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ORIGINAL ARTICLE

Upscaling agroforestry in the tropics through actor-networks: a comparative case study of cacao farming systems in two regions of Colombia

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Abstract

Agroforestry systems (AFS) upscaling has the potential to integrate sustainability and resilience objectives into agriculture. However, this is a daunting task requiring multi-actor collaboration across public and private sectors at multiple governance levels, coupled with innovative approaches to jointly managing AFS knowledge. Understanding such multi-actor interactions from a network perspective may help to unravel how social structures, created by relational patterns enhance or hinder AFS upscaling. Our paper aims to comparatively explore the role of regional actor-networks on AFS upscaling for a selected farming system. By conducting semi-structured interviews, we collected information about the ties of 86 actors supporting cacao agroforestry systems (CAFS) across two regions of Colombia. We use social network analysis (SNA) to comparatively visualize and understand the general structure of these networks, find relational patterns between the diverse categories of actors involved, and identify a set of key players bridging the majority of the actors within these networks. We find highly centralized networks that connect multiple actors by a low number of mostly non-reciprocal ties. Within these networks, we identify a predominance of bridging ties over bonding ties, homophily patterns among research and education institutions, and heterophily configurations among farmer-based organizations. We also find that the composition of the sets of key actors and the platforms where they converge varies substantially from region to region due to decentralized agricultural policies and differing characteristics across regions. Our approach provides key entry points for promoting multi-actor coalitions that can effectively expand the benefits of AFS in tropical agricultural systems.

Keywords Sustainable agriculture · Network analysis · Governance · Knowledge systems · Complex systems

Introduction

Agroforestry systems (AFS) encompass a set of land-use practices in which woody perennials are deliberately grown together with other crops and/or livestock (Lundgren 1982). They are recognized as a key vehicle for globally supporting the transformation toward sustainable agriculture (Plieninger et al. 2020) since they offer a wide range of environmental and socioeconomic benefits at the farm and landscape levels. Predominantly, some approaches have been used to expand their benefits, including better extension delivery services (Landicho et al. 2009; Baig et al. 2020), improved AFS technology (Das et al. 2022), and the development of markets for AFS products (Pandit et al. 2019). However, potential AFS benefits remain inaccessible to farmers (Somarriba et al. 2017), and the responsibility for expanding them is not effectively coordinated by private and political actors (Akamani

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and Holzmueller 2017; Zinngrebe et al. 2020). This situation is also seen in Colombia, where AFS could help to reduce pressures on natural resources (Lerner et al. 2017; Castro-Nunez et al. 2021) and counterbalance an expanding agricultural frontier that causes deforestation (Charry et al. 2017; ADR and FAO 2019; Furumo and Lambin 2020). As AFS are complex and knowledge-intensive innovations that require adaptive management, approaches to expanding and sustaining their potential benefits need to be reframed in ways that facilitate networking, knowledge co-production, and social learning (Coe et al. 2014; Buck et al. 2020; Schut et al. 2020; Dumont et al. 2021; Franzel et al. 2004).

Particularly, a closer look at the upscaling processes is key for transitions toward sustainable agriculture (Lambin et al. 2020) as they help to create an enabling environment and reconfigure the pathways to reach more people and places, i.e., out scaling (Schut et al. 2020). In this paper, upscaling refers to processes aiming to impact higher institutional levels by changing or adapting the rules and logic of incumbent regimes (law, policy, or institutions) via advocacy, lobbying, networking, or supporting alternative visions and discourses (Hartmann and Linn 2008; Moore et al. 2015; Lam et al. 2020). These processes require coalitions between diverse actors[1] at multiple governance levels (FAO 2013; Andreotti et al. 2020; Buck et al. 2020; Lambin et al. 2020; Plieninger et al. 2020; Schut et al. 2020), together with innovative approaches to managing AFS knowledge that consider the varying biophysical conditions of sites, and the specific socioeconomic needs, as well as the local knowledge and perceptions (Clark et al. 2016; van Noordwijk 2019; Rodríguez et al. 2022). In this sense, more open and inclusive forms of governance and knowledge management are required to improve the capacity of actors to understand the complex social-ecological systems (Roling and Jiggins 1998; Tengö et al. 2014; Van Kerkhoff 2014; Berthet and Hickey 2018; Lin et al. 2021) where AFS are promoted.

Although creating more open governance systems and innovative knowledge management approaches seems a daunting task, it has shown multiple benefits (Cornell et al. 2013; Berthet and Hickey 2018). For example, Dumont et al. (2021) find that structured actor engagement to design AFS with the subsequent technical training that integrates local and scientific knowledge results in diverse AFS options tailored to the heterogeneity of the landscape and the needs of the farmers. Similarly, Macke et al. (2021) show that partnerships and cooperation between actors increase the eco-efficiency of AFS. The findings of Andreotti et al. (2020) demonstrate how a facilitated multi-actor process can enable the co-creation of transition pathways toward AFS at the landscape level, providing a platform for sharing knowledge and discussing opportunities and constraints. The results of Buck et al. (2020) suggest that integrated landscape management offers strategies to upscale AFS by engaging key actors in dialogue, planning, and decision-making around the vision of sustainable agroforestry landscapes, as well as by mobilizing their support and resources.

Against this background, understanding actor interactions in the context of AFS through a network approach may not only help to unravel how social structures, created by relational patterns, enhance or hinder upscaling processes (Bodin and Crona 2009; Maciejewski and Baggio 2021), but will also encourage the creation of networks that facilitate transformation toward sustainable agriculture (Spielman et al. 2011; Berthet and Hickey 2018; Zinngrebe et al. 2020). This is particularly important for a highly biodiverse country like Colombia, where institutional fragmentation also undermines the coordination of actors to successfully upscale sustainable agricultural solutions like AFS across different farming systems (FAO 2013). Existing studies use a network approach to analyze the performance of rural innovation systems (Spielman et al. 2011; Saint Ville et al. 2016), to explore the role of actor interactions in AFS adoption and knowledge dissemination (Isaac 2012; Isaac et al. 2021; Lin et al. 2021), and to analyze the governance and decision-making structures that affect sustainable landscape transitions (Hauck et al. 2016; Berthet and Hickey 2018; Riggs et al. 2020; Zinngrebe et al. 2020). However, a network lens has not been used to explore the role of actor relationships in upscaling AFS practices.

We particularly focus on actor-networks supporting cacao agroforestry systems (CAFS) in two regions of Colombia (Caquetá and Cesar), aiming to comparatively explore their role in CAFS upscaling. Our comparative approach across diverse settings will help to capture the geographical differences in terms of land-use dynamics, governance systems, as well as accessibility to resources, extension services, and markets. It will also identify common entry points for effectively upscaling the AFS benefits in other tropical regions through a network perspective. We are guided by the following research question: how do the general structure, relational patterns, and key players of actor-networks supporting CAFS enable or hinder their upscaling in two regions of Colombia?

Analytical framework

The analytical framework underlying this research is based on social network analysis (SNA). A social network is defined as a set of entities of interest (nodes) and their relationships (ties). SNA allows us to answer our research

[1] By actors, we refer to all possible institutions (e.g., farmer-based organizations, research, and education institutions, private companies, NGOs, governmental institutions, development agencies).

question by analyzing relational data (Borgatti and Ofem 2010; Friemel 2017; Maciejewski and Baggio 2021) on how actors supporting CAFS are connected regionally and how the structure of the formed actor-networks enable or hinder key processes like knowledge management, resource mobilization, and cooperation to upscale CAFS at the regional level. Based on this approach, we explore three hypotheses along the following aspects:

The general structure of AFS actor-networks

To understand the interactions between AFS actors at a glance, it is useful to create sociograms (Bojovic and Giupponi 2020). These are graphical representations of networks consisting of nodes indicating actors and lines (or arrows) indicating undirected (or directed) ties. In addition, the calculation of the networks' densities (i.e., the ratio between the existing ties and the possible ties) or average degree (i.e., the average number of ties per node) shows how much the network holds together. Although highly dense networks are key for collective action and cooperation, they may impede the entrance of new information or ideas, and thus innovation (Crona and Bodin 2006; Janssen et al. 2006; Bodin and Crona 2009; Isaac 2012; Saint Ville et al. 2016). Contrastingly, low density networks have fewer ties between actors, thereby having higher network efficiency, as tie redundancy is minimized and the paths to reach other actors are shorter (Isaac 2012). Further, low density networks may open empty spaces (structural holes) between actors that facilitate the development of innovation by increasing the ability of actors to access non-redundant information sources and merge them in new ways (Labun and Wittek 2014). However, they can be a source of inequality among actors embedded in these networks (Hanneman and Riddle 2005). It is also important to examine the direction of the ties and calculate the reciprocity of interactions as collective exploration processes are needed to tailor AFS solutions to local contexts (Berthet and Hickey 2018).

