared and exclusive to each site (Table 3).

When considering the shared changes occurring in both sites, observations of change from the Atmospheric system (170 citations; 37% of the total citations) were particularly salient, specifically the ones regarding changes in the amount of rainfall (e.g., "It rains less now"; 26 citations; 6% of the total) and increasing temperatures (e.g., "Nowadays, temperatures are higher"; 26 citations; 6% of the total). For its part, the reduction in snowfall was one of the most important observations that were exclusively mentioned in Pucón (e.g., "It snows less nowadays"; 12 citations; 5% of the site). One participant from Pucón told us "When I was younger, it was common that snow fell around San Juan [June 23rd]. Nowadays, it hardly snows once a year at this altitude" (Man, 55 years old, Pucón). On the other side, changes in marine environments (e.g., "There are more mussel farms nowadays" and "There are more salmon farms nowadays"; 8 citations each; 3% of the site each) were the most often cited observations that were exclusively mentioned in Chiloé. A participant from Chiloé told us about how her relationship with the sea changed after the irruption of salmon and mussel farms "We have an invasion of salmon and mussel farms [in Chiloé]. There's nothing left, the richness that was in the sea is over. I fought myself with the sea because of the choreras [mussel farms]. I haven't gone to gather seafood ever again" (Woman, 51 years old, Chiloé).

Drivers of social-ecological changes

In the mountainscapes of Pucón, participants mentioned drivers for 41 (73% of the observations) of the 56 observations of change. For those 41 observations, participants mentioned drivers 126 times (drivers' citations) that were grouped into 36 different drivers belonging to nine drivers' categories. The most important driver of social-ecological changes in Pucón was "There is less forest nowadays" (driving 44% of the observations; 14% of the citations), categorized as "Land use change." A participant stressed the importance of forest reduction by saying "Of course it affects us [forest loss], because the forest retains the humidity of the soil" (Woman, 28 years old, Pucón). Drivers categorized as "Climatic" ($n=11$)

Table 3 Observations of social-ecological changes reported by campesinos in Pucón and Chiloé. Each observation reported by local campesinos was grouped into one of four different "systems" (i.e., Atmospheric, Human, Physical, or Biological). The "Total" column represents the total number of different observations in each system and the relative frequency of observations with each one of the four systems reported for both sites. The "Shared" column represents the total number of shared observations, the relative frequency of shared observations with the total number of observations, and the relative frequency of shared observations in each system. The "Exclusive Pucón" column represents the number of observations exclusively reported in Pucón, the relative frequency of observations exclusively reported in Pucón with the total number of observations, and the relative frequency of observations exclusively reported in Pucón in each system. The "Exclusive Chiloé" column represents the number of observations exclusively reported in Chiloé, the relative frequency of observations exclusively reported in Chiloé with the total number of observations, and the relative frequency of observations exclusively reported in Chiloé in each system

System	Total		Shared			Exclusive Pucón			Exclusive Chiloé		
	No Observations	%Total obs	No Observations	%Total obs	%System obs	No Observations	%Total obs	%System obs	No Observations	%Total obs	%System obs
Atmospheric	22	28%	9	11%	41%	12	15%	55%	1	1%	5%
Human	26	33%	8	10%	34%	11	14%	42%	7	9%	27%
Physical	10	13%	3	4%	30%	6	8%	60%	1	1%	10%
Biological	21	27%	2	3%	10%	5	6%	24%	14	18%	67%
Total	79	100%	22	28%		34	43%		23	29%	

were particularly important, driving 28 (68%) of the observations of change and corresponding with 66 (52%) of the drivers' citations (Fig. 2). Notably, most observations of change (66%) were associated with more than one driver (Mean ± SD = 3.07 ± 2.46 drivers per observation of change). Drivers influencing changes in precipitation were particularly salient in the responses of campesinos in Pucón, as it was the subsystem of the observations influenced by most drivers (42% of the drivers), drivers' citations (33% of the citations), and drivers' categories (67% of the categories).

