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Using social-network analysis to map institutional actors' links with vulnerable municipalities under climate change in Honduras' dry corridor. Pathways towards improved cooperation and territorial interventions

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A R T I C L E I N F O

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A B S T R A C T

The Honduras dry corridor, located in Central America's Pacific region, has high natural climate variability. Nearly half of the Honduran population depends on socio-economic activities linked to agriculture, making climate-change adaptation crucial for the agricultural sector to ensure food and nutrition security. This research analyzes how institutional structures function and interact as a network to investigate the spatial coherence and relevance of public- and private-sector interventions related to agriculture, climate change, and food security in 153 municipalities of Honduras' dry corridor. We employed a Social Network Analysis (SNA) approach to examine these interactions over the territories, revealing two network patterns: the first favors a single municipality, observed only in the Central District where Honduras' capital is located; the second is an egocentric network, favoring a single institution, observed in four cases, particularly in municipalities bordering with El Salvador and Guatemala. The SNA results reveal a spatial misalignment, where only 9% of interventions linked to climate-change adaptation are conducted in the highly vulnerable, outlying zones located farthest from the capital. The study highlights the need for improved coordination and strategic prioritization of interventions in the most vulnerable municipalities within the Honduras dry corridor, specifically improvement in collaborative actions, use of resources, and setting strategic priorities in regions where future demand will require progressively mobilizing institutional capabilities. By identifying the current gaps and misalignments in institutional actions, this research provides valuable insights for policymakers and stakeholders to enhance collaborative efforts to ensure that climate-change adaptation measures effectively target the most vulnerable areas.

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1. Introduction

Responding to irreversible climate change requires both an understanding of the plausible future scenarios and threats and knowledge of effective climate-change adaptation measures. Global challenges that affect entire regions in Latin America and its subregions surpass and overwhelm the efforts of local institutions, dissolving their actions when implemented in isolation. In this sense, remedial efforts can be effective if they are approached through harmonized collaboration between national and transnational institutions. Thus, the concept of institutional networks is key to achieving effective transformations, as they enrich debates, knowledge, experiences, and technology transfer.

In the agriculture sector, the concept of climate-smart agriculture (CSA) has been proposed to synergistically achieve climate-change mitigation and adaptation, as well as food security goals, through the scaling of CSA practices (Andrieu et al., 2019). The first step towards achieving this is to identify local and external actors who may be potentially interested in implementing CSA within a specific territory (Andrieu et al., 2019). Since CSA's three primary objectives are: (i) increasing agricultural productivity, (ii) adapting and building agricultural and food security systems' resilience to climate change, and (iii) mitigating greenhouse gas emissions produced by socioeconomic sector, it is important to consider CSA objectives as an underpinning framework for the institutional network analysis applied in this research.

The Pacific region of Honduras is part of Central America's dry corridor. As its name suggests, it is a drought-prone region, with 4 − 6 months without precipitation (Durán-Quesada et al., 2020). In addition to its inherent climatological limitations, Honduras' agriculture and the food and nutrition security of its inhabitants is also impacted by the effects of climate change, specifically through extreme meteorological events. The 2014 − 2019 drought that extended across almost all Central America caused almost 2.2 million people to suffer severe crop losses and 1.4 million people to require urgent food aid (Depsky and Pons, 2021; Pascale et al., 2021; Vaqué, 2017). In Honduras, the impacts of this extended drought on the food security of the families living in the dry corridor led the government to declare a state of emergency (FAO, 2014; República de Honduras, 2015, 2017). This extended drought event contrasts with the 2020 Atlantic tropical cyclone season, in which two hurricanes crossed Nicaragua and Honduras in less than a month, causing major flooding across both countries (Shultz et al., 2021). Droughts and tropical cyclones are events related to the natural climate variability of the region; however, extreme events are expected to intensify as a result of global warming (Barahona Mejia et al., 2022; Pascale et al., 2021), increasing pressure on livelihoods and specifically agricultural production in Honduras.

Besides climate variability, Honduras' dry corridor has high, stagnant levels of social fragility, which have driven low economic development, as shown by its Human Development Index values from 1990 to 2019, which range between 0.52 and 0.63—expressed as a value between 0 and 1—(UNDP, 2018). In the case of 2019, the 0.63 index value is equivalent to 0.47 if we consider the Inequality-adjusted Human Development Index (I-HDI). Both climate variability (and global warming) and low economic development are related to internal and external migration processes as a way for people to mitigate and recover from extreme weather events (Kanta Kumari Rigaud, 2018).

Given the socioeconomic fragility of regions in Honduras such as the Dry Corridor, over the years, different institutions have devoted efforts to minimizing vulnerability to climate change in those regions. We do not know the level of coordination between institutions over the years and the territories. Although each of these institution follow their own objectives, they interact and interrelate, forming a *de facto* institutional network, the complexity of which depending on the interactions these institutions have across the territories. As described by Bodin et al. (Bodin et al., 2011), Social Network Analysis (SNA) can be used to analyze how the institutions interrelate, so as to seek "relationships among entities, and on the patterns and implications of these relations." In SNA, each entity or institution is conceptualized as a node within the network. In socio-environmental contexts, network analysis stands out as a theoretical and technical tool that contributes to understanding the nodes' processes, coalitions, and interventions, especially in multi-scale relationships that seek to manage, solve, and address environmental and social challenges (Bodin, 2017; Huang et al., 2022; Lemos & Roberts, 2008).

Using SNA, the characteristics, density, and spatial coverage of an institutional network are key elements used to investigate the coherence, consistency, and relevance of the network in rural territories, and may facilitate decision-making to prioritize actions and strengthen the institutions' impacts. By conceptualizing each entity as a node in a network, it becomes easier to visualize how they interact and collaborate with each other. This approach allows the identification of key influences and behavior patterns, ultimately leading to more effective strategies to enhance and fortify collective actions and impacts (Campis, 2023).

Published works on institutional networks in Honduras in relation to policy influence, climate change, and environmental and forestry issues concur on the need to explore in greater depth how these networks are related and operate within the territory, to gain a better understanding of how they can collectively improve and strengthen their actions and impacts (Galloway, 2002). When evaluating the Honduran institutions' influence in the agriculture and climate-change sector, Castro Colina et al. (2016) observed a dominance of private-sector actors and a poor representation of public and educational institutions. Navarro Racines et al. (2022) described a centralized network with governmental institutions and international non-governmental organizations (NGOs) when evaluating the Agroclimatic Technical Groups (Mesas Tecnicas Agroclimaticas), whose approach is to support the provision of climate services in various Latin American countries (Giraldo et al., 2019). As far back as 2002, Galloway (2002) identified four difficulties faced by Honduran institutional networks—(i) lack of financial autonomy; (ii) weak or lack of representation of state institutions in these networks, hindering the flow of information from regional initiatives to decision-makers at the central level; (3) weak institutional capacity in some regions; and (4) the regions furthest from the main spheres have limited political participation—all of which weaken the actions, effectiveness, and sustainability of the institutions' interventions. It is not realistic to expect network actors to cooperate with the same intensity, due to differences in resources, capacities, and priorities of each organization. Some actors may be more committed and have more resources to contribute to cooperation compared to others; hence, it is necessary to identify the organizations whose objectives and operational strategies overlap substantially, to reduce cooperation misalignments (Bodin et al., 2011).