Based on this theoretical background, our first hypothesis is that AFS upscaling relies upon networks that connect diverse actors with reciprocal ties and manage efficiency to foster AFS innovations and reduce sources of inequality among actors.

The relational patterns within AFS actor-networks

Some AFS studies recognize that interactions between different groups of actors are crucial for upscaling purposes since institutional arrangements are needed to facilitate co-learning among AFS actors, build local capacities, influence the public policy agenda, and enable the required economic and market conditions (Calle et al. 2013; Chavan et al. 2015; Guteta and Abegaz 2016; Reij and Garrity 2016; Baig et al. 2020). While more bonding ties are associated with maintaining trust and sharing complex information, bridging ties are key not just for getting external information and resources, but also for encouraging agency (Prell et al. 2009; Bourne et al. 2017). A balance between bonding and bridging ties is key for collective action toward sustainability challenges (Bodin and Crona 2009; Ostrom 2009). Another way to analyze relational patterns through groups of actors is by using the concept of homophily (Bourne et al. 2017). Homophily measures the tendency of actors to group together with similar ones, and then become more similar with time. Managing homophily is critical to maintaining agency and encouraging the integration of diverse actors within sustainable development networks (Newman and Dale 2007). In this regard, our second hypothesis is that AFS upscaling depends on balancing ties between actors from the same groups (bonding) and ties between actors from different groups (bridging).

The key actors within AFS actor-networks

The identification and assessment of key actors based on their structural position within networks are crucial for sustainable agricultural management, as they can not only facilitate the integration of new knowledge into local settings (Saint Ville et al. 2016; Bourne et al. 2017) but also influence the action of public and private actors at higher levels based on their understanding of local needs (Bodin and Crona 2009; Berthet and Hickey 2018). Centrality measures provide properties of the actors relating to their structural importance or prominence within a network (Borgatti et al. 2009). Drawing on the literature, our third hypothesis is that AFS upscaling also depends on coordinated and diverse central actors connecting most of the others within the network.

Methodology

Case study description

Cacao cultivation and agroforestry systems in Colombia

Historically, cacao has been produced in Colombia and has served as a culturally important part of the national diet. This is why existing Colombian cacao production is primarily focused on meeting domestic demand with two Latin America-based companies purchasing over 80% of Colombian cacao bean production (Abbott et al. 2018; Escobar et al. 2020). Cacao crops are typically managed by smallholder farmers as part of mixed agroforestry arrangements that vary depending on climate, soils, and household needs. These arrangements tend to include banana plants, fruit trees, and shade trees (Abbott et al. 2018). These

characteristics match with the definition of CAFS, which indicates that they are complex multi-species cropping systems where cacao trees are associated with other permanent or temporary crops and tree species (Cerda et al. 2014; Jagoret et al. 2014). These diversified farming systems make the farmers more resilient to crisis because of their role in food security and the possibility to sell diverse crops (Jacobi et al. 2015). However, Colombian cacao farmers often struggle due to a lack of infrastructure and technical assistance, have been more vulnerable to armed conflict, and face difficulties due to water scarcity (Abbott et al. 2018). Therefore, average yields remain low (around 500 kg per ha), even though total production has increased via planted area expansion (Agronet 2021).

Study regions

For this study, CAFS actor-networks in two regions of Colombia are studied: Cesar in the northeastern part of the country on the Caribbean plain; and Caquetá in the northwestern part of the Amazonian region. Cesar hosts a high diversity of landscapes ranging from the mountain ranges of the Sierra Nevada de Santa Martha and the Serranía del Perijá to the valleys of the rivers Magdalena and Cesar (IGAC 2017). Similarly, Caquetá has diverse landscapes ranging from the mountains of the Eastern Cordillera of the Andes and Serranía de Chiribiquete to the foothills and lowland zones covered by tropical rainforest (IGAC 2014). Both regions are affected by the depletion of natural resources due to inadequate land colonization, occupation, and use (Del Río Duque et al. 2022). While Cesar has experienced an acute loss of tropical dry forest and increased soil degradation (ADR and FAO 2019), Caquetá has faced high deforestation rates in the tropical rainforest (Castro-Nunez et al. 2021). In addition, both regions were affected by more armed conflict-related events (Charry et al. 2017; ADR and FAO 2019), with diversified cacao farmers particularly vulnerable due to their geographic location and the fact that the ecological niche for cultivating cacao aligns with that of illicit coca (Abbott et al. 2018). Therefore, CAFS are promoted and strengthened in both study regions by the government, non-governmental institutions, and international development agencies as a way to bring opportunities to the rural areas, substitute illicit crops, and counterbalance an expanding agricultural frontier that causes deforestation (Charry et al. 2017; ADR and FAO 2019; Furumo and Lambin 2020). In the case of Cesar, the private sector, through a mining company, has also financed CAFS cultivation as part of its environmental compensation plans (ADR and FAO 2019).

We selected these regions because both have exhibited problems linked to unsuitable land-use and armed conflict, but there are differences in accessibility to resources, extension services, and markets. Cesar is closer to the Colombian capital city, and to the region with the largest cacao production in Colombia; it also has much better access to markets and extension services, but is dealing with issues related to water storage and distribution. Caquetá is in a much more remote region, where extension services are less frequent, and markets are further away, but water availability is not a constraint for cacao production.

Consequently, cacao production characteristics are particular in each region, allowing the capture of geographical differences. The cacao planted area in Cesar is larger than in Caquetá, but trends fluctuated throughout the 2010s. By 2021, Cesar had 7948 ha of cacao planted while Caquetá had 4488 (Agronet 2021). In terms of cacao production, an approximate production of 5199 tons and 2265 tons of cacao were reported in Cesar and Caquetá, respectively, in 2021 (Agronet 2021). Finally, cacao yields per hectare in Cesar are higher than in Caquetá. According to FEDECACAO (2021), average yields were 462 kg/ha/year in Cesar and 355 kg/ha/year in Caquetá between 2017 and 2021.

Data collection

To collect data, we followed a two-stage process. For the first stage, a list of actors from the local, regional, and national levels supporting CAFS was created by retrieving information from previous cacao-related projects conducted in the study regions (Charry et al. 2017; USAID 2021) and former studies about the cacao sector at the national level (Abbott et al. 2018). For the second stage, we conducted semi-structured interviews following a purposive sampling method to reach a diversity of actors in terms of their roles within the cacao sector and their geographic areas of influence in each region. Despite these interviews containing multiple questions to characterize the cacao sector and its actors regionally, only five questions were considered in this study to understand the roles of the diverse CAFS-related actors and the support they received from the others. The key questions were:

1. What is the role of your institution within the cacao sector?
2. What are the main CAFS-related activities conducted by your institution?
3. What is the experience of your institution within the region (Cesar or Caquetá)?
4. Which actors support the activities conducted by your institution?
5. What is the relationship that your institution has with each of the named actors?

Although the questions were open, the interviewees were given an overview of the categories of actors that could

be nominated at the time of asking question 4. These categories included governmental, non-governmental, private, civil society, and other actors who influence CAFS through research, education, extension services, input supply, processing, and commercialization. Since the interviewed actors had diverse assets, roles, and interests, we defined *support* as flows of financial resources, information, knowledge, training materials, or agricultural supplies, among others.

We also added actors to the initial list that were identified while conducting the interviews. A total of 96 actors were listed in Cesar and 50 in Caquetá. However, we obtained data about 51 actors from Cesar and 35 from Caquetá. The semi-structured interviews were conducted in Spanish face-to-face or by video call between November 2020 and February 2021. They were recorded with the consent of the interviewees and the synthesis of responses was compiled in an Excel sheet.