In the islandscapes of Chiloé, participants mentioned drivers for 37 (82%) of the 45 observations of change. For those 37 observations, participants mentioned 88 drivers' citations that were grouped in 22 different drivers belonging to eight drivers' categories. The most important driver in Chiloé was "Climate change" (driving 30% of the observations; 13% of the citations), categorized as "Climatic." As in Pucón, drivers categorized as "Climatic" were particularly important, driving 19 (51%) of the observations of change and corresponding to 49 (56%) of the drivers' citations (Fig. 3). A participant reflected on the interrelations between different drivers saying that "Between climate change, forest loss and peat extraction, we are getting drier and drier" (Woman, 42 years old, Chiloé). More than half (54%) of the observations of change were associated with more than one driver (Mean ± SD = 2.0 ± 2.0 drivers per observation of change). Similar to what was reported by campesinos in Pucón, the subsystem of the observations that was influenced by most drivers (55% of the drivers), drivers' citations (25% of the citations), and drivers' categories (75% of the categories) was "Precipitation."

When analyzing mountainscapes and islandscapes data together, participants mentioned drivers for 61 (77%) of the 79 observations of change. For those 61 observations, participants cited drivers 214 times (drivers' citations), which were grouped in 41 different drivers (Mean ± SD = 3.50 ± 3.33 drivers per observation of change). Of these 41 different drivers, 19 (46% of the drivers), corresponding to 164 (77%) of the drivers' citations, were shared among the two sites, 17 (41%), corresponding to 35 (16%) of the citations, were only mentioned in Pucón, and five (13%), corresponding to 15 (7%) of the citations, were only mentioned in Chiloé. From the shared drivers, changes in forest surface (e.g., "There is less forest nowadays"; influencing 33% of the observations; corresponding to 12% of the drivers' citations) and "Climate change" (influencing 30% of the observations; 13% of the drivers' citations) were the most important. In the same line, when drivers were grouped into categories, campesinos in Pucón and Chiloé recognized "Climatic" drivers as the most common (29% of the drivers; 54% of the drivers' citations) and important (influencing 61% of the observations). In Chiloé,

