Protocol and participatory engagement strategy for a community-based research route focused on locally led adaptation capacities

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December 2025

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1. Introduction

Agri-food systems have emerged as one of the main points of interaction between climate change, territorial transformation, and socio-ecological governance. Globally, these systems are responsible for approximately one-third of anthropogenic greenhouse gas emissions and occupy around 37% of the Earth's land surface, while also being highly exposed to the impacts of climate variability and change (Crippa et al., 2021; FAO, 2021). In this context, recent literature emphasizes that agri-food systems not only contribute to climate change but are also highly vulnerable to its effects—particularly in regions where land-use change, deforestation, and the expansion of extensive production systems undermine the ecological functionality of the landscape (Clapp et al., 2018; Ericksen, 2008; Ingram, 2011).

The CGIAR Climate Action Science Program aims to "advance science, innovation, and collaboration to transform food, land, and water systems toward a climate-resilient, equitable, and net-zero future." Within this framework, the research presented here supports the work of the Biodiversity-CIAT Alliance in developing the “Locally Led Adaptations” (LLA) component. This initiative seeks to assist actors in rural territories in addressing gender and other socioeconomic inequalities, recognizing that effective local adaptation requires the integration of new technologies, practices, and services within broader institutional and ecosystem contexts.

In Colombia, these dynamics are particularly critical in the Amazon region, where the AFOLU sector is the main source of greenhouse gas emissions, primarily due to the conversion of forests into pastureland for extensive cattle ranching (IDEAM et al., 2016; IDEAM, 2023). The department of Caquetá exemplifies these tensions: although it still retains a high proportion of forest cover, it also registers some of the highest recent deforestation rates in the country, within a context of weak land-use planning, institutional fragmentation, and high exposure to climate risks (FAO & ADR, 2021; IDEAM, 2023). This combination positions Caquetá as a strategic territory for both emission mitigation and ecosystem-based climate adaptation.

The municipality of La Montañita, in the department of Caquetá, part of the Colombian Amazon, is a predominantly rural area characterized by Amazonian hill landscapes, Andean foothills, and alluvial valleys, where smallholder agri-food systems coexist with highly fragmented remnants of natural forest (IGAC, 2020; La Montañita Mayor’s Office, 2018). From a socio-ecological systems perspective (Berkes & Folke, 1998; Folke, 2006), we explore how the spatial configuration of the territory – including land cover distribution, water networks, rural property structures, and the location of climate and human-induced threats – shapes both climate vulnerability and the local capacities for adaptation. In addition, we analyze the use of agrobiodiversity and its adaptation potential, and we report on the codesign in a community-based action-research route to strength locally led adaptation capacities.

From a socio-ecological systems perspective (Berkes & Folke, 1998; Folke, 2006), we analyze how the spatial configuration of the territory—including land cover distribution, water networks, rural property structures, and the location of climate and anthropogenic threats - shapes both climate vulnerability and local adaptive capacity. We combine spatial analysis using Geographical Information Systems (GIS), multicriteria analysis, social cartography and participatory workshops, integrating biophysical, institutional, and socio-productive information with the territorial knowledge of local communities (Herlihy & Knapp, 2003; Barragán & Amaya, 2020; Rambaldi et al., 2021).

This approach allowed us to identify critical zones of socio-ecological conflict, areas of high climate vulnerability, and local adaptive assets, while also revealing significant mismatches between formal territorial planning and the actual practices of land use and management (PROVIA, 2013; MITECO, 2023). We demonstrate that exposure to extreme events such as flash floods, prolonged droughts, landslides, and flooding interacts with structural processes of environmental degradation, lack of land-use planning, and fragmented governance, creating pathways of deep vulnerability (Adger, 2006; Turner et al., 2003; Hurlbert et al., 2023).

A central focus of the analysis lies in the adaptive potential associated with emerging productive and ecosystem-based strategies, particularly agroforestry systems based on sacha inchi (*Plukenetia volubilis*) and on-farm ecological restoration initiatives. While the literature acknowledges the value of agroforestry and ecosystem-based adaptation as cost-effective strategies for addressing climate change (Chazdon, 2014; Locatelli et al., 2015; Reid et al., 2019), our findings show that their effectiveness is strongly conditioned by spatial and organizational factors. These include water availability, ecological connectivity of the landscape, the size and fragmentation of rural properties, and the continuity of technical support. The high initial failure rate observed in some crops—contrasted with better outcomes in farms with greater forest cover and sustained technical assistance—underscores the importance of integrating spatial analysis, social learning, and adaptive governance in the design of climate adaptation strategies (Pahl-Wostl, 2009; Berkes & Ross, 2013).

Climate adaptation in rural Amazonian territories cannot be understood as a set of isolated technical practices, but rather as a spatial, multi-scalar process shaped by interactions among production systems, ecosystems, and institutional arrangements (Folke et al., 2010; Ostrom, 2009).

2. Conceptual frameworks

2.1. Adaptive governance

Adaptive governance is understood as a polycentric framework of social coordination that integrates multiple actors and institutional levels to respond to uncertainty within socio-ecological systems. This approach emerges from the convergence of adaptive management and co-management, combining "learning-by-doing" cycles with cooperative power-sharing arrangements among communities, state agencies, and intermediary organizations (Folke et al., 2005; Berkes, 2009). Adaptive governance operates through self-organized, networked processes in which institutional arrangements and ecological knowledge are continuously tested and adjusted (Folke et al., 2005). Its polycentric structure enables the articulation of decision-making units coordinated through both vertical and horizontal linkages, enhancing the diversity of responses to environmental change (Lee, 1993; Ostrom, 2010). These networks can strengthen adaptation by facilitating information exchange, inter-institutional cooperation, and trust-building among diverse actors (Schneider et al., 2003; Pretty & Ward, 2001). However, multilevel interactions may also generate tensions when there are regulatory mismatches or fragmented competencies. In this context, distributed leadership, coordination capacity, and the accumulation of social capital are recognized as key factors for sustaining deliberative processes, managing conflict, and fostering institutional innovation in times of rapid change (Wondolleck & Yaffee, 2000; Leach & Pelkey, 2001).

2.2. Resilient socioecological systems

Socio-ecological systems (SES) are conceived as complex adaptive systems in which ecological and social components interact dynamically across multiple spatial and temporal scales (Berkes & Folke, 1998). From this perspective, resilience is defined as a system's capacity to absorb disturbances, reorganize, and continue functioning without losing its essential functions, structure, and the critical feedbacks that sustain its identity (Folke, 2006). This capacity does not imply static stability, but rather the ability to adapt and transform in the face of change and uncertainty.

The literature identifies key attributes of socio-ecological resilience as biological and functional diversity, ecological and social connectivity, social learning, polycentric governance, and the capacity for self-organization (Walker et al., 2004; Folke et al., 2010). These attributes enable communities and ecosystems to adjust their management practices, foster institutional innovation, and sustain the provision of essential ecosystem services—such as water regulation, soil fertility, and landscape stability—even under conditions of environmental and climate pressure.

The adoption of a resilient socio-ecological systems approach is particularly relevant for analyzing the municipality of La Montañita, located in a region of the Colombian Amazon marked by intense landscape transformation. In this territory, the expansion of the cattle frontier, the fragmentation of forest cover, and the degradation of strategic ecosystems have disrupted key ecological processes such as the hydrological cycle, landscape connectivity, and buffering capacity against extreme climate events. These transformations cannot be understood solely as biophysical changes, but rather as the result of historical interactions among productive dynamics, weak institutional arrangements, and fragmented territorial decision-making.

In highly transformed Amazonian contexts such as La Montañita, socio-ecological resilience is shaped by the loss of ecological diversity, reduced connectivity between forest remnants, and the simplification of productive systems – factors that increase the system's sensitivity to climate disturbances such as prolonged droughts, floods, and landslides. At the same time, the persistence of smallholder agri-food systems, emerging agroforestry practices, and ecological restoration processes at both farm and community levels represent a potential foundation for reconfiguring development pathways toward greater resilience – provided these practices are integrated with effective governance mechanisms and social learning processes.

From this perspective, the SES approach enables an analysis not only of a system's capacity to withstand climate impacts, but also of the conditions under which transformative adaptation processes can emerge in transitional Amazonian landscapes. In the case of La Montañita, this analytical framework supports an understanding of how the interaction between ecological attributes (forest cover, connectivity, functional diversity) and social factors (community organization, technical support, institutional arrangements) defines the limits and opportunities of resilience. It offers an integrated perspective that is essential for designing adaptation strategies and land-use planning in regions undergoing significant transformation within the Amazon biome.

2.3. Vulnerability and climate adaptation

Climate vulnerability is defined as the degree to which a system is susceptible or unable to cope with the adverse effects of climate change, determined by the interaction between its exposure to climate hazards, its sensitivity, and its adaptive capacity (IPCC, 2014; IPCC AR6, 2022). This concept recognizes that vulnerability is not solely a biophysical condition but emerges from social and institutional processes that shape the unequal distribution of risks, response capacities, and access to resources (Adger, 2006; Turner et al., 2003; Jessen et al., 2025). Recent literature also emphasizes that socioeconomic factors such as poverty, inequality, and lack of access to basic infrastructure can significantly exacerbate the climate vulnerability of specific populations and territories (IPCC AR6, 2022; Jessen et al., 2025).

Climate adaptation refers to the adjustments made in human or natural systems aimed at moderating potential damage or capitalizing on opportunities associated with climate variability and change (IPCC, 2014; IPCC AR6, 2022). These adjustments can be either spontaneous or planned and include a wide range of interventions—from changes in production practices to the construction of resilient infrastructure and the reform of local institutions and regulations. Contemporary literature highlights that effective adaptation requires not only access to updated climate information and monitoring but also flexible institutions, inclusive decision-making processes, and the integration of both local and scientific knowledge to enhance response capacity and reduce risks under uncertainty (Smit & Wandel, 2006; IPCC AR6, 2022).