Table 1 Number of interviewed actors (nodes) supporting CAFS in Cesar and Caquetá

Categories	Number of institutions	
	Cesar	Caquetá
Extension and advisory services	5	3
Agricultural input supply	5	1
Financial services	1	2
Research and education	6	3
Farmer-based	19	11
Cacao-related business	7	5
Development agencies	2	1
Governmental	2	7
Other actors from private sector	2	0
Non-governmental	2	1
Total	51	35

Data analysis

To perform the SNA, the interviewed actors were represented as nodes, and the support these actors received from others was represented as ties. We tabulated the data from each region in two tables: one corresponding to nodes and the other to the ties. The tables corresponding to nodes initially included three columns: the first with a numerical label for each actor (node), the second with the name of the actor, and the third with a number from 1 to 10 indicating the category of the actor (See Tables 3 and 4 in Appendix). This categorization was made based on the main roles the actors played within the cacao sector in each study region. Table 1 shows the distribution of actors (nodes) by category and by region.

Within the *Extension and advisory services* category, we grouped public or private institutions providing agricultural extension services or technical assistance for CAFS cultivation. We included some Municipal Technical Assistance Units (UMATAs by its Spanish acronym) from cacao-producing municipalities, the National Federation for Cacao Producers (FEDECACAO by its Spanish acronym), and some private or nonprofit entities providing agricultural technical assistance or extension services as part of the national agricultural policy in Colombia (known as EPSEAS by its Spanish acronym). The category named *Agricultural input supply* grouped private companies or individuals supplying agricultural inputs and/or plant material for cacao production. *Financial services* included an agricultural commercial bank (Banco Agrario de Colombia) and the Agricultural Fund for Agricultural Sector (FINAGRO by its Spanish acronym). The category corresponding to *Research and education* grouped research centers, public and private universities, and the National Apprenticeship Service (SENA by its Spanish acronym). The *farmer-based* category comprised associations and committees of agricultural producers as well as two second-level associations in Caquetá that regionally group most farmer-based organizations across different municipalities. *Cacao-related business* included small and large cacao processing companies. *Development agencies* were international organizations supporting agriculture and development such as the United States Agency for International Development (USAID). Within the *Governmental* category, we included municipal, departmental, and national government authorities in charge of agricultural or environmental issues. *Other actors from the private sector* were mainly entities supporting cacao-related entrepreneurship such as the regional chamber of commerce. Finally, we grouped *non-governmental* organizations that support AFS mainly with funding from international cooperation and the private sector.

The tables of ties comprised three columns: the first indicating the source nodes of the ties, the second indicating the destination nodes of the ties, and the third indicating the type of tie (directed or undirected). In our case, all ties were considered as directed since their directionality could be derived from the interviews. Since the people interviewed were asked about the actors who support their institution, the ties derived from each interview were incoming (in-degree).

Based on tabular data, we employed the software Gephi to visualize the sociograms and UCINET to calculate the metrics of SNA. Firstly, we calculated the in-degree, out-degree, and total degree of each node, which correspond to the number of incoming, outgoing, and total ties per actor, respectively. These measures were added as new columns to the table of nodes to create a visualization of the regional CAFS sociograms. They also distinguished the category of each actor using different colors. As a complementary way to understand the overall structure of the network, we calculated the following SNA metrics: (1) the density, which

measures how many incoming and outgoing ties between actors exist compared to how many are possible; (2) the overall reciprocity, which indicates the proportion of total directed ties that are reciprocal within the network; (3) the node-level reciprocity that indicates the proportion of reciprocal ties per node; and (4) the node-level efficiency, which indicates the proportion of each node's ties that are non-redundant. The distributions of node-level degree, reciprocity, and efficiency were tested for normality and were compared to determine significant differences between regions in R.

Secondly, we explored the extent to which CAFS networks group the actors belonging to the same category. For this, we calculated the number of bridging ties and bonding ties of each node. For this study, bonding ties are defined as relationships between actors from the same category (e.g., between farmer-based organizations), and bridging ties as those between actors from different categories (e.g., between one farmer-based organization and one institution providing extension services). We also determined the Yules' coefficient (Yules' Q) as a measure of the tendency of the actors to bond with similar others (i.e., homophily). This coefficient ranges from -1 for perfect heterophily to $+1$ for perfect homophily, and a value of 0 means no pattern of homophily. We selected this measure because we consider groups of different sizes and this coefficient is not affected by the number of ties or the number of same-group nodes (Perry et al. 2018).

Thirdly, we used the Key Player Problem Positive (KPP-Pos) procedure to identify a set of nodes that are optimally positioned within the network, linking to as many distinct others as possible (Borgatti 2006). We run the procedure in the free program KeyPlayer 1.47 aiming to identify KP-sets of different sizes (from 1 to 5) that reach most of the nodes (including the key players) with a direct tie. In the end, we selected the KP-set that reached more than 90% of the network actors and examined in detail the composition of the ego-networks of the members of the selected KP-sets and the relationships between them.

Results

The results of both regions are comparatively presented in the following subsections according to the three hypotheses and the corresponding SNA metrics, which are described in the previous section: (4.1) General structure of networks (sociograms, average degree, reciprocity, and efficiency); (4.2) Relational patterns within networks (distribution of bridging and bonding ties, homophily, and heterophily patterns); and (4.3) Key actors within networks (Composition of the ego-networks of key actors, relationships between key actors).

General structure of CAFS regional actor-networks

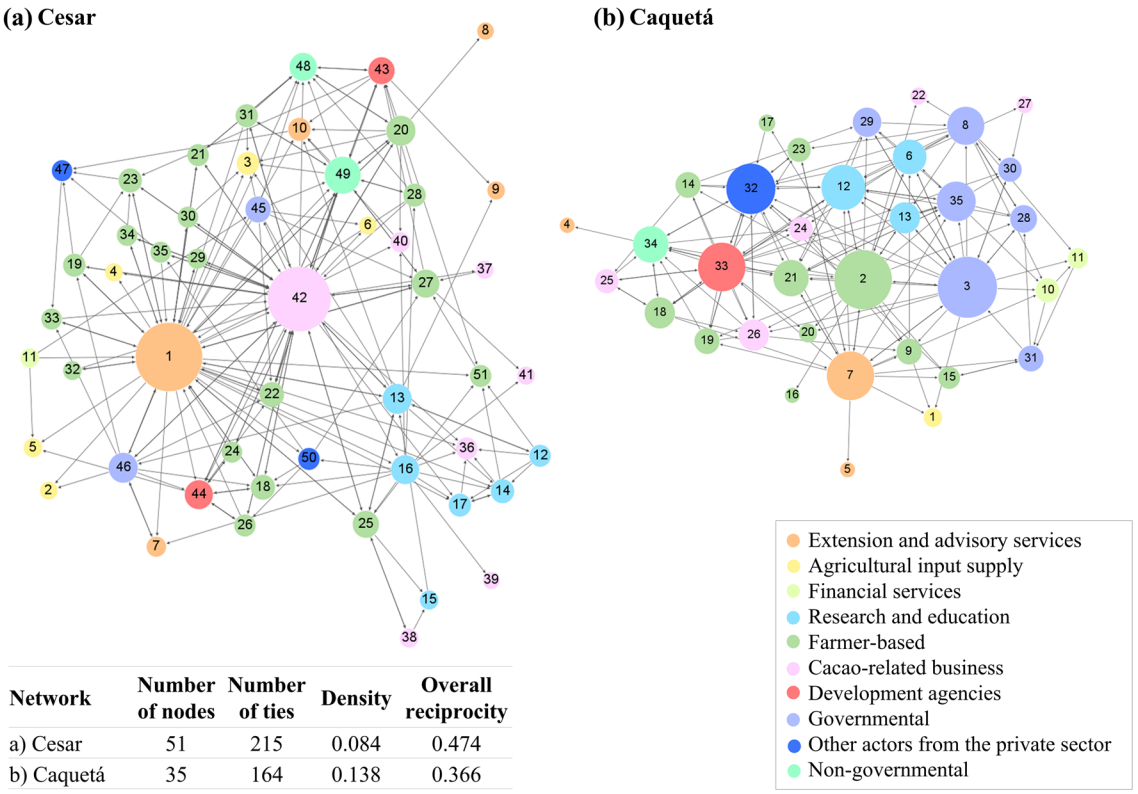
We built the two actor-networks supporting CAFS in Caquetá and Cesar. The CAFS network in Cesar (Fig. 1a) comprises 51 actors (nodes) and 215 ties. The density of this network was 0.084 and there were two actors (1 and 42) with the largest in-degree and out-degree centrality (See Table 3 in the Appendix). In the case of Caquetá, we visualize a network of 35 actors with 164 ties (Fig. 1b). Likewise, the density was 0.138 but there were three actors (12, 21, and 32) with the largest in-degree and four actors (2, 3, 7, and 33) with the largest out-degree (See Table 4 in the Appendix). The calculation of the overall reciprocity of the network was 0.474 in Cesar and 0.366 in Caquetá, indicating a greater number of reciprocal interactions in the ties considered in Cesar than those in Caquetá.

