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Information transfer as a tool to improve the resilience of farmers against the effects of climate change: The case of the Peruvian National Agrarian Innovation System

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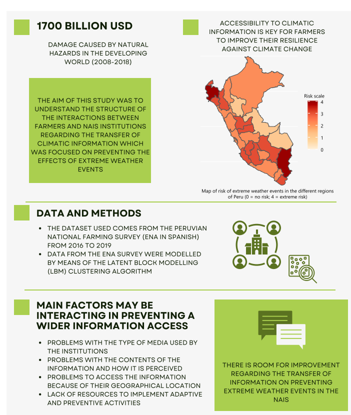
HIGHLIGHTS

- The relationships among farmers and institutions of the Peruvian National Agrarian Innovation System have been analysed.
- Latent Block Modelling revealed different behaviours among farmers and institutions regarding climatic-related information transfer.
- Both regional climatic risk and regional farming systems seem to influence the interest in getting information.
- Radio and TV are the predominant media to reach smallholders.
- Problems with the contents of information, its perception and a lack of resources may prevent a wider information transfer.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: In the last few years, the effects of climate change have impacted heavily on the agricultural sector, particularly in developing countries provided their high vulnerability. In this sense, knowledge and information transference could act as a strategic support service to improve the resilience of their farming systems, as this would help farmers to adapt and take advantage of the new scenarios brought by climate change, as well as to take preventive actions.

OBJECTIVE: The aim of this study was to understand the structure of the interactions between farmers and institutions of the National Agrarian Innovation System of Peru regarding the transfer of information on preventing the effects of extreme weather events. To do so, we aim to understand how farmers and institutions are connected and how the climatic and farming systems' particularities of the territories, the main roles of the institutions and the media through which farmers get the information from each of them could influence such information transfer processes.

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METHODS: The structure of interactions between institutions and farmers is modelled for the period 2016–2019 by means of the Latent Block Modelling clustering algorithm. Given the differences in size, resources and practices between smallholders and large-scale farmers, the relationships between them and the institutions are modelled and analysed separately.
RESULTS AND CONCLUSIONS: This study identifies how actors involved in preventive information transfer in the National Agrarian Innovation System of Peru are connected, quantifies their relevance and detects deficiencies in such transfer processes. Results show that less than 13% of smallholders and 18% of large-scale farmers in Peru are getting this information, which is mainly transferred by the TV and the radio (non-specialized media) and mostly only by one governmental institution. Additionally, we detected some groups of farmers who rely on other institutions too, with regional differences in the access to information. Results suggest that there is room for improvement regarding the transfer of information on preventing extreme weather events.
SIGNIFICANCE: The results obtained and their discussion could be particularly useful to help in the design of policies focused on improving the efficiency and effectiveness of climatic-related information transfer. In the end, this would help to improve the resilience of Peruvian farmers against climate change and thus, to strengthen the Peruvian agricultural sector.

1. Introduction

The climate change issue is global, long-term, and involves complex interactions between environmental, economic, institutional, social and technological processes (Arnell et al., 2019; Fisher et al., 2002; Mendelsohn, 2008). Its adverse consequences have greatly affected the agricultural sector and, thus, hampered two basic objectives of agriculture nowadays: eradicating hunger and achieving a sustainable development. The effects of climate change are particularly serious in the developing countries because of their low capacity to invest resources in facing it, that makes them more vulnerable. Indeed, the damage caused by extreme weather events in the developing world between 2008 and 2018, which are one of the clearest manifestations of climate change (Arnell et al., 2019), cost about US$1700 billion. The agricultural sector, which is particularly sensible to these phenomena, absorbed an average of 26% of these total losses. This share is extremely important to the developing countries, given that agriculture now contributes to between 10%–20% of the GDP in lower-middle-income countries and up to 40% in low-income countries (Dury et al., 2019; FAO, 2021). Thus, it is an urgent need to increase the resilience of their farming systems against climate change.

It is important to consider that the damage caused by the effects of climate change could occur on two fronts: firstly, by a lack of prevention and adaptation, and secondly by not using or underusing farming areas that could potentially benefit from climatic changes (Cradock-Henry et al., 2020). Better management of agricultural risks and the opportunities associated with climate change would help to increase food security rates and rural livelihoods (McKune et al., 2018; Vermeulen et al., 2012). To help farmers achieve better practices and become more resilient, information is key.

In the agricultural sector, information is spread through the so-called Agricultural Knowledge and Innovation Systems (AKIS), which are understood as systems of knowledge flows that involve a wide range of institutions and users within the sector (EU SCAR, 2012). Information transfer through the AKIS is basic in helping farmers, especially smallholders, to innovate and adapt to their context (Ramos-Sandoval et al., 2016). Indeed, climatic information services may become the key to farmer adaptation in terms of specialized agroclimatic information, which may include advisories, weather and climate forecasts along with appropriate agricultural advice, reports on improved, more resistant seed varieties and other locally relevant information for smart agriculture (McKune et al., 2018). However, spreading information effectively and efficiently is currently a big challenge in developing countries, given that although most farmers are concerned about the effects of climate change they lack the provision of timely, relevant and usable information to face it (Donatti et al., 2019). In this regard, the shortcomings of the adoption and use of Information and Communications Technologies (ICTs) in developing countries is negatively affecting the provision of extension services to the agricultural sector (Aker, 2011).

The functioning of the AKIS should be analysed to improve this situation. The analysis of knowledge and information (agroclimatic and other) transfer processes in different AKISs around the world has been progressively addressed (e.g. Aguilar-Gallegos et al., 2015; Hermans et al., 2017; Nidumolu et al., 2020; Sartas et al., 2018; Spielman et al., 2011; Thuo et al., 2013). However, the Peruvian AKIS, known as the "National Agrarian Innovation System" (NAIS) has still not been studied. Peru is highly vulnerable to the effects of climate change and is geographically very diverse, which means a wide range of possible conditions for the Peruvian rural population, whose livelihood mainly depends on agriculture (BID, and CEPAL, 2014; Escobal et al., 2015). A better understanding of how information is currently transmitted through the system and how the actors are connected is thus necessary to identify deficiencies and propose improvements in its dissemination, which would help farmers' decision-making and contribute to increasing the resilience of the Peruvian farming systems.

The aim of this study was thus to understand the structure of the interactions between farmers and NAIS institutions regarding the transfer of climatic information which was focused on preventing the effects of extreme weather events. For this, three factors are discussed that can influence the observed network of relationships: the functions of the institutions, the means by which farmers get information from them, and their regional behaviour, which is linked to the predominant farming systems, understood basically as combinations of regions and main farming products that are grown in such regions and where farms are the core of the system (Meuwissen et al., 2019). Understanding these relationships could have implications for policymakers, researchers, extension agencies and the private sector, as actors that share the mission of transferring climatic and weather-related information throughout the NAIS and contribute to building the resilience of the whole agricultural sector. This is crucial, particularly in developing countries, where many areas basically depend on agriculture, as farmers with resilient livelihoods are more prepared to prevent and reduce the impact of climate change on their lives (FAO, 2017).

The remainder of the paper is structured as follows: Section 2 provides the background to the role of information in helping build farmers' resilience and on the risk derived from extreme weather events in Peru. Section 3 describes the data and methods employed, Section 4 shows the results obtained, Section 5 discusses their implications and Section 6 provides some conclusions.

2. Background

2.1. Building farmers' resilience by transferring information

Farmers' resilience against climate change hinges on three main points: first, their ability to manage changes that happen due to external events such as floods; secondly, their ability to recover from these events; thirdly, their ability to adapt to new short- and long-term scenarios (Chaudhuri and Kendall, 2021). Focusing on farming systems, resilience is considered as their ability to continue providing the system functions despite the occurrence, at a time, of various and complex challenges (whether economic, environmental, social and/or institutional), by means of the capacities of robustness, adaptability and transformability (Meuwissen et al., 2019).