Moreover, recent studies emphasize that climate adaptation must be understood as a dynamic process that interacts with deeper social dimensions, including power relations, structural inequalities, and access to resources. These factors shape both the feasibility and the nature of human and ecological responses to climate disturbances (Jessen et al., 2025). This broader socio-ecological perspective allows adaptation to be analyzed not merely as a set of technical measures, but as a contextualized, multi-scalar, and political process that redefines capacities and vulnerabilities based on existing social structures and specific territorial trajectories.

3. Methodological approach

3.1. Cartographic analysis and participatory mapping

The methodology combines spatial analysis using Geographic Information Systems (GIS) with participatory social mapping to characterize environmental assets, conflicts, threats, and adaptive potential in Montañita (Caquetá).

The spatial analysis component integrates biophysical data (land cover, strategic ecosystems, water sources, etc.) with socioeconomic and governance information, using satellite imagery, official cartographic databases, and geo-referenced fieldwork. The use of GIS will allow for the identification of spatial patterns of land use and pressure on common goods, as well as critical zones of conflict or vulnerability. This approach is supported by the literature that highlights the value of geospatial analysis for the integrated assessment of socio-ecological landscapes and adaptive planning (Löhr et al., 2024; Bocco et al., 2001; McCall, 2021).

In addition, participatory mapping is used as an action-research methodology that enables communities to create spatial representations of their territory, identify resources, challenges, and opportunities, and reinforce organizational processes and local governance (Herlihy & Knapp, 2003; Barragán & Amaya, 2020). Beyond its descriptive function, social cartography serves as a key analytical tool for assessing climate vulnerability, as it integrates local ecological knowledge, risk perceptions, and territorial practices within a spatially explicit framework.

First, participatory mapping plays a central role in spatializing climate exposure by enabling the identification and delineation of areas affected by specific hazards such as floods, prolonged droughts, landslides, water erosion, and flash floods—based on historical experience and direct community observation. Through collective mapping exercises, participants identified recurrently impacted areas, estimated the frequency and intensity of events, and projected future risk scenarios. This process generated valuable information that complements and enriches technical and official records (CARE, 2020).

Second, the participatory approach facilitates the territorialization of climate sensitivity, understood as the degree to which productive systems, livelihoods, and local infrastructure are affected by climate disturbances. Through mapping, participants identified productive areas highly dependent on specific water regimes, zones of vulnerable agrobiodiversity, exposed critical infrastructure, and populations with limited response capacity. In line with Climate Vulnerability and Capacity Analysis (CVCA) exercises, "hotspots" of high vulnerability and "cold spots" of relatively greater resilience were distinguished, allowing for a more nuanced, place-based understanding of the territory (CARE, 2020, p. 42).

Social cartography also plays a key role in visualizing existing adaptive capacities by making visible the resources, practices, and local adaptation strategies that are often underrepresented in conventional technical assessments. These include areas of productive diversification, farms engaged in ecological restoration, community seed exchange networks, local water harvesting and management infrastructure, and agroforestry systems with greater climate resilience. As noted in the Climate Change Risk Assessment Guide by MITECO (2023), identifying these "adaptive assets" is a fundamental step in designing context-specific interventions and avoiding exclusively deficit-based approaches.

Finally, the participatory approach enables multiscalar knowledge integration by linking information generated by communities with geospatial data from satellite imagery, climate models, land cover maps, and GIS analysis. This convergence of scales and data sources is essential for vulnerability assessments that acknowledge the interdependence between local processes, regional territorial dynamics, and global climate trends, thereby strengthening both the analytical coherence and the relevance of the results (PROVIA, 2013).

3.2. Participatory workshops

Participatory workshops are spaces for the collective construction of knowledge, where diverse actors engage in dialogue, negotiate perceptions, and co-produce both diagnoses and proposals (Chambers, 1994). In the context of climate vulnerability assessment, workshops play a complementary role to mapping, contributing in several key ways:

1. *Building consensus on observed climate changes*: Through tools like climate timelines, participants collectively document perceived changes in temperature, rainfall, extreme events, and crop phenology. The CVCA methodology includes "Seasonal Calendar" exercises to compare past and current climate patterns (CARE, 2009, p. 38). These activities complement data collected through the Mitigate+ project, helping spark dialogue on new or shifting perceptions.

2. *Identifying differentiated impacts*: Workshops help make visible how climate change affects different groups in different ways—such as women, youth, or families in mountain vs. lowland zones (CARE, 2020, p. 50). This is crucial for developing inclusive adaptation strategies.

3. *Documenting Local Adaptive Strategies:* Through exercises like the "basket of strategies", communities identify existing responses they are already implementing in the face of climate change. The PROVIA Guidance (2013) emphasizes that effective assessments must begin by recognizing existing autonomous adaptation before introducing external solutions.

4. *Analyzing Governance and Decision-Making:* With tools like actor mapping, participants identify roles, power dynamics, alliances, and conflicts among stakeholders involved in territorial and climate governance. This is vital, as adaptive capacity depends heavily on inclusive institutional arrangements.

3.3. Semi-structured interviews and farm visits

Semi-structured interviews serve as a valuable complement to collective tools by enabling deeper exploration of:

- Individual narratives that may not surface in public group settings
- Specialized knowledge from elders, local experts, and experimental farmers

- Long-term memories of territorial and food system transformations
- Subjective perceptions of risk, uncertainty, and future expectations

The interviews were structured around key thematic blocks that reflect critical dimensions of vulnerability and adaptation:

1. *Territorial history and memory:* Trajectories of socio-ecological change, identifying turning points that have shaped current vulnerabilities.
2. *Agrobiodiversity and production practices:* Crop and varietal diversity is a strong indicator of adaptive capacity. By documenting what is grown, lost, or exchanged, it becomes possible to assess this resilience.
3. *Climate change and adaptation:* Observed changes, experienced impacts, and local responses are central to understanding vulnerability from the community's perspective.
4. *Food systems and autonomy:* High dependence on external food sources increases vulnerability to climate shocks. Food autonomy is a key component of resilience.
5. *Governance and community organization:* Adaptive capacity strongly depends on institutional arrangements that support collective action, shared resource management, information access, and external support.
6. *Ecological restoration:* The recovery of degraded ecosystems enhances the supply of ecosystem services—such as water regulation, erosion control, and microclimate stabilization—that help reduce exposure and sensitivity to climate change.

These interviews were conducted during a farm walk (transect), in which productive systems, management practices, resource flows and relationships between the components of the farm system, and the main threats and opportunities perceived by producers in relation to climate variability and local market conditions were discussed.

3.4. Agroecological resilience assessment

The core of the assessment consisted of a participatory evaluation of 16 agroecological dimensions, covering agricultural, livestock, environmental, and organizational practices[1]. Each dimension was jointly analyzed through three steps: (i) a description of the current situation of the farm, (ii) the consensual assignment of a score on a scale from 1 to 5, based on previously defined operational criteria, and (iii) the identification of gaps and priority improvement actions. The evaluation scale was used as a pedagogical and reflective tool,

[1] The 16 dimensions are: crops rotation, crops association, live fences, vegetation cover, conservation tillage, use of compost and fertilizers, management of pests and diseases, water sources (protection and management), biological corridors, seeds banks, gardens and orchards (species diversity and use), animal diversity, animal nutrition, silvopastoral systems, wood banks, slope and hillside management.

aimed at facilitating dialogue, prioritization, and mutual learning, rather than as a mechanism of control or certification.

The scoring was supported by the triangulation of at least two sources of evidence — the producer's narrative, direct observation, and records or visual documentation — thereby strengthening the validity of the analysis and enhancing the recognition of existing practices, local innovations, and agroecological transition processes. This exploratory tool was piloted on one farm currently undergoing an agroecological transition, with the aim of proposing its broader application as a monitoring instrument for sustainable and resilient transitions. The diagnostic process concluded with the joint definition of short-term priority actions (0–6 months), aimed at enhancing the agroecological resilience of farms and strengthening rural livelihoods.

3.5. Triangulation and validation of findings

Triangulation—the use of multiple methods, data sources, and perspectives—is a fundamental strategy for increasing the validity and reliability of qualitative research (Denzin, 1970; Flick, 2018). In participatory vulnerability assessments, triangulation serves several key functions: 1) Cross-validation across interviews, workshops, mapping exercises, and field visits; 2) Complementarity, by capturing different dimensions of reality; 3) Bias reduction, minimizing the limitations inherent to any single method; 4) Interpretive enrichment, where contradictions reveal underlying complexity and conflict (O'Brien & Vogel, 2006)

The combination of quantitative and qualitative methods, and the integration of scientific and local knowledge, is essential for developing a robust and context-sensitive vulnerability assessment. The integration of local knowledge with geospatial evidence (GIS tools, satellite imagery) enabled a multi-scalar analysis—connecting local realities to broader regional climate change dynamics.

4. Mapping of environmental offer and use conflicts[2]

4.1. Environmental determinants

The municipality of Montañita is located in the western part of the Caquetá Department, 27 km from Florencia, the departmental capital. Montañita is a predominantly rural municipality, with approximately 81% of its population living in the countryside. Most household income is generated through traditional crops such as coffee, sugarcane (for panela), plantain, and maize, as well as dual-purpose cattle ranching. However, agricultural production remains low, resulting in limited commercialization and contributing to the prevalence of informal employment. This situation is especially common during the coffee harvest, sugarcane milling season, and in the context of illicit crop cultivation (IGAC, 2020).

