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Indigenous and local knowledge on social-ecological changes is positively associated with livelihood resilience in a Globally Important Agricultural Heritage System

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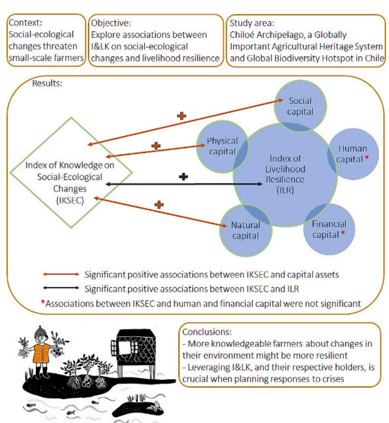
HIGHLIGHTS

- Rapid social-ecological changes threaten farming livelihoods and food security worldwide.
- We used indexes to test the association between I&LK on social-ecological changes and livelihood resilience.
- I&LK is positively associated with natural, social, and physical capital as well as with livelihood resilience.
- Results suggest that more knowledgeable people on social-ecological changes might be more resilient.
- Leveraging I&LK, and their respective holders, is crucial when planning responses to social-ecological crises.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Rapid social-ecological changes such as climate change, biodiversity loss, and resource over-exploitation are threatening food security, livelihoods, and local knowledge of small-scale farmers worldwide. There has been a call from scientists, farmers, and activists to identify and promote the mechanisms for sustaining resilient farming livelihoods. We hypothesize that small-scale farmers who are more knowledgeable

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about changes in their environment are more resilient to current social-ecological changes as they might be more prepared to respond to these disturbances.
OBJECTIVE: Our objective is to understand how Indigenous and local knowledge on social-ecological changes is associated with small-scale farmers' livelihood resilience in the Chiloé Archipelago, a Globally Important Agricultural Heritage System and Global Biodiversity Hotspot in southern South America.
METHODS: We conducted 100 surveys with small-scale farmers whose main livelihood activity relied on agrosilvopastoral systems. By asking questions about noticed changes in the atmospheric, physical, biological, and human system, we built an Index of Knowledge on Social-Ecological Changes. We also built an Index of Livelihood Resilience based on households' information on indicators of five capital assets (i.e., financial, human, social, physical, and natural). Finally, by using general linear mixed models, we tested the association between the Index of Knowledge on Social-Ecological Changes, individual capital assets, and the Index of Livelihood Resilience.
RESULTS AND CONCLUSIONS: We found that the level of small-scale farmers' knowledge was similar across the different systems (atmospheric, physical, biological, and human). We observed a significant positive association between the Index of Knowledge on Social-Ecological Changes and the Index of Livelihood Resilience, as well as with the natural, social, and physical capital of small-scale farmers.
SIGNIFICANCE: By demonstrating the positive association between measures of Indigenous and local knowledge on social-ecological changes and indicators of livelihood resilience, our results suggest that people who are more knowledgeable about changes in their environment might be more prepared to respond to disturbances. While there might be other factors influencing livelihood resilience, our study highlights the importance of leveraging Indigenous and local knowledge, and their respective holders, when planning responses to current social-ecological crises.

1. Introduction

Small-scale farming is responsible for producing at least one-third of the world's food (Lowder et al., 2021; Ricciardi et al., 2018) and accounts for about 475 million households worldwide, mostly from the Global South (Rapsomanikis, 2015). However, food security, livelihoods, and knowledge of local farmers are under threat because of rapid social-ecological changes (e.g., climate change, biodiversity loss, resource overexploitation; Pelletier et al., 2016; Kodirekkala, 2017; Khoury et al., 2022; Antonelli, 2023). For example, about 783 million people faced hunger during 2022 and >120 million jobs in food production are expected to be lost by 2030 due to the aforementioned changes (Brondizio et al., 2023; FAO et al., 2023). Moreover, a recent meta-analysis showed an overall trend of loss in 'agricultural and farming knowledge' due to global and local changes (Aswani et al., 2018). Given the many negative effects of some social-ecological changes on local livelihoods and the agricultural systems that depend on them, it is crucial to identify and promote the conditions and mechanisms for sustaining farming livelihoods (Antonelli, 2023; Pelletier et al., 2016).

Livelihood resilience refers to the ability of households to sustain and improve their livelihood possibilities despite economic, political, environmental, and social disturbances (Tanner et al., 2014). As livelihood resilience cannot be measured directly, the use of quantitative indexes based on objective indicators of resilience have been proposed as effective proxies to better understand it (Jones and Tanner, 2015; Lecegui et al., 2022; Quandt, 2018; Speranza et al., 2014). While this approach has received criticism for its reliance on objective indicators of resilience without considering information on subjective indicators based on people's own perceptions (Jones and Tanner, 2017; Quandt and Paderes, 2023), it has nonetheless gained prominence in livelihood resilience research. For example, indexes derived from the Sustainable Livelihoods Approach —which emphasizes that livelihoods are understood based on people's access, combination, and possibilities to increase their capital assets (financial, human, social, physical, and natural)— have been recently applied to empirically measure livelihood resilience (Aguilar et al., 2022; Awazi and Quandt, 2021; Conroy and Litvinoff, 1988; Natarajan et al., 2022; Quandt, 2018). The relevance of this livelihood resilience approach is that it focuses on people's agency and power relationships while highlighting the importance of access and combination of assets to respond to disturbances (Quandt, 2018; Tanner et al., 2014).

Indigenous Peoples and local communities (IP&LC) are the most responsible for practicing small-scale farming, and thus feeding the world, while simultaneously being the least contributors and the most vulnerable to social-ecological changes (IPCC, 2022; Reyes-García et al., 2024a, 2024b; Savo et al., 2016). IP&LC have dealt with and overcome a series of changes that have allowed them, over centuries in many cases, to adapt their everyday activities to changing conditions (Boillat and Berkes, 2013; García-del-Amo et al., 2020; Ibarra et al., 2023; Pyhälä et al., 2016). The interpretation of social-ecological changes by IP&LC worldwide is, intentionally or not, shaping their livelihoods and influencing their everyday decisions with concomitant impacts on their agricultural systems (Adger et al., 2013; Reyes-García et al., 2024a, 2024b).