Given its importance, official international institutions are promoting the implementation of preventive and adaptive actions against climate change to improve the resilience of farming systems (FAO, 2017; IPCC, 2019). In building the capacity and resilience of farmers, access to climatic and weather information and its use for decision-making could play a key role.

In the work of Antwi-Agyei and Stringer (2021), smallholders declared that they used climatic-related information (that is, information related to long-term climate change impacts or to short-term impacts more related to changing weather patterns) to make critical farming decisions on land preparation, selecting crop varieties, changing cropping patterns or planting time adjustments. Similarly, Gebrehiwot and Van Der Veen (2013) found that access to climatic-related information increased the likelihood of farmers using different crop varieties, adopting soil conservation and irrigation measures and changing planting dates. Mulwa et al. (2017) also verified that the access to climatic-related information is a major driver of farmers' decisions to adopt adaptation practices, while Ponce (2020) found similar results concretely in the Peruvian context.

Moreover, access to climatic and weather-related information, among other key resources such as credits, has been proven to promote the adoption of climate-smart agricultural innovations (Makate et al., 2019), of climate-resilient practices (Rai et al., 2018) and to increase the probability of farmers having better adaptation abilities and finally deciding to adapt (Jiri et al., 2015). Indeed, not only access to information positively influences the adoption of climate-resilient practices, but the lack of this access has been reported as being one of the main barriers for farmers to adapt (Fosu-Mensah et al., 2012; Gebrehiwot and Van Der Veen, 2013; Mulwa et al., 2017). This is particularly important as decisions on whether or not to adapt, and how, in the end influences the resilience of the whole agroecosystem (Jacobi et al., 2015). However, there is some controversy in the literature about the contribution of that kind of information for farmers to adapt depending on its nature, i.e. if it is "formal information" transmitted by official institutions or "informal information", based on the own experience of farmers (Šūmane et al., 2018). It has been pointed out that farmers tend to be reluctant about the relevance of formal knowledge and, in many cases, avoid applying it in favour of using their own experienced-based knowledge (Wood et al., 2014). However, a growing corpus of literature points to the need of combining both formal and informal knowledge to get better results at the farm level (Šūmane et al., 2018). Among official institutions, extension services, which are basic components of the AKIS, are critically important in providing specific, usable information to adopt practices and get abilities against the effects of climate change (Jiri et al., 2015; Makate et al., 2019; Rai et al., 2018). To successfully reach farmers and get them engaged, extension services should focus more on strengthening social networks and learning from the practices and experience of farmers (Skaalsveen et al., 2020), turning them into active participants instead of passive receivers of information.

Given the importance of transferring appropriate information to farmers, and the role of the AKIS agents as information transmitters, the analysis of the information transfer processes in different AKIS around the world has been progressively addressed by, predominantly, Social Networking Analysis techniques. For instance, Spielman et al. (2011) studied knowledge flows within various types of networks composed of farmers and different kinds of institutions (NGOs, governmental institutions, credit institutions), with the aim of relating these relationships to the adoption of innovation practices among smallholders in Ethiopia. Thuo et al. (2014) studied the characteristics of social networks of groundnut farmers in Uganda and Kenya, including their relationships with agents such as extension institutions, and analysed their impact on information acquisition and adoption of new seed varieties. Aguilar-Gallegos et al. (2015) studied the information flows for the adoption of new or improved technologies and practices for Mexican palm oil growers, analysing the links between growers and other actors. Their findings showed that the growers who adopt more new or improved technologies and practices are better connected to extensionists and obtain higher productivity and higher profits. Hermans et al. (2017) and Sartas et al. (2018) used social networking analysis to analyse the structure of relationships in multi-stakeholder platforms (whose objective is increasing collaboration and knowledge exchange among farmers and other agents such as researchers, NGOs, firms and governmental agencies) of three African countries, and identified their strengths and limitations in generating and scaling innovations. Nidumolu et al. (2020) studied the structure of networks of climatic and weather information transfer to farmers in a village in India, concluding that the early identification and understanding of existing information mechanisms could be used to improve the delivery of climatic-related risks information and practices. To do so, this work recommends that the information be disseminated through formal networks (such as government agricultural extension services), which should be linked to informal networks (communication among farmers at a local level), in line with the suggestions of Šūmane et al. (2018).

Given Peru's high climatic vulnerability, considered among the 20 most vulnerable countries against climate change in the world (Altea, 2019) and thus, the potential risks for the livelihoods of its farmers, along with the important role played by actors of the AKIS to transfer technical, climatic and weather information, there is a need to analyse the relationships of information transfer among the actors in the Peruvian AKIS (referred to as NAIS). The NAIS comprises a series of institutions, principles and mechanisms through which the Peruvian Government promotes and implements research, training and technology transfer in the agricultural sector (PNIA, 2019). Farmers are commonly embedded in interactive networks of knowledge, ideas and information with other farmers and with AKIS' official institutions (Liao and Chen, 2017; Ramirez, 2013). These interactions can strongly influence their decisions to adopt preventive and adaptive actions against extreme weather events.

Understanding climatic-related information transfer processes therefore becomes crucial to detecting any possible deficiencies and trying to improve the delivery of this information, which would help farmers to implement mitigation and adaptation strategies and build up their resilience. This is crucial in the context of this study, given the complexity of climatic risk scenarios in Peru and the fact that climate adaptation tools need to be adapted to the context, i.e. to take into account local conditions (Daron, 2014; Rosas et al., 2016).

2.2. Risk of extreme weather events in Peru

Peru is highly vulnerable to climate change due to its wide variety of geographic and climatic characteristics. These include: both coastal areas and arid and semi-arid zones, areas susceptible to deforestation, erosion and desertification, a high occurrence of natural disasters that end in floods or droughts, highly polluted urban areas, and a fragile ecosystem. It is also directly affected by periodic fluctuations of extreme weather events like "El Niño–Southern Oscillation" (ENSO) that happens across the equatorial Pacific Ocean, which causes heavy rains, floods, and even in some areas, droughts (BID, and CEPAL, 2014). The regions in Peru are diverse geographically and ecologically, which means different conditions for the rural population (Escobal et al., 2015). For instance, the quick-changing temperatures in the Andes, which can reach close-to freezing temperatures, highlight the need to help Andean farmers obtain timely and effective information to adapt their current agricultural practices to the changing environmental conditions (Ponce, 2020).