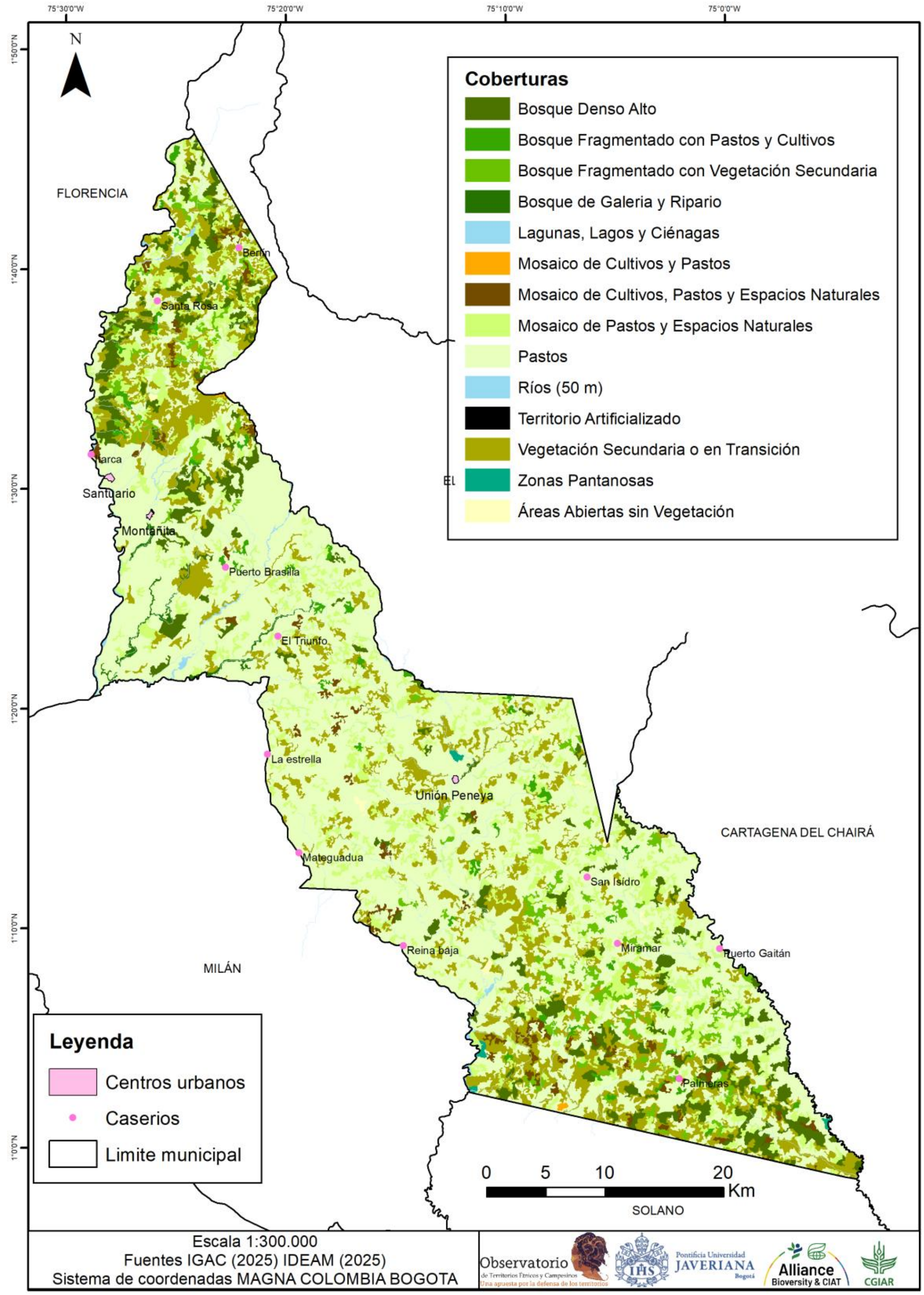
La Montañita covers an area of approximately 170,000 hectares, with an altitudinal range between 200 and 1,574 meters above sea level and features four types of terrain or landscapes: **mountain, piedmont, and hill country** (*lomerío*) **and alluvial valleys.** About 82.9% of the municipality consists of hill country and alluvial valleys (200–260 m.a.s.l. with flat slopes), which extend across the central-western and southern areas. This region is traversed by the Orteguaza, Peneya, Suncilla Rivers and La Niña stream, all part of the Amazon sedimentary megabasin.

Regarding the **water network**, Montañita belongs to two hydrographic subzones: the *Orteguaza River basin*, a tributary of the Caquetá River, and the *Suncilla River basin*, which flows into the Caguán River. Both are part of the Amazon River hydrographic area (IDEAM, 2013). At the local level, water supply comes from Andean rivers known as *San Pedro* and *Peneya*, as well as from streams such as *La Niña*, *María*, *Montañita*, and *Las Margaritas*, which originate in the Amazonian foothill region located in the southeastern part of the municipality (Alcaldía de Montañita, 2018).

In La Montañita, **approximately 88% of the territory consists of transformed land**, forming a mosaic of agroecosystems primarily made up of extensive cattle pastures, interspersed with crop areas and fragmented forests with secondary vegetation in varying stages of regeneration. In contrast, natural ecosystems—including remnants of humid lowland forest, wetlands, and patches of humid sub-Andean forest—make up less than 12% of the total area (Figure 1) (IGAC, 2020).

[2] For a complete analysis of the socio-spatial characterization of La Montañita using GIS and social cartography see: Herrera, J., Álvarez, J., & Zuleta, S (2025) "Vulnerabilidad climática, gobernanza adaptativa y adaptación basada en comunidades en sistemas agroalimentarios amazónicos. Informe sobre la construcción de capacidades para la evaluación participativa de la resiliencia y la adaptación liderada localmente en La Montañita, Caquetá".

Figure 1. Map of Ecosystems Municipality of La Montañita



The social mapping exercise confirmed that extensive cattle ranching is the dominant land use in the municipality of La Montañita. This is true both for large-scale, mechanized farms and smallholder units located in the mountainous areas, contributing to landscape clearing and the fragmentation of remaining forest cover. The expansion of pasturelands for livestock is one of the main drivers of deforestation and loss of landscape connectivity (Estrada, 2025; Reuters, 2025). The conversion of forests and natural areas into pasture undermines the capacity to regulate the hydrological cycle and soil stability, increasing the vulnerability of the socio-ecological system (World Weather Attribution, 2025).

There are no nationally or regionally designated **protected areas** and no part of its municipal territory is currently governed by a Watershed Management Plan (POMCA) zoning regulation (Municipal Government of La Montañita, 2018). However, one of the main territorial determinants is related to the Law 2nd Forest Reserve Areas. According to Resolution 1277 of August 6, 2014, La Montañita has 15,671.4 hectares (9.1% of the total municipal area) under this legal framework, of which only 7,387.7 hectares are currently forested. At the local level, there are also 26 Civil Society Nature Reserves registered in the National Registry of Protected Areas (RUNAP) that together account for 1,638.8 hectares of the municipal area.

Most of the municipal land has been classified as having productive **forest land use potential (80%),** corresponding to clayey soils found in the extensive hilly terrain. These soils are highly prone to erosion when vegetation cover is removed and are generally low in nutrients. Therefore, sustainable forest management and avoiding deforestation are essential to prevent land degradation and desertification. Meanwhile, 14% of the area is classified as protective forest land, located in mountainous landscapes where steep slopes, shallow effective soil depth, and high erosion susceptibility are key limitations. In these areas, agricultural and livestock activities should be avoided, and land use should be oriented toward the conservation of water sources and the recovery of native flora and fauna (Municipal Government of La Montañita, 2018; IGAC, 2014).

Previous research (Clavijo et al., 2024; Maya et al., 2024) has shown that, although restorative practices have begun to be adopted in the region, significant environmental constraints persist. These include high levels of soil degradation, elevated acidity, and low natural fertility, all of which limit the effective implementation of agroforestry and silvopastoral systems. Additionally, there is a low level of technical uptake of previous diagnostics—such as soil analyses—which are not consistently translated into informed on-farm management decisions.

4.2. Identification of critical zones of socio-ecological conflict and climate vulnerability

First, we elaborate a spatial-temporal analysis of **changes in vegetation cover** (dense forest, fragmented forest, and secondary vegetation) using supervised classification at a mapping scale of 1:25,000. The data sources were two satellite images from Sentinel satellites, obtained from the USGS Glovis server: the oldest comparable image from 2015 (Sentinel-1) and the most recent from October 2025 (Sentinel-2). The images were selected to ensure similarity in temporal resolution (time, day, and month), spatial extent (area), and climatic conditions between both dates.

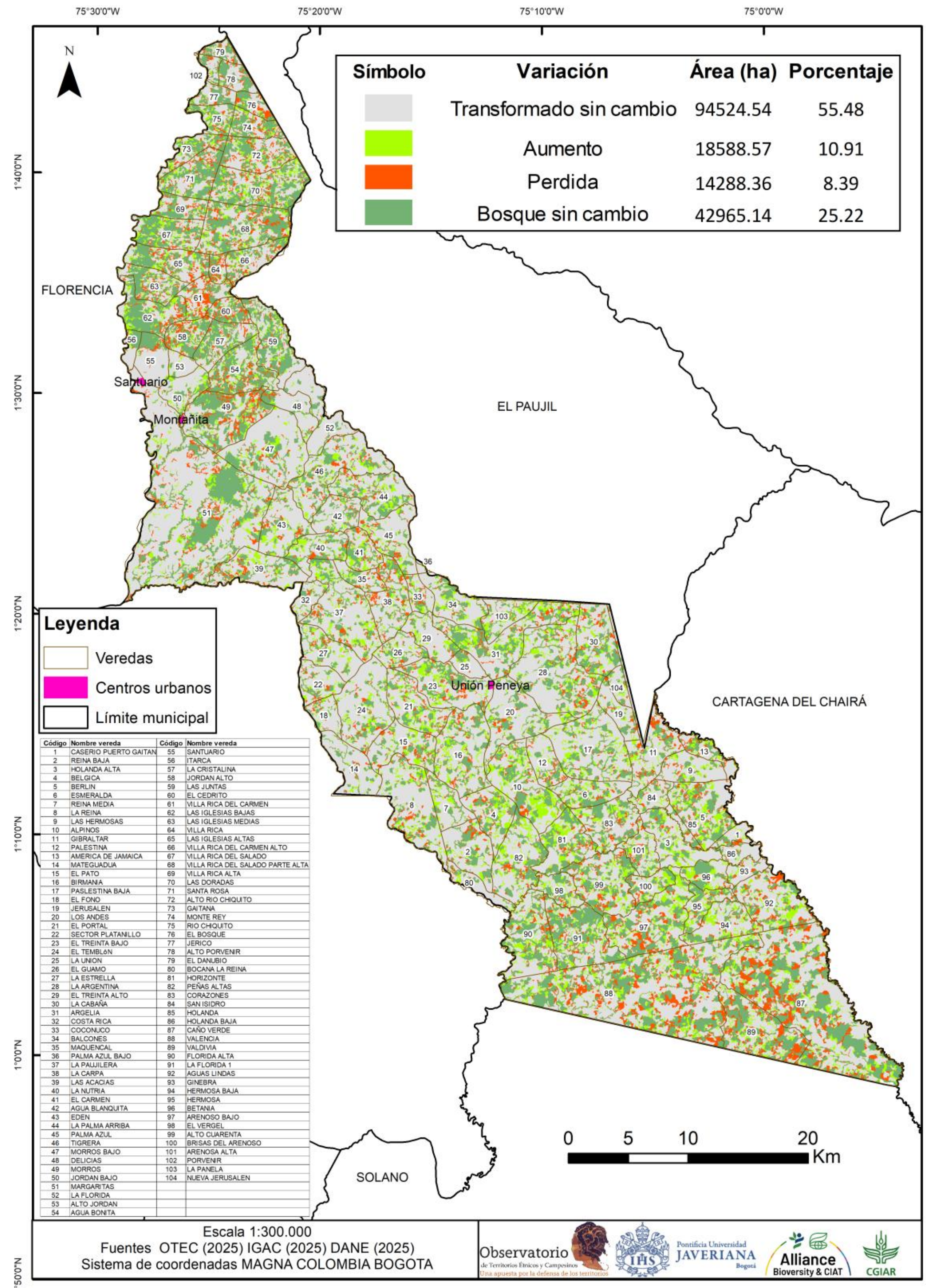
Natural vegetation covered 33.6% of the municipality's total area in 2015 (57,245.1 hectares) and increased to 36.2% in 2025 (61,554.6 hectares), representing a net gain of 2.6% (4,309.5 hectares). This increase corresponds with a decrease in pastureland and cropland areas over the same period (Figure 2). However, the largest proportion of transformed land (pastures and crops), 55.48%, remained unchanged during the period.