While there are studies that assess the vulnerability and adaptative capacity of the agricultural sector (Engle, 2011; Martinez-Baron et al., 2018; Young et al., 2012), to our knowledge, there have been no studies that make a holistic evaluation of the interventions of an institutional network in Honduras related to agriculture and food security in the context of climate change. Moreover, institutional nodes could be configuring an intricate structure of cooperation and territorial intervention that responds to current geographic needs. However, it has yet to be studies have yet to understand how this social system of response and collaboration (i) can adapt and respond to potential future needs in response to climate change, and (ii) how it will prioritize its actions in this region to avoid spatial mismatches and over-interventions, thus contributing to more efficient environmental governance. Hence, our SNA plays a pivotal role in seeking to advance research on institutional networks, by 1) assessing the level of cooperation and integration of the network of institutions that conduct interventions in 153 municipalities in Honduras' dry corridor, and 2) spatial uncoupling, related to the relevance of the institutional networks' interventions at the territorial level, considering the potential climate-change vulnerability of the municipalities.

2. Methodology

Our study methodology was based on a mixed methods approach combining SNA (Fig. 1A and B) and climate-change vulnerability (Fig. 1C). Data was collected through surveys and secondary sources, that allowed us to identify network patterns and assess the spatial coherence of three types of interventions: agricultural, climate change, and food security. We choose these criteria based on the principles of CSA, which is an approach to climate-change adaptation and mitigation strongly linked to these three components. By obtaining data on regional vulnerability and networks, it was possible to process and identify institutional interventions in vulnerable territories (Fig. 1D).

2.1. Study area

The study area evaluated by this research corresponds to the Honduras dry corridor, and includes 153 municipalities across four development regions, as per the National Plan of 2010 (Fig. 2) (República de Honduras, 2018). Located in Central America, Honduras is a small, bi-oceanic country, bounded by Nicaragua to the southeast, Guatemala to the west, the Caribbean Sea to the north, and El Salvador and the Pacific Ocean to the south. Honduras' economy relies on agriculture, manufacturing, and services. The main crops grown here are maize and beans—which are both subsistence crops for most of the Honduran population—in addition to bananas, coffee, oil palm, and sugarcane. The four development regions are physically related to hydrographic basin borders, not to socioeconomic or cultural similarities. Although all four regions are located within the dry corridor, they are not climatically similar. Most of the country is characterized by an annual rainfall distributed within two well-defined seasons (rainy and dry). While over the Caribbean slope it rains almost all year round, the Pacific slope, where the dry corridor is located, is characterized by a decrease in rainfall during the rainy season (May – October) and a mid-summer drought that occurs between July and August (Argeñal, 2010). For example, R13-Fonseca Gulf region (Fig. 2) is more highly influenced by the Pacific Ocean, hence it has higher rainfall compared to R12-Central District (Fig. 2), which is the driest region.

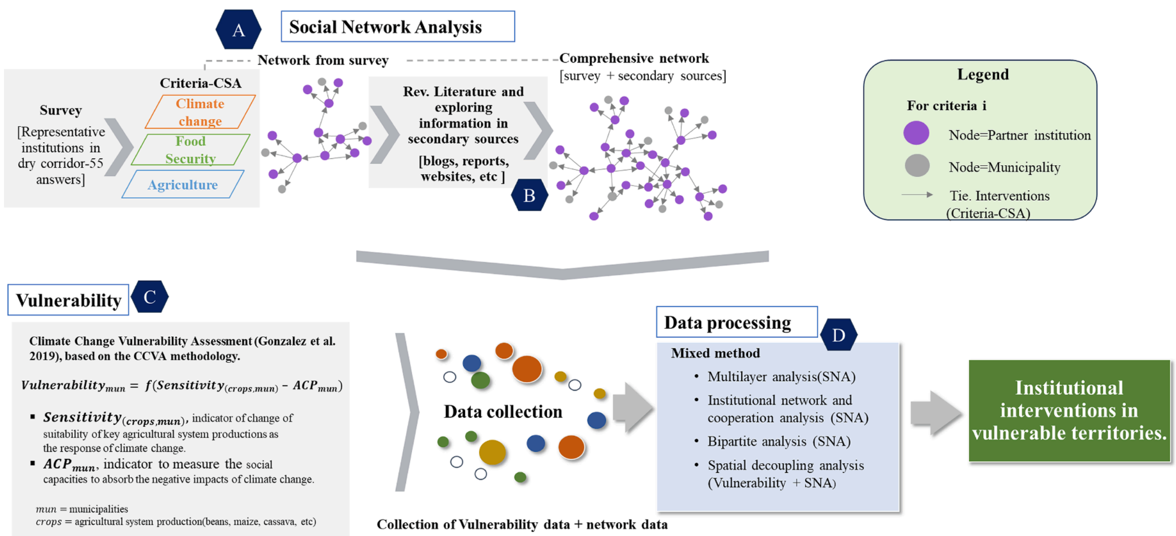

Fig. 1. Our studies' methodology process flow chart.

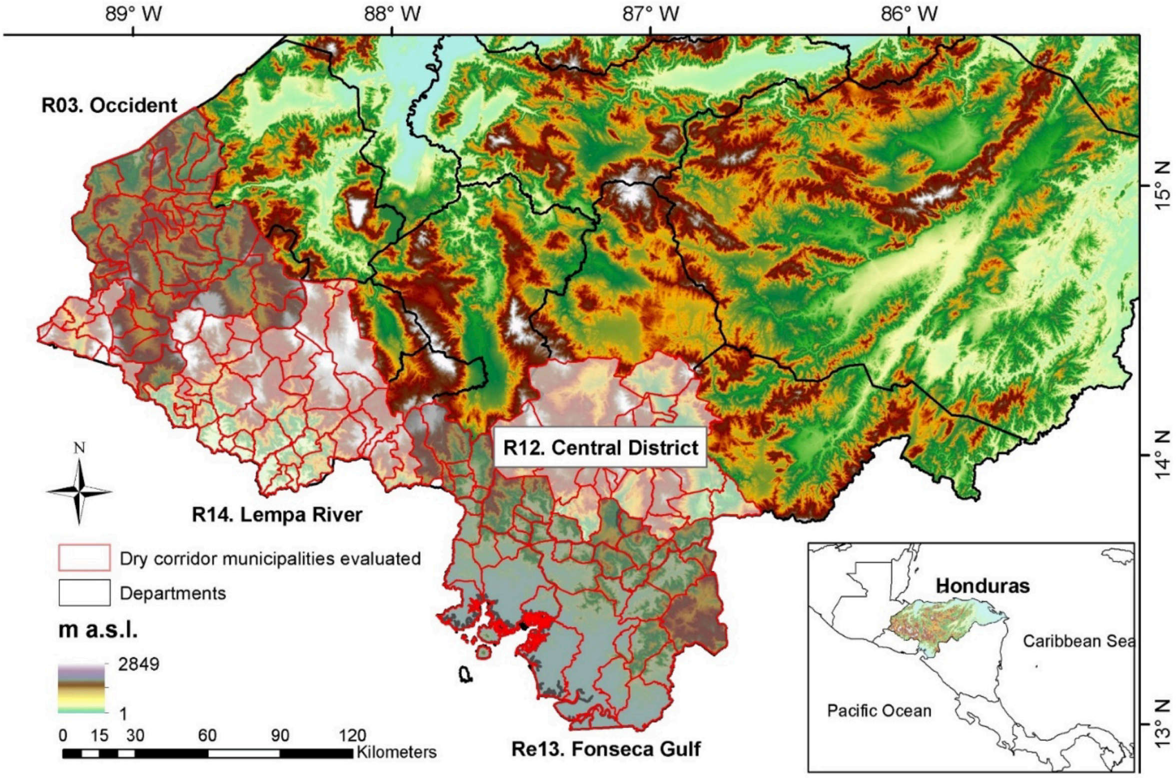

Fig. 2. The 153 municipalities in Honduras' dry corridor, divided into four development regions: R03 (Occident); R12 (Central District); R13 (Fonseca Gulf); and R14 (Lempa River). Elevation model derived from shuttle radar topography mission (SRTM) data (Farr et al., 2007).