Fig. 1 shows the level of agricultural risk to extreme weather events

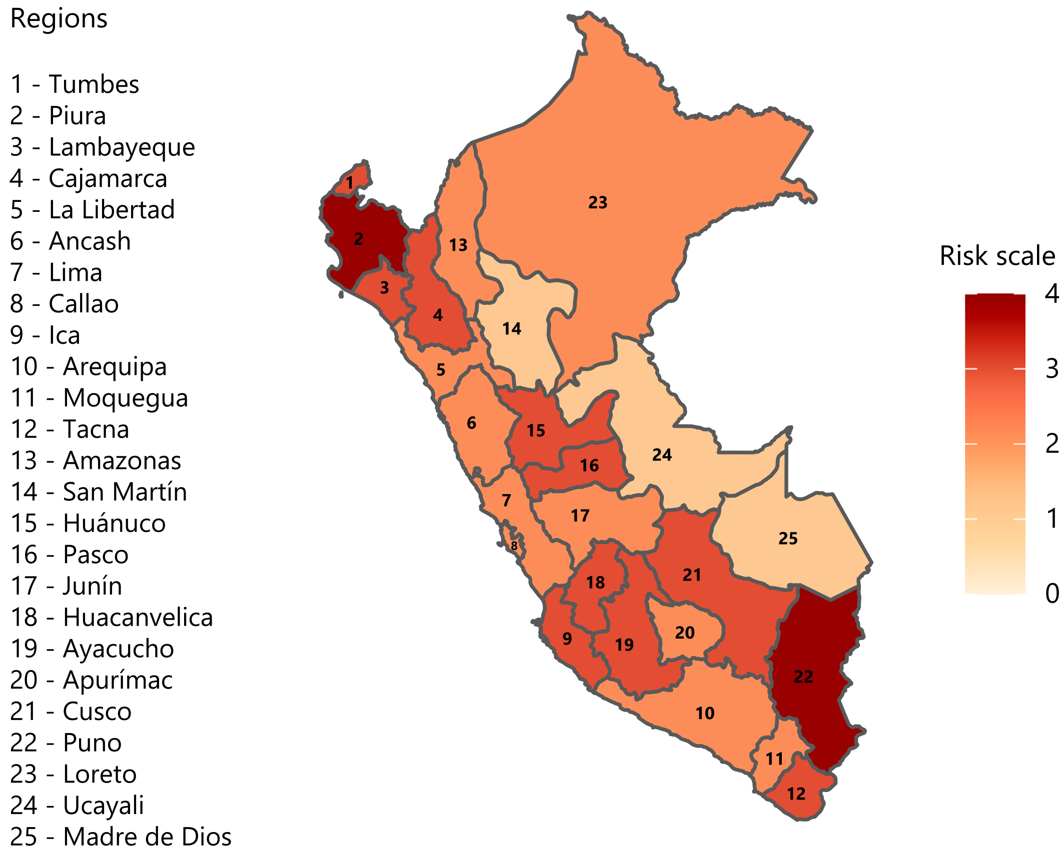

Fig. 1. Risk of extreme weather events in the different regions of Peru.
(Source: Own elaboration from data of the PLANGRACC-A (MINAGRI, and FAO, 2012).)

associated with the Peruvian regions according to the climatic vulnerability rates reported by MINAGRI, and FAO (2012). The extreme weather events considered are: frosts, droughts, floods and cold snaps. This risk is measured on a scale that can take five different values: zero = no risk, one = low risk, two = medium risk, three = high risk, four = extreme risk. This way, the regional agricultural vulnerability to extreme weather events can be considered to analyse the structure of the networks of relationships between farmers and the institutions.

On balance, the overall picture of vulnerability to extreme weather events in Peru suggests many perspectives on how agriculture can face these effects of climate change. This is an important challenge, especially since not all farmers are currently in a position to take preventive actions to mitigate negative effects of climate change or to adapt and benefit from possible new opportunities, and that many types of agricultural-related risks are likely to occur simultaneously (Komarek et al., 2020).

3. Data and methods

This section describes the data used in the study and the methods used to perform the analysis, which mainly relied on the Latent Block Modelling clustering algorithm.

3.1. Data

The dataset used comes from the Peruvian National Farming Survey (ENA in Spanish) from 2016 to 2019. This survey has been conducted yearly since 2014 by the Peruvian National Institute of Statistics and Informatics (INEI in Spanish) to provide the statistical information to build indicators of the Peruvian agricultural sector. The ENA data were collected through direct interviews by the INEI conducted each year from May to October (cultivation and harvesting season). From the available data we focused on analysing from 2016 to 2019, as the structure of the information for this study was different in 2014 and 2015 and homogeneous from 2016 on.

The total survey population was 2,244,000 smallholders or family farms as well as 4000 farming units managed by large-scale growers, all of them located in Peru (INEI, 2020). The survey was conducted in the 24 Peruvian departments and the Callao constitutional province on a representative sample of 29,218 smallholders and around 1500 large-scale farmers each year.

From the entire survey, we focused on Chapter 700: Agricultural Extension Services, Subsection 700C: Agricultural Information Access (see Table 1). Both smallholders and large-scale farmers were asked in question #711 about their access to information on the prevention of damages caused by extreme weather events in the last 12 months, while question #712 asked about the formal institutions that provided that kind of information. This information may include weather forecasts, information on varieties of more resistant crops or seeds and agro-climatic advice, among others (PNIA, 2019). Question #713 inquired into the media by which smallholders got access to this information, so that this data is not available for the subsample of large-scale farmers. Since some answers are missing each year, the total number of respondents differed from the total sample. The composition of the data samples specifically used in this study is summarized on Table 2.

Data obtained from Question #712 were structured as a rectangular incidence matrix with farmers in rows and institutions in columns, and represented as a bipartite network, i.e. a network with two different sets of nodes where only the connection (edges) between nodes of different sets is possible (Borgatti and Halgin, 2011; Easley and Kleinberg, 2010).

Table 1
Subsection 700C of the ENA survey: Agricultural Information Access. Questions: #711- #712-#713.

Question # 711. In the last 12 months, from................to…............. Have you received information on the prevention of damage caused by climatic events such as hailstorms, frost, excess rainfall, droughts, etc.? (Yes = 1; No = 2)
Question # 712. Which institution or person provided the information?

(1) MINAGRI - Watering and Agriculture Ministry
(2) Agrarian Agency
(3) INIA - National Institute for Agricultural Innovation
(4) SENASA - National Agricultural Health Service
(5) NGO - Non-Governmental Organization
(6) INDECI - National Civil Defense Institute
(7) Private Enterprises
(8) SENAMHI - National Meteorological and Hydrological Service
(9) Other

Question # 713. By means of which media have you accessed to the information about the prevention of damage caused by climatic events?

(1) Radio
(2) Television
(3) Phone
(4) Newspaper
(5) Brochure
(6) Internet
(7) Workshops
(8) Other

Source: Own elaboration from the ENA (INEI, 2018).

In this case, this means that no two farmers and no two institutions are connected in the network. The incidence matrix used was a 0/1 matrix in which rows are indexed by the set of farmers and columns are indexed by the set of institutions. The entry *Xij* of this matrix takes value one only when institution *j* provided information to farmer *i*. Given that the characteristics and nature of smallholders and large-scale farms are different their data are analysed separately. Thus, eight incidence matrices are built, one for each of these categories in each year of the period 2016–2019, which are the input data for the Latent Block Modelling (LBM) clustering algorithm.

3.2. Latent block modelling

The aim of this study was to analyse the structure of relationships between farmers and NAIS institutions as transmitters of information on the prevention of extreme weather events. Latent Block Modelling was applied to analyse the institution-by-farmer network data. Latent Block Modelling is a probabilistic model that assumes a mixture distribution both on the rows and columns (Govaert and Nadif, 2008; Keribin et al., 2015) and allowed us to cluster the farmers (in rows) and institutions (in columns) simultaneously on the basis of the incidence matrix. This method is appropriate for this study as it helps to inspect thoroughly the structure of the network, given that it reveals groups of farmers and groups of institutions that tend to be highly connected (Thomas et al., 2015).

The number of blocks (or clusters) of farmers and institutions were chosen according to the maximum value of the Integrated Completed Likelihood (ICL) criterion, as proposed in previous works (Keribin et al., 2017). The R package *blockcluster* (Bhatia et al., 2017) was used to perform the estimations and model selection. Since smallholders and large-scale farmers have different characteristics, we explored their relationships with the NAIS institutions in different LBM models.