Regarding specific biophysical units, the loss of natural vegetation in relation to the biophysical units was 7.7% of the *lomerío* area (9,877.783 ha), 12.5% (2,321.489 ha) in the mountain region, 7.8% (1,006.879 ha) in the valleys and 10.2% (1,065.959 ha) in the piedmont, which indicates that the mountain zone has experienced the greatest loss of natural vegetation cover which increases vulnerability to natural disasters such as landslides and avalanches.

With respect to the presence of **extractive industries**, the National Mining Agency (Agencia Nacional de Minería - ANM) has granted two mining titles for the extraction of construction materials, including clayey sands, gravel, limestone rock or stone, industrial sands, and siliceous gravels, among others that cover 86.6 hectares. Additionally, the agency records twelve pending mining requests for the extraction of materials such as construction aggregates, asphalt, coal, iron, nickel, gold, industrial sands, clays, and siliceous gravels, which together amount to 1,601.4 hectares

Regarding oil exploration and exploitation, the National Hydrocarbons Agency (Agencia Nacional de Hidrocarburos – ANH) reports that, as of 2024, a total area of 31,670.9 hectares in the municipality of Montañita has been assigned to the British company EMERALD ENERGY for exploration. This represents 18.6% of the municipality’s total territory. The remaining 81.4% of the municipality's area, equivalent to 138,702.9 hectares, is reported as "available" for potential allocation.

Figure 2. Changes in Forest Cover 2015-2025



Símbolo	Variación	Área (ha)	Porcentaje
	Transformado sin cambio	94524.54	55.48
	Aumento	18588.57	10.91
	Perdida	14288.36	8.39
	Bosque sin cambio	42965.14	25.22

Código	Nombre vereda	Código	Nombre vereda
1	CASERIO PUERTO GAITAN	55	SANTUARIO
2	REINA BAJA	56	ITARCA
3	HOLANDA ALTA	57	LA CRISTALINA
4	BELGICA	58	JORDAN ALTO
5	BERLIN	59	LAS JUNTAS
6	ESMERALDA	60	EL CEDRITO
7	REINA MEDIA	61	VILLA RICA DEL CARMEN
8	LA REINA	62	LAS IGLESIAS BAJAS
9	LAS HERMOSAS	63	LAS IGLESIAS MEDIAS
10	ALPINOS	64	VILLA RICA
11	GIBRALTAR	65	LAS IGLESIAS ALTAS
12	PALESTINA	66	VILLA RICA DEL CARMEN ALTO
13	AMERICA DE JAMAICA	67	VILLA RICA DEL SALADO
14	MATEGUADUA	68	VILLA RICA DEL SALADO PARTE ALTA
15	EL PATO	69	VILLA RICA ALTA
16	BIRMANIA	70	LAS DORADAS
17	PASLESTINA BAJA	71	SANTA ROSA
18	EL FONO	72	ALTO RIO CHIQUITO
19	JERUSALEN	73	GAITANA
20	LOS ANDES	74	MONTE REY
21	EL PORTAL	75	RIO CHIQUITO
22	SECTOR PLATANILLO	76	EL BOSQUE
23	EL TREINTA BAJO	77	JERICO
24	EL TEMBLóN	78	ALTO PORVENIR
25	LA UNION	79	EL DANUBIO
26	EL GUAMO	80	BOCANA LA REINA
27	LA ESTRELLA	81	HORIZONTE
28	LA ARGENTINA	82	PEÑAS ALTAS
29	EL TREINTA ALTO	83	CORAZONES
30	LA CABAÑA	84	SAN ISIDRO
31	ARGELIA	85	HOLANDA
32	COSTA RICA	86	HOLANDA BAJA
33	COCONUCO	87	CAÑO VERDE
34	BALCONES	88	VALENCIA
35	MAQUENCAL	89	VALDIVIA
36	PALMA AZUL BAJO	90	FLORIDA ALTA
37	LA PAUJILERA	91	LA FLORIDA 1
38	LA CARPA	92	AGUAS LINDAS
39	LAS ACACIAS	93	GINEBRA
40	LA NUTRIA	94	HERMOSA BAJA
41	EL CARMEN	95	HERMOSA
42	AGUA BLANQUITA	96	BETANIA
43	EDEN	97	ARENOSO BAJO
44	LA PALMA ARRIBA	98	EL VERGEL
45	PALMA AZUL	99	ALTO CUARENTA
46	TIGRERA	100	BRISAS DEL ARENOSO
47	MORROS BAJO	101	ARENOSA ALTA
48	DELICIAS	102	PORVENIR
49	MORROS	103	LA PANELA
50	JORDAN BAJO	104	NUEVA JERUSALEN
51	MARGARITAS		
52	LA FLORIDA		
53	ALTO JORDAN		
54	AGUA BONITA		

In the municipality of Montañita, the most common **types of land ownership** are medium-sized rural properties, which cover 49.9% of the territory, and smallholdings (microfundios), which account for 26.4%. According to the Rural Agricultural Planning Unit (UPRA, 2016), this type of land fragmentation can limit the productivity and profitability of rural families—unless there are strong community organization, producer associations, or cooperative networks such as Agrosolidaria.

The **climate-related susceptibility** and hazards faced by the municipality are directly linked to the increasing occurrence of natural events such as landslides, water erosion, slow-onset flooding, and flash floods. These phenomena are associated with rising rainfall intensity, the advanced degradation of ecosystems, and geomorphological characteristics of the territory, such as steep slopes and parent materials like sand, gravel, and clay.

The cartographic analysis (Herrera et al, 2025) demonstrated that the mountainous sector in the north and the piedmont of the mountain range present a very high hazard level covering 4.4% of the area, and a high hazard level covering an additional 3.7%. In general, the greatest impacts are observed in canyon-like areas, influenced by rock substrate faulting and by the removal of natural vegetation cover (through logging and burning). On lower and sloped hillsides, hydric erosion—including sheet erosion, rill erosion, and in some areas, gully erosion—is also common. These processes are intensified by the dominant land-use pattern of extensive cattle ranching. Runoff and soil particle displacement increase significantly during periods of heavy rainfall (IGAC, 2020). Deforestation, the planting of pasture grasses, and livestock grazing on these slopes further accelerate moderate erosion processes.

Flash floods or avalanches and slow-onset flooding are also recurring threats for the intermediate alluvial valleys and the large lowland valleys located within the Amazonian depression. The heavy rains that characterize the region drastically increase the flow of the hydrographic network, which, as it descends into the eastern plains, lead to flooding, especially in floodplains, low terraces, and concave depressions with wetlands and canangucha palm swamps (Alcaldía de Montañita, 2018).

The participatory workshop and mapping exercise enabled a deeper understanding of climate vulnerability as a structural phenomenon, aligning with the concept of deep vulnerability proposed by Hurlbert et al. (2023). In La Montañita, exposure to extreme events—avalanches, prolonged droughts, landslides, and intense wind phenomena—interacts with a very limited adaptive capacity. This limited capacity is the result of institutional neglect, fragmented governance, and the absence of preventive risk management systems.

The avalanche that occurred between May 17 and 18, 2022, illustrates this structural vulnerability. Triggered by several continuous hours of intense rainfall, the event drastically altered the geomorphology of the riverbed, completely destroyed a home, and left a family without a means of livelihood. The institutional response was inadequate and misaligned, revealing a significant gap between the real extent of the damage and the official records of affected individuals. According to participants, political clientelism and corruption in the distribution of aid deepened existing inequities, leaving the direct victims without support.