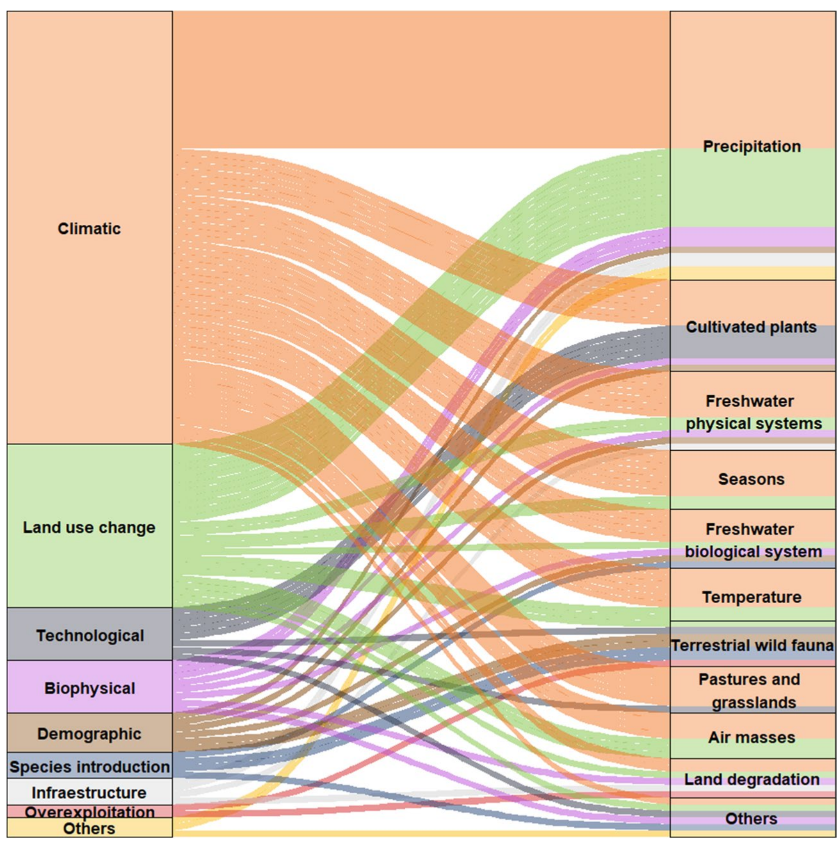

Fig. 2 Alluvial plot representing the connections between drivers' citations and their categories, with the observation subsystems mentioned by local campesinos in Pucón. The left column represents the categories of drivers while the right column represents the observations of change, grouped in subsystems. Different colors represent different categories of drivers. The size of the boxes in both columns is proportional to the number of drivers' citations. The observation subsystems "Cryosphere," "Livestock and raised animals," "Human health," and "Terrestrial physical systems" were all grouped under the category "Others"

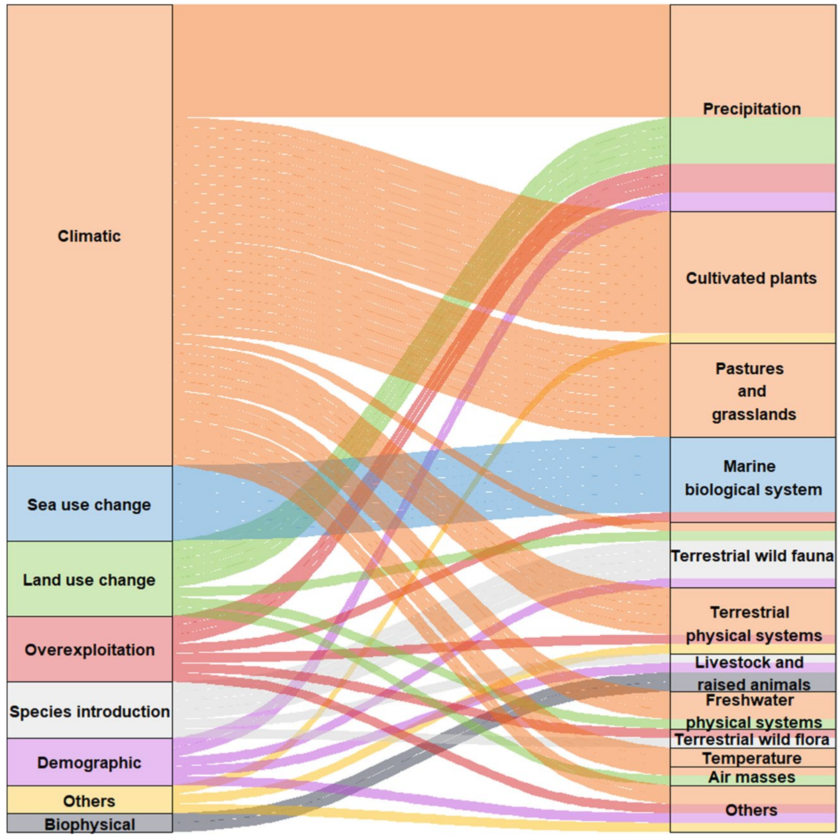

Fig. 3 Alluvial plot representing the connections between drivers' citations and their categories, with the observation subsystems mentioned by local campesinos in Chiloé. The left column represents the categories of drivers while the right column represents the observations of change, grouped in subsystems. Different colors represent different categories of drivers. The size of the boxes in both columns is proportional to the number of drivers' citations. The observation subsystems "Sociodemographic," "Seasons," "Marine physical systems," "Land degradation", and "Human health" were all grouped under the category "Others"

overexploitation, specifically regarding peatlands extraction and reduction in forest loss, was especially important. On the other side, regarding observations of change, campesinos in both sites identified a myriad of drivers influencing changes mainly in the Atmospheric system, as more than 40% of the drivers were influencing the observation "Droughts are more intense now" (44%) and the subsystem "Precipitation" (42%). The complexity in the interrelations between drivers and observations can be visualized in Figs. 2 and 3, where it is shown how, in both sites, a single driver can affect multiple changes, and how similar changes are simultaneously affected by different drivers.