4. Results

This section first summarises the access to information on the prevention of extreme weather events by type of farmer and region and describes the role of the institutions that provide it in the NAIS. Second, the relationships between farmers and institutions are shown, modelled by means of different LBM models for the different groups (smallholders and large-scale) and years. The clusters detected by the LBM were further explored to detect regional patterns in the access to information, and for smallholders, also the patterns of the predominant media used to obtain the information.

4.1. Characteristics of farmers and institutions

As shown in Table 2, about 95% of the whole sample each year are smallholders, who, according to the INEI (2020) criteria, are those with farms of up to 50 ha. They present a mean area of around 8.7 ha with a standard deviation near 41. The remaining 5% are large-scale farmers, who present a mean area around 550 ha with a standard deviation near 3200. This sample composition is in line with the structure of the Peruvian agricultural sector, of which 95% of farmers are smallholders (INEI, 2014). From all the respondents, between 8.6% to 12.5% smallholders and between 13% and 17.1% of large-scale farmers, according to each year, declared having received information from NAIS institutions. A summary of the percentages of access to information on the prevention of extreme weather events by region and type of farmer is shown in Table 3.

Puno, Cusco, Tacna, Apurímac and Moquegua were the regions in which more smallholders received information (with respect to the total respondents in each region) throughout the period 2016–2019. These regions have a medium to extreme climatic risk and are in the southern mountain range where small farms of cattle, potatoes, quinoa and alfalfa predominate (see Table S2). The share is notably low for highly climate-risky regions such as Piura or Cajamarca, located in the north of the country. In contrast, the highest share of large-scale farmers who got information throughout the period correspond to the regions of Tumbes, Ica, Ancash, Junín and La Libertad (in the south and centre of the country, with a medium to high level of climatic risk), although Apurímac and Tacna also appear in this case, in addition to the case of smallholders.

Major variations in the access to information are shown for some regions. We have identified that especially smallholders in some regions on the North Coast and on the South Mountains, had an erratic and even opposite information-seeking behaviour during the period studied. While there was an important decrease in users who accessed information in the regions of Tumbes ($n = 289$ in 2016, drops since 2018

Table 2
Total and relative composition of the data samples.

	N_{small_total}	% (total)	N_{large_total}	% (total)	N_{small_access}	% (over small)	N_{large_access}	% (over large)	Mean area small (ha)	SD area small (ha)	Mean area large (ha)	SD area large (ha)
2016	27,500	95.4	1334	4.6	2895	10.5	215	16.1	8.7	40.9	561.0	3181.3
2017	27,443	95.3	1355	4.7	3436	12.5	232	17.1	8.9	45.6	547.6	3345.7
2018	27,088	95.1	1399	4.9	2329	8.6	182	13.0	NA	NA	NA	NA
2019	26,937	95.0	1427	5.0	2904	10.8	241	16.9	8.6	40.4	562.6	3119.2

Notes: $\mathbf{N_{small\_total}}$: Total number of smallholders that are part of the sample. $\mathbf{N_{large\_total}}$: Total number of large-scale farmers that are part of the sample. $\mathbf{N_{small\_access}}$: Number of smallholders who declared to have received information from institutions of the NAIS. $\mathbf{N_{large\_access}}$: Number of large-scale farmers who declared to have received information from institutions of the NAIS. NA: Not available.
Source: Own elaboration from the ENA (INEI, 2020).

Table 3
Percentage of access to information on the prevention of extreme weather events by region and type of farmer.

Region			Smallholders (% access)				Large-scale farmers (% access)			
Name	Location	Climatic risk	2016	2017	2018	2019	2016	2017	2018	2019
Piura	Coast North. Mountains North	Extreme	2.2	2.1	5.3	1.7	7.5	14.9	12.1	7.7
Puno	Mountains South. Jungle	Extreme	25.9	42.7	33.5	56.3	30.8	5.0	5.9	75.0
Ayacucho	Mountains Center. Jungle	High	17.1	9.9	5.0	8.5	8.3	18.2	0.0	10.0
Cajamarca	Mountains North. Coast North. Jungle	High	6.1	1.5	0.7	1.9	5.3	12.9	17.0	2.3
Cusco	Mountains South. Jungle	High	11.6	15.2	19.8	21.0	50.0	5.0	7.9	6.3
Huancavelica	Mountains Center	High	9.1	11.4	3.9	8.9	0.0	0.0	0.0	0.0
Huánuco	Mountains Center. Jungle	High	4.3	5.8	6.1	9.0	9.3	10.2	4.6	37.7
Ica	Coast Center. Mountains Center	High	4.6	1.9	1.2	3.9	25.8	30.3	23.9	21.2
Lambayeque	Coast North. Mountains North	High	18.8	15.8	1.7	2.1	16.0	24.4	18.1	35.7
Pasco	Mountains Center. Jungle	High	2.8	4.5	7.6	4.8	0.0	5.2	8.5	10.8
Tacna	Coast South. Mountains South	High	39.0	41.4	33.0	42.8	25.0	8.7	19.2	41.7
Tumbes	Coast North	High	34.4	39.3	13.1	6.8	50.0	50.0	0.0	50.0
Amazonas	Jungle. Mountains North	Medium	13.4	3.0	1.3	1.8	0.0	0.0	15.0	4.5
Ancash	Mountains Center. Coast Center	Medium	2.0	7.9	0.9	2.2	35.2	13.0	14.6	22.0
Apurímac	Mountains South	Medium	11.9	21.1	16.0	13.0	33.3	0.0	66.7	33.3
Arequipa	Coast South. Mountains South	Medium	5.9	10.1	4.8	3.4	17.8	22.2	15.1	1.4
Callao	Coast Center	Medium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Junín	Mountains Center. Jungle	Medium	7.7	2.4	3.1	6.3	20.5	25.6	4.9	17.5
La Libertad	Coast North. Mountains North	Medium	2.8	4.8	1.3	1.5	17.0	25.7	14.3	14.7
Lima	Coast Center. Mountains Center	Medium	12.1	5.2	3.3	1.3	19.5	20.3	9.1	10.3
Loreto	Jungle	Medium	1.5	5.4	1.5	3.0	3.7	0.0	6.7	0.0
Moquegua	Mountains South. Coast South	Medium	11.6	22.8	19.5	27.8	0.0	0.0	0.0	100.0
Madre de Dios	Jungle	Low	4.7	20.9	12.0	9.8	5.1	8.3	58.8	38.5
San Martin	Jungle	Low	4.8	1.7	1.8	2.7	6.3	8.8	2.4	5.4
Ucayali	Jungle	Low	2.9	9.7	8.2	6.8	18.9	25.7	15.0	0.0

Notes: For each region, the percentages disclosed represent the proportion of farmers (distinguishing between smallholders and large-scale farmers) that declared to have received climatic information over all respondents. Source: Own elaboration from the ENA (INEI, 2020).

achieving $n = 55$ in 2019) and Lambayeque ($n = 204$ in 2016, drops since 2017 to $n = 23$ in 2019), in regions such as Puno, Cusco and Moquegua there was a growing trend of users of information throughout the period. In Puno, the number of smallholders who received information on the prevention of extreme weather events increased from 360 in 2016 to 793 in 2019; in the same period, in Cusco it increased from 143 to 264, while in Moquegua it increased from 133 to 327 . In the case of large-scale farmers, the large variations observed in many regions throughout the period could mainly owe to the small number of respondents per region. For instance, in this case an important variation is observed for Tumbes, where just between one and four affirmative respondents (depending on the year) represented 50% of its total respondents. The same happens with Apurímac, where one respondent represented 33.3% of the total large-scale farmers surveyed. However, we observe an increase in the demand of information by large-scale farmers in Puno, Huánuco and Tacna, where the underlying numbers are higher.