Recent studies, often relying on qualitative data for local knowledge or lacking empirical indexes, have suggested that Indigenous and local knowledge (I&LK) could enhance livelihood resilience (Marschke and Berkes, 2006; Postigo, 2014). For instance, in Argentinian Patagonia, rural livestock smallholders used 23 plant species as bioindicators for improved rangeland management (Castillo et al., 2020), while in Senegal, Sereer farmers' local observations of environmental changes led to crop diversity management (e.g., abandonment and adoption of crop varieties) responses to climate change (Ruggieri et al., 2021). Nevertheless, despite these putative associations between I&LK and resilience, there is a gap in empirical studies testing this relationship. Examining the association between specific domains of I&LK (e.g., I&LK on social-ecological changes) and livelihood resilience is crucial, as locally-led and knowledge-based responses to social-ecological changes, are expected to minimize current and potential threats to their livelihoods (Adger et al., 2013; Caviedes et al., 2023). Moreover, I&LK could provide alternative approaches and viewpoints to conventional agriculture and Western science regarding the management and utilization of natural resources (DeWalt, 1994; Melash et al., 2023).

In 2002, the Food and Agriculture Organization of the United Nations (FAO) launched the Globally Important Agricultural Heritage Systems (GIAHS) initiative in response to the negative effects that several social-ecological changes were generating on small-scale farming livelihoods and systems worldwide (Koohafkan and Altieri, 2011). GIAHS are 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 sustainably provide multiple goods and services, food, and livelihood security for millions of small-scale farmers' (FAO, 2018:4). To this day, FAO has designated 78 systems in 24 countries. However, the designation of a site as a GIAHS has not ensured farmers' livelihood resilience to current social-ecological changes. The Chiloé Archipelago in southern Chile was designated as a GIAHS in 2011, due to the system's high levels of agrobiodiversity, importance for local food sovereignty, and variety of traditional agricultural practices (Barrena et al., 2014). However, the I&LK and livelihood resilience of small-scale farmers livelihoods in Chiloé is threatened by several social-ecological changes (Bustos-Gallardo et al., 2021; Caviedes et al., 2023; Philip Hayward, 2011). For example, the prevalence of drought has led small-scale farmers in Chiloé to abandon some local landraces (Frêne et al., 2022), while the irruption of salmon farms have made young farmers to abandon agriculture (Philip Hayward, 2011). Therefore, using the Chiloé context as a case study, our objective was to quantitatively explore the association between I&LK on social-ecological changes and livelihood resilience. Here, we (i) build an Index of Knowledge on Social-Ecological Changes (IKSEC), (ii) build an Index of Livelihood Resilience (ILR), and (iii) test the association between the two indexes. We hypothesize that small-scale farmers who are more knowledgeable about changes in their environment are more resilient to current social-ecological changes. Hence, we expect to observe a significant positive association between I&LK on social-ecological changes and livelihood resilience.

2. Methods

2.1. Study area

We conducted this study in the Chiloé Archipelago (41°-43°S), located in the southern Pacific Ocean, Chile (Fig. 1). The archipelago is composed of one large island (Isla Grande; 8394 km^2) and >40 small islands and is located within the 'Chilean Winter Rainfall-Valdivian Forests' Global Biodiversity Hotspot (Myers et al., 2000). The climate is temperate, with mean annual temperatures of 10–12 °C and mean precipitations of 2000 mm/year (http://explorador.cr2.cl/). The landscape is characterized by an extensive coastline, while the inland part is composed of a mosaic of native forest, non-native trees plantations, agrosilvopastoral systems, grasslands, shrublands, small towns, and wetlands including peatbogs.

Culturally, the Chiloé Archipelago has a rich heritage, which emerged from the contact between Chonos and Huilliche Indigenous Peoples with long-term European settlers that arrived at Chiloé after the Spanish colonization in the XVI century (Daughters and Pitchon, 2018). The archipelago is presently inhabited by Indigenous Peoples, descendants of long-term settlers, non-Indigenous campesino families, and lifestyle migrants. Nowadays, Chiloé has a population of 171,487 inhabitants (35% self-identified as Indigenous) of which 41% lives in rural areas (INE, 2022). Historically, Chiloé has based its economy on small-scale farming, fishing, and forestry. However, since the introduction of mid and large-scale salmon and mussel farms in the 80's, the main economic activities in Chiloé have diversified to agriculture, aquaculture, and tourism. Chiloé's agricultural heritage has derived in different manifestations that are present to this day, including farming and fishing practices, food preparations, mythologies, and beliefs (Nahuelhual et al., 2014). Moreover, Chiloé is considered a subcenter of origin of the potato (*Solanum tuberosum*), with >200 native potato varieties grown today, and this staple food is a pillar of local food sovereignty (Solano, 2019). Farming systems in Chiloé have historically been small-scale farming systems in the form of agrosilvopastoral systems (i.e., integrated farming systems that combine crops, livestock, and trees in the same unit). Traditionally, agrosilvopastoral systems in Chiloé were integrated with coastal components and managed under an agroecological approach, for example, by preparing fertilizers out of algae and animals' manure and by using manual tools. However, this has changed during the last decades and now small-scale farmers in Chiloé have widely adopted the use of agrochemicals and machinery (Billaz et al., 2005).

2.2. Data collection

We conducted a six-month fieldwork (December to February of 2021–2022 and 2022–2023), which included participant observation (principally in activities related with agriculture, food preparations, and seafood harvesting), semi-structured interviews, and surveys (Newing, 2011). Initially, we conducted 15 semi-structured interviews with campesinos (i.e., small-scale farmers whose livelihood is deeply intertwined with their connection to the land[1]) who were locally recognized as knowledgeable about agrosilvopastoral systems. For the latter, we followed a Data Collection Protocol (Reyes-García et al., 2023) developed under the 'Local Indicators of Climate Change Impacts' project (https://licci.eu/; Reyes-García et al., 2023). We used successive-referral sampling to select the participants (Newing, 2011) and interviewed five participants from three different localities; each locality was separated by a minimum distance of 5 km from the nearest one. Participants of this study were Indigenous and non-Indigenous campesinos whose main livelihood activity depended on agrosilvopastoral systems. We choose to include Indigenous and non-Indigenous campesinos as both cultures are intertwined after cohabiting the archipelago for centuries (Naqill Gómez, 2021).

Semi-structured interviews aimed to obtain information about social-ecological changes observed by campesinos in their territories, which served as the basis for creating the list of social-ecological changes used to generate an Index of Knowledge on Social-Ecological Changes (IKSEC; Caviedes et al., 2023). Each semi-structured interview was registered in a field notebook and later analyzed following a hierarchical classification of social-ecological changes, which categorizes locally perceived changes into four distinct 'systems' (i.e., atmospheric, physical, biological, and human; Caviedes et al., 2023; Reyes-García et al., 2023). The interactions derived from the participant observation helped us gain a deeper knowledge of Chiloé's agricultural and social-ecological context, which are challenging to capture with closed questionnaires or highly structured techniques (Newing, 2011).