Discussion

Global and local social-ecological changes are causing uncertainty and hardship to small-scale farmers worldwide. This study extends previous research on the knowledge of local communities about social-ecological changes, and their interrelated drivers, occurring in their territories. We found that campesino communities experience a wide range of social-ecological changes occurring in their territories, expressed in different systems (i.e., Atmospheric, Physical, Biological, and Human), and recognize complex interrelations between these changes and the (multiple) drivers influencing them. Based on the LK of local campesinos, our results show that mountainscapes and islandscapes of southern Chile have both similarities and differences regarding social-ecological changes and the drivers influencing them. On the one hand, similarities between the two sites were expressed as a result of global environmental changes (e.g., increased temperatures and drought) as well as to similar local social-economic pressures (e.g., conversion of native habitats, resource overexploitation). On the other hand, differences between both sites may be due to both differences in the biophysical environment and on people's relationships with the mountain or the sea in Pucón and Chiloé, respectively. Here, we discuss the major findings of this paper stemming from the LK on social-ecological changes and their drivers and discuss the implications of these findings for campesino livelihoods in IAHS.

Before discussing these results, we would like to acknowledge some of the caveats of this study. First, it is well known that local knowledge and understandings about social-ecological changes may be influenced by multiple socio-economic and cultural factors (e.g., age, schooling, access to information, gender; Kibue et al. (2016)), which we did not measure in this study. Still, we tried to cover a wide range of socio-economic profiles in our sampling aiming to reduce potential biases in our data. Second, as LK is highly context-dependent, we also recognize that it is difficult to generalize specific results of this study to other cultural and environmental contexts. Yet, we demonstrate how this situated nature of LK also allows a deeper understanding and nuances of social-ecological changes on local livelihoods, which can be useful to understand and act upon similar changes taking place elsewhere. Last but not least, another important limitation is that we use a Western science classification system to classify local observations, which is an over-simplification that does not encompass the whole complexity of LK.

Observations of change: local knowledge for the better understanding of complex global and locally induced social-ecological changes

Campesinos in the mountainscapes of Pucón and the islandscapes of Chiloé observed a myriad of global and locally induced changes occurring in their territories, highlighting the importance of LK for improving the understanding of social-ecological changes. Our results show that observed changes in the Atmospheric system were especially important in both sites, specifically the ones regarding a decrease in precipitations, increased temperatures, and drought. This is likely because campesinos' livelihoods are mainly dependent on precipitation for domestic, livestock, and agricultural activities. A common pattern in studies on ILK and farmers' perceptions of climate is the salience of changes in the Atmospheric system, as changes in this system are especially harmful to small-scale farmers whose livelihoods directly depend on them, and because changes in rainfall tend to be connected with several other changes (e.g., cascading effects; Pearce et al. 2018; Piya et al. 2013; Pyhälä et al. 2016; Sánchez-Cortés and Chavero 2011). In South Africa, for example, farmers attributed drought and rainfall variability as some of the main drivers of cropland abandonment (Blair et al. 2018). Similarly, in the mountain region of the Catalan Pyrenees in Spain, farmers (locally known as *pagès*) stated that rainfall decrease and variability had negative consequences on the yields of crops grown on larger fields and homegardens (Blanch-Ramirez et al. 2022).

Historically, agriculture in southern Chile has been rainfed; however, and mainly due to a reduction in precipitations and increased temperatures during the last decades, agricultural lands are now increasingly being irrigated (Donoso 2021). During summertime, when campesino farms are more productive, irrigation water in Pucón depends on the water descending from the rivers of the Andes mountains. Most of these waters come from reserves accumulated during winter in the form of snow and ice. Campesinos in Pucón unanimously reported that rivers are drier, and many others mentioned changes in snowfall patterns and glacier reductions; changes that were infrequently or not even mentioned in Chiloé, highlighting how the assemblage of observed changes is contingent on local biophysical characteristics. The reduction in the form of frozen water is already affecting agricultural communities in mountain ecosystems worldwide, for example, in the Andes mountains of Bolivia where local campesinos abandoned highland agricultural production and increased off-farm activities due to a decrease in precipitations and reduced availability from snowmelt and glacier runoff (McDowell and Hess 2012).