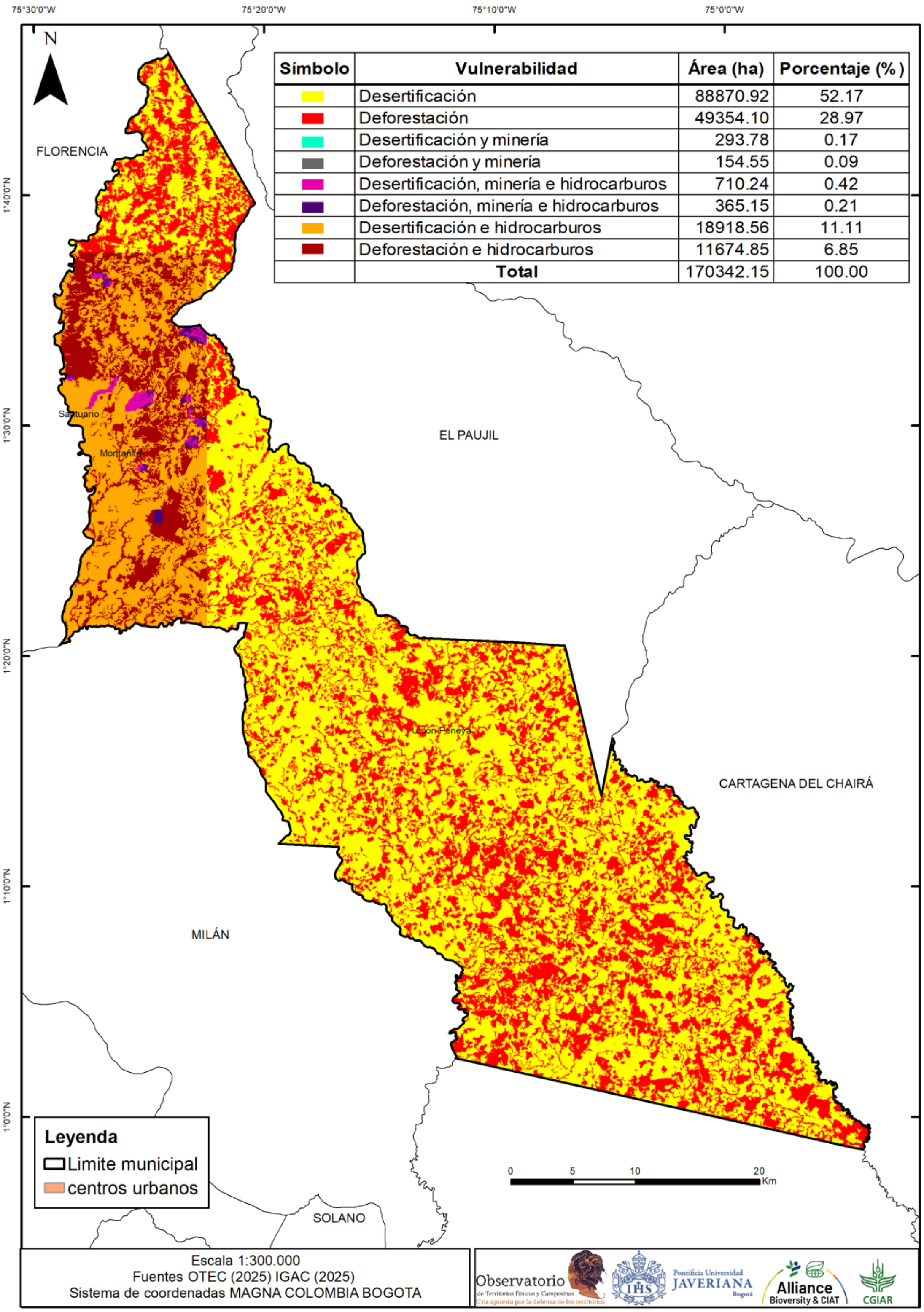
This forced abandonment, driven by the inability to rebuild or the fear of future events, constitutes a form of climate-induced forced displacement. Unlike displacement caused by armed conflict, this type of displacement remains institutionally invisible and lacks formal mechanisms for recognition, assistance, or reparation (Gambiwa & Sibanda, 2025). The combination of biophysical factors – including rugged topography, water-saturated soils, deforestation, and livestock expansion – amplifies the risks of landslides and ground failure. This highlights the urgent need to integrate climate risk information into territorial planning and sustainable production systems.

The recurrence of droughts associated with the El Niño phenomenon—with periods of up to 30 days without rain—represents the most frequent and persistent climate threat. These droughts affect productive systems differently: in extensive livestock farming, they cause weight loss in cattle and increase pressure on new forested areas, while in crops such as *sacha inchi*, they pose a critical limitation due to the crop's high sensitivity to water deficits (Ruiz-Vásquez et al., 2022). Together, these events reveal a recurring pattern of climate vulnerability, where impacts are intensified with each new episode due to the lack of recovery processes and institutional learning regarding adaptation to climatic events.

Finally, to explore future climate vulnerability, we developed a **socio-ecological scenario** for the municipality, based on projected climate change impacts for the Amazon region, as outlined by Flores et al. (2024). This analysis integrated data layers on forest cover, transformed areas, mining, and hydrocarbons (Figure 3). Our findings indicate that 63.87% of the municipality's territory is vulnerable to desertification processes, driven by forest loss, erosion, rising temperatures, and increased fire risk (Flores et al., 2024). Within this percentage, 12% (5,071.93 ha) is also at risk of environmental degradation due to mining and oil exploration activities.

On the other hand, the 36.2% of current forested areas, which represent the local adaptive potential to climate change, are also vulnerable to deforestation caused by the expansion of the agricultural frontier—particularly due to the absence of state regulations protecting forest remnants. In addition, 4,064.85 hectares of forest (7%) are at risk of being lost or degraded due to the expansion of extractive (mining and energy) activities.

Figure 3. Socio-ecological conflicts and vulnerability to mining, hydrocarbons, deforestation, and desertification



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5. Identification of community-led adaptation conditions and potential

5.1. Local adaptation capacities

The territory's adaptive capacity is severely weakened by the complete absence of preventive mechanisms, contingency plans, community emergency funds, and climate response protocols. Participants described a context that operates exclusively in reactive mode – actions are taken only during or after extreme events, with no prior preparation or institutionalized learning afterward.

This reality directly contradicts the principles of adaptive risk management outlined in the Sendai Framework for Disaster Risk Reduction (Hurlbert, 2017). The lack of community emergency plans means that rural populations face extreme climate events without basic information on evacuation procedures, shelter options, safe routes, or access to emergency aid—leading to avoidable human and economic costs.

In the absence of institutional support, local residents have developed minimal individual prevention strategies, mostly based on personal experience of past disasters. While these actions demonstrate some level of individual learning, they also contribute to the individualization of climate risk, creating unequal vulnerability: families with greater economic resources can afford to relocate, while poorer households remain trapped in high-risk areas.

The community's heavy reliance on NGO-led and internationally funded projects further reinforces this fragile adaptive system. While such initiatives promote agroforestry, ecological restoration, and bioeconomy practices, their temporary nature and dependence on external funding limit their long-term sustainability (Andrade et al., 2018).

Table 1. Climate vulnerabilities and adaptation capacities, by threat

Event	Perceived Frequency	Severity	Exposed Population	Current Response Capacity
Avalanches	Low (extreme events)	Very high	Foothill villages (approx. 15–20)	Very low – no early warning systems
Strong Winds	Emerging (2 recent events)	High	Regional (across multiple municipalities)	None – no protocols in place
Droughts (El Niño)	Medium–High (every 3–7 years)	Medium–High	Entire territory	Low – limited to small-scale/manual irrigation
Landslides	Medium	Medium - High	Mountainous areas	Very low – no risk mapping
Flooding	Low - Medium in floodplains	Medium	Flat riparian zones	Medium – based on local knowledge

Source: Authors' elaboration

5.2. Agroecological resilience assessment[3]

To pilot the proposed 16-dimension field assessment tool for evaluating sustainability and resilience transitions, a technical visit and participatory diagnosis were conducted on a 4-hectare farm located in the village of *Aguabonita* (La Montañita, Caquetá). The assessment yielded an overall average score of 2.58 out of 5, placing the farm in a general condition of "In transition."

The farm demonstrates a clear trajectory toward agroecological transition, with advances in management practices and the establishment of vegetative components. Key strengths identified include pest and disease management (3.75), gardens and orchards (species diversity and use) (3.75), and conservation tillage (3.5). The weakest dimensions were seed banks (1.0), crop rotation (1.5), and animal diversity (2.0).

The farmer also shows a commitment to maintaining the transition through minimal use of synthetic inputs and the utilization of locally available resources. However, the diagnosis revealed critical gaps that hinder system stability and the pace of improvement, particularly in areas such as planned crop rotation, seed banking/management, permanent ground cover, and slope management.

The critical areas to consolidate the transition are:

- Soil and cover: reduce bare soil, increase organic matter and regularity of management (mulch, green manure, compost/bioles, barriers).
- Functional diversification: increase useful and multi-layered diversity (food, fruit trees, medicinal and multipurpose native plants) and their spatial arrangement.
- Seeds and autonomy: organize seed banks, selection/storage, and exchange/renewal protocols.
- Risk management: strengthen measures against droughts/summers, runoff points, and slope stability (simple works and maintenance).

A feasible farm-level implementation plan to improve resilience, based on the agroecological assessment, includes:

[3] For a complete analysis of the agroecology resilience assessment see: Fundación Ancestral (2025) *Diagnóstico rural participativo sobre el uso de la agrobiodiversidad y su potencial de adaptación y resiliencia. Co-diseño de la agenda comunitaria de Investigación-acción en el municipio de La Montañita, Caquetá.*

Timing	Action	Responsible	Monitoring indicator
0-3 months	Install/strengthen mulch coverage and reduce bare soil in exposed areas; prioritize areas with runoff.	Family + technical assistance	Ground cover increases (visual estimate/photos) and localized runoff decreases.
0-3 months	Define minimum rotation/planting schedule and basic records (tasks, inputs, pests, yield).	Family + technical assistance	Calendar and active record (notebook/forms) per cycle.
0-3 months	Design and initiate seed bank protocol (selection, drying, storage, labeling).	Family + producer organization	Existence of bank (labeled containers) and list of varieties.
0-3 months	Scale up and improve pests and disease management practices.	Family + technical assistance	Incidence of pests/diseases (simple record).
3-6 months	Establish green manure/legumes and compost/bioles according to availability; integrate stubble management.	Family + technical assistance.	At least one batch of green manure; compost bin/biol in use.
3-6 months	Complete hedges/barriers at critical points and define a plan for replacement/pruning.	Family	Critical sections completed; replacement recorded.
3-6 months	Intervene on hillside points: living/dead barriers, simple infiltration ditches where applicable.	Family + technical assistance	Less furrow formation; evidence of erosion/runoff at critical points (before/after).
6-18 months	Functional diversification enrichment (fruit trees/medicinal plants/native plants).	Family + technical assistance	Increase in the abundance of useful species, Survival of new plantings.