With the inputs from the participant observation and semi-structured interviews, we constructed and conducted surveys with 100 *chilote* (as how inhabitants in Chiloé are called) campesinos. We used a stratified random sampling that ensured a spatial distribution representing the populated places on the islands (Fig. 1). For doing so, we pre-defined regions on the map, and on each of these regions we surveyed the first household that we found. The criteria for selecting participants required them to have a historical family relationship with agriculture (i.e., more than one generation) and small-scale farming in the form of agrosilvopastoral systems as their main livelihood activity. In each household, we surveyed the female or male household head, depending on their availability and willingness to participate in the study. Our sample comprised 75 localities, including all the Municipalities in the archipelago. Households were at least 3 km apart from each other. Semi-structured interviews and surveys were conducted by the first author, a 34-year-old, Chilean male researcher. Conversations were in Spanish which was the participants and first author's first language. The study was approved by the Universitat Autònoma de Barcelona Ethics Committee (CEEAH-CA02), and we asked the written (or oral when participants preferred not to sign a document) prior, free, and informed consent from all participants.

2.3. Data processing

2.3.1. Index of Knowledge on Social-Ecological Changes (IKSEC)

We created an Index of Knowledge on Social-Ecological Changes which focused on a specific domain of I&LK (i.e., knowledge on social-ecological changes; Benyei et al., 2022; Reyes-García, 2015). To

[1] For a broader definition about the term campesino see https://www.heifer.org/blog/a-word-about-the-word-campesino.html

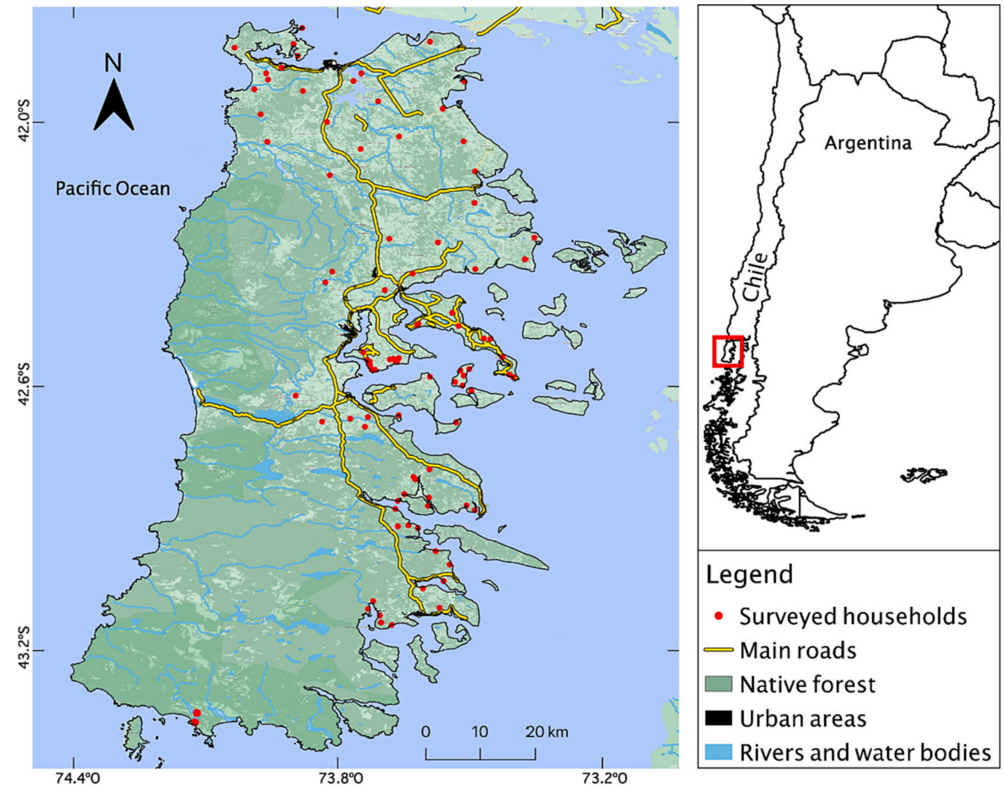

Fig. 1. Map of the study area and the 100 surveyed households in the Chiloé Archipelago, a Globally Important Agricultural Heritage System in southern Chile.

Table 1
Summary statistics of the indicators used to build an Index of Livelihood Resilience (ILR) to social-ecological changes in a Globally Important Agricultural Heritage System of southern South America. The total number of participants was 100, hence, for binary indicators, descriptive statistics can be interpreted as percentages. Only the statistics for continuous and binary variables are shown.

Asset	Quantitative indicator (0–1)	Unit	Min	Median	Mean	SD	Max
Financial capital (0–1)	Salaried job	Yes = 1/No = 0	–	–	0.32	–	–
	Access to a bank account	Yes = 1/No = 0	–	–	0.84	–	–
	Number of livestock	Number/seven options	–	–	–	–	–
	Size of farmland (ha)	Number	0.50	5.00	12.31	22.28	163.00
	Ownership of farm equipment	Number/seven options	–	–	–	–	–
	Savings	Yes = 1/No = 0	–	–	0.36	–	–
	Debts	Yes = 0/No = 1	–	–	0.31	–	–
	State benefits	Number	0.00	1.00	1.11	0.95	3.00
	Member of an agricultural State program	Yes = 1/No = 0	–	–	0.60	–	–
	Sell farm products	Five options	–	–	–	–	–
Human capital (0–1)	Labor availability (working age ≥ 15 years old[a])	Number	1.00	2.00	2.30	1.00	6.00
	Education	Four options	–	–	–	–	–
	General health of family	Five options	–	–	–	–	–
	Effects of health problems to practice agriculture	Four options	–	–	–	–	–
Social capital (0–1)	Family living nearby	Four options	–	–	–	–	–
	Participation in groups	Number	0.00	2.00	2.50	1.60	6.00
	Participation in agriculture groups	Number	0.00	1.00	0.74	0.63	3.00
	Relationship with neighbors	Four options	–	–	–	–	–
	Board member of the participating groups	Number	0.00	0.00	0.68	0.98	4.00
	Practice 'vuelta de mano' (reciprocity labor day)	Four options	–	–	–	–	–
	Exchange seeds	Yes = 1/No = 0	–	–	0.42	–	–
Physical capital (0–1)	Presence of facilities	Number/five options	–	–	–	–	–
	Access to irrigation schemes/infrastructure	Number/five options	–	–	–	–	–
	Ownership of farming equipment	Number/seven options	–	–	–	–	–
Natural capital (0–1)	Size of farmland (ha)	Number	0.50	5.00	12.31	22.28	163.00
	Diversity of potatoes varieties	Number	0.00	4.00	4.96	3.15	18.00
	Number of livestock	Number/seven options	–	–	–	–	–
	Farm age (years)	Number	4.00	100.00	69.49	37.31	100.00
	Sources of water	Number/five options	–	–	–	–	–
	Gathers products from the forest	Four options	–	–	–	–	–
	Gathers products from the sea	Four options	–	–	–	–	–