About the institutions, their roles within the NAIS are summarized in Table 4. The NAIS is composed of different actors, both public and private, that fulfil the role of "knowledge generation" and/or "knowledge transfer and extension". All the institutions except SENASA act as transmitters of knowledge and extensionists, while INIA (the governing body of the NAIS), SENAMHI, private firms and NGOs are also in charge of creating knowledge. These different roles could influence their relevance as sources of climatic-related information. More details on these institutions can be found in Table S1, including their main functions, that show the complementarities and differences among them. This table also shows that most of the institutions are physically present in all the Peruvian regions and that they use a variety of media and activities to transfer information, ranging from mass media to repositories in the case of institutions whose role is to generate knowledge, while from demonstrative parcels to field visits (that is, more direct and personal channels) in the case of institutions in charge of knowledge transfer and extension. To explain the apparently low rates of access to information in many of the regions, factors such as the media through which information is transmitted and the characteristics of the regional predominant farming systems were analysed, as shown in Section 5.

4.2. Detecting the structure of networks of information transfer

The application of LBM revealed different clusters of farmers and institutions each year. To summarize the evolution over time of the clusters of institutions in their relationship with farmers, Sankey diagrams are represented in Fig. 2 (smallholders) and Fig. 4 (large-scale farmers). Regarding the clusters of farmers and their percentage of access to information from each institution, results are shown in Fig. 3 (smallholders) and Fig. 5 (large-scale farmers). Fig. 2 shows that two clusters of institutions are found in all the years, whose composition slightly varies: while in 2016 and 2019, SENAMHI and INDECI form one cluster, in 2017 and 2018 SENAMHI forms one cluster while all the rest of institutions form the other.

Regarding the smallholders' clusters shown in Fig. 3, three of them were found in 2016 and 2017, being one of them large (Cluster 3S in 2016 ($n = 1923$) and Cluster 2S in 2017 ($n = 1982$)), another

Table 4
Roles fulfilled by institutions within the NAIS.

	SENAMHI	INDECI	MINAGRI	SENASA	Agrarian Agencies	INIA	Private firms	NGOs
Knowledge generation	X			X		X	X	X
Knowledge transfer and extension	X	X	X		X	X	X	X

Notes: MINAGRI - Watering and Agriculture Ministry; INIA - National Institute for Agricultural Innovation; SENASA - National Agricultural Health Service; SENAMHI - National Meteorological and Hydrological Service; INDECI - National Civil Defense Institute. Source: Own elaboration from the Peruvian Program for Agricultural Innovation (PNIA, 2019).

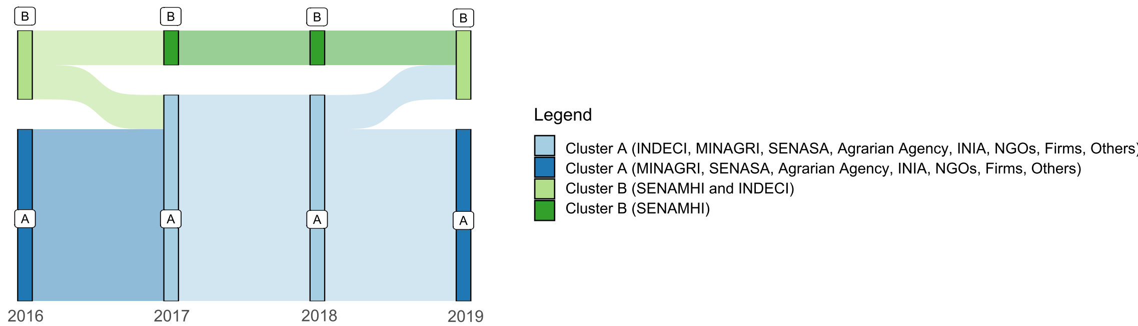

Fig. 2. Sankey diagram of the composition of clusters of institutions when interacting with smallholders.

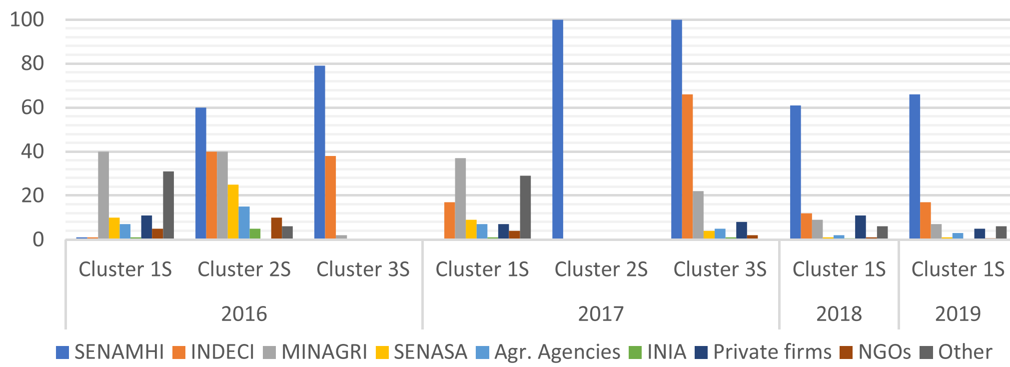

Fig. 3. Percentage of smallholders in each cluster who receive information from each institution.
Note: Each farmer could have received information only from one institution, from more than one or from all of them, so that the total sum per cluster could differ from 100%.

intermediate (Cluster 1S in 2016 ($n = 794$) and 2017 ($n = 1070$)) and the remaining one small (Cluster 2S in 2016 ($n = 178$) and Cluster 3S in 2017 ($n = 374$)). Cluster 3S in 2016 and Cluster 2S in 2017 represent the smallholders who rely mainly only on SENAMHI (also on INDECI in second place in 2016); that is, on Cluster B (see Fig. 2). Cluster 1S in 2016 and 2017 include smallholders who receive almost no information from SENAMHI or INDECI, while they rely much more on MINAGRI or on “Other” non-identified sources, that belong to Cluster A. SENASA, the Agrarian Agencies and private firms also seem to play a more important role in these clusters in comparison. Cluster 2S in 2016 and Cluster 3S in 2017 represent smallholders who relied predominantly on SENAMHI as well as on other institutions, particularly on INDECI, MINAGRI and SENASA. It can be seen that the smallholders in each cluster were grouped together because they share a common information sourcing profile.

However, only one smallholders' cluster is found in 2018 and 2019. In these cases, SENAMHI continue to predominate, followed at a distance by INDECI. All the other institutions (Cluster A) are checked by less than 10% of the smallholders, with the exception of private firms in 2018, which are slightly above this threshold. MINAGRI is found in third place, but experienced an enfeeblement process: while around 14% of all the smallholders got information from it in 2016 and 2017, this reduces to 7% in 2019. This process is also found for other institutions such as SENASA and may explain why no different groups of smallholders are found: SENAMHI has gained ground as the predominant source of information on the prevention of extreme weather events towards over the rest of the institutions.

Regarding large-scale farmers, the clustering method detected two clusters of institutions each year, as Fig. 4 shows. Their composition is similar in 2016 and 2017, as well as in 2018 and 2019, but is very different between both of these periods. In 2016 and 2017, one cluster is formed by SENAMHI along with other institutions, while from 2018 one cluster is solely formed by SENAMHI.