Source: Authors' elaboration

Observations on evidence and photographic records: It is recommended to maintain fixed photo points (at least 4 per property: panoramic view, main plot, critical soil/water area, and enrichment area) for before/after comparisons and verification of actions.

5.3. Adaptation strategies

The implementation of productive systems based on sacha inchi (*Plukenetia volubilis*) has been integrated into sustainability initiatives due to its adaptability to tropical conditions, growing market demand, and suitability within agroforestry schemes that help reduce pressure on forests. Although ecological restoration requires process-based approaches—such as the recovery of ecosystem functions, soil stability, and natural regeneration—agroforestry systems can contribute to these goals by improving landscape structure and enhancing ecological connectivity (Chazdon, 2014; Society for Ecological Restoration, 2004). The incorporation of perennial crops like sacha inchi supports productive diversification and strengthens community strategies for the sustainable use of territory.

The analysis presented in this section is based on primary data collected in the field through two case studies located in the municipality of La Montañita, Caquetá: (i) a productive system of sacha inchi (Plukenetia volubilis) established in the village of Los Morros, and (ii) a passive ecological restoration initiative in the village of El Alto Jordán.

The evidence comes from direct field observations, technical records, and community-based support processes. Data on production yields, replanting rates, pest incidence, and management and conservation practices are drawn from both primary and secondary sources, specifically the technical report prepared by the agroecological engineer from Agrosolidaria La Montañita, who leads the monitoring of the sacha inchi cultivation program.

This report is based on 117 technical assistance visits conducted between March and July 2025 with program beneficiaries. This level of follow-up provides strong empirical grounding for the analysis and allows for a systematic evaluation of vulnerability levels, adaptive capacity, and socio-ecological governance in the face of climate change impacts.

5.3.1. Adaptation strategies based on sacha inchi cultivation

In the case of *Sacha Inchi* cultivation, agroecological strategies are clearly reflected in the diversity of perennial, annual, and tree crops, as well as in practices such as integrated cropping, fallow conservation, and the use of organic inputs. Together, these actions aim to strengthen the functional stability of the agroecosystem, reduce production risks, and support adaptation to climate variability. This approach aligns with the core principles of agroecology and socio-ecological resilience (Altieri, 1999; Gliessman, 2015; Folke et al., 2010). Sacha inchi is cultivated in agroforestry systems (AFS) that complement this agroecological arrangement with other practices such as preparation and use of organic fertilizers, productive diversification, mulching with crop residues (rastrojo), seeds bank, technical pruning and phytosanitary management, planting according to lunar phases, and biocontrol preparations (garlic, urine.

Productive seasonality and the coexistence of species with different phenological cycles increase the ecological stability of agroecosystems by spreading production risks over time and reducing the likelihood of simultaneous failures in the face of climatic and biotic disturbances (Altieri, 1999; Gliessman, 2015). However, this same temporal heterogeneity can create critical periods of vulnerability, particularly when certain phenological stages coincide with population peaks of pests. This underscores the need for adaptive management approaches based on ongoing monitoring and prevention. At the same time, socio-ecological conflicts linked to extreme weather events, the presence of wildlife (such as jaguars), and pressures on crops must be understood as outcomes of interactions among multiple actors and scales. In this context, the system's ability to adapt depends heavily on collective response capacity and institutional design, in line with the governance frameworks of socio-ecological systems (Berkes, 2009; Ostrom, 2009).

Despite its potential, the Sacha inchi project recorded an initial failure rate of 68%, which required complete replanting in 36 out of the 53 participating farms. These figures highlight a structural vulnerability of the crop to climate variability, particularly during prolonged droughts in the establishment phase. However, this outcome cannot be attributed solely to extreme climatic events; rather, it reflects the interaction between climatic exposure, ecological sensitivity of the production system, and limited adaptive capacities. This aligns with contemporary frameworks of climate vulnerability (IPCC, 2022; Adger, 2006), which emphasize that vulnerability emerges from the combined effect of exposure, sensitivity, and adaptive capacity.

Sacha inchi's sensitivity to water and nutrient deficits during its early developmental stages is significantly affected when agroecosystems lack vegetative cover, adequate organic matter, and consistent technical support. Although the incidence of pests is relatively low - 0.35% caused by insects and 0.48% by nematodes – it is important because they are associated with plants already weakened by water stress. This creates negatively reinforcing cycles, where climate change amplifies phytosanitary vulnerability (Khanal et al., 2023). This pattern is well-documented in tropical agroecosystems under climate stress, where the loss of ecological functionality reduces the self-regulating capacity of the system (Altieri & Nicholls, 2017; Folke et al., 2016).

In this context, the role of sacha inchi as a strategy for sustainable productive diversification is both ambiguous and strategic. On one hand, the accumulated production of 4,578 kg over six months, generated by 7,360 plants older than seven months, demonstrates that the crop has real economic potential once it surpasses critical establishment thresholds. On the other hand, the significant monthly fluctuations in production—from 1,352 kg in March to just 381 kg in August—reflect both climatic seasonality and phenological desynchronization caused by staggered replanting. However, this productive variability can be interpreted as a basic form of climate risk management, as it avoids the temporal concentration of losses during extreme events—aligned with the principles of functional diversification promoted by agroecology (Gliessman, 2015).

The agroecological management practices implemented have proven to be one of the main success factors. The production of 2,448 kg of compost through the **biofactory at Agrosolidaria La Montañita** not only has reduced dependence on external inputs, but also improves soil structure, increases water retention, and strengthens the agroecosystem's resilience during droughts. The use of organic mulching at the base of plants acts as a thermal and moisture buffer, reducing evapotranspiration and protecting root systems during dry periods. These practices are complemented by the **conservation of 187.25 hectares of primary forest**, which provide key ecosystem services such as microclimate regulation, biological control, organic matter supply, and hydrological stability. Together, they support ecosystem-based adaptation (EbA), widely recognized as a cost-effective strategy for climate resilience (Locatelli et al., 2015; Reid et al., 2019).

One of the most relevant findings is that the adaptive capacity of the system was highly dependent on **technical support and social learning**. The 85% compliance rate with technical recommendations among beneficiaries who received systematic follow-up, versus abandonment and failure in farms without consistent assistance, confirms that knowledge sharing – rather than biophysical conditions alone – was the main driver of productive resilience. The 117 technical visits reported in the *Agrosolidaria Technical Report* over five months enabled the consolidation of integrated management practices – including pruning, organic fertilization, weed control, and harvesting – demonstrating that climate adaptation in family farming systems is fundamentally a social and institutional process (Pahl-Wostl, 2009; Berkes & Ross, 2013).

However, structural barriers persist that limit effective adaptation. The ratio of one technical assistant for every 77 beneficiaries creates a bottleneck for adaptive governance, reducing the frequency and depth of support needed for iterative adjustments in response to climate variability. In addition, the lack of irrigation infrastructure, local climate information systems, and response protocols for droughts or excess rainfall severely restricts producers' capacity to anticipate and respond to climatic events (FAO, 2018; Tendall et al., 2015).

5.3.2. Adaptation strategies around passive restoration

The second case involves an ecological restoration process in the village of Alto Jordán, led by a farmer and community leader participating in a program coordinated by the Amazonian Institute of Scientific Research (SINCHI). On his 10-hectare farm, 4 hectares have been allocated to passive ecological restoration for approximately one year. This initiative was launched following a landslide in 2022 that severely damaged road infrastructure and prompted the abandonment of several nearby farms.

The initial decision to "let the land rest" allowed for the activation of natural regeneration processes, which were later strengthened by institutional support focused on fencing the restored area and excluding livestock. This practice is widely recognized as a key enabling condition for the recovery of degraded ecosystems in tropical rural landscapes (Chazdon, 2014; Holl & Aide, 2011).

The restoration program implemented in the region currently benefits 100 community stewards in the *Santa Rosa* hub and 100 stewards in *Alto Jordán*, under a system of economic incentives based on activities completed. This approach uses locally led restoration and sustainable livelihoods as a foundation (Aronson et al., 2020). Actions carried out include:

- Installation of acclimatization beds for seedlings (chapolas) adapted to local conditions
- Progressive transplanting of young plants
- Physical isolation of restoration areas using 133 wooden stakes and wire fencing, which reduces direct human pressure and prevents livestock intrusion, facilitating secondary succession

Each participant receives approximately 20 million Colombian pesos, helping offset opportunity costs related to the temporary removal of land from production—a key factor for ensuring the social sustainability of restoration processes (Meli et al., 2017). The stewards, including the farmer mentioned earlier, underwent 20 days of intensive training in the city of *Florencia*. This training combined technical and practical content on passive restoration, forest enrichment, and preparation of organic fertilizers.

The program's approach integrates passive restoration, enrichment with native species, and restorative agroforestry systems. Producers are allowed to designate up to one hectare for agroforestry arrangements that combine crops like cacao with native timber species such as: cedro (*Cedrela odorata*), caoba (*Swietenia macrophylla*), abarco (*Cariniana pyriformis*), roble (*Tabebuia rosea*), cativo (*Prioria copaifera*), espavé (*Anacardium excelsum*), canalete (*Jacaranda copaia*), and palo de leche (*Rauvolfia nitida*).

These combinations follow ecological and functional compatibility criteria. Such systems have been well-documented as effective strategies for reconciling ecological recovery, productive diversification, and climate resilience in disturbed Amazonian landscapes (Brancalion et al., 2019; IPBES, 2019).

Early signs of success are evident. According to the farmer, *"approximately 90% of the families visited are actively carrying out the agreed-upon activities"*. Additional indicators include:

- Noticeable increase in vegetation cover
- Improved soil conditions
- Gradual return of local biodiversity

At the territorial level, the program aims to benefit nearly 4,000 families, contributing to restoration of degraded areas and climate change mitigation through improved ecological connectivity, microclimate regulation, and recovery of key ecosystem functions in a regional context characterized by transitions in land use from coca cultivation to livestock farming and the need to recover degraded soils. Community-led ecological restoration is a central component of ecosystem-based adaptation strategies, especially in highly vulnerable rural contexts (IDEAM, 2023; World Resources Institute, 2023).