[a] Minimum legal age to be allowed to work in Chile.

construct the index, we utilized a list of social-ecological changes compiled from information obtained in the semi-structured interviews, as reported in Caviedes et al. (2023). In that study, the authors reported that campesinos in Chiloé observed 45 different social-ecological changes. From that list of 45 social-ecological changes, we randomly selected and prepared a list with 16 social-ecological changes that were categorized into four systems (i.e., atmospheric, physical, biological, and human; four social-ecological changes in each system; Table 2). We then asked each of the 100 participants whether they had noticed each of the social-ecological changes from the list with the question '*In relation to the past, have you noticed changes in*'. Responses were coded as 1 or 0 if they noticed or not the change, respectively. For example, if a participant noticed a 'decrease in the duration of rains' (atmospheric system), we coded that answer as 1. For each system, an index was built ranging from 0 to 1 with the average value per system, with a minimum score of 0 if the person did not notice any changes, and 1 if the participant noticed all the listed social-ecological changes for a system (hereafter 'IKSEC at the system level'). Finally, we added the IKSEC at the system level values, resulting in an overall index that went from 0 (less knowledgeable) to 4 (more knowledgeable; hereafter 'IKSEC').

2.3.2. Index of Livelihood Resilience (ILR)

Based on the Household Livelihood Resilience Approach proposed by Quandt (2018), we built an Index of Livelihood Resilience at the household level. During the surveys, we asked questions to obtain measurable indicators that were grouped into one of five capital assets (i.e., financial, human, social, physical, and natural; Table 1). The selected indicators were empirically tested on previous studies, focusing on farmer's livelihood resilience and were adapted to Chiloé's specific context and characteristics based on our previous knowledge of the area (Aguilar et al., 2021; Awazi and Quandt, 2021; Barrena et al., 2014; Cassidy and Barnes, 2012; Caviedes et al., 2023; Nahuelhual et al., 2014; Quandt et al., 2019). Twelve contextualized indicators of resilience for Chiloé were included in this study. For example, the practice of 'Vuelta de mano' (i.e., reciprocity practice of help between family or neighbors for agricultural works traditionally practiced in Chiloé) was included as a contextualized indicator of social capital. Each indicator received a score from 0 to 1, and all values were averaged per capital to obtain a score for each capital that ranged from 0 to 1. For questions with categorical answers, scores ranging from 0 to 1 were divided by the number of possible categories (e.g., for the question Do you collect products from the sea?, an indicator of natural capital, potential answers were coded as Never [0], Rarely [0.33], Sometimes [0.66], and Frequently [1]). Finally, the scores from each of the five capital assets were added to build an unweighted and simple composite index that went from 0 (less resilient) to 5 (more resilient).

2.4. Analysis

We used descriptive and inferential statistics to analyze our data. We calculated the minimum, median, mean, standard deviation, and maximum values for (i) IKSEC at the system level, (ii) IKSEC, (iii) individual indicators of resilience of each capital asset, and (iv) ILR. To compare the values of the IKSEC between systems we used general linear mixed models (GLMMs), followed by a Tukey post-hoc test to assess the individual differences between systems.

To assess the association between IKSEC and ILR, we performed GLMM with IKSEC as explanatory variable and ILR as response variable, as well as individual regressions with IKSEC as explanatory variable and each one of the five capital assets as response variable. Location (i.e., Municipality) was considered in all GLMMs as a random effect. Packages 'ggplot2' and 'nlme' of the R software version 4.2.0 (R Core Team, 2022) were used for all analyses and visual representations. Fig. 1 was prepared with QGIS software version 3.30.3 (QGIS Development Team, 2023). We integrated quotations from the participant observation and semi-structured interviews to exemplify and provide support to the interpretation of the quantitative results (participant names were omitted to safeguard their privacy and confidentiality).

3. Results

We interviewed 71 women and 29 men, with ages ranging from 23 to 82 years old (Mean $\pm$ SD $= 58 \pm 12$), from which 46% self-identified as Indigenous. Agrosilvopastoral systems managed by participants were complex and heterogeneous, characterized by the combination of multiple management units such as potato fields, homegardens, livestock rearing (i.e., cows, sheep, pigs, and poultry), shrublands, forest, and exotic trees. These units are interlinked and combined in various ways within these systems, occasionally overlapping in the same space and sometimes adjacent to each other. Native and fruit trees (mostly apples) played an important role in Chiloé's agrosilvopastoral systems and landscape, as they were acknowledged by participants as important sources of firewood, timber, and refuge for livestock. To this day, the use of ancestral management practices (e.g., crop rotation), local landraces, and traditional food preparations are still present on the archipelago. However, threats to small-scale farming were also reported by participants, resulting from the adoption of modern practices (e.g., chemical fertilization), climate change, lack of solidarity between campesinos, and disinterest from young generations, among others. For example, many campesinos indicated that they were not going to plant potatoes for the next season because of the increase in fertilizer prices (mainly due to the war in Ukraine; Behnassi and El Haiba, 2022). They mentioned that it was cheaper to buy potatoes (usually grown outside Chiloé) in the market than to grow them.

3.1. Indigenous and local knowledge on social-ecological changes

On average, participants noticed 11 changes (Mean $\pm$ SD $= 10.86 \pm 2.34$; 69% of the total changes), being 'Increase in the use of agrochemicals' (noticed by 96% of the participants; human system) followed by 'Reduction in forest surface' (noticed by 93% of the participants; biological system) the most frequently noticed individual changes (Table 2). Both results are in line with common narratives that we heard in Chiloé; for example, a 66-year-old man told us 'In the old days soils were better. Just with a little guano and manure, potatoes piled up. Nowadays if you don't have the soil well ground and you don't pour liquid to kill the grass and a lot of (chemical) fertilizers, you don't get any potatoes'. Similarly, regarding a reduction in forest surface, a 72-year-

Table 2
List compiled from Caviedes et al. (2023) with the 16 social-ecological changes, categorized into four systems, that were used to build the Index of Knowledge on Social-Ecological Changes (IKSEC). The percentage of participants who noticed each of the 16 social-ecological changes are presented in brackets.

