Received: 10 October 2024 | Accepted: 5 May 2025

DOI: 10.1002/pan3.70068

People and Nature

RESEARCH ARTICLE

# Livelihood resilience: The role of social-ecological filters in a Globally Important Agricultural Heritage System of southern Chile

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**Funding information**
Fondo Nacional de Desarrollo Científico y Tecnológico, Grant/Award Number: 1240070, 1200291 and 1231664; REDES, Grant/Award Number: 190033; Center for Intercultural and Indigenous Research, Grant/Award Number: 15110006; Center of Applied Ecology and Sustainability, Grant/Award Number: AFB240003; Cape Horn International Center, Grant/Award Number: PFB210018; ERC Consolidator Grant, Grant/Award Number: FP7-771056-LICCI; Fons de Solidaritat de la Fundació Autònoma Solidària; Laboratory for the Analysis of Social-Ecological Systems in a Globalized world (LASEG); Universitat Autònoma de Barcelona and Generalitat de Catalunya, Grant/Award Number: 2021-SGR-00182; European Union, Grant/Award Number: NDICI CSO/2023/451-084; Spanish Ministry of Science, Innovation, Universities, Grant/Award Number: CEX2019-000940-M, PID2021-123129NB-C43 and TED2021-130333B-C33; The National Research and Development Agency of Chile

**Handling Editor:** Truly Santika

## Abstract

1. The global agrifood system faces significant threats due to rapid and interconnected social-ecological changes, including climate change, land-use shifts, demographic changes and emerging diseases. Small-scale farmers are among the most vulnerable groups to these changes due to their direct dependence on their environment.
2. The resilience of small-scale farming livelihoods may be influenced by several social-ecological filters, which are the coupled human–nature factors that could either hinder or increase resilience, directly impacting local agrifood systems. Our study aims to assess how different social-ecological filters (i.e. sociodemographic factors, diversity of agroecosystems and on-farm landscape composition), operating at multiple levels, are associated with small-scale farmers' livelihood resilience in the Chiloé Archipelago, a Globally Important Agricultural Heritage System within a Global Biodiversity Hotspot in southern Chile.
3. We conducted 100 household surveys with small-scale farmers to calculate the diversity of agroecosystems within each farm and an Index of Livelihood Resilience (ILR) based on indicators of five capital assets (i.e. social, physical, natural, financial and human). We also took aerial photographs of their farms, from which we derived information on landscape composition. Using Generalized Linear Mixed Effects Models, we tested the association between eight different social-ecological filters and the ILR.

4. We found that the age of the household head and shrubland surface in the farm were negatively associated with livelihood resilience, while the diversity of agroecosystems within the farms was positively associated with the livelihood resilience of small-scale farmers.
5. Identifying factors that enhance the livelihood resilience of small-scale farmers is essential for developing effective initiatives and policies aimed at ensuring global and local food security and sovereignty. Based on our results, we propose recommendations to strengthen small-scale farmers' livelihood resilience to mitigate the global agrifood crisis.

**KEYWORDS**
agroforestry systems, agrosilvopastoral systems, campesinos, Chile, climate change, GIAHS, smallholder farmers, small-scale farmers

## 1 | INTRODUCTION

There is increasing evidence indicating that the world is facing an agrifood crisis (Abay et al., 2023; Allee et al., 2021; Kakaei et al., 2022). The negative impacts of rapid social-ecological changes, such as climate and demographic changes, land-use shifts, emerging diseases and wars, acting at both global and local scales, have placed small-scale farmers' livelihoods under severe pressure (Abay et al., 2023; Krishnamurthy et al., 2022; Ren et al., 2023). According to the Food and Agriculture Organization of the United Nations (FAO), the number of people facing hunger increased by 122 million from 2019 to 2022, reaching between 691 and 783 million in 2022 (FAO et al., 2023). Moreover, a recent meta-analysis projected that global food demand will increase from 35% to 56% between 2010 and 2050 (van Dijk et al., 2021). In response to this scenario, it is imperative to promote farming livelihoods that can cope with this crisis while sustaining food production and ensuring food sovereignty.

While small-scale farmers' livelihood resilience is constantly challenged by rapid and intertwined social-ecological changes, they still manage to produce at least one-third of the world's food (Lowder et al., 2021; Ricciardi et al., 2018). Tanner et al. (2014, p. 23) define livelihood resilience as 'the capacity of all people across generations to sustain and improve their livelihood opportunities and wellbeing despite environmental, economic, social and political disturbances'. A livelihood resilience approach has its foundations in that livelihood resilience depends on people's access, combination and capacity to increase different capital assets, highlighting the role of people's agency in building livelihood resilience (Quandt, 2018). Recently, different methodologies based on empirical indexes have attempted to quantify livelihood resilience (e.g. Aguilar et al., 2022; Quandt, 2018). Applying indexes is advantageous because they are easy to implement and effective in providing a broader picture of complex issues, such as livelihood resilience to rapid social-ecological changes (de le Polain Waroux et al., 2024). Quandt (2018), for example, proposed and empirically tested the Household Livelihood Resilience Approach (HLRA), an index based on five capital assets (i.e. social, physical, natural, financial and human), to measure livelihood resilience. The HLRA has been recently applied in small-scale farming households across different contexts and countries, including Cameroon (Awazi & Quandt, 2021), Chile (Caviedes et al., 2024), Jamaica (Campbell, 2021) and Kenya (Quandt, 2019).

Small-scale farmers are among the most vulnerable groups to the current agrifood crisis due to their direct dependence on their environment, their historical marginalization and their structural disadvantages (Porcuna-Ferrer et al., 2024). They generally manage areas ranging from less than 1 to 10 ha. In our study, while many farmers may own more than 10 ha, they productively manage less than 10 ha of land. Regardless of land ownership, small-scale farming is characterized by family-focused motives, including favouring the resilience of a farming livelihood, relying primarily on family labour for production and using part of their produce for family consumption (FAO, 2013). Therefore, understanding the factors that enhance their livelihood resilience is critical for both their livelihoods and global and local food security and sovereignty. By applying empirical indexes, local agricultural extension agencies could better understand each small-scale farmer's household reality and make more informed decisions, with input from the farmers, on where to allocate resources (Ibarra et al., 2023). Other studies have emphasized the importance of using indexes to help policymakers understand complex relationships in small-scale farming (e.g. applying an agrobiodiversity index to monitor food systems policies) and influence local and global policies to identify priority interventions for building more resilient agrifood systems (Jones et al., 2021).