As Fig. 5 shows, LBM resulted in three clusters of large-scale farmers in 2016 and 2019; two clusters in 2017 and one cluster in 2018. Cluster 1L in 2016 ($n = 171$) and 2017 ($n = 220$) shows similar behaviour

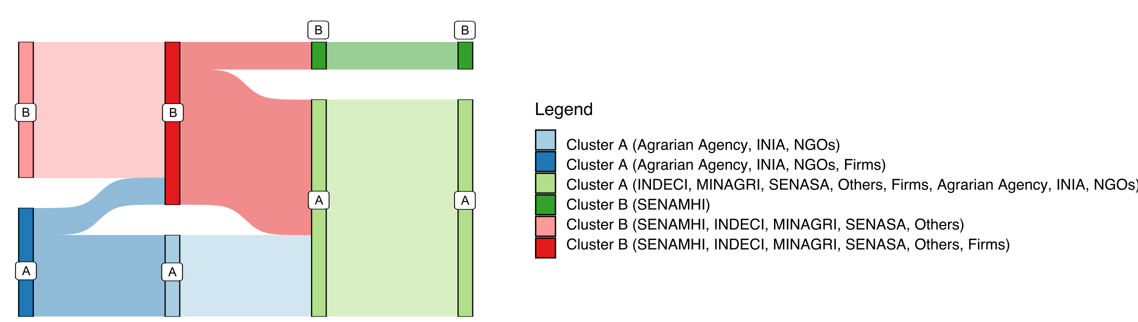

Fig. 4. Sankey diagram of the composition of clusters of institutions when interacting with large-scale farmers.

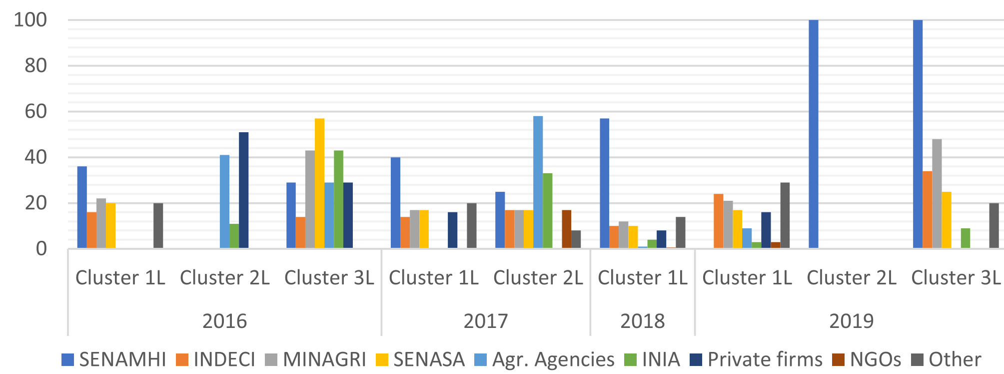

Fig. 5. Percentage of large-scale farmers in each cluster who receive information from each institution.
Note: Each farmer could have received information only from one institution, from more than one or from all of them, so that the total sum per cluster could differ from 100%.

among large-scale farmers, who only got information from one cluster of institutions, among which SENAMHI and "Other" sources predominate. Cluster 3L in 2016 ($n = 7$) shows a similar behaviour to Cluster 2L in 2017 ($n = 12$), in which farmers rely on institutions of both Clusters A and B (see Fig. 4). In 2018, farmers mainly rely on SENAMHI to get information on the prevention of extreme weather events, while in 2019 this is also true and is observed in Clusters 2L ($n = 92$) and 3L ($n = 44$), but not in Cluster 1L ($n = 105$). This latter cluster includes large-scale farmers who turned particularly to INDECI, MINAGRI and "Other" sources, while Cluster 3L (2019) shows a profile of particularly active large-scale farmers, in which about 50% of them got information from at least two institutions at a time.

SENAMHI has gained in importance over the study period, and this may explain the differences in the composition of clusters from 2018 on. While in 2016, about 30% of all large-scale farmers had received information on the prevention of extreme weather events from SENAMHI, this percentage increased to 57% in 2018 and remained almost the same in 2019. Comparing between smallholders and large-scale farmers, the clusters obtained show some differences in their composition that tend to reduce over the years, as SENAMHI becomes more predominant over the rest of the institutions in both cases.

4.3. Characterization of the clusters including the regional and media perspectives

Fig. 6 shows the distribution pattern of smallholders and large-scale farmers' clusters across regions. Cluster 3S in 2016 and 2S in 2017, where SENAMHI is the main institution, predominate in most regions, although in some others the rest of clusters predominate. This occurs in 2016 in regions of high climatic risk in the Andean zone such as Piura, Ayacucho and Huancavelica, where the majority of smallholders belong to Cluster 1S. In 2017, Cluster 3S, which corresponds to smallholders who check both SENAMHI and other institutions, predominates in regions of high climatic risk such as Puno, Cusco and Tacna, as well as in regions of medium climatic risk such as Ancash, La Libertad, Loreto and Moquegua. In Tumbes, we observed that while most farmers belonged to Cluster 3S in 2016, they were split into Clusters 1S and 3S in 2017. This could owe to the shift of INDECI from Cluster B to A, as it had some

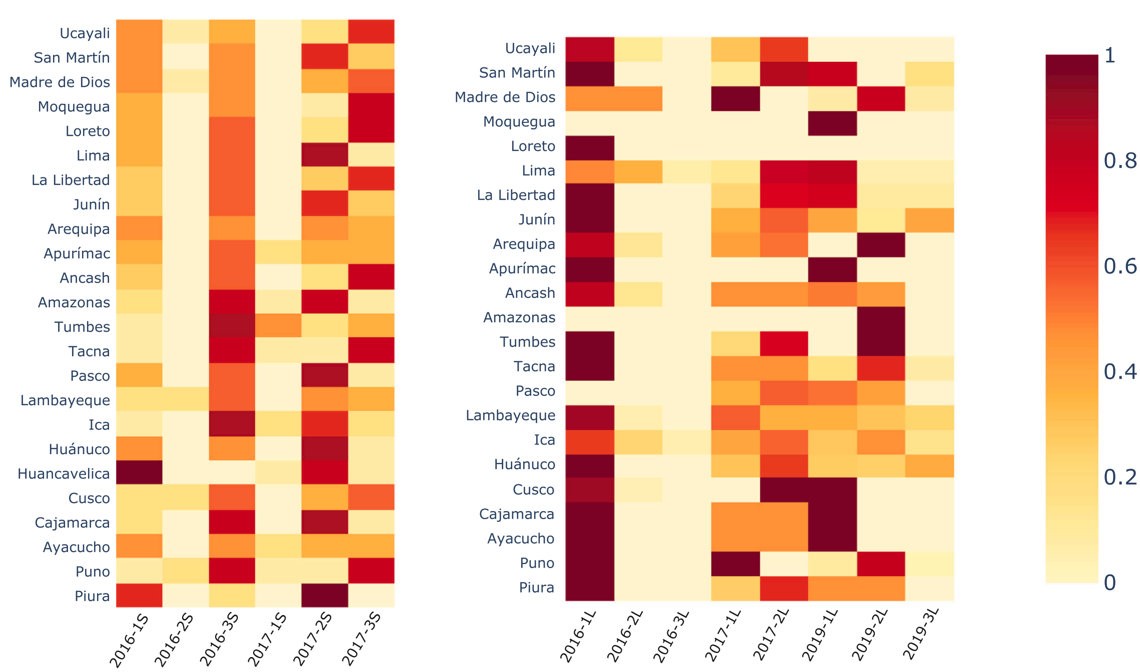

Fig. 6. Heatmap based on the percentage of smallholders (left) and large-scale farmers (right) who belong to each cluster, per region and year.
Note: The years for which only one cluster was found are not represented, as all farmers belong to the same cluster. The scale colour goes from zero (0% farmers) to one (100% farmers).

degree of relevance in such region. The density of access to information seems thus slightly higher throughout the period for the regions with a high to extreme climatic risk, where among other things, tubers and quinoa are grown (see Table S2).