2.2. Data collection

Study data was collected between 2019 and 2020, within the framework of the project "Designing Inclusive Climate Change Policies for Resilient Food Systems in Central America and the Caribbean" (FP1 LAM) of the CGIAR Research Program for Climate Change, Agriculture and Food Security (CCAFS) Latin America program (CCAFS, 2019). Information was obtained through a survey of actors within government institutions, the private sector, municipality associations (*Mancomunidad* in Spanish), the community sector, international organizations, and NGOs. The secondary data sources complement the links and attributes described in the surveys for the non-responding actors. This activity included reviewing the institutions' official websites to verify relations with other institutions, to ascertain their areas of action and verify the types of intervention they implement in the territories and with partners. A description of the information sources follows (also see Fig. 1A and 1B).

2.2.1. Data sources: Survey

We surveyed institutions involved in interventions in Honduras' dry corridor, considering one response per organization. These were selected through a directory of existing national, regional, and local institutions working in the Honduran dry corridor, which was reinforced with information provided by some of the municipality associations operating in the region. The survey targeted area representatives, directors, scientific leaders, political representatives, and technical and project managers. Most of the survey responses were obtained in the capital city of Tegucigalpa, given that the survey respondents' headquarters are close to the public authorities and the national government, in addition to the mobility limitations imposed during the COVID-19 pandemic.

Among the 55 organizations that responded to the survey, 22 were NGOs, 12 public-sector institutions, and 10 municipality associations. The remaining 11 institutions are part of public–private partnerships, academia, multilateral cooperation agencies and projects (see total number of nodes identified in the network in Supplementary Material I).

The survey (see Supplementary Material II) was designed to evaluate each of these institutions, the type of actors operating within them, the territories and municipalities in which their actions take place, the types of intervention (e.g., conducted as a cooperation intervention, its financial support, among other parameters), the institutions with whom they collaborate as partners and the nature of that collaboration. The survey was posted on virtual channels and distributed by email, accompanied by a cover letter explaining the purpose of the study. In other cases, both documents were printed and physically delivered to potential respondents in the selected institutions. In general, it was difficult to obtain a response from government institutions, for which, in most cases, support was requested from the Office of Institutional Transparency. Overall, the information provided by the institutions addressed was scant, except for the Unit Technical Food Safety (UTSAN), which prior to 2022 was housed under the Presidential House and has since been housed under the Ministry of Agriculture (SAG).

2.2.2. Data sources: Literature research

The literature review was specifically focused on the Honduras dry corridor and based on the survey inputs, targeting institutions operating within and actions falling under the three CSA thematic areas of agriculture, climate change, and food security. The secondary sources included public policy documents, municipal plans, projects undertaken by private institutions, and other documents from open sources, which were used to identify institutional actors operating in the dry corridor (see Supplementary Material III). The authors explored available secondary resources associated with the responses and information obtained from the survey; the collection of complementary information was based on three criteria: (a) identifying actors, institutions, and organizations with effective and operational actions in the area of interest; (b) types and categories of interventions connected to the key issues; and (c) coalitions and/or integrated group efforts between different associated nodes (Fig. 1B). With this information, the networks and relationship attributes were amplified, adding greater coverage to the study, also overcoming mobility and funding difficulties.

2.3. Data processing

2.3.1. Social network analysis

Information derived from the survey and literature research was used to develop three types of analysis: (a) a bipartite network analysis evidencing the institutions' linkages to describe the types of interventions in the study area (Fig. 3a); (b) an analysis of the institutional network at both global and local levels, through topology measures (diameter, density, and centrality) differentiating between layers (agriculture, climate change, and food security) and how the network is distributed in the territory (Fig. 3b); and (c) a cross-analysis between the number of institutions associated with each municipality and the municipalities' level of vulnerability (Fig. 3c).

Fig. 3 summarizes the SNA flow process, the bipartite analysis, first between similar actors (institutions' network and municipalities' network) (Fig. 3a), followed by the type of intervention links between both networks (Fig. 3b). For this research, cooperation misalignment—as per the SNA framework—refers to actors that work in isolation and to more than one institution conducting a similar intervention in the same municipality. Hence spatial misalignment is related to how the interventions are implemented in the territory and if these interventions are prioritized to the potentially most-vulnerable municipalities. Complementary to this is the multilayer analysis (Fig. 3c), which shows how interventions for agriculture, climate change, and food security are related between networks and across institutional layers.

According to (Akhtar, 2014; Scott, 1988; Wasserman & Faust, 1994) a network is mathematically represented as $G = (V, E)$. V represents the set of vertices or nodes—for this research, the nodes/vertices are the institutions and municipalities—that make up the network, while E represents the edges or multiversity of links between the different vertices of V obtained from the configured dataset

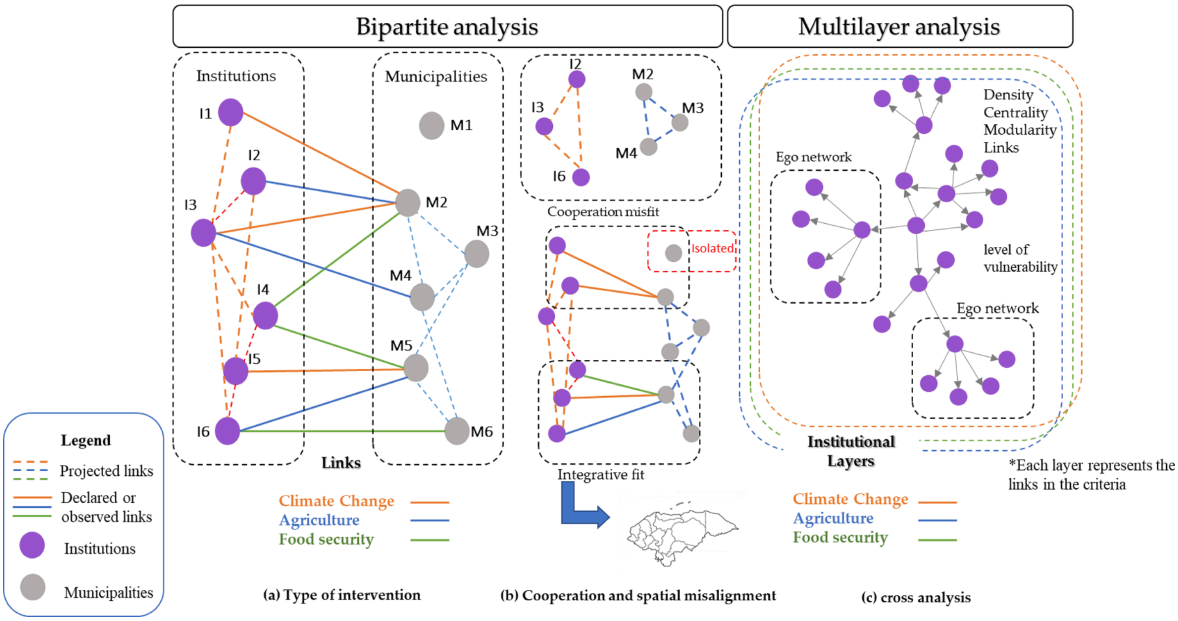

Fig. 3. Methodological framework and type of Social Network Analysis SNA: (left) Bipartite analysis between nodes (institutions and municipalities) and (a) type of intervention; (center) bipartite analysis projection for each network (b) cooperation and spatial misalignment; and (right) (c) multilayer analysis between institutions. Note: In (a) the bipartite and (c) multilayer analyses the lines represent the existing connections between institutions and municipalities, reflecting the interactions based on the three thematic areas: orange line = climate-change criterion, blue line = agriculture criterion, and green line = the food security criterion.