We also plotted two relationships between variables: total node degree vs node-level reciprocity (Fig. 2a, c), and total node degree vs node-level efficiency (Fig. 2b, d), revealing more information about the structure of the regional CAFS networks.

Regarding node-level reciprocity, most actors in both regions were concentrated in the bottom left of the scatter plots, indicating low connectivity and reciprocity between them. Some values with higher levels of reciprocity were observed in the case of actors with the lowest degrees. However, two actors from Cesar (1, 42) had more than 45 ties and reciprocity ratios bigger than 0.5. In the case of Caquetá, two actors (2, 3) had more than 25 incoming and outgoing ties to the actors in this network, but actor 3 had a bigger reciprocity ratio than actor 2.

As for node-level efficiency, most actors in both regions were grouped in the upper left part of the scatter plots, showing that ties from nodes connected to less than 50% of the actors in their respective networks were not redundant in a proportion greater than 40%. Nevertheless, the two most connected actors from Cesar (1, 42) and Caquetá (2, 3) had efficiency levels greater than 70%, meaning that more than 70% of their ties are not redundant.

As the distributions of node-level degree, reciprocity, and efficiency in Cesar and Caquetá were not normally distributed based on Kolmogorov–Smirnov and Shapiro–Wilk tests, respectively, their medians were compared using the Mann–Whitney test. We did not identify statistically significant differences between the regional distributions of degree, reciprocity, and efficiency at the 5% significance level.



Network	Number of nodes	Number of ties	Density	Overall reciprocity
a) Cesar	51	215	0.084	0.474
b) Caquetá	35	164	0.138	0.366

Fig. 1 Networks of cacao actors supporting CAFS in **a** Cesar and **b** Caquetá departments of Colombia. The size of the nodes denotes the number of ties an actor has and the colors of the nodes indicates the category of each actor

Relational patterns within CAFS regional actor-networks

We examined the distribution of bridging and bonding ties per node concerning the 10 categories of actors. For all categories of actors in both study regions, Fig. 3 shows more bridging ties than bonding ties on average, whereby the distribution among the different categories of actors varies between the regions.

In Cesar (Fig. 3a), the maximum number of bridging ties went out from and into one actor, who provided extension and advisory services. An outlier was observed within the category of cacao-related business, which corresponded to the largest company processing cacao from this region, but the rest are small local enterprises that had fewer than 5 bridging ties. The bonding ties per actor in this region were equal to or less than 4 and the maximum number was observed within research and education institutions.

In Caquetá (Fig. 3b), actors corresponding to the categories of Development Agencies and Other actors from the private sector concentrated the maximum number of bridging ties. However, an outlier was observed within the farmer-based organizations, which corresponded to a second-level association grouping the remaining farmer-based organizations. The number of bonding ties from the same second-level farmer association was also observed as an outlier because it was connected to the majority of the farmer associations. However, the category with the most bonding ties on average corresponded to Governmental institutions.

To better understand the relational patterns within and between actor categories, we calculated the Yule's Q per node (See Tables 3 and 4 in the Appendix). Seeking commonalities across study regions, we observed homophily patterns in all the nodes corresponding to Research and Education institutions ($1 \geq$ Yules' $Q > 0$) and heterophily patterns in the majority of the nodes corresponding to Farmer-based organizations and Cacao-related business ($0 >$ Yules' $Q \geq -1$). Comparing the different relational patterns between study regions, we evidenced a tendency toward heterophily in the category of governmental institutions in Cesar while a tendency toward homophily in the same category in Caquetá. No distinct patterns of homophily or heterophily were observed in the remaining categories of actors in both regions. In some cases, comparisons were not possible since some categories only comprised one actor in any of the study regions.

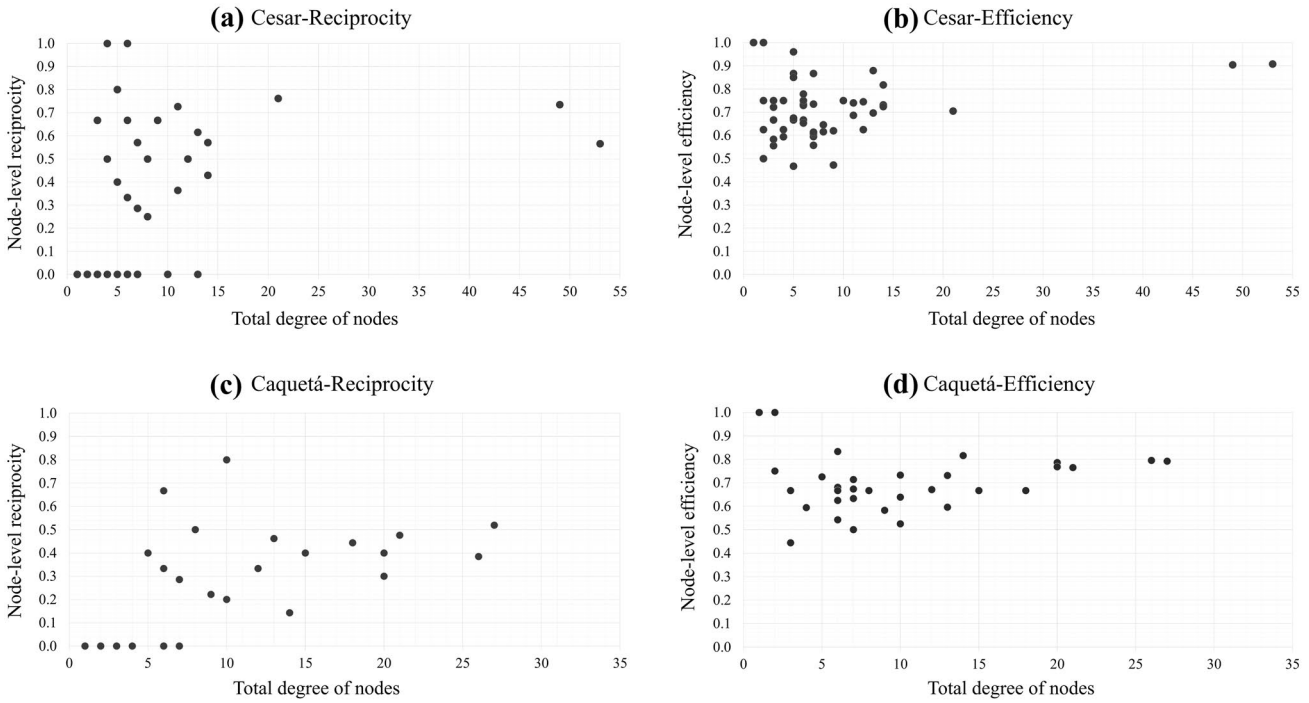


Fig. 2 Degree of nodes vs node-level reciprocity among CAFS networks in **a** Cesar and **c** Caquetá and degree of nodes vs node-level efficiency among CAFS networks in **b** Cesar and **d** Caquetá

Key actors within CAFS regional actor-networks

After running the KPP-Pos procedure for different sizes of KP-sets, we found that a 3-node KP-set in both regions reached more than 90% of the institutions in both CAFS networks (Table 2). Figure 4 visualizes the composition of the ego-networks of the sets of 3 key players in both study regions.