The resilience of small-scale farmer livelihoods can be influenced by multiple social-ecological filters acting at different levels (e.g. household, farm, landscape). These filters include factors such as household demographics, agroecosystem diversity and landscape composition (Jansuwan & Zander, 2021; Mariel et al., 2021; Milheiras et al., 2022; van der Lee et al., 2022). A social-ecological filter refers to the coupled sociocultural and environmental factors that shape the resilience of small-scale livelihoods in a given location. Foundational studies describe both environmental and sociocultural

processes as metaphorical 'sieves' or 'filters' that allow only certain plant and/or animal species, varieties or local livelihoods, to establish and persist within a social-ecological system. Originally rooted in community ecology (see Kraft et al., 2015 for a review of the concept), this notion has recently gained attention in the context of resilience thinking and its application to social-ecological system analysis (e.g. Cortés et al., 2023; Ibarra et al., 2021, 2024). At the household level, the age of the household head is a social-ecological filter influencing the livelihood resilience of small-scale farmers, as older household heads experience declines in health and physical capacity, limiting their ability to perform the physically demanding tasks required to maintain a productive farm (Jansuwan & Zander, 2021). In China, for example, the aging of household heads has been linked to reductions in farm size and decreased agricultural productivity, further acting as a filter on livelihood resilience (Ren et al., 2023). At the farm level, agroecosystem diversity is another social-ecological filter associated with livelihood resilience. In Ethiopia, promoting a higher diversity of agroecosystems—including different species, structures and management practices—acts as a social-ecological filter that enhances resilience (Morel et al., 2024). At the landscape level, agricultural landcover composition acts as a social-ecological filter that can either strengthen or weaken resilience. In Kenya, for example, the livelihood resilience of small-scale farmers in agricultural landscapes practicing agroforestry was 10% higher compared to those who did not (Quandt et al., 2019). Despite the growing body of literature on livelihood resilience, there is still a knowledge gap explaining how multiple social-ecological filters, acting at different scales, interact and simultaneously influence the resilience of small-scale farmers' livelihoods.

In response to the negative impacts of rapid social-ecological changes on small-scale farming, the FAO launched the Globally Important Agricultural Heritage Systems (GIAHS) program in 2002 (Koohafkan & Altieri, 2011). Alongside national governments, the program aims to conserve specific agricultural systems that hold high levels of agrobiodiversity, intricate knowledge systems and traditional farmers' livelihoods. To date, 86 systems in 26 countries have been designated as GIAHS, including seven systems in four countries in Latin America and the Caribbean, with the Chiloé Archipelago in southern Chile being one of them. However, the designation of a GIAHS has not diminished the challenges to small-scale farmers in Chiloé, whose livelihoods are impacted by climate change (Frêne et al., 2022; Oyarzo et al., 2024), land-use shifts (Carmona et al., 2010) and demographic trends (Bustos-Gallardo et al., 2021), threatening the island's food security and sovereignty. Using the Chiloé Archipelago as our case study, we aimed to assess how multiple social-ecological filters acting at different levels are associated with the livelihood resilience of small-scale farmers. We developed an Index of Livelihood Resilience (ILR) and tested its association with eight different social-ecological filters, including farmers' household head profile, diversity of agroecosystems and landscape composition within a farm. Finally, we present recommendations aimed at enhancing the livelihood resilience of small-scale farmers to address the current agrifood crisis.

This study builds on a previous investigation that examined associations between an Index of Knowledge on Social-Ecological Changes (IKSEC), an ILR and five capital assets (i.e. financial, human, social, physical and natural) among small-scale farmers in Chiloé (Caviedes et al., 2024). That study found a significant positive association between local knowledge on social-ecological changes and livelihood resilience, as well as with farmers' natural, social and physical capital. Authors discussed that, despite identifying significant positive associations, the strength of those associations was weak; suggesting that other factors were also playing simultaneous roles in building livelihood resilience. In this follow-up study, other factors (i.e. social-ecological filters) potentially associated with livelihood resilience are further investigated.

## 2 | METHODS

### 2.1 | Study area

The study was conducted in the Chiloé Archipelago, located along the southern Pacific coast of Chile (41°–43° S). The main island (Isla Grande; 8394 $km^2$) and the 40 smaller islands that compose the archipelago are inhabited by 171,487 people, of which 41% live in rural areas (INE, 2022; Figure 1). Besides being a GIAHS, Chiloé is located within the 'Chilean Winter Rainfall-Valdivian Forests' Global Biodiversity Hotspot (Myers et al., 2000). The climate is temperate, characterized by a significant oceanic influence, with mean annual precipitations ranging from 2000 to 2500 mm, of which only 14% occurs during the summer and mean annual temperatures ranging from 10°C to 12°C (http://explorador.cr2.cl/; Frêne et al., 2022). The islandscape results from historical interactions between human populations and their environment, forming a complex and heterogeneous mosaic (Daughters & Pitchon, 2018). This social-ecological islandscape is characterized by an extensive coastline, while the inland areas are predominantly covered by agrosilvopastoral systems, native forests, grasslands, shrublands, exotic-tree plantations, small towns and wetlands encompassing patches of peat bogs.

The Chiloé Archipelago has a rich cultural heritage, shaped by the interaction of Chonos and Huilliche Indigenous Peoples with European settlers who arrived in the islands following Spanish colonization in the 16th century (Daughters & Pitchon, 2018). Historically, the economy of Chiloé relied on coastal fishing, forestry and small-scale farming, which remain a fundamental aspect of the region's identity, reflected in rural households' economic activities, practices, beliefs and food (Cárdenas Álvarez & Villagrán Moraga, 2005; Delgado et al., 2022). Furthermore, Chiloé is recognized as a sub-centre of origin for the potato (*Solanum tuberosum*), home to over 300 native potato varieties still under cultivation, playing a vital role in the area's local food sovereignty (Solano, 2019). Today, the archipelago is inhabited by Indigenous Peoples, descendants of long-term settlers, non-Indigenous campesino families and lifestyle migrants. This syncretic relationship has shaped Chiloé's iconic agrosilvopastoral systems, composed of diverse agroecosystems and agricultural