(see Fig. 3). Therefore, the network construction principle uses the concept of bipartite networks. Following this principle, in Fig. 3, the nodes that belong to the set $I = \{I_0, I_1, \ldots I_n\}$ represent the institutions, while nodes $M = \{M_0, M_1, \ldots M_n\}$ represent the municipalities. For the bipartite analysis, first we built a network between the set of I and M nodes (Fig. 3a), followed by multilayer networks (Fig. 3c) to establish connections between nodes implementing the same type of intervention, starting from the neighborhoods they have in common. In this way, the second network layer with emergent connections of the bipartite interaction was obtained (Fig. 3b).

When the bipartite institutional municipalities network and interventions network (agriculture, climate change, and food security) were structured, we calculated the following network metrics: number of **nodes** (n) and **links** (l) used to globally assess the size of the system obtained from the network; and **density** to evaluate the interactive capacity between institutions, municipalities, and intervention areas. In other words, density gives a first approximation of the articulation between the institutions and the municipalities according to the homogeneity presented by the distribution of the network's nodal links. **Degree** measures the total number of nodes (n) adjacent to another one. **Betweenness centrality** is a way of detecting the amount of influence a node has over the flow of information in a network (see Supplementary Material V). It is calculated by identifying the shortest paths between pairs of nodes in the network and then counting how many of those paths pass through each institution (Opsahl et al., 2010). Betweenness centrality is often used to identify nodes that serve as a bridge from one part of a graph to another. This measure can be applied to individual nodes and can then be used to identify the actors that contribute the most to linking the network (Akhtar, 2014; Scott, 1988; Wasserman & Faust, 1994). Finally, the clustering coefficient was used to evaluate the pattern from setting groups of institutions as blocks of relationships as global indicators, which results from the **density** and **assortativity** (Noldus and Van Mieghem, 2015). The metrics were evaluated using R (Douglas Luke, 2015), and igraph (Csardi and Nepusz, 2006), SNA (Engelhardt, 2009), dplyr (Kodali, 2015), and tidyr (Kjytay, 2020) packages were used.

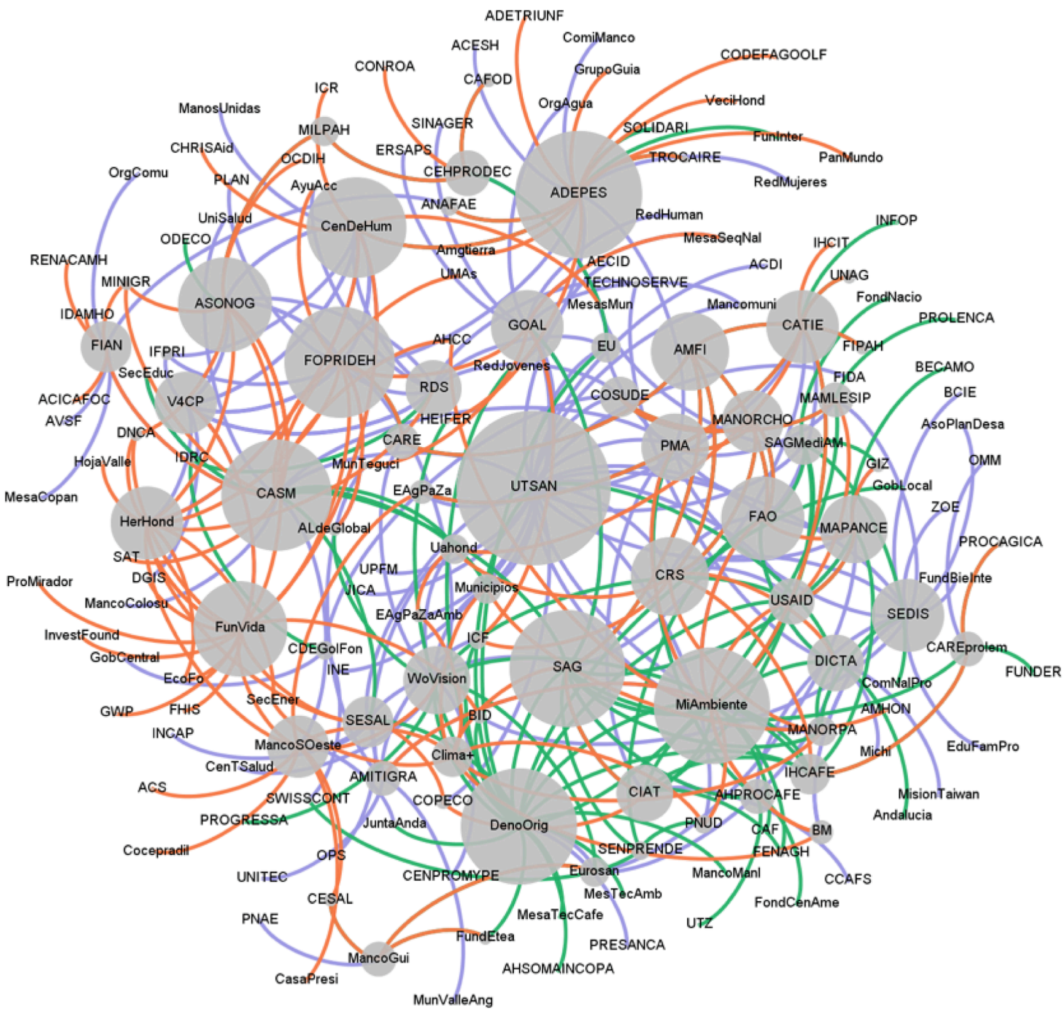

Fig. 4. Graphic representation of the multilayer institutional networks' analysis between 167 organizations in 153 municipalities. The green lines represent the agriculture layer linkages, the orange lines represent the climate-change layer linkages, and the purple network lines represent the food security layer linkages. The 167 institutions are represented by their acronyms, which are provided in full in Supplementary Material VI.

2.3.2. Vulnerability indicator

The vulnerability assessment was conducted using the Climate Change Vulnerability Assessment (CCVA) and was performed in a previous study (Gonzalez et al., 2019), of which a summary is provided here (see also Supplementary Material IV). At the municipal level, the authors calculated an indicator that measures the level of vulnerability considering several vectors of agricultural, social, and institutional capacity variables over future climate projections (Fig. 1C). This CCVA is based on the Intergovernmental Panel on Climate Change methodology and has been used in similar studies (Bouroncle et al., 2017; Parker et al., 2019).

The vulnerability approach used in this study was developed from the statements of Turner et al. (2003) that is determined by the degree to which a system will experience stress due to a combination of pressures. Vulnerability in the context of climate change is the result of a vector of variables that measure sensitivity and adaptive capacity. Adaptive capacity is the socioeconomic position of the community and how it can cope with the potential impact. Sensitivity is the projected changes in climate (precipitation and temperature) and the impacts on climatic suitability for key agricultural crops (Lane & Jarvis, 2007; Ramirez-Villegas et al., 2013). Therefore, the CCVA is a crucial factor in determining the integral and strategic endowment of a territory, contributing to its local governance and future sustainability (O'Brien et al., 2004).