For their part, the islandscapes of Chiloé lack frozen water and large rivers; henceforth, water reservoirs for irrigation during drier months depend in great measure on precipitation partitioning by forest and peatlands (Frêne et al. 2022). Pearce et al. (2018) reported that, in small-scale farming villages on the island of Fiji, a reduction in precipitation directly affected agriculture, while indirectly creating anxieties and reducing farmers' well-being by not being able to sustain their farming livelihoods. Changes in the Atmospheric system in Chiloé and concomitant drought were also related to other observed and locally occurring changes on the island such as the reduction of forest cover, the establishment of exotic tree plantations, and resource overexploitation (e.g., peat extraction). Peat extraction on the island illustrates how a locally contextualized change impacts local livelihoods, but also has global consequences, as the destruction of peatlands and deforestation for agricultural purposes are some of the main contributors to greenhouse gas emissions worldwide (Zurek et al. 2022). These results suggest that, if local and contextualized adaptation measures against water scarcity are not taken, for example, for the water descending from mountains or reserved in peatlands, this may trigger abandonment of small-scale agriculture with concomitant devastating effects on local livelihoods and food security (Benayas et al. 2007; Zantsi and Bester 2019; Moyo and Ravhuhali 2022). This was the case with rural communities in the hill agroecological region of Nepal, where the reduction of irrigation availability was perceived as one of the main drivers for abandoning mountainous small-scale agriculture (Subedi et al. 2021). Campesinos in Pucón and Chiloé mentioned a larger number of changes in the Human system (e.g., changes in pastures, cultivated plants, livestock) in comparison to the other systems. This could be interpreted by the experience of "being campesino," as LK not only refers to the capacity of local communities to observe changes and understand their drivers in their "environment," but also to their complex, contextualized, and cumulative knowledge inherited from the continuous experience throughout generations that allows them to perceive changes in their livelihood activities (van der Ploeg 2013).

Drivers of change: local knowledge fosters a better understanding of interrelated drivers of social-ecological changes

We found that campesinos in two IAHS of southern South America not only experience a wide number of observations and drivers of social-ecological changes, but also complex interrelations between them in a holistic and integrated way (Junqueira et al. 2021; Blanch-Ramirez et al. 2022). Campesinos acknowledged how ecological changes were usually driven by multiple drivers at once, often operating at different scales (e.g., resulting from global changes and local processes), and identified how the same driver could influence, at the same time, multiple other social-ecological changes. As in other cases worldwide, social-ecological changes affecting small-scale-farming communities are a result of global and locally induced activities, whose interactions exacerbate the negative impacts on most vulnerable people (Nelson et al. 2006; McDowell and Hess 2012; Sapiains et al. 2019; IPBES and IPCC 2021). In the tropics, for example, it was shown that deforestation resulted in warmer and drier conditions at a local scale, while also contributing to global climate change, with strong negative outcomes for agricultural-dependent livelihoods and local food security and sovereignty (Lawrence and Vandecar 2015).

Globally occurring changes, such as changes in climate, were identified by campesinos in both sites as the most relevant drivers of social-ecological changes occurring in their sites. Agriculture in the mountainscapes of Pucón and Chiloé is mostly rainfed; hence, changes in precipitation patterns, drought, and increasing temperatures are specially identified by campesinos as drivers of other changes. Moreover, the mountainous and archipelagic biophysical conditions of both systems make them even more vulnerable to the negative impacts of climate change (Ingty 2017; Veron et al. 2019). In India, small-scale farmers identified climate variability as the most important driver of change which, at the same time, acted as an amplifier for socio-economic, ecological, and political drivers, with devastating consequences on their farming livelihoods (Singh et al. 2020). A recent study showed how drought is already impacting Chile, since 2010 a mega-drought has affected more than 10 million people with detrimental effects on vegetation, forest fires, and water availability that derived into economic and social impacts (Garreaud et al. 2020). Campesinos in Pucón and Chiloé identified that climatic drivers were also influencing non-climatic changes, changes which at the same time were identified as drivers of other changes, demonstrating the understanding of local communities on the complex nature of this drivers-observations network. Similarly, Bunce et al. (2010) reported that farmers in coastal communities of Tanzania and Mozambique perceived drivers and impacts that were mixed in space and time, hence complicating an objective identification of causal relationships.