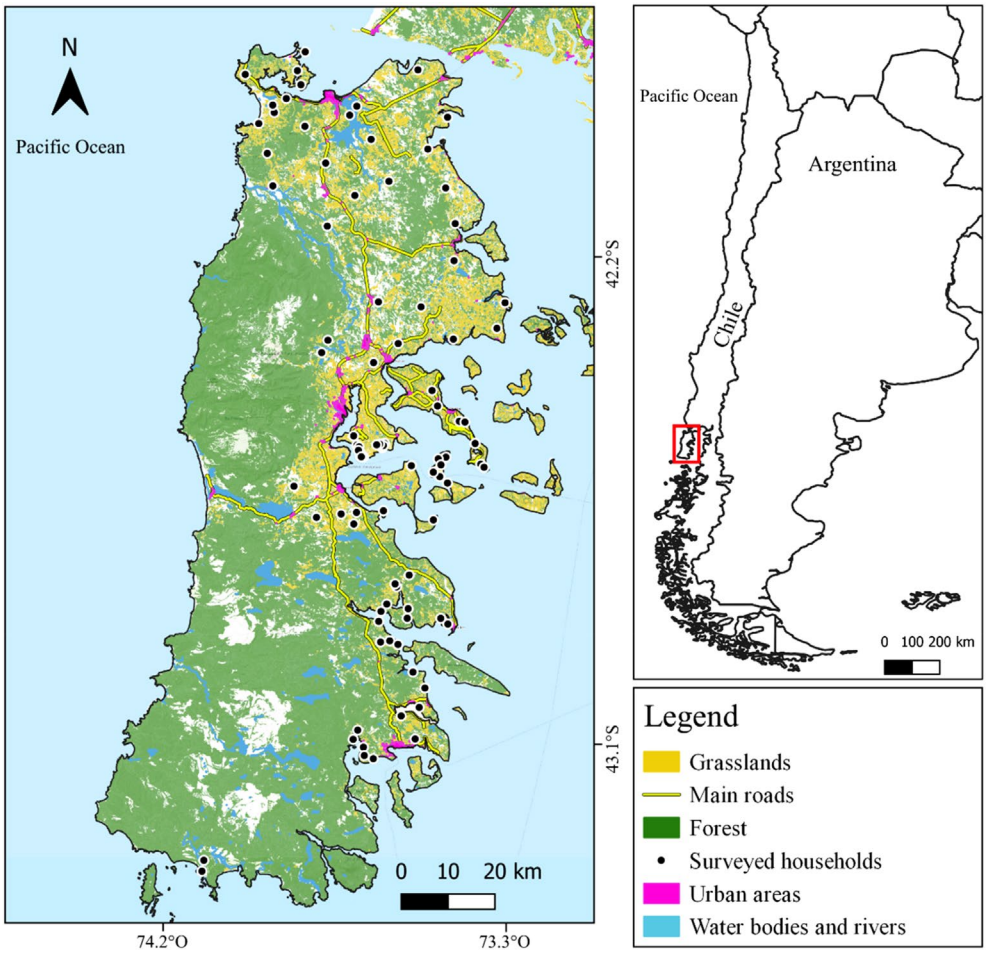


**FIGURE 1** Study area and the location of the 100 surveyed households within the Chiloé Archipelago, a Globally Important Agricultural Heritage System within a Global Biodiversity Hotspot, in southern Chile. The white areas on the map on the left correspond to unclassified areas, areas devoid of vegetation and snow and glaciers. The map was prepared by the authors using data from CONAF (2018) and IDE MBN (2024).

landcovers within a single farm, including potato fields, homegardens with a mix of crops and medicinal plants, grasslands for animals, shrublands and the presence of poultry, pigs, sheep, as well as a variety of native, exotic and fruit trees (Almonacid Burgos et al., 2023). Historically, agrosilvopastoral systems have been managed using agroecological practices rooted in local agricultural knowledge (e.g. fertilizers derived from algae and animal manure). However, agricultural modernization—characterized by increased reliance on agrochemicals and machinery—has increasingly displaced traditional methods (Billaz et al., 2005). While the inhabitants of Chiloé were once self-sufficient, they now engage in a bidirectional exchange with the mainland, exporting products such as salmon, mussels and timber while importing market goods like flour and other food items (Billaz et al., 2005; Bustos & Román, 2019).

## 2.2 | Data collection

We performed a 6-month fieldwork divided into two field seasons (December 2021 to February 2022 and December 2022 to February 2023). We conducted 100 household surveys with local small-scale farmers (who identify themselves as campesinos), whose main livelihoods relied on agrosilvopastoral systems. We also took aerial photographs of each of their farms using a drone (which is described in Section 2.2.2). We used a stratified random sampling approach that ensured spatial, demographic and socioeconomic representation based on the most populated places, including 75 human settlements (localities) from all the 10 Municipalities of the archipelago (Figure 1). To achieve this, we selected areas on a map, and we sought interviews with the first available household in each area. Selection criteria stipulated that participants must have been inhabiting the area for more than one generation and practicing small-scale farming with agrosilvopastoral systems as their primary livelihood. We interviewed either the female or male household head, depending on availability and willingness to participate in the study. The study was not designed with a gender-specific focus, as surveys were structured at a household level. Surveyed households were spaced at least 3 km from each other.

We considered relevant ethical regulations and guidelines to conduct our study, which received the approval of the Universitat

Autònoma de Barcelona Ethics Committee (CEEAH-CA02). We also obtained written or oral (based on participant preference) prior, free and informed consent from all participants. The first author, a Chilean, 34-year-old male researcher, conducted all the surveys in Spanish, which is both the participants' and the main author's first language. We conducted this study as a group of eight researchers with different backgrounds, including ecology, agronomy, human geography, anthropology and biology. This interdisciplinary approach allowed us to apply mixed methods, integrating tools from both the social and natural sciences. Five of the authors were born in Chile and live close to the study area. One author is from Brazil and was an advisor for the first author's doctoral thesis. Two authors are from Spain, one of whom also was as a doctoral advisor to the first author. While our team brings a mix of academic perspectives, we acknowledge that our positionalities, methods and interpretations capture only a portion of a complex and multifaceted topic.

### 2.2.1 | Household surveys

To better describe the participants, we collected sociodemographic information, including the number of family members in the household, and the gender and age of the surveyed household head. The sample size was determined using the formula proposed by Scheaffer et al. (1990). Aiming to obtain information on quantifiable indicators of resilience, we conducted surveys to 100 households (Table 1). This number is considered adequate for research on small-scale farming systems of a similar scale to those in the study area (Albuquerque et al., 2014). We categorized indicators

**TABLE 1** Household survey indicators used to build an Index of Livelihood Resilience (ILR) to social-ecological changes in a globally important agricultural islandscape of southern South America.

| Asset | Quantitative indicator | Unit |
|---|---|---|
| Social capital | Participation in groups | Number |
| | Participation in agriculture groups | Number |
| | Board member of the participating groups | Number |
| | Exchange seeds | Yes = 1/no = 0 |
| | Family living nearby | Four options |
| | Relationship with neighbours | Four options |
| | Practice 'vuelta de mano' (reciprocity labour day) | Four options |
| Physical capital | Ownership of farming equipment | Number/seven options |
| | Access to irrigation schemes/infrastructure | Number/five options |
| | Presence of facilities | Number/five options |
| Natural capital | Diversity of potatoes varieties | Number |
| | Farm age (years) | Number |
| | Size of farmland (ha) | Number |
| | Number of livestock | Number/seven options |
| | Sources of water | Number/five options |
| | Gathers products from the sea | Four options |
| | Gathers products from the forest | Four options |
| Financial capital | Size of farmland (ha) | Number |
| | State benefits | Number |
| | Salaried job | Yes = 1/no = 0 |
| | Access to a bank account | Yes = 1/no = 0 |
| | Savings | Yes = 1/no = 0 |
| | Debts | Yes = 0/no = 1 |
| | Member of an agricultural state program | Yes = 1/no = 0 |
| | Number of livestock | Number/seven options |
| | Ownership of farm equipment | Number/seven options |
| | Sell farm products | Five options |
| Human capital | Labour availability (working age >15 years old) | Number |
| | General health of family | Five options |
| | Health problems' effect on agriculture | Four options |
| | Education level | Four options |

of resilience into five capital assets (social, physical, natural, financial and human; Quandt, 2018). The selection of indicators was based on their empirical testing in prior research on small-scale farmers' livelihood resilience elsewhere (Aguilar et al., 2022; Awazi & Quandt, 2021; Cassidy & Barnes, 2012; Quandt, 2018, 2019; Quandt et al., 2017), as well as on insights from earlier studies in Chiloé (Barrena et al., 2014; Nahuelhual et al., 2014), and on our understanding of the unique context and characteristics of the area (Caviedes et al., 2023, 2024).

To assess the diversity of agroecosystems on the farms, we asked for the presence or absence of eight different agroecosystems within each farm. Agroecosystems are sites where agricultural and productive activities take place, supplying food and other economic resources to small-scale farming households. The selected agroecosystems were: (i) potato fields, (ii) homegardens, (iii) orchards, (iv) native forest, (v) greenhouse, (vi) grasslands, (vii) animal shed and (viii) exotic-tree plantations. These systems were selected based on their significance within Chiloé's agrosilvopastoral systems, as well as their representation of diverse livelihood strategies practiced by campesinos in the archipelago (Billaz et al., 2005; Carmona et al., 2010; Daughters & Pitchon, 2018).