In the case of Cesar, we identified nodes 1, 13, and 42 as the key players reaching 90.2% of actors in the CAFS network (Fig. 4). Node 1 was FEDECACAO, which is dedicated to cacao research, knowledge transfer, and commercialization throughout Colombia since 1960 (Abbott et al. 2018; Escobar et al. 2020). This actor operates through a public parafiscal fund to which all cacao producers must contribute, but the distribution of resources for implementing its activities from region to region depends on the total cacao production registered at the regional level. These resources are also used to support democratic spaces for cacao farmers at different governance levels through the municipal, inter-municipal, and departmental committees of cacao farmers. In Cesar, FEDECACAO mainly provides extension services and supports cacao commercialization, conducts CAFS research to a lesser extent, and supports one inter-municipal committee of cacao farmers. However, FEDECACAO is part of collaborative partnerships to improve its capacities to support cacao farmers in Cesar. At the interview, FEDECACAO collaborated with two actors from the same category and 36 from the others, reaching 100% of the categories and 75% of the actors. For example, they were working together with one governmental institution and farmer-based organizations on a project to renovate and restore cacao crops through demonstration farms.

Node 13 was AGROSAVIA, the Colombian Corporation for Agricultural Research, which has a research center in Cesar and has been producing CAFS-related knowledge about plant material and AFS arrangements by means of plot trial research. AGROSAVIA's research is guided by the needs of value chains from region to region, which are compiled on the website siembra.gov.co and in the Strategic Plan for Science, Technology, and Innovation of the Colombian Agricultural Sector 2017–2027 (PECTIA by its Spanish acronym). This research institution collaborated with 3 actors from the same category and 7 actors from 5 different categories. AGROSAVIA reached 60% of the categories and 20% of the actors.

Node 42 corresponded to CHCH, the Compañía Nacional de Chocolates from Nutresa group, one of the two large companies that buy and process most cacao beans in Colombia. This private company has been buying cacao beans in Cesar since the 1990s, but it has also been carrying out development activities (including technical assistance to farmers) for the cacao sector in this region. For example, they promote cacao planting in the region

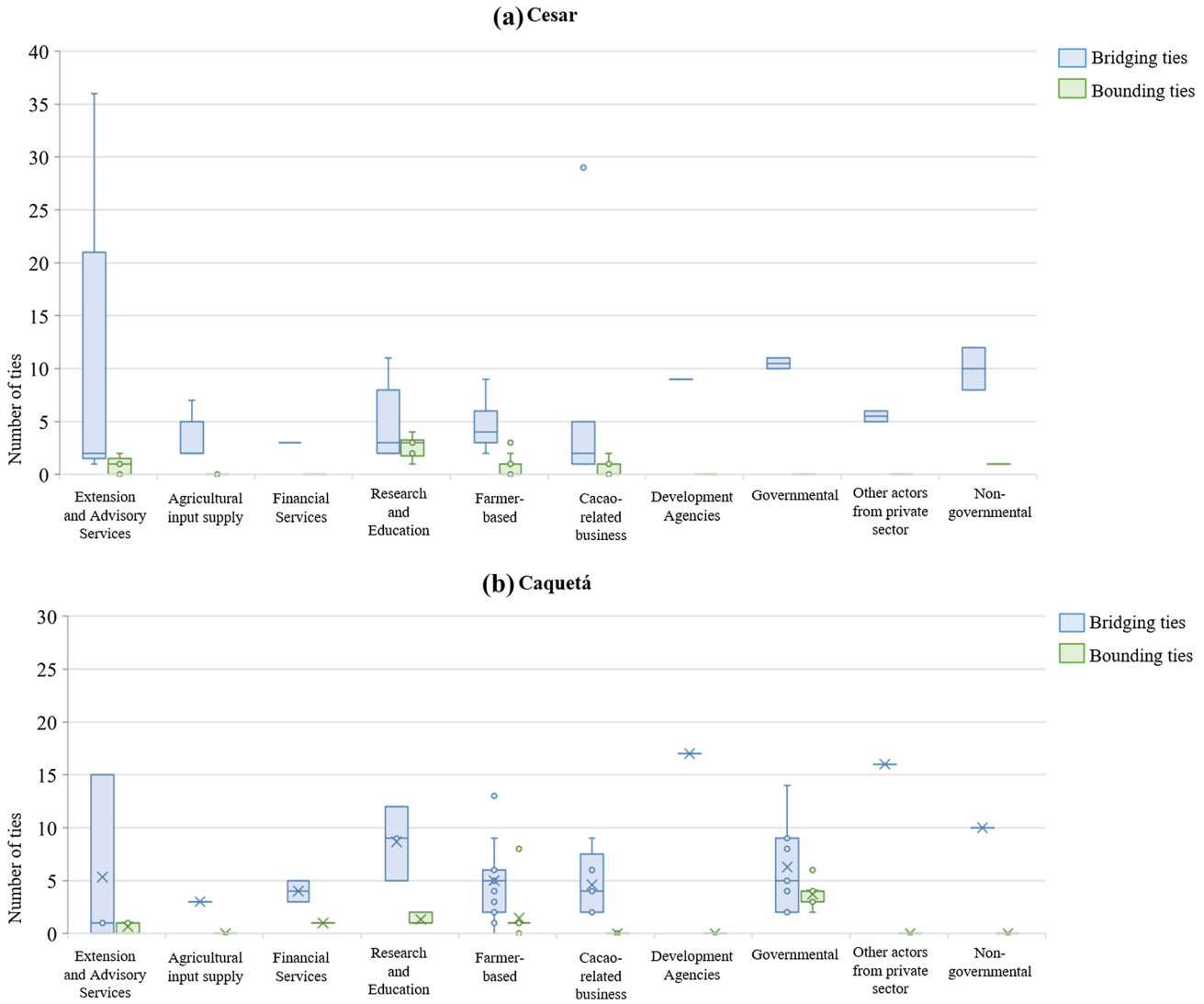


Fig. 3 Distribution of bonding and bridging ties within CAFS networks in **a** Cesar and **b** Caquetá

through a cacao nursery project (*Vivero para La Paz*), which has a capacity of 1,200,000 seedlings per year and is managed by farmers. CHCH collaborated mainly through projects with two small companies from its same category and 29 actors from 7 more categories, thus reaching 80% of the categories and 61% of the actors. In one of these projects (*Agroemprende Cacao)*, which aims to improve the living conditions for household members of cacao-producing associative enterprises in 3 municipalities of Cesar (SOCODEVI 2022), CNCH is the commercial ally and the co-financer.

Table 2 Proportion of nodes reached via direct ties by KPP-sets of size 1 to 5

Size of KP-set	Cesar		Caquetá	
	KP-Set	% of network reached	KP-Set	% of network reached
1	{1}	76.5	{2}	62.9
2	{1,13}	84.3	{2,3}	82.9
3	{1,13,42}	90.2	{2,3,33}	91.4
4	{1,13,16,42}	94.1	{2,3,7,34}	97.1
5	{1,13,16,20,42}	96.1	{2,3,6,7,34}	100

Looking at the relationships between the three key actors in Cesar, we found that there is no reciprocal collaboration between FEDECACAO and CHCH. However, AGROSAVIA has collaborated with both, via joint management with CHCH of the *Vivero para la Paz*, and knowledge exchange with FEDECACAO through its demonstration plots established in Cesar. AGROSAVIA also acknowledged that working groups involving the three key players were established to formulate joint initiatives, but none had been formalized as of February 2021.