System	Atmospheric	Physical	Biological	Human
Observations of social-ecological changes	Rains - shorter duration (84%)	Soils - worse quality (72%)	Forests - smaller surface (93%)	Weeds - higher abundance (54%)
	Winds - weaker intensity (62%)	Lakes and lagoons - drier (61%)	Espinillo (*Ulex europaeus*) - higher abundance (65%)	Agrochemicals - higher use (96%)
	Frosts - fewer amount (59%)	Rivers - drier (79%)	Fish - fewer species (65%)	Dog attacks on livestock - higher frequency (66%)
	Seasons - less marked (81%)	Tides - higher (43%)	Peat moss - smaller amount (46%)	Livestock - fewer amount (60%)

old woman indicated 'We've seen how the forest has diminished in Chiloé; before it was all forest. We, ourselves, used to go look for firewood near our house. Now we must go far, far away to get just a few sticks. We don't touch the forest that we [still] have nearby anymore'. Regarding the Index of Knowledge on Social-Ecological Changes (IKSEC), values ranged from 1.25 (one participant) to 4 (one participant; 100% correspondence) with a mean of 2.72 (SD = 0.59; 68% of correspondence; Table 3; Fig. 2; for stratified results on gender and age see Supplementary material 1). There were no significant differences in the IKSEC at the system level.

3.2. Livelihood resilience

Regarding the indicators of financial capital, 84% of the participants had access to a bank account and the median size of the farms was five hectares. We also found that there were on average two people of working age (> 15 years old; human capital) per household. Regarding the indicators of natural capital, the median age of farms was 100 years old and households cultivated on average five potato varieties. The practice of sharing seeds (social capital) among family and neighbors is an important social practice with 42% of the participants reporting that they keep doing it. ILR values ranged from 0.94 (less resilient) to 3.30 (more resilient) with mean values of 2.19 (SD = 0.49; Table 4; Fig. 3).

According to research participants, small-scale farming in Chiloé has historically been dependent on the relationship of campesinos with their territory, the ocean, and other campesinos in reciprocal ways. Strong social relationships (social capital) have been a pillar in the archipelago food system by means of reciprocity work among families, neighbors, and friends. Traditionally, physically demanding work such as planting potatoes or threshing wheat was a shared work done between families, neighbors, or friends. For example, the practice of 'vuelta de mano' (indicator of social capital) involved reciprocal labor arrangements, where individuals assist a family with their agricultural work on one occasion and, in return, expect the same family to provide labor assistance on their own farm when needed. However, from our conversations with people, there was a common feeling that the practice of 'vuelta de mano' was now rare and that it would soon be 'a thing of the past'. A 63-year-old man stressed: 'Here (Chiloé) people no longer want to work the land and that is why it's being lost; people no longer help each other. In the old days, we all helped each other among family and neighbors, it was sacred! One day we planted potatoes there, another day we planted potatoes here. The same thing happened with wheat; all the work for producing wheat was done by all of us. When people stopped helping each other, wheat disappeared in Chiloé. Nowadays we must pay for help and buy flour'. This quote represents a commonly expressed feeling by older people in Chiloé, stating how a shift in social capital through time has negatively affected campesino livelihoods.

3.3. Associations between the Index of Knowledge on Social-Ecological changes (IKSEC) and the Index of Livelihood Resilience (ILR)

We found a significant positive association between IKSEC and natural, social, and physical capital, as well as ILR (Fig. 4). R-squared values for the significant associations ranged from 0.08 (natural capital) to 0.14 (social and physical capital) suggesting a weak association between these variables. Associations between IKSEC and financial and human capital were not significant, with financial capital showing a positive tendency and human capital a negative tendency.

Regarding the association between local knowledge and livelihood resilience, a 78-year-old woman pointed out: 'I love my campesino life. I'm proud of being a campesina, having my piece of land, my animals, my plants, my seeds. I like all that and it's good for me. I've raised all my sons by working the land and we have lacked nothing. This farm is my history. I couldn't live peacefully away from my farm. I wouldn't know how to live. Everything I know I learned from my grandmothers and parents. I inherited my farm from them and learned how to plant, the seasons, the rains, the forest. It's a very rich knowledge they left to me'.

Table 3
Summary statistics showing the minimum, median, mean, standard deviation, and maximum values of the Index of Knowledge on Social-Ecological Changes (IKSEC) at the system level and the overall IKSEC, based on social-ecological changes reported by local campesinos in Chiloé.

System (Range)	Min	Median	Mean	SD	Max
Atmospheric (0–1)	0.00	0.75	0.72	0.28	1.00
Physical (0–1)	0.00	0.75	0.64	0.25	1.00
Biological (0–1)	0.25	0.75	0.67	0.22	1.00
Human (0–1)	0.25	0.75	0.69	0.23	1.00
IKSEC (0–4)	1.25	2.75	2.72	0.59	4.00

4. Discussion

The current context of rapid social-ecological changes and their negative effects on small-scale farming and food security requires a thorough understanding of the mechanisms building farmers' livelihood resilience to these disturbances. Our study in a Globally Important Agricultural Heritage System (GIAHS) and Global Biodiversity Hotspot empirically demonstrates associations between Indigenous and local knowledge on social-ecological changes and livelihood resilience. We found that there was a significant positive association between the knowledge on social-ecological changes by local campesinos in Chiloé and natural, social, and physical capital as well as with livelihood resilience. This suggests that campesinos who are more knowledgeable about current social-ecological changes tend to be more resilient to them.

Before discussing our findings, we examine three important limitations derived from our study. First, we recognize that the use of quantitative indexes is undoubtedly insufficient to thoroughly understand the whole complexity of I&LK and livelihood resilience to social-ecological changes. However, developing indexes that are well rooted in local contexts, and subjecting them to empirical testing, can offer pathways for in-depth exploration of specific facets of this complexity (Speranza et al., 2014). Second, we acknowledge that I&LK is both rooted and influenced by cultural, demographic, and socio-economic factors that we did not account for in our study (Aswani et al., 2018; McDade et al., 2007; Quandt, 2019; Reyes-García et al., 2010). Still, we tried to reduce this bias by using a broad geographical and socio-cultural sample that included the main populated places in the archipelago. Further research that consider differences in gender and age could enhance the understanding on livelihood resilience, contributing to valuable insights in the field (Quandt, 2019). Third, our analysis focuses on a specific aspect of a more complex relationship involving the associations between I&LK on social-ecological changes, capital assets, and livelihood resilience. The low R^2 values of our results support this assertion, highlighting that this association represents just one facet of the overall picture, with the recognition that other factors (to examine) may also simultaneously play a role.