2.3.3. Mixed methods

This stage of the process overlaps the interventions of the institutional network obtained and analyzed by SNA on the map of vulnerabilities calculated by the CCVA at the municipal level. This integration of both processes reveals: (a) coincidence and (b) spatial mismatch between both components. First, the current collaborations in the mapped criteria (agriculture, climate change, and food security) are located in the territories with greater future exposure to vulnerability; on the other hand, the mismatch between the network links are expressed when projects, actions, and interventions are not located in the regions where persistence in social inequality, tangible, and social assets are limited in their response to the evaluated climate scenarios (Fig. 1D).

3. Results and discussion

3.1. Institutional network in the Honduran dry corridor territory

Through the 55 surveys and literature review of secondary sources, 167 organizations operating in the Honduras dry corridor were identified, of which private institutions (including national NGOs) represent 47 %, public institutions represent 27 %, while international cooperation entities and international NGOs make up the remaining 26 %. Among the public institutions, the limited number of high-level education institutions (universities) and research institutions is noteworthy. These results are consistent with Castro Colina et al. (2016) who observed a dominance of private actors and a poor representation of public and educational institutions when evaluating the Honduran institutions' influence in the agriculture and climate-change sectors. The metrics allow to parameterize and establish the structure of the network. On the global scale, the density shows a low interaction between the nodes, meaning only 2.7 % of the possible interactions have been effective between all the identified actors. This structure, obtained through these metrics, reveals that there are actors with a certain degree of betweenness centrality, for which about 21 % of the interactions are captured by central nodes. Another characteristic of the network is the presence of modules or blocks, measured by the coefficient of modularity of 0.53, indicating the presence of an agglomeration of actors with shorter distances within their neighborhoods than with other groups of nodes. On average, the network of actors in the dry corridor has set up about five links with other institutions. The relationship between actors in this region reveals a certain tendency in the linkages, whereby the actors with less interaction seek to relate not with their peers but with nodes that have a higher level of centrality and connectivity.

The results of the multilayer analysis (Fig. 4) exhibit an isomorphic structure, since many of the institutions undertake interventions with more than one specific objective (agriculture, climate change, and food security).

An analysis of the institutional-municipality networks by intervention topic (agriculture, climate change, and food security) reveals differences among networks (see Table 1). The agriculture network includes 81 institutions that are related through 99 links, with a high betweenness centrality of 0.43. There are a variety of institutions that have interacted around agricultural issues, of which 28 % of the actors are international cooperation agencies and non-profit organizations such as NGOs. Likewise, there is an important interaction between private actors (companies, private organizations with public functions such as municipality associations, local foundations, and projects), which account for 47 % of the 81 institutions. Only 25 % are public-entity actors. When analyzed by node, one

Table 1
Characteristics of the institutional networks by intervention topic (agriculture, climate change, and food security).

Network	No. of institutions	No. of links	Betweenness centrality	Public institutions (%)	Private institutions* (%)	International institutions (%)
Agriculture	81	99	0.43	25	47	28
Climate change	93	118	0.28	26	48	26
Food security	109	155	0.47	25	43	32

* Within private institutions there are first and second level producer associations. AHPROCAFE, for instance, is the association of Honduran coffee producers and brings together several organizations. Meanwhile, the Marcala Coffee Designation of Origin (DenomOrig) is a private institution that certifies coffee from several coffee associations and individual producers with specific characteristics.

private-company project “Denominación de origen del café Marcala” (DenomOrig)—a label used on products that have a specific geographical origin and possess qualities or a reputation that are due to that origin—alone accounts for a degree of betweenness centrality of 20 (i.e., related to 20 institutions of the network), followed by the Ministry of Agriculture (SAG) with a degree of betweenness centrality of 11, and the Ministry of Environment with a betweenness centrality of 8.

The institutional network related to climate-change interventions comprises 93 institutions and 118 links, and has the lowest degree of betweenness centrality of 0.28. Similarly to the agriculture-related network, the climate-change network includes 26 % international institutions, 48 % private actors, and 26 % governmental actors. However, a major difference is the prominence of private organizations in this network, where three alone—Fundación Vida, HerHond, and the Pespirense’ Development Association with degree of betweenness centrality of 15, 11, and 10, respectively—present the highest degree of betweenness centrality. This indicates their significant influence and control over the information flow within the network (see Supplementary Material VI).

Finally, the institutional network related to food security has the largest institutional participation (109 actors), 155 links, and the highest degree of betweenness centrality (0.47) of all three networks. The distribution of actor types is similar to the other networks: 32 % are international organizations, 43 % are private-sector actors, and 25 % public institutions. However, in this network, the public-sector actors have the largest influence. This is indicated by their degree of betweenness centrality (indicated in brackets): UTSAN attached to the Ministry of Agriculture (SAG) (27), the Secretary of Development and Social Inclusion (12), and the Federation of Non-Governmental Organizations for the Development of Honduras (10).

This study’s network analysis identified 372 institutional interventions in the municipalities related to agriculture, climate change, and food security. These include a wide range of interventions, from financial cooperation, technical cooperation, or a combination of both, of which 31 % were related to a combination of financial-technical cooperation, while nearly 50 % were only for technical cooperation.

3.2. Relations between the institutions’ interventions and the municipalities

The relationship between institutional interventions and the municipalities is presented in Fig. 5. Note that the Food and Agriculture Organization of the United Nations (FAO), United States Agency for International Development (USAID), Inter-American Development Bank, the Spanish Agency for International Development Cooperation (AECID), and the United Nations World Food Program (WFP) count as international cooperation with interventions reported in the 153 municipalities, therefore they are not present in Fig. 5. Additionally, by law, public institutions implement interventions throughout the country; however, some of these institutions such as SAG and the Forest Conservation Institute (ICF) have conducted a limited number of regional institutional interventions (8 and 12, respectively). Because the response to climate change in the agricultural sector requires close coordination of policies spanning different sectors—to reduce deforestation, protect biodiversity, and manage water resources (Lennox, 2013)—Honduras’ Nationally Determined Contributions presented at the 26th Conference of the Parties (COP26) (República de Honduras, 2021) have two common objectives that are split between the two institutions SAG and ICF. This was done since the links related to