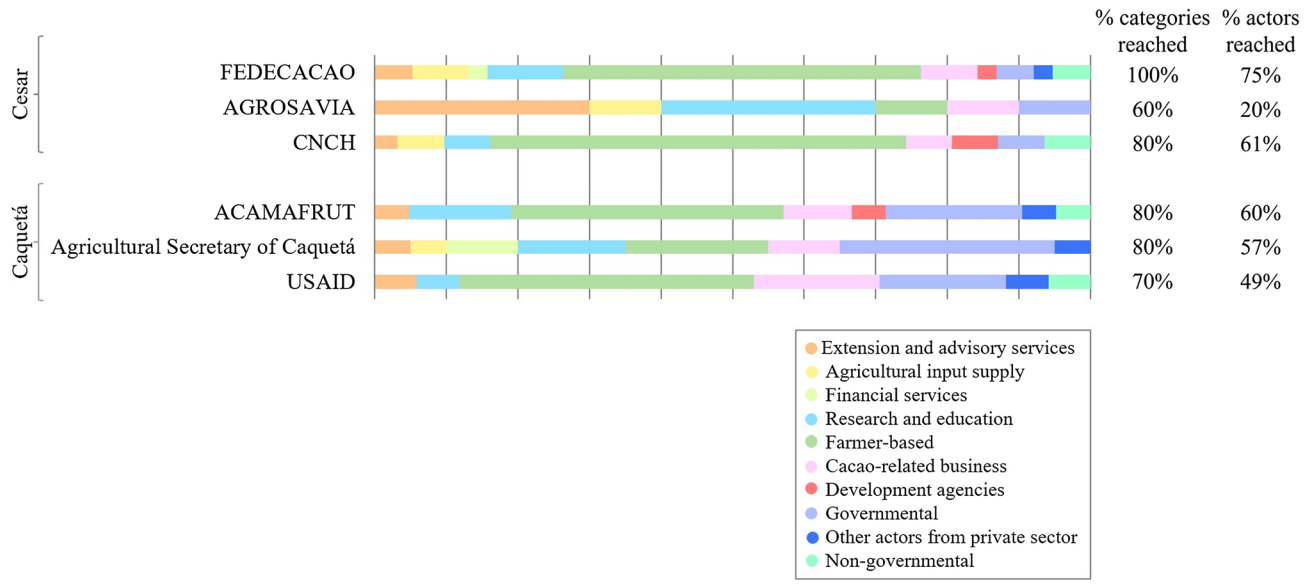


Fig. 4 Composition of the ego-networks of 3 key players in CAFS upscaling in **a** Cesar and **b** Caquetá

In the case of Caquetá, we found that nodes 2, 3, and 33 reached 91.4% of the actors in the network (Fig. 4). Node 2 was ACAMAFRUT, a second-level farmer association that groups most farmer-based associations from different municipalities in Caquetá and represents them in the regional committee of the cacao value chain. This association supports CAFS by supplying cacao and forest plant material, and providing technical assistance to cacao producers from local associations, as well as commercializing and transforming cacao beans. This actor collaborated with 8 farmer-based organizations and 13 institutions from 7 different categories. In total, ACAMAFUT reached 80% of the categories and 60% of the actors in its network.

Node 3 corresponds to the Agricultural Secretary of Caquetá, which is a governmental institution supporting regional agricultural policy and serves as the chair of the management board of the regional committee of the cacao value chain. This actor supports public–private partnerships between diverse CAFS actors to facilitate credit access, training, and extension services to cacao farmers, helps to define CAFS research priorities for the PECTIA, and promotes cacao transformation through entrepreneurship. Because of its role, this secretary had ties with 6 more governmental actors, including municipal governments where cacao is produced, regional environmental authorities, and national agricultural regulation authorities. In addition, it collaborates with 14 CAFS actors from 7 diverse categories. Overall, this secretary reached 80% of the categories and 57% of the actors.

Node 33 was USAID, the United States Agency for International Development, which has financially supported CAFS public–private partnerships to upscale them as zero-deforestation and legal alternatives in areas affected by illegal economies. Given its role, USAID supported 17 actors (49%) from 70% of the different categories.

Exploring the relationships between the three key players in Caquetá, we did not find any relationship between the Agricultural Secretary of Caquetá and USAID. However, ACAMAFRUT had relations with both institutions. For example, ACAMAFRUT received funding from USAID in the frame of the Commercial Alliances Program (PAC, by its Spanish acronym). In addition, ACAMAFRUT interacts with the Agricultural Secretary of Caquetá through two scenarios: the regional committee of the cacao value chain and the Sectional Agricultural Council (CONSEA, by its Spanish acronym). Finally, ACAMAFRUT is supported by the Agricultural Secretary of Caquetá through a bailment agreement to use property owned by the government of Caquetá for a nursery.

Discussion

By understanding the collaboration of CAFS actors at the regional level through networks, our study revealed key entry points for AFS upscaling in highly diverse regions. Clear differences and similarities were identified across the two regions.

General structure of CAFS regional actor-networks

The analysis of the general structure of the networks showed a wide range of institutions from different sectors (e.g. agriculture, environment) and policy levels (e.g. municipal,

regional, national, and international) supporting CAFS regionally, as previous studies also evidenced (Callo-Concha et al. 2017). However, most of these actors had relationships with few others in their respective regional networks, and, thus, low density. This is an expected result because the larger and more complex the network, the more resources are required to create or maintain ties between actors (Friemel 2017).

The general structure of the networks also revealed low levels of reciprocity between actors. According to Teodoro et al. (2021), reciprocal ties are established and nurtured within participatory processes, and these, in turn, can foster social learning. In addition, reciprocity is seen as supporting the development and maintenance of trust within networks, which, in turn, is the basis for ongoing coordination and collaboration among actors (Hauck and Schiffer 2014). However, in the networks we studied, reciprocity building among the actors could be hampered by project-based activities with few partner organizations (Zinngrebe et al. 2020), where interactions do not continue beyond the project period. Reciprocity between diverse actors is also key for the co-production of knowledge (Tengö et al. 2014; Van Kerkhoff 2014; Berthet and Hickey 2018) because it allows complementarities of knowledge systems. However, our results in terms of reciprocity suggest that approaches for AFS knowledge generation do not go beyond generating new AFS technologies through research-led experiments on specific farms or research plots, as previous studies also found (Sinclair et al. 2012), which could hinder the dissemination of such knowledge over a broad context by farmers, extension staff, or policymakers, especially in highly diverse landscapes like those in tropical countries.

Overall, the efficiency of the actors was high because a low number of node ties decrease potentially redundant ties (Borgatti 1997). This may be convenient for institutions supporting AFS training and extension services since the paths for information flows are direct and shorter (Isaac 2012). In our study, the most connected actors in both regions had higher efficiency, which may imply a more streamlined discourse about the AFS and their management practices (Berthet and Hickey 2018). However, these nodes with high efficiency may open structural holes within the social fabric that can be a source of inequality among actors embedded in these networks (Hanneman and Riddle 2005). This can be the case for local farmer-based organizations in our study, which mostly had a low number of ties.

Relational patterns within CAFS regional actor-networks

The distribution of bridging and bonding ties within CAFS networks evidenced a predominance of bridging ties in both regions. Previous studies showed that the presence of bridging ties enhances the capacity of actors to find solutions to complex problems (Davidson-Hunt 2006) and to exchange complex information (Demiryurek 2010; Isaac 2012), which is key for AFS management. In addition, the establishment of bridging ties to various external and formally more powerful actors enables local organizations to influence decision-making processes in their favor (Bodin and Crona 2009; Berthet and Hickey 2018). These two factors are major reasons for the adoption and persistence of AFS (Isaac 2012). However, as Saint Ville et al. (2016) stated, bridging ties alone are not enough to support the management and innovation of agricultural systems but well-connected local actors (i.e., bonding ties) are essential.

For example, the low number of bonding ties and heterophily patterns within farmer-based organizations may imply a lack of local knowledge exchange and diffusion, which is key for increasing the impact of agricultural extension and advisory services (Esparcia 2014). In addition, a low number of bonding ties between institutions with similar roles (e.g. extension services providers, agricultural inputs suppliers, NGOs) supporting AFS may be translated into a lack of coordination between their efforts and discourses. Therefore, our results may suggest that the predominance of bridging ties has led to a decrease in bonding ties between local farmer-based organizations, as other studies found (Isaac 2012). Consequently, this may affect the local exchange of information and agency, in turn affecting local capacities for sustainable agricultural management (Spielman et al. 2011; Saint Ville et al. 2016).

In addition, homophily patterns were observed in nodes corresponding to Research and Education institutions, thus suggesting that universities and research centers have a tendency to collaborate among themselves and that there is a lack of dialogue between scientific knowledge and local and technical knowledge. Although homophily patterns can create trust between actors, they can hinder information exchange across diverse knowledge systems and cooperation between actors with different roles (Riggs et al. 2020), which, in turn, hinders the management of sustainable alternatives like AFS (Newman and Dale 2007).