Regarding large-scale farmers, most of them in 2016 were part of Cluster 1L, the biggest one in which farmers turn to a variety of institutions of Cluster B, including SENAMHI. In 2017, Cluster 1L clearly predominates in regions such as Puno and Lambayeque, while Cluster 2L where farmers get information from INIA, the Agrarian Agency or the NGOs, predominates in regions of extreme to medium climatic risk such as Piura, Cusco, Tumbes, La Libertad and Lima. In 2019, Cluster 2L where farmers only turn to SENAMHI predominate in Puno, Tacna, Tumbes, Amazonas and Arequipa, while Cluster 3L in which farmers check SENAMHI and other institutions is relevant in Huánuco and Junín. Cluster 1L in 2019, where farmers do not get information from SENAMHI, predominates in Ayacucho, Cajamarca and Cusco. In general, we observe that SENAMHI tends to be progressively more used among large-scale farmers throughout the country, while the relevance of the other institutions changes across some regions over the period studied, so these institutions have no clear permanent regional predominance.

Fig. 7 shows the percentage of smallholders who used each type of media to get information from NAIS institutions within each cluster. The radio is the most frequently used media in all the clusters in the whole period 2016–2019, followed in general in second place by the TV. However, the percentage of use is higher in those clusters that rely more on SENAMHI (Clusters 2S and 3S in 2016 and 2017, and Cluster 1S in 2018 and 2019) than in those that do not (Cluster 1S in 2016 and 2017), while at the same time the rest of media are used much less. It thus seems that SENAMHI mainly relies on the radio and the TV to transfer information on the prevention of extreme weather events to smallholders. In Cluster 1S in 2016 and 2017, in contrast, workshops appear as a relevant media used by about one out of four smallholders. In these clusters the relevance of "Other media" is the highest of all the clusters obtained, in which MINAGRI and "Other sources" appear as the most relevant sources of information, with usage percentages near to 40% and 30%, respectively.

5. Discussion

The aim of this study was to understand the structure of the interactions between farmers and NAIS institutions regarding the transfer of information on preventing the effects of extreme weather events. The effectiveness of this kind of formal information has been discussed in the literature in contrast to that of informal information obtained from peers, which farmers seem to prefer (Wood et al., 2014), although both are necessary to get better results at the farm level and achieve a more resilient agroecosystem (Šūmane et al., 2018; Slijper et al., 2022). Our results show a percentage of access to information of institutions in the NAIS (the Peruvian AKIS) that could be considered low in general and, particularly, in some regions. This could owe to problems of trust, as farmers have been traditionally considered as passive actors within the AKIS and their own-generated knowledge and innovations are still undervalued by AKIS' official institutions (Knickel et al., 2018; Skaalsveen et al., 2020). This may also explain why smallholders who obtained information from "Other" non-identified agents did not used any other source.

However, our findings suggest that there may be also other factors preventing a wider information access, particularly; problems with the type of media used by the institutions; problems with the contents of the information and how it is perceived; and among smallholders particularly, problems to access the information because of their geographical location, and a lack of resources to implement adaptive and preventive activities and to access the information, as well as a lack of knowledge of which sources of official information are available and how to reach them. This is in line with previous results in the literature that revealed that, in the context of a developing country, the main factors making information access difficult for smallholders are related to a lack of knowledge about which sources of information are available, inadequate funds, socioeconomic status, problems with the skills of the extensionists and the number of visits they do, and a poor response from governmental agencies (Phiri et al., 2019; Magaji and Maidabino, 2020).

Regarding the major variations observed in the access to information among smallholders over time, in some regions, it is important to consider that regions such as Tumbes and Lambayeque are particularly susceptible to climate variability because they are desert regions that are directly affected during the episodes of ENSO, for which the most recent took place at the north coast of Peru in 2017. This post-ENSO period in which there is a decrease in the demand for climatic-related information in such regions could be associated with the predominance of activities of the reconstruction period, where technical and financial assistance is rather required. Additionally, it is possible to consider effects such as the migration of smallholders to regions with less risk of extreme weather events, given the growing damages caused by extreme weather events and the lack of adaptation policies (Bergmann et al., 2021). The opposite could be happening in the high Andean areas such as Puno, Cusco and Moquegua, where the cold and icy climate, which is progressively becoming more extreme, means that the agricultural sector is more exposed to more severe and continuous cold weather (MINAGRI, and FAO, 2012). Thus, seeking prevention information would be a resilience activity that farmers in these regions could identify as more necessary or useful compared to other regions with less extreme climates. In the case of large-scale farmers, the increase in the demand of information on the prevention of extreme weather seems to be very much related to the evolution in the type of crops and productive methods used over the last

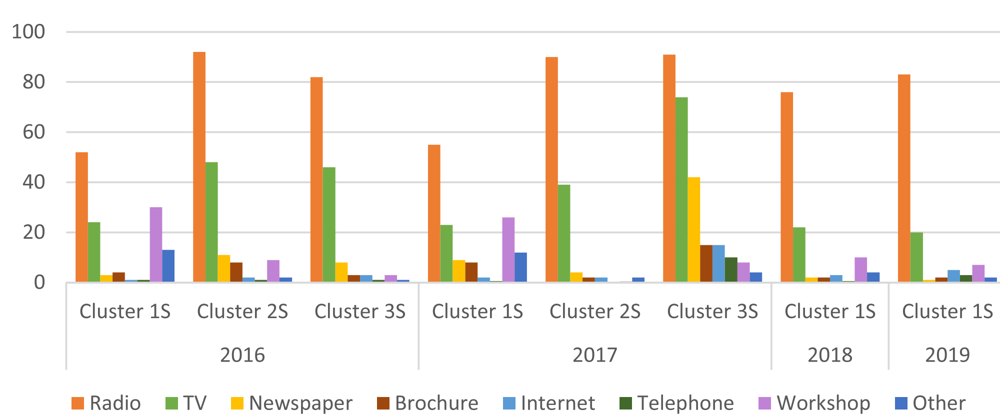

Fig. 7. Percentage of access to information on the prevention of extreme weather events by cluster of smallholders and type of media. Note: Each farmer may indicate various types of media.

years. Tacna has transformed into the first national producer of watermelon with intensive practices by part of agro-exporters, while in Huánuco coffee and cocoa cultivation have progressively intensified at the same time that new cooperatives made up of smallholders are appearing, which could be promoting the appearance of agricultural firms in the area. The activity in the high plateau area of Puno around quinoa is decisive for both smallholders and large-scale farmers in terms of getting and managing information (Ruiz et al., 2014).

About the differences found between the sourcing profile of large-scale farmers and smallholders, we can highlight that while most smallholders mainly rely only on one institution, SENAMHI, during the whole period, large-scale farmers show a more heterogenous behaviour particularly in 2016 and 2017, where no institution has a clear predominance. From 2018 on SENAMHI turns also to be the most checked institution by them (more than 50% of large-scale farmers got information from it), although its importance is not as high as in the case of smallholders. It is reasonable that SENAMHI plays this central role and that has gained relevance as transmitter of information, since one of its main functions is to provide agrometeorological information and consultancy. However, results showed that the main media used by SENAMHI is the radio, so that probably consultancy, in which information and advice can be tailored to the specific needs of each farmer or group of farmers within a specific farming system, is almost not reaching them. Additionally, the fact that SENAMHI is mainly reached by farmers through the radio and the TV may explain precisely why this is the most used source of information by them: the radio and the TV have been consistently found as the main media used by smallholders in developing countries to access agricultural-related information (Antwi-Agyei et al., 2021; Hoang et al., 2022). This is important, given that the specificity and technicality of the information provided in other less used media, such as workshops, is expected to be higher. Additionally, workshops play a more proactive role on the part of farmers, while the radio and the TV are one-way channels in which interaction is not possible or very limited. On the one hand, this may be affecting the farmers' perception of the relevance of information to prevent extreme weather events in a real and effective way. On the other hand, this information may be conflicting or inconsistent with their own experience or perceptions, and may end up by discouraging some of them to make changes (Fisher, 2013). In contrast, large-scale farmers, who have more resources, tend to check more other institutions apart from SENAMHI, such as MINAGRI, private firms and “Other”, that seemed to tend to use more direct methods to transfer information such as workshops (to which probably large-scale farmers travel to attend them, a case which is much more difficult for many smallholders), or more sophisticated ones such as the Internet or smartphones, in line with the findings of previous works (Phiri et al., 2019; Hoang et al., 2022).