Besides climatic drivers, campesinos also recognized different locally occurring (i.e., national and site scale) drivers which were influencing changes in different systems and subsystems. The reduction in forest surface was widely acknowledged in both sites as one of the main drivers of the social-ecological changes occurring in the last years. This is in line with what Gnonlonfoun et al. (2019) reported for local farmers in agroforestry systems in Benin, as they perceived that clearing the forest for agriculture and timber harvesting were the main drivers for deforestation which, at the same time, were resulting in a decrease in rainfall and increasing temperatures. Similarly, the Indigenous Zoques from Chiapas, Mexico, identified how larger trees attracted water, cloud, and fog, being cooler and rainier in old-growth forests than in deforested areas (Sánchez-Cortés and Chavero 2011). The relationship with the forest of Indigenous and non-Indigenous communities inhabiting Pucón and Chiloé has been important for centuries as temperate and rainforest ecosystems were dominant in both sites respectively (Cárdenas Álvarez and Villagrán Moraga 2005; Gray 2016). Fragmentation and deforestation of Chilean native forests have been occurring for decades (Echeverría et al. 2006). Interestingly, and in contrast to what campesinos reported, recent studies have shown that forest surface has increased in both sites mainly due to large-scale agriculture abandonment (Díaz et al. 2011; Petitpas et al. 2016). Overexploitation was a local driver of change identified by campesinos in Pucón reinforcing the idea that the understanding of changes and drivers by local communities depends on the biophysical, social, and economic conditions of their territories. The extraction of peats for international trade, previously reported in different studies (Díaz et al. 2012; León Valdebenito et al. 2012; Zegers et al. 2006), is a generalized and long-term problem that was commonly observed by campesinos in Chiloé. This ongoing and locally induced change has endangered small-scale agriculture on the island by reducing water availability leading to farm abandonment, while also generating broader social-ecological conflicts (Zegers et al. 2006; Bustos and Román 2019). Moreover, campesinos observed how cumulative local drivers of change were intensifying different impacts of climate change, for example, with peat extraction and its capacity for water filtration, regulation, and storage, and as carbon sinks (Díaz et al. 2012).

Conclusion

Social-ecological changes are impacting small-scale farmers worldwide, hindering their capacity to sustain their livelihoods. The current human-caused social-ecological crisis is generating unevenly distributed harm and risks across the world, with intensified effects on most vulnerable people, such as campesinos. We show that campesinos observed multiple globally induced changes that directly affected their livelihoods such as changes in precipitation, temperature, and drought. But they also observed different local changes which were shared among the sites, such as deforestation, and specific changes derived from each site's biophysical, social, and economic conditions. Moreover, campesinos mentioned that different global and locally induced changes were interrelated, identifying many of them as drivers of change, illustrating how local campesinos understood a complex network of changes occurring in their territories. Climate change was identified as the main driver of change, acting upon not only climate-driven observations but also influencing changes in other systems. In addition, different local changes were also identified to drive a myriad of changes. Changes and global and local drivers identified by campesinos were intertwined, hence increasing the complexities when addressing the impacts of social-ecological changes. International and national policies regarding adaptation to climate change often overlook the realities of local ecological and social contexts, generating and promoting top-down and standardized adaptation measures. Indigenous and local knowledge are reservoirs of site-specific information developed from a strict, intimate, and long-term relationship of communities with their territories. Campesino's knowledge should form the basis of vulnerability assessments, as it provides a more complete understanding of changes, drivers, and connections to develop adaptation measures that are well suited to the local context. Moreover, including local communities will bring more legitimacy to the process by ensuring accountability and validation of the information (Ibarra et al. 2023). Therefore, decision-makers and institutions must be tuned with local dynamics and situated knowledge to promote adaptation measures that be locally contextualized to reduce the vulnerability of campesino communities to global and local social-ecological changes.

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Data Availability The data that support the findings of this study are available from the corresponding author, upon request.

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