We also observed contrasting relational patterns between regions regarding the category of governmental institutions. Homophily patterns were identified in Caquetá in comparison with the heterophily patterns in Cesar and earlier studies (Zinngrebe et al. 2020). This distinctive pattern in Caquetá may be the response to a regional pattern where development agencies have been supporting the agenda alignment of governmental institutions through projects promoting sustainable agricultural systems as a way to curb deforestation and substitute

illicit crops in the Amazon region (Furumo and Lambin 2020).

Key actors within CAFS regional actor-networks

We found a set of key players in each region supporting more than 90% of the actors from its respective network by producing and disseminating CAFS knowledge, providing extension services or agricultural inputs, enabling cacao beans commercialization or processing, supporting public–private partnerships between cacao actors, or mobilizing resources for the cacao sector. These sets of 3 actors may suggest that the networks are highly centralized, perhaps not the most appropriate structure to address complex challenges over time (Janssen et al. 2006; Bodin and Crona 2009), such as those related to AFS management, due to the high dependence on a few institutions (Bourne et al. 2017). However, all the actors we identified in these sets belonged to different categories, potentially fostering diverse perspectives for dealing with the complex AFS challenges.

In this sense, a better understanding of those factors affecting AFS upscaling implies carefully examining the attributes of these key actors and their relationships, as their influencing positions have a strong impact on network outcomes in terms of knowledge management and governance (Bodin and Crona 2009; Bourne et al. 2017; Zinngrebe et al. 2020). Overall, these sets of key actors were completely different within and across regions, which may be the result of (1) decentralized agricultural policies and privatized extension services that generate differentiated support for cacao farmers (Abbott et al. 2018); (2) the lack of an established regulatory framework that comprehensively supports AFS and assigns clear roles across sectors and political levels (FAO 2013; Zinngrebe et al. 2020; Macke et al. 2021; Rodríguez et al. 2022); and (3) distinctive regional characteristics in terms of cacao production and access to resources.

Regarding the first two points, we noted the following differences. First, two key players in Cesar (FEDECACAO and CNCH) exclusively support cacao farmers. Although they also operate in Caquetá and throughout the country, the distribution of their resources depends on the volumes of cacao production that are sold and registered in each region. Meanwhile, the most connected key actor in Caquetá's network has similar roles but it only operates regionally and does not exclusively support cacao producers. Secondly, while in Caquetá, a farmer-based organization, the regional government, and one development agency were central to bridging CAFS actors and articulating their efforts, these roles in Cesar were assumed by one private actor that is one of the major cacao buyers in the country, a national federation that favors the interests of the cacao sector mainly, and one agricultural research institution. Thirdly, although the regional counterpart of the Agricultural Ministry had the strongest influence on the CAFS network in Caquetá, the counterparts from the Environmental Ministry were not well-connected in any of the regions, thus replicating the finding of Zinngrebe et al. (2020). As other studies showed (Isaac et al. 2007, 2021; Lin et al. 2021), farmer-based organizations and regional governments are regarded as particularly important in coordinating network efforts and disseminating AFS knowledge. However, it is noteworthy that farmer-based organizations and regional governments were not central in one of the regions. In addition, we also found that private businesses in Cesar and development agencies in Caquetá seemed to be taking over many governance roles. In relation to the third point, the focus of cacao cultivation differs from one region to the other. Cacao production in Cesar is mainly promoted to supply the national demand, alongside other initiatives that promote CAFS as an alternative economy to coal mining and as a strategy for land restoration. Meanwhile, CAFS in Caquetá is encouraged within the frame of projects promoted by development agencies to curb deforestation and combat illegal economies. In addition, cacao production in Cesar is higher and better connected to markets than in Caquetá.

Although diverse key players linked to each other within CAFS networks, connect multiple actors and integrate new knowledge into local settings, the lack of coordination between them may be generating duplicated efforts and incoherent discourses, which usually undermine AFS upscaling (Sinclair et al. 2012; Berthet and Hickey 2018). Finally, as the role of these key players is so influential in network formation (Isaac et al. 2021), they should encourage the central participation of local-based organizations and governments to support AFS knowledge dissemination and persistence.

Conclusion

Our exploratory study finds highly centralized CAFS networks with low density and, thus, high efficiency defined as low tie redundancy. While low tie redundancy may allow for more direct pathways for AFS knowledge dissemination and less conflicting AFS narratives, it may also imply a lack of financial or technical support for less connected and vulnerable actors, as well as information asymmetries among actors. The resulting actor-networks also show that the ties connecting multiple actors with different experiences and knowledge are mostly non-reciprocal and the ties between similar actors are lower. In addition, the composition of the set of key actors within networks and the governance platforms in which they converge vary from region to region since they are shaped by decentralized agricultural policies, the lack of an established AFS regulatory framework, and distinct regional characteristics. The critical analysis of

these results provides three entry points for creating actor-networks that effectively upscale AFS in tropical agricultural systems such as cacao farming.

First, AFS upscaling requires reciprocal cooperation among diverse actors and their multiple knowledge systems through the institutionalization of approaches where multiple sources of experience, insights, and innovations are integrated for knowledge co-production and joint decision-making. However, the efficiency criteria for managing relationships between these diverse actors are not suitable in all cases and depend on the type of actors and the ways support is provided. While redundant ties should be avoided between the institutions providing training and extension services and local and farmer-based organizations to efficiently disseminate and exchange AFS knowledge and information, these should be encouraged among local and farmer-based organizations to encourage communication, cooperation, and trust between them.

Secondly, networks supporting AFS require balancing bridging and bonding ties, as well as homophily and heterophily patterns. On the one hand, this balancing scenario favors the integration of multiple perspectives to address the complex challenges typically faced when managing AFS and, on the other hand, it generates coherence in the activities and discourses of actors with similar roles and knowledge exchange among local actors.

Thirdly, AFS upscaling not only depends on well-established and diverse key players connecting multiple actors, but also on their own coordination to avoid duplicated efforts and create coherent discourses around AFS. The privileged positions of these key actors should be used in favor of AFS persistence by encouraging the central participation of local-based organizations and governmental entities within networks, when this is not the case.

However, our study showed some limitations. First, we did not manage to interview many representatives of the same institution, which may have affected the number of possible responses related to each actor's ties. Secondly, the ties between actors were collected based on a single question that asked about the support that the interviewed actor received from others, but did not categorize the type of support. This could have implications in terms of the structure of the networks described through SNA. By recognizing and addressing these limitations, future developments of this approach may obtain richer data about the quality of the relationships between actors and the differentiated influence exerted by them. In addition, future research could take a closer look at actor platforms where actor collaborations occur and their role in network creation and AFS upscaling.

Finally, our approach based on a network perspective can easily be applied in other tropical regions and would be particularly helpful to practitioners from development agencies and governments seeking to mobilize the resources of sustainability upscaling projects toward the creation of actor-networks where synergies among key actors are strengthened and the adequate inclusion of local actors is promoted.

Appendix

See Tables 3, 4.

Table 3 List of actors supporting CAFS in Cesar and node-related SNA metrics

Node	Actor abbreviation	Actor category	In-degree	Out-degree	Degree	Reciprocity	Efficiency	Yule's *Q*
1	FEDECACAO	Extension and Advisory Services	22	31	53	0.566	0.908	−0.69
2	Vivero Agroambiental Costa Verde SAS	Agricultural Input Supply	2	0	2	0.000	0.500	−1.00
3	Vivero para la Paz	Agricultural Input Supply	7	0	7	0.000	0.867	−1.00
4	Trabajador independiente	Agricultural Input Supply	2	0	2	0.000	0.750	−1.00
5	AGROVET	Agricultural Input Supply	3	0	3	0.000	0.722	−1.00
6	AGRORIEGO	Agricultural Input Supply	2	0	2	0.000	0.625	−1.00
7	UMATA La Paz	Extension and Advisory Services	3	1	4	0.500	0.625	0.69
8	FUNDA-PRODEAGRO	Extension and Advisory Services	1	0	1	0.000	1.000	−1.00
9	ASOPROAGAM	Extension and Advisory Services	2	0	2	0.000	1.000	−1.00
10	ASOTECPROS	Extension and Advisory Services	6	1	7	0.000	0.735	0.25
11	Banco Agrario	Financial Services	0	3	3	0.000	0.667	−1.00