At the farm-level, a diagnosis was implemented, that combined an evaluation of restoration and management practices—rated on an ordinal scale (0–3)—with the measurement of biophysical and social sustainability indicators, establishing an operational baseline for the process. Using these indicators, the **Rapid Restoration Progress Index (RRPI)** was calculated to classify the farm's restoration trajectory and guide the prioritization of actions[4]. The results were then translated into recommendations framed within an adaptive management approach, with actions prioritized according to their time horizon and linked to verifiable indicators.

The results indicate a favorable restoration trajectory currently in the intermediate phase, with notable progress in vegetation cover and structural development. However, the system still exhibits medium-low resilience due to key bottlenecks, including insufficient control of stressors (such as livestock, fire, and invasive species), limited soil recovery (in terms of ground cover, moisture retention, and organic matter), and gaps in social sustainability (notably in community agreements and monitoring practices like logbook use). The Rapid Restoration Progress Index (IRPR), which serves as the operational baseline, stands at 52.8 out of 100. This reflects a transitional state with high potential for improvement—provided that a minimum adaptive management package is implemented within the next six months.

- Install effective control of stressors (livestock fencing, fire prevention, early management of invasive species).

[4] For a detailed analysis of the restoration assessment see: Fundación Ancestral (2025) *Diagnóstico rural participativo sobre el uso de la agrobiodiversidad y su potencial de adaptación y resiliencia. Co-diseño de la agenda comunitaria de Investigación-acción en el municipio de La Montañita, Caquetá.*

- Activate soil support (cover/mulch, moisture conservation, biomass input).
- Formalize social support (roles, agreements, and restoration log) to ensure continuity.
- Reinforce maintenance and replacement to achieve survival >=75% and improve vigor.

To complement the qualitative data, we analyzed the municipality's adaptive potential exploring the ecological restoration processes of riparian buffer zones (Figure 4). These processes are essential for maintaining key ecosystem services, such as water retention and regulation. To conduct the analysis, we used data from the **priority areas for restoration in riparian zones** across the Amazon region—developed by the Instituto SINCHI and current as of 2024. This dataset is based on the intersection of watercourses, slopes, and land cover relative to the municipal boundaries.

The land cover data were reclassified into five intervention levels, based on the degree of transformation of areas prioritized by SINCHI. The classification is as follows:

- Class 1 – Very Low Intervention Need: Areas capable of regenerating passively. Includes secondary vegetation and fragmented forest.
- Class 2 – Low Intervention Need: Includes mosaics of pasture, crops, and natural spaces.
- Class 3 – Moderate Intervention Need: Includes weedy pasturelands.
- Class 4 – High Intervention Need: Includes mosaics of pasture, crops, and tree-dotted pastures.
- Class 5 – Very High Intervention Need: Includes bare soils, burned areas, and clean pastures, which require intensive ecological restoration to recover.

Key Findings:

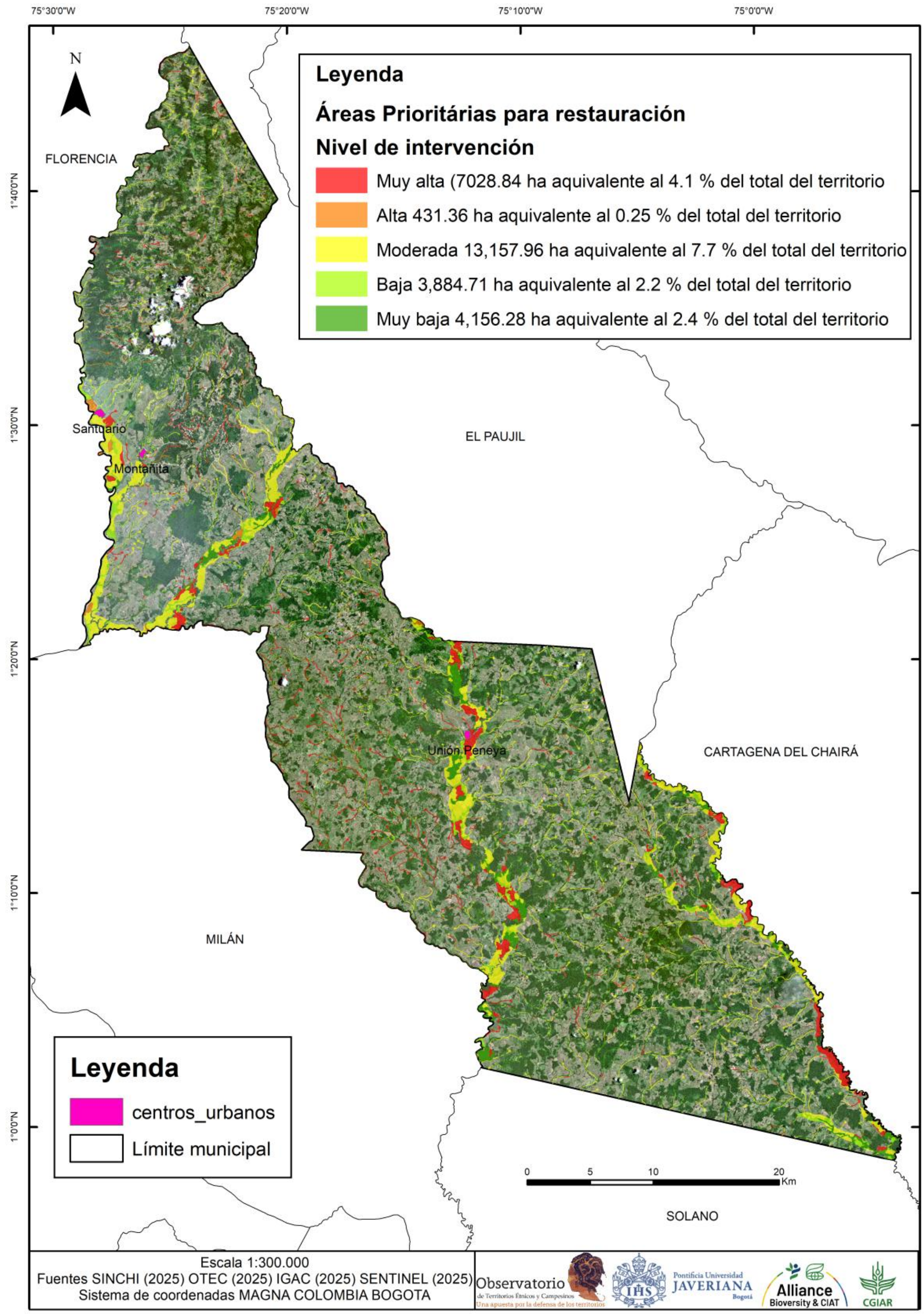
The adaptive potential through ecological restoration applies to 16.65% of the municipality's total area (28,659.15 ha). Of this area:

- 45.9% corresponds to moderate intervention level.
- 24.5% to very high intervention level.
- Only 1.5% falls under the high intervention category.

This means that approximately 6,872.7 hectares require intensive restoration efforts at the municipal level. The remaining 28.1% (13.6% low priority + 14.5% very low priority), or about 4,020.49 ha, could be restored through passive regeneration processes.

This analysis provides critical insight for targeting restoration efforts and guiding local adaptation strategies under changing climate conditions.

Figure 4. Socio-ecological conflicts and vulnerability to mining, hydrocarbons, deforestation, and desertification



5.4. Adaptive governance

Participatory mapping confirms that territorial governance in La Montañita follows an emerging model of hybrid governance, typical of Amazonian frontier regions (Milhorance & Bursztyn, 2018). In this context, non-state actors—such as NGOs, international cooperation agencies, and producer organizations—take on roles of regulation, capacity-building, and incentive provision that would traditionally fall under the responsibility of the State.

While this configuration has enabled progress in areas like ecological restoration, silvopastoral systems, and social learning, it has also created structural dependence on external funding and support. This reliance weakens local institutional capacities and fosters power asymmetries that limit the adaptive autonomy of communities. The sustainability of these initiatives after the withdrawal of external actors remains a central concern.

The Junta de Acción Comunal (Community Action Board) illustrates the weaknesses of collective action institutions described by Ostrom (2009). Although it maintains a formal role in local governance, its actions are largely reactive and lack clear, stable rules for the management of common resources. Inconsistent rule changes—such as the relaxation of forest protection regulations—have eroded institutional legitimacy and enabled widespread deforestation.

Moreover, a significant disconnect exists between municipal institutional efforts and community perceptions. Although areas have been designated as Civil Society Reserves, these actions remain largely invisible to the rural population, revealing serious shortcomings in institutional communication and trust-building (Lampis & Rubiano-Galvis, 2020).

These factors shape a socioecological system undergoing a critical transition—where fragmented decision-making, weak land-use planning, power asymmetries, and the absence of multi-scalar adaptive governance reinforce patterns of vulnerability and environmental degradation (Ostrom, 2009; McGinnis & Ostrom, 2014).

6. Towards the construction and scaling-up of community adaptation capacities

6.1. SWOT analysis

We integrated the results from the participatory workshops with prior diagnoses conducted within the framework of the CGIAR Climate Action Program projects (Clavijo et al., 2024; Maya et al., 2024), in order to identify the key strengths, weaknesses, opportunities, and threats (SWOT) that shape the local community's resilience and adaptive capacity. The following table presents the SWOT analysis, which is then described in detail by thematic dimensions.