### 2.2.2 | Aerial photographs

To assess the spatial composition of the farms, we captured aerial photographs of each farm from an altitude of 80 metres using a DJI Air 2S drone. Drone missions were executed with Dronelink 4.7.0 automated flight-planning software, each lasting approximately 12 min and resulting in the capture of 104 photographs per farm, acquired with a 70% lateral and frontal overlap. Landscape composition parameters were calculated using a 5-ha circle buffer (126.2 m radius) centred on the centroid of each farm's main house, representing the median farm size among the 100 surveyed farms (Caviedes et al., 2024).

## 2.3 | Data processing

### 2.3.1 | Index of Livelihood Resilience (ILR)

With the information about the indicators gathered from the surveys, we developed an Index of Livelihood Resilience (ILR) at the household level, building upon Quandt's (2018) HLRA (Table 1). We choose this methodology because the HLRA (i) is one of the few livelihood resilience indexes that has been empirically tested with small-scale farmer households, (ii) it focuses on resilience to social-ecological changes in general, rather than resilience to a specific disturbance (e.g. to climate change) and (iii) it was tested on agroforestry systems from the Global South, which are the focus of this study. Each indicator was assigned a score between 0 and 1, and the sum of these values for each capital asset was then averaged to calculate a score for each capital, ranging from 0 to 1. For indicators with categorical responses (e.g. 'How is the relationship with your neighbours?'; social capital), we provided a list of options with corresponding scores ranging from 0 to 1 (e.g. none [0], distant [0.33], good [0.66], very good [1]). Finally, we aggregated the scores from each of the five capital assets to construct an unweighted and straightforward composite index, which ranged from 0 (lower resilience) to 5 (higher resilience). More details from this methodology can be found in Caviedes et al. (2024).

### 2.3.2 | On-farm landscape composition

We used the dataset of 104 photographs per farm to generate an orthomosaic of each farm, with a resolution of approximately 2.5 cm per pixel. The 100 orthomosaics, featuring RGB (red–blue–green) data, were processed using Agisoft Metashape Professional version 1.6.1 software. To calculate the surface of key landcover categories and assess on-farm landscape metrics within the 5 ha buffer around each farm, we initially defined 10 landcover categories that are characteristic of Chiloé's islandscape: (i) grasslands, (ii) native forest, (iii) shrublands, (iv) bare soil, (v) roads, (vi) crop areas (i.e. homegardens and potato fields), (vii) infrastructure (e.g. houses, greenhouses, water storage tanks, sheds), (viii) sea, (ix) water bodies and (x) exotic-tree plantations (Figure 2; Billaz et al., 2005; Carmona et al., 2010; Daughters & Pitchon, 2018). Utilizing the maximum likelihood approach, we conducted a supervised classification that grouped image pixels into respective landcover categories and quantified the land-use area of each category in each of the 100 orthomosaics (Chuvieco, 2008). The classification and quantification of surface per category were performed using the image classification algorithm and the zonal statistics tool in ArcGIS Pro version 2.9. After classification and quantification, each orthomosaic was revised to assess for potential mis-classifications and to check that each category for each orthomosaic complied with a minimum standard based on the Kappa coefficient (>0.7; Rwanga & Ndambuki, 2017). Finally, with the 'landscapemetrics' package of the R software version 4.2.1 (R Core Team, 2022), we calculated the diversity of productive landcovers using the Shannon diversity index which included the following landcover categories: (i) grasslands, (ii) native forest, (iii) crop areas and (iv) exotic-tree plantations. We selected these four landcover categories for calculating the Shannon diversity index because they represent the main on-farm landcovers where the primary productive activities are carried out by campesinos in Chiloé (Billaz et al., 2005; Carmona et al., 2010; Daughters & Pitchon, 2018).

## 2.4 | Data analysis

After reducing multicollinearity for the explanatory variables, we examined the fixed effects of eight social-ecological filters (explanatory variables; Table 2) on ILR (response variable) using Generalized Linear Mixed Effects Models (GLMMs). Social-ecological filters included the age of the household head, diversity of agroecosystems, surface of five landcover categories (i.e. grasslands, native forest,

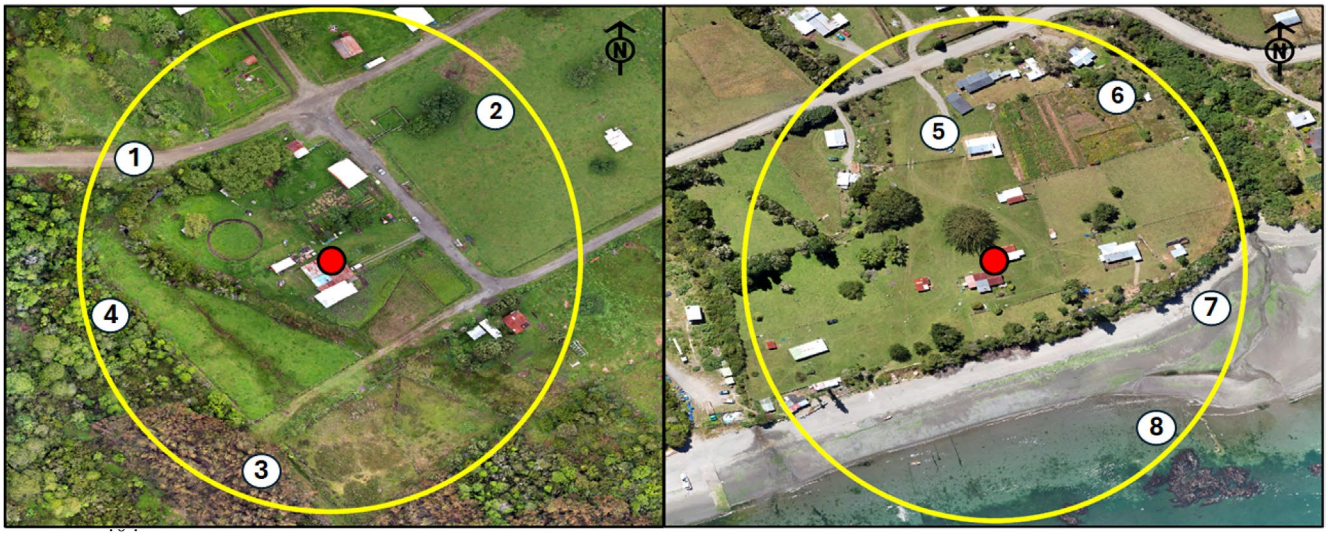


FIGURE 2 Orthomosaics of two farms used to calculate on-farm landscape composition, including eight key landcover categories common to Chiloé's islandscape. The landcover categories shown in the figure include: 1. roads, 2. grasslands, 3. shrublands, 4. native forest, 5. infrastructure, 6. crops, 7. bare soil, 8. sea. The landcover categories 'water bodies' and 'exotic-tree plantations' are not present in the two shown cases. The yellow circle represents a 5 ha circle buffer centred on the centroid of each farm's main house (red dot). The authors took the photographs.