4.1. Campesino understandings and local effects of social-ecological changes

Campesinos in Chiloé noticed, on average, the majority (69%) of the social-ecological changes that were present in the survey, with no significant differences in the number of noticed changes between systems (i.e., atmospheric, physical, biological, and human). This shows how campesinos identify changes in various elements of their social-ecological system, stemming from their holistic understanding of the environment and from the complexity of I&LK. Moreover, as most of the noticed changes are relatively recent (<50 years), this shows how I&LK is dynamic and built through experience (Berkes et al., 2000; Reyes-García et al., 2014).

Interestingly, the two most noticed individual changes (i.e., increase

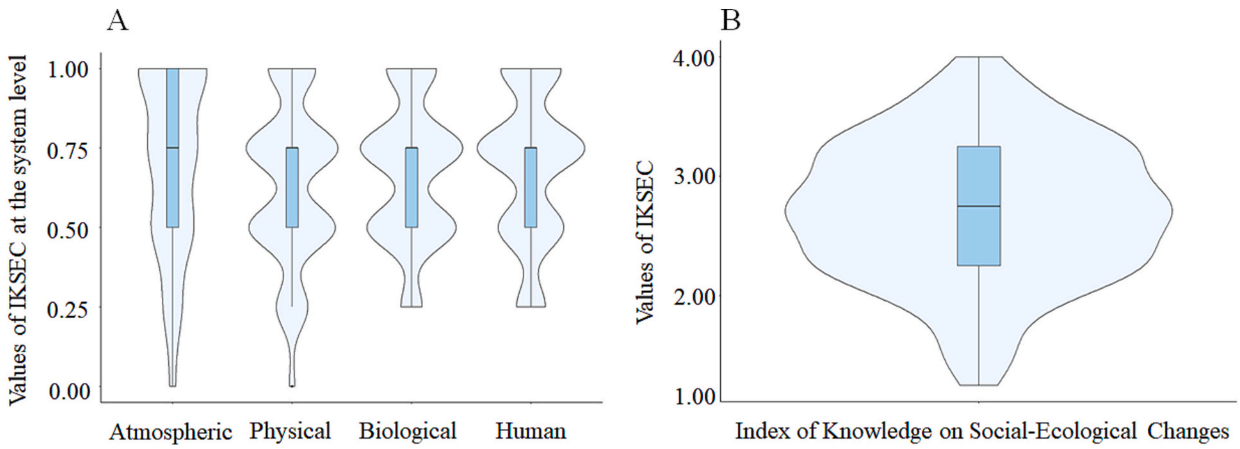

Fig. 2. Graphical representation of the distribution of IKSEC (Index of Knowledge on Social-Ecological Changes) at the system level (A) and IKSEC (B). In the boxplots, the 1st and 3rd quartiles are represented by the box limits and the median by the horizontal line. Whiskers represent the distance to the highest value not larger than 1.5 * inter-quartile range. The width of the violin plot represents the relative frequency of data.

Table 4
Summary statistics showing the minimum, median, mean, standard deviation, and maximum values of individual indicators of resilience of each capital asset and on the Index of Livelihood Resilience (ILR) reported by local campesinos in Chiloé.

Asset (Range)	Min	Median	Mean	SD	Max
Financial capital (0–1)	0.10	0.42	0.42	0.16	0.74
Human capital (0–1)	0.15	0.56	0.54	0.18	0.94
Social capital (0–1)	0.07	0.46	0.47	0.18	0.89
Physical capital (0–1)	0.02	0.37	0.40	0.15	0.87
Natural capital (0–1)	0.09	0.35	0.36	0.12	0.72
ILR (0–5)	0.94	2.22	2.19	0.49	3.30

in the use of agrochemicals and reduction in forest surface) are locally driven and campesinos may have had direct agency on them. Similar to what was reported by Nair and Sreedharan (1986) in Kerala, southern India, the introduction of agrochemicals in Chiloé was mainly promoted by government agencies. Billaz et al. (2005) and Cárdenas Álvarez and Villagrán Moraga (2005) argue that the adoption in the use of agrochemicals in Chiloé has been detrimental to local agricultural knowledge, for example by replacing traditional organic fertilizers (e.g., application of manure and algae-derived preparations). Moreover, the same authors discuss that it has reduced social interactions among families and neighbors, generated dependency, and introduced a monetary cost that did not exist before. Reduction in forest surface may be affecting the livelihoods of campesinos in Chiloé, as they historically have used the forest for timber and firewood, the main heating strategy in the archipelago (Billaz et al., 2005). A reduction in forest surface could also have negative repercussions on local agricultural knowledge, as it happened in a horticultural society in South India, where increased pressure on the forest and expansion of cash crops had drastic consequences for local knowledge on traditional forest crops, and their associated management (Kodirekkala, 2017).

4.2. Building livelihood resilience through capital assets

Our results support the idea that enhancing livelihood resilience trough capital assets is an effective strategy to tackle the negative effects of social-ecological changes on farming livelihoods and communities (Antonelli, 2023; Nyamwanza, 2012; Quandt et al., 2017; Speranza et al., 2014). Regarding social capital, 42% of the participants reported that they exchange seeds with their family, neighbors, and friends. This is a traditional practice that increases social capital as exchanging seeds not only pertains to the physical act of passing a seed from one person to another but is also a practice where knowledge is transmitted creating a relationship between the 'exchangers' (Calvet-Mir et al., 2012; Porcuna-Ferrer et al., 2023; Teixidor-Toneu et al., 2023). This is reported in Western Guatemala, where local seed banks and seed exchanges