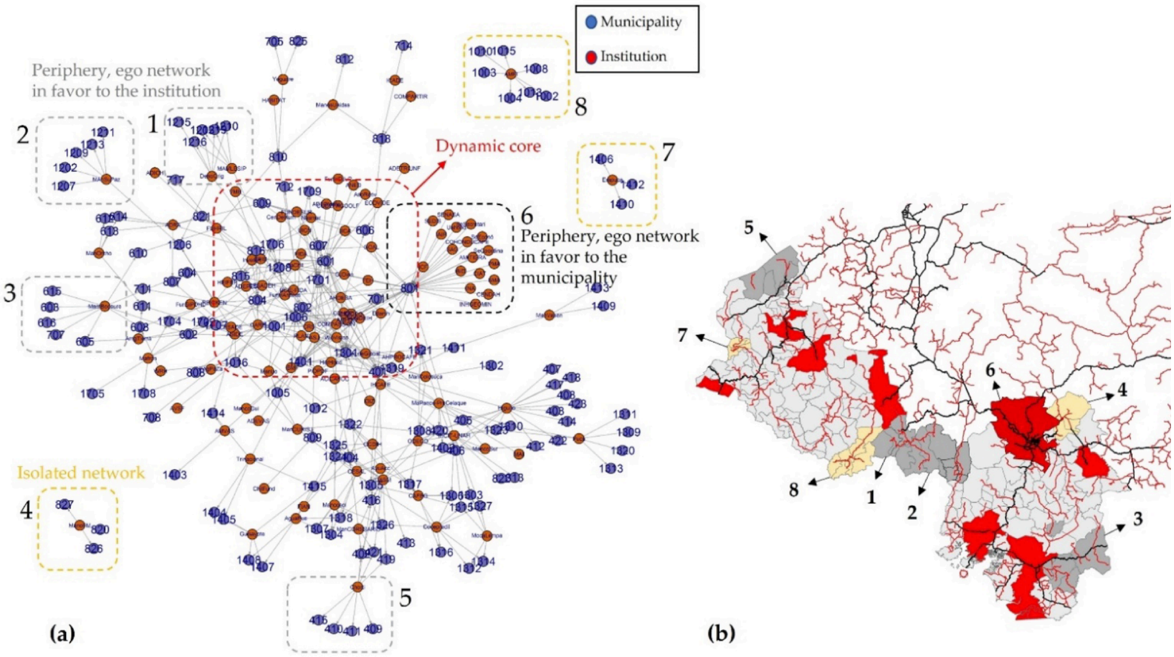

Fig. 5. Connections between institutions and municipalities, presented as a social network graph (a) and described on the map (b). In the map (b), the study area is shaded in light gray; the darker gray represents four egocentric networks, and red indicates the department.

land-use change and the forestry sector are key to coping with climate change and to interrelate both institutions' regional interventions to cover more regions. This approach is not unique to Honduras or the region. In Ethiopia, Bergsten et al. (2019) observed a collaboration gap for forest and wildlife conservation, but dense collaboration around agricultural production, defining this as a collaborative misalignment that occurs when governance actors are not linked even though they may be working on the same ecological issue.

When presented as a graph (Fig. 5a), the network connections between institutions and municipalities show as a series of fat-tailed distribution patterns (Natarajan Meghanathan, 2017) especially in the network's peripheral areas. For example, in networks 2, 3, and 5, one institution conducts its interventions in multiple municipalities, and these are located on the periphery of the graph. This pattern reveals two important linkage dependencies for their operations and interactions: (a) many municipalities are highly dependent on a few key institutional actors; and (b) certain institutions are linked to only a few municipalities. In the case of (a), it implies that a structure providing specialized care and support services at the territorial level is present, but it could also express egocentric relationships with a high level of risk and fragility. Case (b) implies a territory with a high demand for attention or concentration of actions; this configuration may also indicate a process of over-presence of institutional actors in the same region.

On the periphery of the network graph (Fig. 5a), we see multiple egocentric networks (1–3, and 5 in Fig. 5a and b), made up of few institutions conducting their interventions in municipalities that are located close to the Honduran borders with neighboring countries. In the case of egocentric networks 1 and 2 located close to El Salvador, they are connected to the municipalities through their own Municipality Association (*Mancomunidad*) that acts as their unique institution. Thus, these municipalities unify efforts towards common strategic plans. Moreover, these two egocentric networks are connected to each other through one of their central network's municipalities. In the case of network tail 1, the association includes the municipality of Marcala in which the DenomOrig (institution) for coffee is located and is linked to 10 institutions. This private project brings together more than 2,300 coffee producers and connects 20 municipalities within and outside of the study area (Docafe Marcala, 2017). In the case of network tail 2, it is Guajiquiro municipality that connects the other municipalities with the core network and the DenomOrig.

Egocentric networks 3 and 5 are also connected to the network's core through their Municipality Association—network tail 3 is connected through the international Amigos de la Tierra, n.d., and tail 5 (close to the border with Guatemala) is connected through the Mennonite Social Action Committee (CASM in Spanish), which acts as a bridge with international cooperation agencies and donors such as OXFAM, Lutheran World Relief, Help in Action (Ayuda en Acción), among others (Comisión de Acción Social Menonita (CASM), n.d.). Through their analysis of the multi-level water governance network in Central America, Hileman and Lubell (2018) identify the network opportunities and constraints offered by fostering such linkages with international cooperation bridging actors. For example, they note that they can act as a bridge to reach and involve regional network actors; however, such linkages make the network vulnerable to common exit problems, such as when a project or its funding end. This seems more evident for the insolated egocentric networks 7 and 8 (Fig. 5), which might be part of international cooperation projects (i.e., USAID, FAO), but somehow are disconnected from the institutional-municipality network identified in this study. However, the same reasoning would not apply to isolated network 4, whose three municipalities are close to the Honduran capital of Tegucigalpa. Valle de Ángeles municipality, which is one of these, is a tourist location and a dormitory municipality for people working in the capital on which it can rely for economic stability.

Conversely, 34 institutions are linked to the Central District in tail 6 (Fig. 5). This is to be expected because it is where government secretariats are located. Fig. 5b also shows that eight departmental capitals (municipalities marked in red on the map), including the Central District, are part of the main network core (the border marked in a red square in Fig. 5a). This includes Intibucá municipality, which is separated from La Esperanza (departmental capital) just by a street; hence, both are highly connected. In fact, the capitals Intibucá and Marcala are among the municipalities with a large in-degree (>4%), related to the number of institutions linked to them.

Municipalities outside the network core, and not discussed in the four periphery networks, are scattered (mostly) between the development Regions Re 03 (Occident) and R14 (Lempa River). Both regions possess the largest multidimensional poverty incidence (>85 %), which measures an individual's level of poverty above 50 % of the weighted sum of indicators related to health, education, work, and living conditions between 2012 and 2016 (Evolucion Indice de Pobreza Multidimensional-Honduras (2012)-2016 | OPHI, n.d.). Indeed, regarding physical connections in the study area, these municipalities are only connected by unpaved roads (marked in red in Fig. 5b) that cross a highly mountainous region. The country's main road network (black lines in Fig. 5b) mainly connects the departmental capitals, and in the south and west, their connection with the national borders is also observed.

The lack of a well-developed national highway infrastructure is one of multiple causes for some institutions' limited interventions. Andersson and Van Laerhoven (2007) evaluate how local rural government representatives in 390 municipal governments in Brazil, Chile, Mexico, and Peru engage with and involve farmers in planning, implementing, and monitoring public services in the agricultural sector. They observed that local politicians were less interested in participatory governance, at least in Peru. The authors hypothesize that the greater prevalence of poverty and socioeconomic inequalities in Peruvian rural societies, compared to the other three countries but like in rural Honduran communities, could be related to the lack of participatory governance. This is relevant because the potential of local actors and resources is needed for an endogenous and bottom-up development approach (Bosworth et al., 2020).

It is also important to consider that there are other network links and connections with municipalities from other countries that are not shown in Fig. 5. This applies to municipalities in development regions Re 03 (Occident) and R14 (Lempa River). The Trifinio Plan is a regional environmental protection program that is part of the Central American Integration System (SICA), which, among other goals, seeks to improve living conditions in 8 municipalities in El Salvador, 15 in Guatemala, and 22 in Honduras through environmental and territorial management, particularly related to halting forest degradation from local population pressure. Hence, the municipalities in Honduras' development regions Re 03 (Occident) and R14 (Lempa River) can also undertake regional interventions under the Trifinio Plan and were therefore excluded from the survey (SICA, 2016).

3.3. Decoupling of institutional actions and climate-change vulnerability

The concentration of resources and projects in the municipalities is not necessarily homogenous across the Honduran dry corridor. The results of the relationship between institutional interventions and the municipalities presented in Section 3.2 reveal the existence of municipalities that exert a greater attraction for the execution of projects and programs for certain institutions. Fig. 6 presents the spatial distribution of climate vulnerability superimposed on the interventions of the institutional network. In general, the results are consistent with the findings of Bouroncle et al. (2017) for Central America and studies obtained by Gonzalez et al. (2019) in the Honduran dry corridor.