TABLE 2 Social-ecological filters used to evaluate campesino's livelihood resilience in the Chiloé Archipelago, southern Chile.

| Social-ecological filter | Description | Type of variable |
|---|---|---|
| Age household head | Age of the surveyed household head | Discrete |
| Diversity of agroecosystems | Number of agroecosystems per farm | Discrete |
| Grasslands | Grasslands surface in a 5 ha circle buffer around the main house | Continuous (ha) |
| Native forest | Native forest surface in a 5 ha circle buffer around the main house | Continuous (ha) |
| Shrublands | Shrubland surface in a 5 ha circle buffer around the main house | Continuous (ha) |
| Crop areas | Crops surface in a 5 ha circle buffer around the main house | Continuous (ha) |
| Infrastructure | Infrastructure surface in a 5 ha circle buffer around the main house | Continuous (ha) |
| Shannon index | Shannon diversity index of productive landcovers | Continuous |

*Note*: Diversity of agroecosystems corresponds to the additive presence in each farm of: (i) potato fields, (ii) homegardens, (iii) orchards, (iv) native forest, (v) greenhouse, (vi) grasslands, (vii) animal shed and (viii) exotic-tree plantations.

shrublands, crop areas and infrastructure) and the Shannon index of productive landcovers (Table 2). Locality was a random effect in all models. To identify the best models, we employed Akaike's Information Criterion (AIC) to generate a candidate set of models, considering both the accuracy of the predicted coefficients and the model weights (wi). We considered models with $\Delta AIC \leq 2$ as our competitive models with support, where $\Delta AIC$ represents the difference in AIC values from the best model. GLMMs were run using packages 'lmer' and 'AICcmodavy', and graphs were produced with the 'ggplot2' package of the R software version 4.2.1 (R Core Team, 2022).

## 3 | RESULTS

### 3.1 | Households profile and livelihood resilience

We conducted surveys with a total of 100 campesinos (71 women and 29 men), aged 23–82 years (mean ± SD = 58 ± 12). On average, households had three (mean ± SD = 2.56 ± 1.10) members, of which two (mean ± SD = 2.30 ± 1.00) were engaged in agricultural activities on the farm. Moreover, 32% of households had at least one member engaged in off-farm salaried jobs and 47% reported health problems that affected their farming capacity. The farms had an average size

of 12.31 ha (SD = 22.28) and were older than 69.49 years (SD = 37.31). 60% of the surveyed households were members of an agricultural State program while 74% of the households participated in at least one group related to agriculture, and 57% practiced 'Vuelta de mano' (i.e. reciprocity practice of unpaid help for agricultural tasks between family or neighbours; Caviedes et al., 2024). Moreover, 87% of participants reported having a 'good' or 'very good' relationship with their neighbours. Campesinos also reported gathering products from the sea (68% of households) and from the forest (50% of households). Values for the ILR for campesinos in Chiloé ranged from 0.94 (less resilient) to 3.30 (more resilient), with a mean value of 2.19 (SD = 0.49).

### 3.2 | Agroecosystems diversity and landscape composition of farms

Survey results indicated that the diversity of agroecosystems on each farm comprised at least two agroecosystems (mean ± SD = 5.53 ± 1.37), with six farms comprising all the agroecosystems ($N = 8$). 'Potato fields' and 'homegardens' were the most common agroecosystems, present in 97 and 95 farms, respectively, while 'Exotic-tree plantations' was the least common, being present only in 22 farms.

Regarding on-farm landscape composition, 'grasslands' and 'native forests' were the landcover categories with both the highest median and mean surfaces among the 10 on-farm landcover categories (Table 3). The median surface of 'sea', 'water bodies' and 'exotic-tree plantations' was less than 0.05 ha. The Shannon diversity index of productive landcovers, including 'grasslands', 'native forests', 'crop areas' and 'exotic-tree plantations', ranged from 0.49 to 1.16 (mean ± SD = 0.78 ± 0.13).

### 3.3 | Associations between social-ecological filters and livelihood resilience

The two best models for ILR included age of the household head, diversity of agroecosystems, surface of shrublands (ha), surface of infrastructure (ha) and Shannon diversity index of productive landcovers as the most influential social-ecological filters (explanatory variables; Table 4). Nonetheless, the effects of infrastructure surface (ha) and Shannon index were not significant ($p > 0.05$; Table 5). The best model showed that the ILR was positively correlated with the diversity of agroecosystems and negatively correlated with the age of the household head and the surface of shrublands (ha) (Table 5; Figure 3).

## 4 | DISCUSSION

Identifying factors that enhance or halt livelihood resilience is crucial for developing effective strategies to cope with the rapid social-ecological changes that small-scale farmers are currently experiencing. By applying a cross-level analysis (i.e. household, farm, landscape), we explored how social-ecological filters, sociodemographic factors, the diversity of agroecosystems within the farm, and on-farm landscape composition are related to livelihood resilience in the Chiloé Archipelago, a GIAHS within a Global Biodiversity Hotspot in southern Chile. We found that livelihood resilience is related to household sociodemographic characteristics, but also to the diversity of agroecosystems and the landscape composition of the farm. These factors, and the combination of them, could have positive or negative impacts on the livelihoods of campesinos and food sovereignty and hence need to be addressed to promote small-scale farming livelihood resilience. For example, the aging of the household heads might translate into fewer resources (e.g. physical and health problems) to control shrublands on their farms, and this could translate into less surface to make use of productive agroecosystems.

Assessing resilience within a GIAHS is particularly relevant, as these landscapes are not only ecologically and culturally significant but are also often exposed to rapid social-ecological changes negatively impacting the livelihoods of small-scale farmers. GIAHS designations, such as that of Chiloé, are intended to support and

**TABLE 3** Minimum, median, mean and maximum values of surface (ha) of 10 landcover categories for the 100 surveyed farms.

| Landcover category | Min (ha) | Median (ha) | Mean (ha) | SD | Max (ha) | % of farms |
|---|---|---|---|---|---|---|
| Grasslands | 0.40 | 2.13 | 2.18 | 0.75 | 4.11 | 100 |
| Native forest | 0.28 | 1.19 | 1.26 | 0.61 | 3.21 | 100 |
| Crop areas | 0.00 | 0.11 | 0.18 | 0.19 | 0.97 | 100 |
| Infrastructure | 0.02 | 0.11 | 0.11 | 0.05 | 0.29 | 100 |
| Bare soil | 0.00 | 0.36 | 0.42 | 0.29 | 1.14 | 98 |
| Roads | 0.00 | 0.15 | 0.16 | 0.07 | 0.48 | 98 |
| Shrublands | 0.00 | 0.46 | 0.52 | 0.48 | 1.78 | 79 |
| Exotic-tree plantations | 0.00 | 0.00 | 0.02 | 0.06 | 0.49 | 27 |
| Water bodies | 0.00 | 0.00 | 0.05 | 0.26 | 1.72 | 18 |
| Sea | 0.00 | 0.00 | 0.09 | 0.30 | 1.60 | 11 |

*Note*: Surfaces were calculated in a 5 ha circle buffer around each farm's main house. The percentage of farms containing each landcover category is presented in the last column.