Table 3 (continued)

Node	Actor abbreviation	Actor category	In-degree	Out-degree	Degree	Reciprocity	Efficiency	Yule's *Q*
12	Universidad Popular del Cesar/ UDES	Research and Education	1	5	6	0.333	0.733	0.91
13	AGROSAVIA	Research and Education	5	9	14	0.571	0.818	0.69
14	Fundación Universitaria del Área Andina (Valledupar)	Research and Education	5	3	8	0.250	0.616	0.93
15	Corporación de Investigaciones Biológicas	Research and Education	2	1	3	0.000	0.556	0.62
16	SENA	Research and Education	2	11	13	0.000	0.879	0.21
17	Universidad Nacional de Colombia (La Paz)	Research and Education	5	2	7	0.286	0.595	0.87
18	APRAMESA	Farmer-based	6	3	9	0.667	0.620	−1.00
19	ASOSEYNEKUN	Farmer-based	3	4	7	0.571	0.557	−0.44
20	ASOCAJAGUA	Farmer-based	4	10	14	0.571	0.732	−0.75
21	CACAORIENTE	Farmer-based	3	3	6	1.000	0.667	−1.00
22	ASOAGROPERIJÁ	Farmer-based	6	3	9	0.667	0.472	−1.00
23	ASOPROSIN	Farmer-based	5	3	8	0.500	0.646	−0.10
24	ASOPROVIVOCUR	Farmer-based	2	3	5	0.800	0.667	−1.00
25	CACAOMA	Farmer-based	5	6	11	0.727	0.740	−0.61
26	ASOPROAGROP	Farmer-based	3	3	6	0.667	0.729	−1.00
27	ASOCOPE	Farmer-based	7	5	12	0.500	0.745	−0.71
28	Emutual Becerril	Farmer-based	2	5	7	0.286	0.607	−1.00
29	ASOPROAGROGAR	Farmer-based	2	2	4	1.000	0.750	−1.00
30	APROFRUVER	Farmer-based	2	3	5	0.800	0.867	−1.00
31	ASOMAKENKAL	Farmer-based	2	5	7	0.571	0.614	−1.00
32	ASOPROCOAC	Farmer-based	1	2	3	0.667	0.750	−1.00
33	AAGRONO	Farmer-based	3	2	5	0.400	0.675	−1.00
34	ASOPROKAN	Farmer-based	2	3	5	0.800	0.467	−0.09
35	ASOCIT	Farmer-based	2	3	5	0.400	0.850	−1.00
36	Col Agroforestal	Cacao-related business	6	0	6	0.000	0.653	0.13
37	Intermediario Independiente	Cacao-related business	1	1	2	0.000	0.500	0.76
38	Compañia Colombiana de Cacao	Cacao-related business	1	2	3	0.667	0.583	−1.00
39	CHOCOJAGUA	Cacao-related business	1	0	1	0.000	1.000	−1.00
40	CHOCOMINE	Cacao-related business	3	1	4	0.000	0.594	−1.00
41	CHARP	Cacao-related business	2	0	2	0.000	1.000	−1.00
42	Compañia Nacional de Chocolates	Cacao-related business	22	27	49	0.735	0.904	−0.66
43	USAID	Development Agencies	6	5	11	0.364	0.687	−1.00
44	PNUD	Development Agencies	7	6	13	0.615	0.697	−1.00
45	Secretaria de Agricultura Departamental	Governmental	2	8	10	0.000	0.750	−1.00
46	ICA	Governmental	4	10	14	0.429	0.724	−1.00
47	Asociación Agroambiental del Perijá	Other actors from private sector	4	1	5	0.000	0.960	−1.00
48	Fundación Nutresa	Non-governmental	9	3	12	0.500	0.625	0.67
49	SOCODEVI	Non-governmental	10	11	21	0.762	0.705	0.51
50	Cámara de Comercio de Valledupar	Other actors from private sector	2	4	6	0.000	0.750	−1.00
51	Comité Intermunicipal de Cacaoteros del Cesar	Farmer-based	5	1	6	0.000	0.778	0.29

Table 4 List of actors supporting CAFS in Caquetá and node-related SNA metrics

Node	Actor abbreviation	Actor category	In-degree	Out-degree	Degree	Reciprocity	Efficiency	Yule's *Q*
1	Agroservicios del Caquetá SAS	Agricultural input supply	3	0	3	0.000	0.444	−0.16
2	ACAMAFRUT	Farmer-based	6	20	26	0.385	0.795	0.24
3	Secretaria de Agricultura Departamental	Governmental	8	19	27	0.519	0.792	−0.27
4	CORDESPA	Extension and Advisory Services	1	0	1	0.000	1.000	−0.05
5	Trabajador independiente	Extension and Advisory Services	1	0	1	0.000	1.000	0.21
6	SENA	Research and Education	4	8	12	0.333	0.671	−0.01
7	FEDECACAO	Extension and Advisory Services	5	15	20	0.400	0.786	−0.04
8	Alcaldía Belén de los Andaquies	Governmental	5	9	14	0.143	0.816	0.05
9	ASOHECA	Farmer-based	5	2	7	0.000	0.633	−0.04
10	Banco Agrario	Financial Services	4	2	6	0.000	0.681	0.13
11	Finagro	Financial Services	3	1	4	0.000	0.594	0.09
12	Universidad de la Amazonia	Research and Education	10	8	18	0.444	0.667	0.08
13	AGROSAVIA	Research and Education	5	5	10	0.800	0.525	0.25
14	COMCAP	Farmer-based	2	5	7	0.000	0.673	−0.19
15	PROCACAO	Farmer-based	3	2	5	0.400	0.725	−0.05
16	COCROCABEL	Farmer-based	1	0	1	0.000	1.000	0.12
17	COMUCAM	Farmer-based	1	1	2	0.000	0.750	0.06
18	ASOACASAN	Farmer-based	4	6	10	0.800	0.733	−0.30
19	COCAREP	Farmer-based	4	3	7	0.286	0.500	−0.14
20	CHOCOAMAZONIA	Farmer-based	3	0	3	0.000	0.667	0.17
21	COMCAFLOR	Farmer-based	10	3	13	0.462	0.596	−0.17
22	Intermediario independiente	Cacao-related business	2	0	2	0.000	1.000	0.05
23	ASPROABELEN	Farmer-based	4	2	6	0.667	0.625	−0.21
24	CHOCOPENEYA	Cacao-related business	5	1	6	0.000	0.667	−0.02
25	Chuculat	Cacao-related business	3	3	6	0.667	0.542	0.09
26	Compañía Nacional de Chocolates	Cacao-related business	7	3	10	0.200	0.639	−0.16
27	CHOCO AMAZONIC	Cacao-related business	1	1	2	0.000	1.000	0.05
28	CORPOAMAZONIA	Governmental	5	3	8	0.500	0.667	−0.05
29	ICA	Governmental	5	4	9	0.222	0.583	−0.11
30	PNIS	Governmental	5	1	6	0.333	0.833	0.33
31	Visión Amazonia	Governmental	4	3	7	0.286	0.714	0.15
32	FINTRAC	Other actors from private sector	14	7	21	0.476	0.765	−0.16
33	USAID	Development Agencies	5	15	20	0.300	0.768	0.12
34	Patrimonio Natural	Non-governmental	8	5	13	0.462	0.731	0.06
35	Secretaria de Ambiente y Desarrollo Rural de Florencia	Governmental	8	7	15	0.400	0.667	−0.16

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Availability of data and material The data that support the findings of this study are available on request from the corresponding author, Tatiana Rodríguez. The data are not publicly available because it contains information that could compromise the privacy of research participants.

Declarations

Conflict of interest We have no competing interests to declare that are relevant to the content of this article.

Ethics approval This research is part of the project "Implementing sustainable agricultural and livestock systems for simultaneous targeting of forest conservation for climate change mitigation (REDD+) and peace-building in Colombia," which was reviewed and approved by the Institutional Review Board (IRB) of the International Center for Tropical Agriculture (CIAT). The IRB reviews all research that involves human participants to ensure their protection.

Consent Informed consent was obtained from all individual participants included in the study.

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