One element that can be seen in Fig. 6 is the misalignment between the institutions present in the network and the municipalities with high levels of predicted future climate vulnerability. Historically, certain municipalities have not received a high institutional presence due to their diverse needs and long-term requirements, such as agricultural demands or policy interventions, particularly territories situated farther from urban areas and the central district. Therefore, climate vulnerability projections indicate that future interventions need to focus on other municipalities currently less exposed but predicted to become more vulnerable.

As shown in Fig. 2, the 153 municipalities in Honduras' dry corridor are divided into four development regions: Re 03 (Occident), R12 (Central District), R13 (Fonseca Gulf), and R14 (Lempa River). Across the map presented in Fig. 6, only two departmental capitals in region Re 03 (Occident) present more than 12 institutions, although they have low vulnerability. Region 14 (Lempa River) shows the same in terms of number of institutions; however, the municipalities of Marcala and Intibucá also have 10 and 23 institutions, respectively working in the territory. Bowen (2010) noted when evaluating two projects with Geographical Denomination of Origin (DenomOrig) in Marcala, that these two entrepreneurship projects had the potential to foster endogenous rural development. This type of development is also observed in two Territorial Action Groups (TAGs)—Sensenti-TAG and Belen Gualcho-TAG—established by the Inter-American Institute for Cooperation on Agriculture in Honduras as part of the Central American Strategy for Rural Territorial Development (Sistema de integración Centroamericana, 2012).

Since 2011, Sensenti-TAG includes eight municipalities, five of which are in region Re 03 (Occident) and the rest in region R14

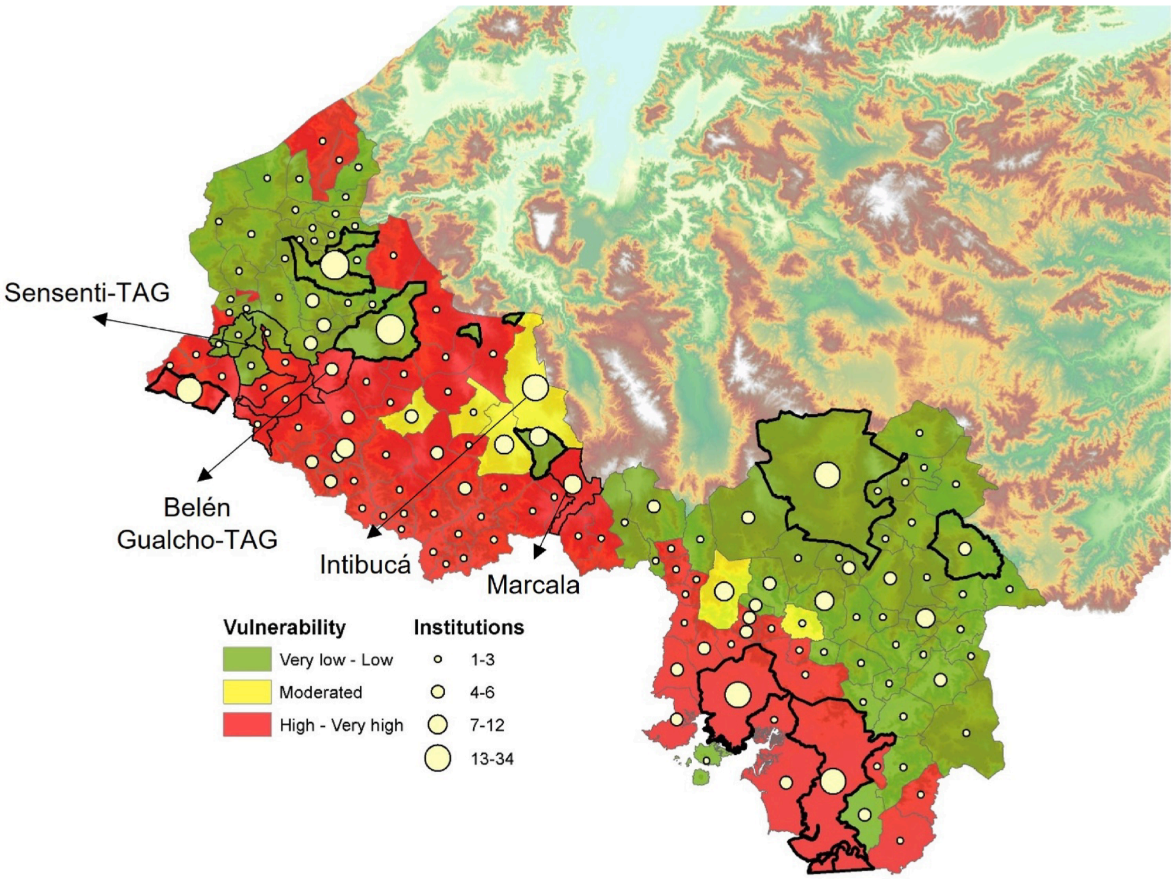

Fig. 6. The agricultural sector's livelihood vulnerability due to climate change and the number of institutions working to address it across the 154 municipalities of the Honduran dry corridor. The vulnerability index relates to all municipalities. Municipalities with thick black borders indicate the department capitals.).
Source: Livelihood vulnerability adapted from (República de Honduras, 2018

(Lempa River). While Belen Gualcho-TAG is just one municipality in region R14. Even though there is no marked difference between the two TAGs and the surrounding municipalities, in terms of number of network institutions, it is possible that each TAG has facilitated a better organization of interventions within each municipality. The successful experiences from self-management and local development through the establishment of TAGs in Central America or territorial planning based on biophysical features (such as setting the river-basin limits) and socio-cultural characteristics can contribute to the sustainability and efficiency of local networks. The basins' boundaries provide the basis for regions Re 03 and R12, highlighting the importance of hydrological boundaries. The two examples presented here for Honduras have a common characteristic—the population identifies as part of the Lenca Indigenous Group—and it is possible that this facilitates a better coordination among Municipality Associations.

Region R12 (Central District) is the only region in which all the municipalities are categorized as low vulnerability. The presence of the Honduran capital in this region could be expected to influence the number of institutions present, but this is not the case. Region R13 (Fonseca Gulf), in the south of the country, goes from low vulnerability where it borders with region R12 to high vulnerability in the south, confirming observations by Bouroncle et al. (2017) that municipalities located farthest from urban areas tend to have a reduced adaptative capacity and are most vulnerable. Across Region R13, vulnerability is higher because the institutions are concentrated in the departmental capitals and not in the other municipalities.

Of all the interventions in the dry corridor directly related to coping with climate change, 33 % are implemented in municipalities profiled as having high climatic vulnerability and, of these, only 9 % are associated with a high level of interventions. Interventions related to agriculture and food security have similar proportions, of which 34 % and 30 %, respectively, are concentrated in municipalities categorized as having a high climatic vulnerability.

3.4. Limitations of the research

An in-depth analysis of the dynamical mechanisms—how and why certain interaction patterns emerge and how these can be optimized to enhance effectiveness of interventions—in which the institutional network interacts within the territories, is beyond the scope of this study. However, while the analysis offers a clear view of institutional interventions in the Honduran dry corridor, it represents a mere snapshot and does not capture all dynamic or informal interactions among actors. Additionally, social network studies can be resource-intensive and require significant information for their application. Despite the challenges in fully reproducing the network and its spatial interactions, this article proposes a mixed-methods approach that can overcome these limitations and develop adequate representations, particularly based on secondary sources.