**TABLE 4** AIC ranking of models for the Index of Livelihood Resilience as a function of social-ecological filters.

| Model structure | *K*[a] | AICc | ΔAIC[b] | wi[c] | Cum wi[d] | LL[e] |
|---|---|---|---|---|---|---|
| **Age + Agroecosystems + Shrublands + Infrastructure** | **7** | **136.30** | **0.00** | **0.50** | **0.50** | **−60.54** |
| **Age + Agroecosystems + Shrublands + Infrastructure + Shannon index** | **8** | **136.9** | **0.55** | **0.38** | **0.88** | **−59.64** |
| Age + Agroecosystems + Shrublands | 6 | 139.70 | 3.36 | 0.09 | 0.97 | −63.38 |
| Age + Agroecosystems + Forest + Shrublands + Infrastructure + Shannon index | 9 | 142.00 | 5.74 | 0.03 | 1.00 | −61.02 |
| Age + Agroecosystems + Grasslands + Forest + Shrublands + Infrastructure + Shannon index | 10 | 147.00 | 10.71 | 0.00 | 1.00 | −62.27 |
| Age + Agroecosystems + Grasslands + Forest + Shrublands + Crops + Infrastructure + Shannon index | 11 | 149.80 | 13.47 | 0.00 | 1.00 | −62.38 |

*Note*: Locality was a random effect in all tested models. Best models (ΔAIC ≤ 2) are presented in bold.

Abbreviation: AIC, Akaike's Information Criterion.

[a]Number of estimated parameters.

[b]Difference in AICc values between each model and the lowest AICc model.

[c]AICc model weight.

[d]AICc cumulative weight.

[e]Log likelihood.

**TABLE 5** Coefficients of the best Generalized Linear Mixed Effects Models of the Index of Livelihood Resilience versus social-ecological filters according to the AIC model selection process.

| Social-ecological filter | *β*std[a] | SE(*β*std)[b] | *β*[c] | SE(*β*)[d] | *p*-Value |
|---|---|---|---|---|---|
| (a) Best model | | | | | |
| Intercept | 0.00 | 0.00 | 2.18 | 0.29 | 0.00 |
| Age | −0.33 | 0.09 | −0.01 | 0.00 | 0.00 |
| Agroecosystems | 0.36 | 0.08 | 0.13 | 0.03 | 0.00 |
| Shrublands | −0.24 | 0.08 | −0.24 | 0.09 | 0.01 |
| Infrastructure | N/A. | N/A. | 1.68 | 0.81 | 0.05 |
| (b) Second best model | | | | | |
| Intercept | 0.00 | 0.00 | 1.86 | 0.36 | 0.00 |
| Age | −0.34 | 0.09 | −0.01 | 0.00 | 0.00 |
| Agroecosystems | 0.36 | 0.08 | 0.13 | 0.03 | 0.00 |
| Shrublands | −0.26 | 0.08 | −0.27 | 0.09 | 0.01 |
| Infrastructure | N/A. | N/A. | 1.49 | 0.81 | 0.08 |
| Shannon index | N/A. | N/A. | 0.47 | 0.31 | 0.14 |

*Note*: Locality was a random effect in all tested models.

[a]Standardized regression coefficient.

[b]Standard error of the standardized regression coefficient.

[c]Regression coefficient.

[d]Standard error of the regression coefficient.

enhance the livelihoods of local communities. However, the impact of such designation on resilience remains understudied. Our findings contribute to filling this gap by providing empirical insights into the multiple dimensions of livelihood resilience in this unique context. While the GIAHS designation may facilitate access to funding, training and institutional support, the extent to which these opportunities translate into tangible benefits for campesino households varies and often depends on governance structures, policy implementation and local engagement. By analysing livelihood resilience indicators at the household scale, our study offers a nuanced understanding of how broader recognition through GIAHS interacts with local social-ecological dynamics and highlights the need for more targeted, inclusive strategies to ensure that such designations truly strengthen community resilience.

Before delving deeper into our findings, we acknowledge four limitations of this study. First, the use of an ILR, based on unweighted quantitative indicators, might be insufficient to completely understand the complexity of small-scale farmer's livelihood resilience. Utilizing indexes to measure livelihood resilience has drawbacks, being criticized for representing only a snapshot in time of much more complex issues that cannot be thoroughly understood just by applying quantitative methods (Mayer, 2008).

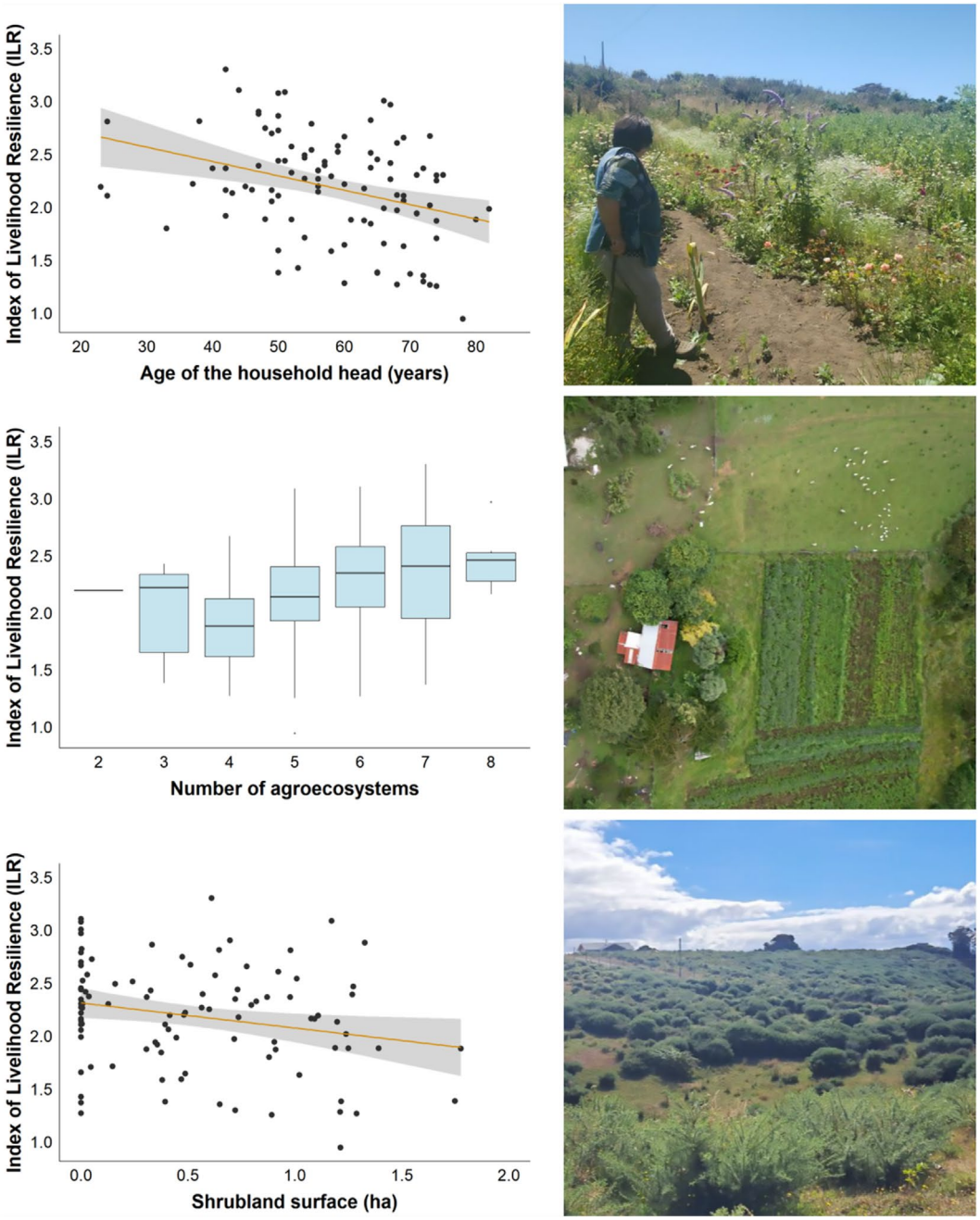


FIGURE 3 Response of the Index of Livelihood Resilience (ILR) to the most influential social-ecological filters in the best model, including age of the household head (years), diversity of agroecosystems per farm and surface of shrublands (ha). Infrastructure surface (ha) was not significant in the best model. Locality was a random effect in all models. The shaded areas represent the 95% confidence interval for model predictions. The photographs from the right column illustrate each of the social-ecological filters in the left column. All photographs were taken by the authors.