The Internet and smartphones, which are interactive communication media, had very low rates of use among all the clusters. This weakness is reasonable, since in Peru the Internet penetration rate is low and there is a digital gap between urban and rural areas. While in urban areas 36% of the households use the Internet, just 5% of those in rural areas do so (INEI, 2020). Previous works have highlighted the need to promote Information and Communication Technologies (ICTs), especially Internet, in rural Peru because of its benefits for smallholders such as increased participation in both national and foreign markets (Aker, 2011; Fan and Salas Garcia, 2018). Reinforcing these more interactive media could be an option to reach a greater number of farmers and get them more engaged in the implementation of preventive and adaptive strategies. Additionally, organizing specialized workshops in every region of the country to reach the local communities of farmers, is necessary. Currently, many farmers may not be attending such events because of a lack of mobility (Phiri et al., 2019) or because they are not properly informed about how and where they are organized.

From a regional view, the exploration of smallholders' clusters revealed that particularly the northern region of Tumbes, the central regions of Huancavelica and Huánuco, and the southern region of Piura are those more engaged with other institutions apart from SENAMHI or along with SENAMHI. These regions present a high to extreme climatic risk and share some productions such as tubers (potatoes and cassava) and bananas (see Table S2). These crops are of vital importance in some areas of Latin America, including Peru, particularly for self-supply and for selling to the domestic market, and thus the need to particularly adapt their farming practices to account for the effects of climate change have already been stated in the literature (Thiele et al., 2017). Regarding large-scale farmers, although there are some differences over the years, in general the more proactive regions in terms of seeking information correspond to Huánuco, Ayacucho, Cajamarca and Cusco (high climatic risk) and Junín (medium climatic risk). These regions share the production of tubers and bananas as well, but they also present important productions of quinoa, cocoa and coffee that are mainly devoted to exports (Rossing et al., 2014) and that are particularly relevant for large-scale agro-exporters. These crops are already being object of analysis because of their vulnerability against climate change (de Sousa et al., 2019), reason why agro-exporters in these areas may be particularly interested in taking preventive and adaptive actions. The interaction of climatic risk and type of farming systems could therefore help to understand the particular behaviour of such regions. However, none of the institutions seem to have marked regional roots, since their levels of importance generally vary across regions throughout the period. The type of functions they perform in the NAIS as well as the use of remote media (radio, TV, newspapers) may be behind this.

The contributions of this study to the literature are varied. First, we compare the behaviour of smallholders and large-scale farmers regarding information access from AKIS' institutions, while in general, studies are focused only on one of these groups. Second, analyses are done for all regions in Peru, instead of focusing on a particular locality or region which is more frequent in the literature, particularly in the case of developing countries. This way, we provide inputs for rethinking policies both at the national and regional levels. Third, we analyse the evolution of the sourcing profile of farmers over a four-year period, which provides more robustness to the results in comparison to a cross-sectional study. Finally, we analysed a sample of data that remained unexplored in the literature and that contains potentially important information about the farmers-institutions relationships, considering also that it is representative of the entire population of farmers of each region of Peru.

By exploring these relationships with a network analysis method such as LBM, we have been able to identify different clusters of farmers over the country who share a common pattern in their interaction with the NAIS institutions, and to follow the evolution of the structure of clusters over time. This has helped to provide interesting insights into the relevance of the different institutions within the NAIS, into the predominance of the media used, and into the regional profile of farmers regarding information access. This kind of network analysis applied at a multi-regional level brings a new perspective to the literature on agroecosystems resilience. First, the concept of resilience is accentuating the importance of dynamics and learning (Knickel et al., 2018), so that studying these relationships of information transfer from the point of view of networking analysis is increasingly needed. Second, building social capital, in which formal and informal networks are involved, is a basic sphere of agroecosystems resilience (Cabel and Oelofse, 2012; Tittonell, 2020). This study has contributed to measure it by analysing the structures of relationships among farmers and institutions, where some specific patterns and deficiencies have been detected. These could help policymakers to rethink and redesign the way in which NAIS institutions are interacting with farmers in order to get more of them on board, which could contribute in the end to boost the resilience of the Peruvian agricultural sector. Third, approaches to enhancing resilience are progressively more focused on systemic, socially-based interventions where the national, regional and local levels should be considered (Bullock et al., 2017; Knickel et al., 2018). In line with this, our study provides a wide view of the relationships of climatic-related information transfer among farmers and NAIS institutions, discussing differences across regions, farming systems and types of farmers. This would help policymakers to make changes in order to reinforce the formal relationships of information transfer considering the reality of one and all regions at a time. Our results point out that the networks of information transfer should be reinforced in order to boost the resilience of agroecosystems, in line with previous studies (Knickel et al., 2018; Aguilera et al., 2020; Magaji and Maidabino, 2020; Labeyrie et al., 2021).

Finally, we discuss some limitations of this study. First, the frequency with which institutions interact with farmers is not available, and this could help to quantify the strength of the relationships. Second, the effectiveness of the information transferred has not been measured, given that we did not dispose of evidences on the implementation of actions to mitigate and to adapt to extreme weather events as a result of receiving information, or on whether these actions are working or not. This is a key aspect that we propose to be included as a question in the ENA survey, along with the option to identify other farmers as a source of information to have the chance to tackle peer interactions in the network. Third, assessing their relationships of trust with institutions could have helped to confirm whether, in addition to problems related to the media or the geographical location, there is a structural problem within the AKIS that prevents the transfer of information, as previous works show (O'Flynn et al., 2018; Šūmane et al., 2018). However, this information was not available in the dataset of the survey, so that we have discussed the results relying on literature. Fourth, results are related to the Peruvian context, so that they should be taken with caution when talking about other contexts.

6. Conclusions

This study has contributed to understanding the structure of relationships of information transfer among farmers and institutions of the Peruvian National Agrarian Innovation System. Some weaknesses which could hinder the implementation of preventive actions against the effects of climate change have been detected. These are mainly related to problems of trust among farmers and institutions, which are linked, among other things, to the perception that farmers have of formal information; as well as to problems accessing and using the information. Improving these issues could help more farmers to get formal information on the prevention of the effects of climate change and to know how to use it, so that the Peruvian agricultural sector could strengthen its resilience towards climate change. To confirm these first insights, more profound analyses with additional data would be necessary.

Providing more insights into how social networks in the AKIS context influence the dissemination of information focused on the adoption of preventive and adaptation strategies against the effects of climate change has major implications for extension agencies, the private sector, researchers and especially for policymakers. The findings of this study could be used to design specific plans and policies to spread preventive information to reach a greater number of farmers, for instance, by strengthening the resources of the institutions that have been identified as more relevant and by getting farmers more involved in information generation, treating them as active actors in the system instead of as passive receivers of information.

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.

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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.2022.103431.

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