3.5. Contributions to the governance of the Honduran dry corridor

Environmental, agricultural, and food governance in the Honduran dry corridor, a region with multiple challenges, needs deeper cooperation between the institutions involved. Using a mixed-methods approach that integrates SNA, agroclimatic modeling, and vulnerability indicators allows governance opportunities to be identified. This method focuses on the spatial misalignment (Dingkuhn et al., 2024; Jenelius et al., 2006) between the institutions' intervention mechanisms and the levels of socioeconomic, climatic, and agricultural vulnerability in the region. This article offers two dimensions on how to strengthen responses to territorial vulnerability, based on the complex social network that has been formed, and specifically at two levels:

- *Institution–institution level:* this is a perspective where the common scope, purposes, and conflicts addressed by institutional nodes can lead to a functional overlap of interventions between network agents. This can facilitate scalability and integration in cooperation formats, and more precise and efficient governance.
- *Institution–-territory level:* this dimension elevates the territory's importance, from its physical and environmental component to the social structure attached to the territory, in both the interventions' processes and the institutional network's prioritization. Looking at current processes, but also at possible future climate scenarios.

3.5.1. Institution–institution level

Cooperation and discourse between actors at the local level should be strengthened through better communication and coordination mechanisms, by identifying common goals that align the institutions' interests and clearly define each institution's functions in the collaboration process. This would allow a more effective and coherent response to climate challenges, especially in vulnerable municipalities that have been excluded from the public agenda (Licha & Molina, 2006). An example in recent years in Honduras (since 2016) is the coordination of civil society with government and private institutions in the so-called Participatory Agroclimatic Roundtables (MAPs) (Martinez & Obando, 2023). One of the MAPs' objectives is the discussion and generation of agroclimatic bulletins to report rainfall and temperature conditions in their territories or development regions for the productive cycles (Giraldo Mendez et al., 2019). These bulletins, in addition to reporting the seasonal forecast, also generate agricultural recommendations to minimize effects on livelihoods, given the forecasted conditions. These measures include short-, medium-, and long-term recommendations, as it is essential that these are territory-specific, i.e., climate-smart. Meanwhile, as of 2023, two participatory collaboration and innovation networks called Innovahubs have been established in Honduras. These networks seek to develop and leverage innovations in the agricultural sector, harnessing the participation and interaction of local actors in a territory (Martínez et al., 2023). Although these networks have only been operational for two years and only cover subregions in the east and west of Honduras, they have managed to connect first- and second-level producer associations and MAPs in these regions. These institutional coordination initiatives, even on a small territorial scale, are an example of possible pathways for cooperation and interaction between institutions in these regions.

3.5.2. Institution–territory level

The creation of national-level policies aligned with the geography of each region fosters a more integrated and multi-sector collaboration, adjusting the distribution of resources and projects among a diversity of stakeholders and with a more effective regional deployment (Nordbeck & Steurer, 2016). This is even more necessary considering that 13 of the 153 municipalities in the dry corridor have indicated a nexus between current interventions and future potential needs. Without a policy exercise that brings together the actors, interventions, geographies, and strategic foresight, there is a risk that cooperation will be directed to areas where it is not really necessary, resulting in over-intervention.

4. Conclusion and perspectives

In this study, we assessed the institutional network present in the Honduran dry corridor to identify future gaps in the municipalities' interventions aimed at coping with and/or mitigating climate change in the agricultural sector. We identified 167 institutions that are part of the institutional network in 153 municipalities, which we then mapped, leveraging the topological characteristics of SNA at global and local scales. Our key informant survey and literature review together revealed the dominance of private institutions (including national NGOs) representing 47 % of the institutions identified, international cooperation agencies and NGOs representing nearly 26 % of the institutions, and public institutions accounting for the remaining 27 %. The low influence exerted by the academic and research institutions —where only two universities were listed, and two research institutes had applied limited local interventions—contrasts with the dominance of private actors.

Climate change has a heterogeneous impact across the dry corridor territories. Our analysis highlights a misalignment between the current institutional network dealing with agriculture, climate change, and food security interventions, and the territories' vulnerability to climate change. The mismatch between current spatial distribution of institutional density and territorial vulnerability should be further explored, in particular by detailing actors' interventions on the ground, and the extent of their reach. The possibility of extending policy development on a geographical basis should be explored. The role of institutions and their coverage in the region can be an excellent channel for designing and implementing such policies. Regarding the climate scenarios and the institutions' interventions, there could be greater coordination among institutions using a foresight strategy, and the territoriality of the interventions' impacts should also constitute a key element in prioritizing and targeting their actions.

Finally, the dichotomy between the needs and priorities of municipal governments and the objectives of institutions remains unresolved. While the institutions within the territory seek to improve development project indicators, the municipal governments—that are often short-term in nature—seek ties among their neighbors with common needs (e.g., municipality associations and agro-climatic roundtables, among others). However, the objectives of municipal governments and those of institutions are not sufficiently aligned to efficiently address long-term development planning. Similarly, without an understanding of the social and cultural dynamics of the Honduran territories, it is difficult to design and execute policies and projects that have a long-term impact. Both of these factors are undoubtedly needed for adapting to and mitigating climate variability and severe climate-change events impacting agriculture, and food and nutrition security in the Honduras dry corridor in the long and short term.

Author contributions

Carlos Eduardo Gonzalez-Rodriguez conceived of the presented idea and performed the data analysis, Irma Ayes-Rivera developed the theory, collected the data, and contributed to the writing, Jean-Francois Le Coq verified the analytical methods, analyzed the results, and contributed to the writing, Rafael Renteria-Ramos contributed to the data analysis, and Johana Marcela Castillo-Rivera edited and contributed to the writing.

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.crm.2024.100664.

Data availability

Data will be made available on request.

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Glossary

Honduras dry corridor: A dry region in Honduras located in the Pacific area of Central America, characterized by high natural climate variability ((Depsky & Pons, 2021, 2021; Durán-Quesada et al., 2020)

Climate-change adaptation: Measures and strategies to adjust human and natural systems in response to the effects of climate change (Engle, 2011).

Social Network Analysis (SNA): A methodological approach to study social network structures by identifying patterns of relationships between entities (Wasserman & Faust, 1994)

Egocentric network: A network centered on a single node (institution or municipality) that has a high degree of centrality and connectivity with other nodes(Scott, 1988).

Institutional network: A network of relationships between different institutions collaborating on specific interventions in a territory (Bodin et al., 2011).

Climate-smart agriculture (CSA): An agricultural approach that seeks to simultaneously achieve climate change adaptation, mitigation, and food security (Andrieu et al., 2019).

Multilayer analysis: Social network analysis that considers multiple layers or levels of interaction between different types of interventions or actors (Opsahl et al., 2010).

Betweenness centrality: A measure of a node's influence in a network, based on the number of shortest paths that pass through that node (Opsahl et al., 2010).

Clustering coefficient: A measure that evaluates the degree of clustering of a node within a network, indicating the tendency to form groups or clusters (Noldus & Van Mieghem, 2015).

Human Development Index (HDI): A composite indicator that measures human development based on data on health, education, and living standards (UNDP, 2018).

Inequality-adjusted Human Development Index (I-HDI): Human Development Index adjusted for inequality, which considers disparities in the distribution of achievements within a country (UNDP, 2018).

Climate Change Vulnerability Assessment (CCVA): An assessment of vulnerability to climate change, considering agricultural, social, and institutional capacity variables (Parker et al., 2019).