Future research should include subjective indicators of resilience based on participants' perceptions alongside qualitative analysis (Jones & Tanner, 2017; Monterrubio-Solís et al., 2023; Quandt & Paderes, 2023). Additionally, methods for weighting the objective indicators of resilience, for example by applying participatory approaches, should be considered (Quandt, 2018). Still, our simplified approach provides insights that are useful in highlighting general patterns on small-scale farmers' livelihood resilience and for informing policy. Second, our spatial analysis may have comprised adjacent landscapes when farms were smaller than 5 ha in surface area. To reduce this bias, we chose the median size of the 100 farms when deciding on our buffer area to collect our spatial data. This choice aimed to create a standardized spatial unit for comparing across households while minimizing extreme variation. Moreover, social and biophysical interactions have historically played a pivotal role in the livelihood resilience of campesinos in Chiloé (Billaz et al., 2005; Caviedes et al., 2024; Pérez-Orellana et al., 2020), suggesting that the situation of a household and

farm could also be affecting the resilience of the neighbouring one. Third, focusing on specific aspects associated with livelihood resilience might overlook other factors simultaneously playing a role in this association. However, the inclusion and combination of eight social-ecological filters in different models increase the chances of obtaining a more holistic and representative picture of the phenomenon under study. Fourth, our study was not designed with a gender-specific focus; therefore, we consider that a gender-related analysis may be inaccurate. Recent research suggests that gender plays a role in enhancing livelihood resilience (Quandt, 2019). Consequently, to get a deeper understanding of what builds livelihood resilience, future studies should integrate gender considerations from the outset. Nevertheless, to reduce this bias, all our analyses were conducted at the household level rather than at the individual level.

### 4.1 | Diversity of agroecosystems favours livelihood resilience

We found a positive association between the diversity of agroecosystems on a farming landscape and livelihood resilience. A higher diversity of agroecosystems on a farm could favour a broader portfolio of agricultural activities, which are helpful when dealing with disturbances and hence may increase farmers' capacity to respond to them (Ellis, 1998; Marschke & Berkes, 2006; Scoones, 1998). This can be explained by the flexibility derived from having a higher diversity of agroecosystems; for instance, if one agroecosystem fails (e.g. crops due to pest attacks), households can make use of alternative agroecosystems (e.g. forestry plantations) to cope with change. This is particularly important for small-scale farmers as they are especially vulnerable to the impacts of social-ecological changes on their systems because of their strong connection to their land and dependence on it for their livelihoods (Quinn & Halfacre, 2014; Shmelev, 1996).

Consistent with our results, in agroforestry systems in Kedougou, Senegal, farms with more agroecosystems allowed farmers to diversify their agricultural activities, for example by combining crops, animal husbandry and timber products, to cope with climate change (Papa et al., 2020). Moreover, Lan et al. (2023) reported that a diverse portfolio of agricultural activities derived from different agroecosystems reduced the climate change sensitivity of farmers in southwest China. In Namibia, small-scale farmers adopted crop and livestock diversification strategies to build resilience and increase food security (Mulwa & Visser, 2020). The diversification of productive ecosystems has also been applied as a strategy to cope with disturbances in non-farming local communities. For example, in Cambodia, fishing communities diversified their economic activities (i.e. protecting nearby forests or growing fingerlings for aquaculture) to cope and adapt to different social-ecological changes (Marschke & Berkes, 2006). Our results stress that, in spite of the complexity of rapid social-ecological changes taking place in the Chiloé Archipelago (Caviedes et al., 2023), the diversification of agroecosystems has been a promising and useful strategy to cope with changes and hence should be promoted at different levels (e.g. household, local, political).

### 4.2 | Age of farmers and livelihood resilience

We found a negative association between the age of the household head and livelihood resilience. The surveyed household heads were on average 58 years old, of which a third were hired in a salaried job, and half of them reported having health problems that affected their capacity to work in agriculture. Moreover, the average family size consisted of three members, of which two were able to work in agriculture-related activities. This suggests a limited generational turnover among campesinos and that parallel off-farm economic activities must be pursued to make a living. This is a worldwide phenomenon to which Chiloé and Chile are not an exception. In European Union countries, for example, a recent report showed that, on average, 56% of farmers were older than 55 years old, about 30% were beyond retirement age, and only 6% were under 35 (ENRD, 2019). Similarly, in China, 81% of agricultural labourers were older than 40 years of age in 2020 (Liu et al., 2023; State Council Census Office, 2022).

In agricultural contexts, household heads often make the main decisions on the farm. While their experience and knowledge are essential and highly valued for resilience building at household and community levels (Caviedes et al., 2024), the combination of their age-related effects in physical and health capacity, along with reduced available workforce, may be diminishing their ability to perform intense and physically demanding labours required to maintain a productive farm, thereby hindering their household's overall resilience (Jansuwan & Zander, 2021). This is the case in the Prachin Buri province of Thailand, where over 60% of farmers aged 60 and older intend to stop farming due to declining health and reduced farm work capacity (Jansuwan & Zander, 2021). Similarly, in Ireland, almost half of farmer participants reported not having a successor, and 39% intended to fully retire from agriculture due to age-related health issues among other causes (Duesberg et al., 2017). Rural exodus may be negatively affecting small-scale farmers' livelihood resilience; therefore, different initiatives and conditions must be promoted to counteract this global phenomenon.

### 4.3 | Unproductive shrublands and livelihood resilience

We found a negative association between the surface of shrublands in farms and small-scale farmers' livelihood resilience. Shrublands in the Chiloé Archipelago are dominated by 'quilantales' (Bamboo; *Chusquea* spp.) and the invasive 'espinillo' or 'chacay' (Common gorse; *Ulex europaeus*), with the latter being the most aggressive and problematic (Daughters & Pitchon, 2018). Gorse was introduced to Chile from Europe for use as hedge plant in the late 19th century and, by the 1930s, it was spread over Chiloé (Opazo, 1930). Since then, this plant has had negative consequences for agriculture, forestry and local

native ecosystems, mainly due to its highly invasive capacity and difficulties in its control (Altamirano et al., 2016; Figueroa et al., 2004; Norambuena et al., 2000). A recent global study including 299 studies regarding gorse management reported that, despite intensive efforts to control and eradicate gorse from agricultural landscapes worldwide, this has had limited success (Broadfield & McHenry, 2019).