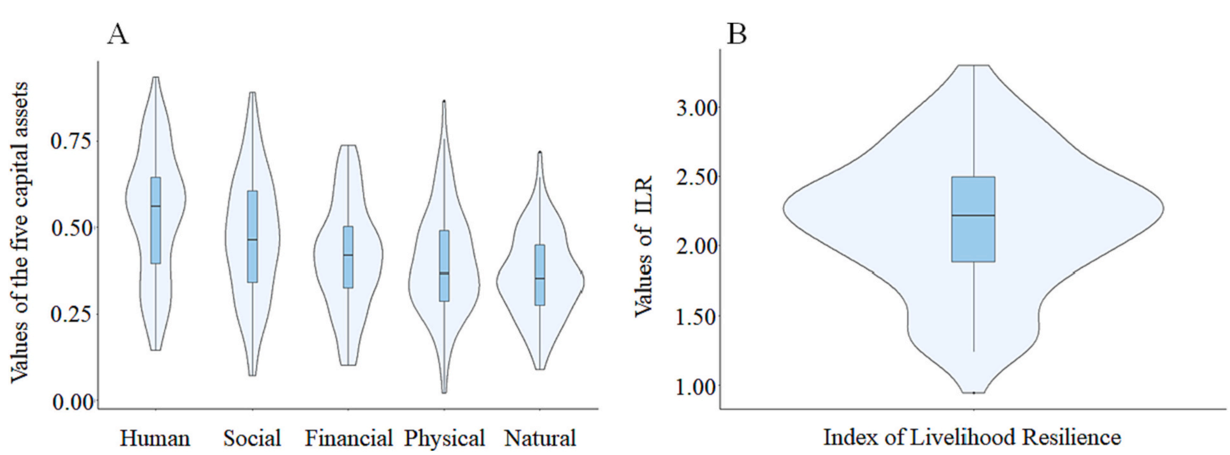

Fig. 3. Graphical representation of the distribution for individual indicators of resilience of each capital asset (A) and the Index of Livelihood Resilience (ILR) (B). In the boxplots, the 1st and 3rd quartiles are represented by the box limits and the median by the horizontal line. Whiskers represent the distance to the highest value not larger than 1.5 * inter-quartile range. The width of the violin plot represents the relative frequency of data.

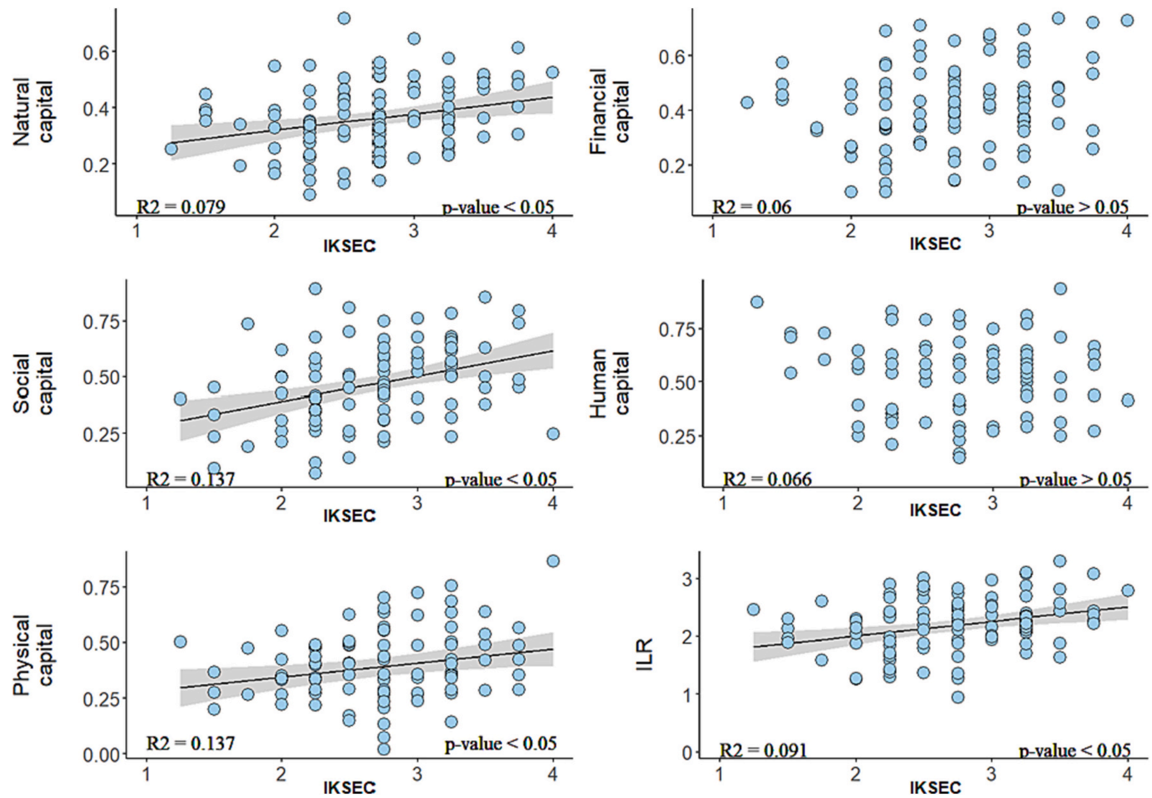

Fig. 4. Association between the Index of Knowledge on Social-Ecological Changes (IKSEC) and the five capital assets and the Index of Livelihood Resilience (ILR). Linear regressions with IKSEC (explanatory variable) and each of the five capital assets (response variable) and the association between IKSEC (explanatory variable) and ILR (response variable). Location (i.e., Municipality) was considered in the model as a random effect. The shaded areas represent the 95% confidence interval for model predictions (outcomes of the models are shown in Supplementary material 2).

increased local social-ecological resilience by promoting social interactions (Porcuna-Ferrer et al., 2020). Regarding financial capital, in Chiloé most participants reported that they had access to a bank account (84%). Having access to and money in a bank account, and therefore increased financial capital, would eventually increase farmers' capacity to prepare or respond to disturbances. This is the case with Mapuche Indigenous People in the Andes of Chile, where money saved in bank accounts is critical to buy fodder during winter when other incomes are scarce (Vergara and Barton, 2013). Another significant characteristic proposed to enhance livelihood resilience, as identified in our study, is the age of farms (natural capital). The median age of farms in Chiloé was 100 years old. In that sense, farms with a historical relationship to the local territory often exhibit structural complexity similar to neighboring forest ecosystems, potentially resulting in benefits enhancing resilience such as enhanced pollination (Eyzaguirre and Linares, 2004; Ibarra et al., 2021).

Potatoes are at the core of Chiloé culture, and we found that *chilote* campesinos in average, cultivated five different varieties. This result is important, as it has been reported that crop diversity (natural capital) leads to higher resilience. For example, crop diversification and intercropping helped farmers in Rwanda deal with droughts and market changes (Isaacs et al., 2016). In Bolivia's cocoa plantations, the increase in tree planting and agrobiodiversity diversification were the most effective adaptation strategies to floods and droughts (Jacobi et al., 2015). However, the reports by campesinos in Chiloé should be interpreted with caution as this was also accompanied by a generalized feeling of a decrease in potatoes cultivation, mainly because of the increase in fertilizer prices. This could have catastrophically cascading effects on small-scale farming livelihoods in Chiloé as potatoes are a pillar of the archipelago food sovereignty and are not only grown for human consumption but also to feed animals during the year.