Although some studies have shown that protecting shrublands could potentially contribute to farmers' livelihood resilience (e.g. by increasing habitat for pollinators; Vogel et al., 2023), this is not the case for gorse in Chiloé as, to date, no agricultural or economic use has been identified for this species (Cárdenas Álvarez & Villagrán Moraga, 2005). Moreover, it has been reported that this plant prefers to establish in soils with previous agricultural use (Altamirano et al., 2016) and local farmers' perception in Chiloé is that gorse surface has increased in the last years (Caviedes et al., 2024). Henceforth, to enhance the livelihood resilience of small-scale farmers, it is imperative to intensify management efforts to control and, hopefully, eradicate invasive species shrublands in agricultural landscapes. This is the case of the Mediterranean mountainscapes of La Rioja, Spain, where the clearance of shrublands has been implemented as an effective strategy to promote extensive livestock farming. This strategy, along with increasing livestock farming surface, promoted the establishment of people from outside the study area while also providing environmental benefits (e.g. landscape and soil conservation; Lasanta et al., 2019). Our findings show that historical processes of species introduction and landscape degradation can have important (negative) effects on livelihood resilience. This calls the attention for considering these historical processes, and to promote actions that mitigate landscape degradation to promote small-scale farmers' livelihood resilience.

For their part, the effects on the local environment of shrublands dominated by *Chusquea* species in southern Chile are context dependent. For example, in the Chiloé Archipelago it has been reported that the 'quilantales' are associated with disturbed landscapes and deforested forests, inhibiting the establishment and regeneration of native vegetation because of their fast growth and large biomass (González et al., 2002; Veblen, 1982). Nonetheless, in the temperate forests of the La Araucanía Region, Chile, it has been reported that *Chusquea* spp. is a key attribute in the habitat of understory fauna (Caviedes & Ibarra, 2017; Concha et al., 2023) while also being considered a cultural keystone species because of their significance and historical use by the Mapuche Indigenous People (Levaggi & Ibarra, n.d., under review).

## 5 | CONCLUSIONS AND RECOMMENDATIONS TO PROMOTE SMALL-SCALE FARMERS' LIVELIHOOD RESILIENCE

Small-scale farmers produce at least 35% of the world's food (Lowder et al., 2021). However, their livelihoods—and food-producing capacity—are under threat because of current social-ecological changes, having devastating impacts on global food security and sovereignty. We found a positive association between the diversity of agroecosystems on a farm and livelihood resilience and a negative association between the age of the household head and on-farm shrubland surface with the livelihood resilience of small-scale farmers in Chiloé.

Based on our results, we propose four recommendations to inform policies and initiatives at different levels and contexts aimed at enhancing small-scale farmers' livelihood resilience to address the global agrifood crisis. First, the fact that livelihood resilience is positively associated with the diversity of agroecosystems shows that diversification must be promoted as a strategy to enhance the livelihood resilience of small-scale farmers. Small-scale farming has always been complex, dynamic and diverse; current policies aiming at specializing farmers into one or few livelihood strategies (i.e. 'putting all the eggs in one basket') might be hindering livelihood resilience. Second, our results show that the age of the household head was negatively associated with livelihood resilience. Therefore, the promotion of generational turnover among small-scale farmers is key to build resilience, as both older and younger farmers have an essential role to play in sustaining resilient farming livelihoods. The exodus of young people from rural to urban areas is a global phenomenon with negative consequences on small-scale farming livelihoods and food sovereignty (e.g. Kriebs, 2023; Liu et al., 2023; Llorent-Bedmar et al., 2021). Creating policies and developing strategies and incentives to encourage younger generations to remain in rural areas and continue working the land should become a priority. Third, we found that the surface of shrublands on a farm is negatively associated with livelihood resilience. Increasing efforts to control unproductive areas both on and near farms could help small-scale farmers build resilience to rapid social-ecological changes. Shrublands composed of invasive species may expand into agricultural lands, reducing farmers' productive capacity; therefore, their control and eradication should be promoted. One initiative that has yielded positive results is the Plan for Shrub Clearing (PSC) in La Rioja, Spain, where shrub clearing has reduced the occurrence of wildfires and provided additional environmental benefits, such as the creation of mosaic landscapes and the enhancement of ecosystem services (Lasanta et al., 2019). Fourth, consult the farmers. Small-scale farming communities have developed an intricate relationship with their environment for generations and are the ones suffering in situ the consequences of social-ecological changes. Policies and actions involving farmers should always include their input, prioritizing a bottom-up and participatory approach. In line with this and our recommendation to promote young farmers' engagement in agriculture, the National Public Consultation by INDAP in Chile is currently underway, targeting individuals who live, study and/or work in rural areas. This initiative aims to identify needs, aspirations, opinions and suggestions to inform the development of the National Policy on Rural Youth.

## AUTHOR CONTRIBUTIONS

**Julián Caviedes:** Conceptualization; methodology; data analysis; investigation; writing—original draft; writing—review and editing; funding acquisition. **André Braga Junqueira:** Conceptualization; methodology; investigation; writing—review and editing; supervision. **Laura Calvet-Mir:** Conceptualization; methodology; investigation; writing—review and editing; supervision. **Camilo Oyarzo:** Methodology; writing—review and editing. **Santiago Kaulen:** Methodology; writing—review and editing. **Santiago Álvarez-Fernández:** Data analysis; writing—review and editing. **Carla Marchant Santiago:** Writing—review and editing; funding acquisition. **José Tomás Ibarra:** Conceptualization; methodology; investigation; writing—review and editing; funding acquisition; supervision.

## ACKNOWLEDGEMENTS

We are grateful to chilote campesinas and campesinos for their generosity and willingness to participate in this study and for sharing their time and knowledge with us. We thank Pablo Rodríguez and Rafael Cerda from INDAP-Chile for logistics and support in the field.

## FUNDING INFORMATION

This research was funded by ANID/Fondecyt Regular 1240070, 1200291, 1231664 and ANID/REDES 190033, the Center for Intercultural and Indigenous Research (CIIR)—ANID/FONDAP 15110006, the Center of Applied Ecology and Sustainability CAPES—ANID PIA/BASAL AFB240003, and the Cape Horn International Center (CHIC)—ANID PIA/BASAL PFB210018. It also received support from the ERC Consolidator Grant to Victoria Reyes-García (FP7-771056-LICCI), the Fons de Solidaritat de la Fundació Autònoma Solidària, and from the Laboratory for the Analysis of Social-Ecological Systems in a Globalized world (LASEG), Universitat Autònoma de Barcelona and Generalitat de Catalunya (2021-SGR-00182). JTI acknowledges the support of the European Union to the 'Observatorio de los Bosques (NDICI CSO/2023/451-084)'. This research contributes to ICTA-UAB 'María de Maeztu' Programme for Units of Excellence of the Spanish Ministry of Science, Innovation, Universities (CEX2019-000940-M). This research was also made possible by the Becas-Chile scholarship for PhD studies 2020, granted to the first author by The National Research and Development Agency of Chile (ANID). LC-M also wants to thank two projects funded by the Spanish Ministry of Science and Innovation on agroecological transitions (PID2021-123129NB-C43 and TED2021-130333B-C33).

## CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request. Data are available at the repository from the Open Science Framework: https://doi.org/10.17605/OSF.IO/WKEXY.

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

**Data S1.** Survey used to calculate agroecosystem diversity and the Index of Livelihood Resilience of small-scale farmers.

**How to cite this article:** Caviedes, J., Junqueira, A. B., Calvet-Mir, L., Oyarzo, C., Kaulen, S., Álvarez-Fernández, S., Santiago, C. M., & Ibarra, J. T. (2025). Livelihood resilience: The role of social-ecological filters in a Globally Important Agricultural Heritage System of southern Chile. *People and Nature*, *7*, 1889–1904. https://doi.org/10.1002/pan3.70068