4.3. Indigenous and local knowledge on social-ecological changes and livelihood resilience: A reciprocal relationship

4.3.1. Indigenous and local knowledge on social-ecological changes and individual capital assets

We found a positive association between I&LK on social-ecological changes and natural capital which could mean that people that interact and rely more directly on their natural environment are more sensitive to changes in their local ecosystems and might be more prepared to respond to disturbances. This could be understood as in the case of small-scale farmers in Kenya, where the practice of traditional agroforestry (i.e., inclusion of trees in their farms) increased resilience by a 10% in comparison to farmers that did not, being the lack of knowledge about how to plant trees one of the main reasons that hindered tree planting (Quandt, 2019). Our study also shows a positive association between I&LK on social-ecological changes of campesinos in Chiloé and social capital, suggesting that people that interchange knowledge and skills while promoting collaboration are more prone to notice changes in their environment and might be more prepared to respond to those changes. I&LK relies on social processes where conditions are allowed so it can be shared and passed through generations (Berkes et al., 2000). Our results are in line with has been reported for arable farmers in the Netherlands, where bonding and knowledge exchange improved responses to economic, environmental, and institutional disturbances (Slijper et al., 2022). Similarly, women farmers' social capital, based on trust and reciprocity, was essential in facilitating the exchange of local knowledge that contributed to successful peatland restoration in the tropics (Jalil et al., 2021). In Zimbawe, the traditional practice of Zunde raMambo (i.e., social practice aim to protect vulnerable groups) was applied by local farmers as a response to address food insecurity because of drought (Mavhura, 2017). We also found a positive association between I&LK on social-ecological changes and physical capital which could be understood because people that notice more changes in their environment could increase or enhance their physical capital to respond to those changes. For example, in the Peruvian southern Andes, campesino communities made irrigation adjustments (e.g., wetland creation) based on their perception on climate change impacts (Postigo, 2014). Moreover, Inuit People in Baffin Island (Canada), adopted new equipment for hunting and fishing as a response to their perceptions on climate change impacts (Galappaththi and Schlingmann, 2023).

Even though our study did not show a significant association between I&LK on social-ecological changes and human capital, this was the only one that showed a negative tendency. This could be understood as our study measured human capital in terms of access to formal school system and not as a capital of I&LK. Different studies have reported that access to certain formal school regimes, which do not consider local culture (e.g., food, traditions), can have adverse effects on I&LK. This was reported by McCarter and Gavin (2011) in the Malekula Island, Vanuatu, where rural residents reported that the main driver eroding I&LK was the formal school system. Future research on livelihood resilience indexes should consider incorporating additional human capital indicators derived from I&LK, such as, the use of traditional agricultural practices. On the other side, we did not find a significant association between I&LK on social-ecological changes and financial capital, suggesting that having a greater knowledge on social-ecological changes would not favor higher financial resources, or vice versa. Even though it has been reported that higher financial capital could increase response capacity to disturbances (Quandt et al., 2023; Talanow et al., 2021; Tittonell, 2014), the association between I&LK and financial capital is not always evident. This could be explained as I&LK is place, culture, and context specific, relying on the people's historical relationship with their ecosystems (Berkes et al., 2000; Nazarea, 2006). Some studies have shown how this relationship could be eroded when searching for greater financial opportunities. This is the case of our study site, where migration from rural to urban sites and moving from agricultural work to jobs in industries pursuing greater financial income has led to the abandonment of traditional small-scale farming (Billaz et al., 2005).

4.3.2. Indigenous and local knowledge on social-ecological changes and livelihood resilience

We found that I&LK on social-ecological changes is positively associated with small-scale farmers' livelihood resilience. Even though we found significant associations between I&LK on social-ecological changes and individual capitals, it is the combination between individual capitals which will increase livelihood resilience while enabling a higher response capacity to disturbances. For example, in line with our study, Bailey et al. (2019) reported that, in Eswatini, a combination between social (e.g., engagement in community organizations) and natural capital (e.g., increase crop diversity) enhanced small-scale farmers response to the perceived impacts of drought in comparison to other types of capitals. In that study, participants showed long-standing cultural connections with their environment and applied adaptation responses to drought based on local knowledge and on their access to natural resources, such as diversifying their crops, harvesting and selling firewood and fruits, and selling handicrafts. Similarly, landslide risk perception of rural residents in Bajedi, Nepal, was primarily influenced by their household's physical (e.g., energy sources and water collection systems), social (e.g., contacts for landslide emergencies), and financial (e.g., income and savings) capitals. On the other side, the lack of access to capitals could be detrimental to I&LK. This is the case for Mapuche Indigenous People in Chile, where access to formal school regime (human capital) and the lack of access to the forest (natural capital) were identified as the main drivers interrupting the transmission of Indigenous knowledge from elders to younger generations (Barreau et al., 2016). Our findings provide quantitative support to the positive associations between specific domains and dimensions of I&LK and livelihood resilience suggested by previous studies.

5. Conclusion

The current context of global social-ecological crises demands identifying and promoting novel mechanisms that build farmers' livelihood resilience to social-ecological changes. Our study demonstrates the importance of I&LK in building small-scale farmers' livelihood resilience to social-ecological changes. IP&LC are the most responsible for practicing small-scale farming, while also holding complex and situated knowledge, many times underestimated by policy makers and decision takers. On a local scale, our results could help inform agricultural extension agencies on how to best allocate agricultural resources aimed at increasing livelihood resilience based on specific households' needs. Moreover, our results could also help inform policies that promote adaptation to social-ecological changes by stressing the importance of conserving and promoting I&LK as a strategy to build livelihood resilience to social-ecological changes.

Our study represents an original attempt to empirically test the relationship between I&LK on social-ecological changes and livelihood resilience, providing valuable insights into their associations. Recent studies have proposed how the current crises must be turned into opportunities in which I&LK, Western science, and policy makers should dialogue to co-produce knowledge (Barth et al., 2023; Ibarra et al., 2023). As such, our study provides new empirical evidence about the role of I&LK in building livelihood resilience, highlighting the importance of leveraging I&LK, and their respective holders, when planning responses to the current social-ecological crises.

CRediT authorship contribution statement

Julián Caviedes: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **José Tomás Ibarra:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Laura Calvet-Mir:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Investigation, Conceptualization. **Santiago Álvarez-Fernández:** Writing – review & editing, Visualization, Software, Formal analysis, Data curation. **André Braga Junqueira:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2024.103885.

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