Strengths	**Weaknesses**
• Community recognition of the ecosystem value of Amazonian forests. • Implementation of local practices aimed at ecological restoration. • Diversified productive systems, with increasing adoption of agroecological practices such as biological pests' management and fertilization and minimum tillage. • Active network of community organization that includes producer associations, women's groups and spaces for collective coordination and dialogue. Local associations also play a key role in commercialization. • High levels of reflexivity by farmers to analyze historical changes on their farms, the impacts of their productive decisions, and the expectations regarding future transformation processes. • Basic infrastructure at a community level such as local sales points, associative spaces, and emerging productive equipment.	• High levels of ecosystem transformation, particularly through the conversion of forests into pastures. • High levels of soil degradation, high acidity and low natural fertility. • Weak food sovereignty and security. • Absence or incipient nature of seed banks and seed management, which reduces autonomy and resilience. • Gaps in water collection, storage, and source protection, which become especially critical during prolonged dry seasons. • Limited participation of the youth in productive systems. • Low productivity and profitability of predominant productive systems. • High production costs and lack of financial literacy. • Lack of property and community infrastructure for processing, storage, and marketing. • Low access to stable, larger and/or more specialized markets. • Weak relations with local and regional government agencies.
Opportunities	**Threats**
• Short commercialization circuits, local farmers' markets and fairs. • Favorable context for the development of value-chains based on Amazonian products. • Potential to develop agroecological territorial brands, strengthen direct commercialization, and connect with rural tourism and agrotourism initiatives. • Existence of climate funding mechanisms and projects aimed at ecological restoration. • Potential to build and strengthen community processes of recovery of seeds, ancestral knowledge, and diversified agricultural practices.	• Ongoing presence of illegal economies and armed groups. • Price volatility in agricultural products, affecting income stability. • Persistence of economic incentives that favor environmentally unsustainable production models. • Rising climate variability, manifested through severe droughts and intense rainfalls. • Deficient network of roads and other rural infrastructure. • Institutional threats, such as the discontinuity of technical assistance and regulatory restrictions resulting from the location of farms within forest reserve zone. • Outmigration of young people.

Source: Authors' elaboration

Environmental dimension

Regarding the strengths, there is a widespread recognition of the ecosystem value of Amazonian forests, both for the provision of environmental services and for the sustainability of productive systems. Likewise, community-led practices aimed at ecological restoration, such as reforestation of water sources, creation of nurseries with native species, and the reduction of harmful practices like burning and deforestation. In addition, there is evidence of cumulative local knowledge on agroecological practices such as crop rotation, the use of bio-inputs, and the gradual reduction of agrochemicals. This contrasts with the high levels of ecosystem transformation and the low adoption of agroforestry and silvopastoral systems.

The most critical factor identified is the absence or underdevelopment of seed banking and management, which significantly limits productive autonomy and the system's recovery capacity in the face of adverse events. Therefore, it is recommended to implement **protocols for the establishment of germplasm banks**, along with training in seed selection, drying, and proper storage techniques. Additionally, it is suggested to promote **community-based strategies for seed exchange and genetic material renewal**, in order to strengthen agroecological resilience at both farm and territorial levels.

Preventive biological control of pests and diseases stands out as a key strength, as it reduces dependence on external inputs and promotes ecological stability. Composting and organic soil management, although still in early stages, contribute to improving soil structure and moisture retention, gradually decreasing the need for external fertilizers. Regarding water security, there are still gaps in water collection, storage, and source protection, which become especially critical during prolonged dry seasons.

In addition, significant environmental constraints persist, such as high levels of soil degradation, elevated acidity, and low natural fertility. The "water knot" emerges as an enabling condition for almost everything else. Gaps in rainwater harvesting, storage, and collection increase the risk of shortages for both household consumption and garden maintenance during the dry season. As discussed throughout the document, increasing climate variability – manifested in severe droughts and intense rainfall – is having a growing impact on producers' well-being, particularly by amplifying the risks of crop loss, landslides and flooding. Therefore, immediate actions are recommended, such as fencing and revegetating watercourses, installing tanks and rainwater harvesting systems, and developing water conservation and management plans.

I n addition, in some of the workshops and interviews emerged that the elimination of practices such as burning and the use of agrochemicals is not primarily driven by increased environmental awareness, but rather by the high cost of inputs. This reveals a structural weakness, as the sustainability of positive environmental practices depends on external economic factors. Consequently, an opportunity lies in deepening training processes that foster a comprehensive agroecological understanding, while the main threat is the potential reversal of practices if input prices or availability change

Social dimension

There is an active organizational network, made up of productive associations, women's organizations, and actors involved in rural tourism, which play a central role in the collective management of the territory. There is a strong participation of women in productive, organizational, and innovation processes.

The workshops in 2025 provided a new relevant qualitative finding: a high level of campesino reflexivity, evidenced by the families' ability to analyze the historical changes on their farms, identify the impacts of their productive decisions, and express clear expectations regarding future transformation processes.

Regarding the weaknesses, there is a perception of insufficient food sovereignty, linked to the historical livestock orientation of farms. There are opportunities to coordinate processes for the recovery of seeds, ancestral knowledge, and diversified agricultural practices, while the main social threat continues to be the discontinuity of participatory processes, which could erode community motivation and commitment.

Limited participation of youth in productive systems, together with the pressures of illegal actors and recruitment to armed groups, reduces generational renewal and long-term sustainability of rural livelihoods. In this context, strengthening female and youth leadership, as well as consolidating organizations as platforms for productive, commercial, and educational services, emerge as key opportunities for territorial development.

Economic / productive dimension

Agri-food systems of Montañita are characterized by an economic reproduction strategy based on income diversification and self-consumption which allows rural households to reduce their dependence on the cash economy and partially buffer the risks associated with agricultural price volatility. In this context, livestock plays an important role as a savings asset and store of value, particularly in times of economic or climatic emergencies. However, in general, these economic systems are characterized by their low productivity and profitability[5], high production costs and dependence on external inputs. In addition, access to credit is low, restricting their ability to invest, renew their production systems and adopt agroecological practices. There is also a weak use of costing tools and financial analysis, which hinders informed economic decision-making and the long-term sustainability of productive initiatives.

There is an increasingly critical view of cattle ranching by the producers themselves, who now recognize it as a high-investment, low-efficiency activity for small-scale farms. This growing awareness represents a strength that could support structural changes in the medium term. However, a key weakness remains the near absence of agricultural product commercialization, as most of the produce is used for self-consumption or non-monetary exchange.

Nevertheless, there are significant economic opportunities to strengthening local production, particularly through the scaling up of agroforestry and silvopastoral systems, as well as the implementation of agroecological innovation pathways, the local transformation of agroecological products, the diversification of productive portfolios (including bio-inputs, processed foods, and dairy derivatives), and the consolidation of territorial agroecological economies that enable greater value capture at the source. These opportunities are threatened by the volatility of agricultural prices, rising production costs, the persistence of economic incentives that favor environmentally unsustainable production models and the increasing climate variability.

In addition, while productive diversification opens up opportunities for small-scale local economies, the main threat is that, without clear marketing strategies, these efforts will not translate into economic improvements and will end up being abandoned. In this regard, the field visit reaffirmed that without improvements in land infrastructure, especially water and post-harvest management, productive diversification loses stability and directly affects income and sustainability. Thus, the economic dimension is structurally linked to environmental findings: when water fails, gardens and surpluses shrink, and the continuity of agroecological practices is weakened.

Institutional dimension

Several farms have begun intentional production diversification processes, incorporating agroecosystems, fruit trees, and beekeeping as complementary or substitute alternatives to livestock farming. This change constitutes a new emerging strength, as it demonstrates the

[5] Productivity in sectors such as cacao and livestock remains below the national average, which is attributed to soil degradation and reduced fertility, weak technical management, and the lack of permanent, specialized technical assistance (Maya et al., 2024).

families' capacity for adaptation and experimentation. However, it also highlights a new technical weakness: the productive transition is taking place without a solid foundation of technical support, which is reflected, for example, in the lack of knowledge of the results of soil analyses carried out in previous projects and the lack of technical criteria for fertility management.

In this sense, there is a clear strategic opportunity to strengthen training processes in practical agroecology, especially in biofertilizer production and soil management, a demand explicitly expressed by workshop participants. The main threat associated with this dimension is that the transition will be limited to isolated and unsystematic efforts if a continuous research-action process is not consolidated.

In terms of institutional support, although there is a growing relationship with academic institutions (universities and research centers) and national-level actors, a key weakness lies in the limited engagement of regional and local government entities—such as the Governor's Office and the Mayor's Office—which have not significantly contributed to the sustainable productive initiatives led by Agrosolidaria families. However, this gap also presents an opportunity: the initiative could position itself as a pilot project for the rest of the department and the Amazon region, offering a model for building sustainable productive systems while promoting environmental restoration.

Infrastructure and markets

In terms of infrastructure, the territory has some basic community-level capacities, such as local sales points, associative spaces, and emerging productive equipment. However, limitations in rural infrastructure remain one of the main bottlenecks for territorial development. There is a significant lack of adequate infrastructure at both the farm and community levels for processing, storage, and commercialization, along with the absence of stable market channels. Additionally, a deficient network of tertiary roads increases transportation costs, restricts market access, and hampers the delivery of technical assistance—particularly during the rainy season. The lack of suitable infrastructure for irrigation, post-harvest storage, processing, and product preservation negatively impacts both the quality and commercial value of agricultural production

In this context, there are clear opportunities for collective investment in strategic community infrastructure, managed by local organizations and designed for multiple uses—productive, commercial, and educational. However, these opportunities are threatened by the physical isolation of rural areas during the rainy season and by regulatory restrictions linked to the location of farms within forest reserve zones, which limit the development of essential infrastructure.

In terms of markets, there are short commercialization circuits, local markets and farmers' fairs that allow for direct product sales and strengthen the ties between producers and consumers. Local associations play a key role as intermediaries in commercialization. However, access to larger and more specialized markets is limited by low production volumes, inconsistencies in quality, poor commercial presentation, and a high dependency on a small number of buyers, which reduces producers' bargaining power (Maya et al., 2024) There is also low visibility, associated with the absence of consolidated local brands, lack of systematic marketing strategies, and limited use of digital tools (Clavijo et al., 2024).

Despite these limitations, the territory presents clear opportunities for the development of agroecological territorial brands, strengthening direct commercialization, and connecting with rural tourism and agrotourism initiatives as complementary sales and positioning channels. These opportunities, however, are threatened by competition from lower-cost industrial products, market saturation in informal sectors, and demand volatility.

6.2. Scaling up adaptation capacities

Based on the results of spatial analysis, participatory social mapping, and farm-level case studies, a community-based climate change adaptation strategy is proposed. The strategy to build and scale-up adaptation capacities is conceived as a progressive bottom-up process that recognizes rural producers as central actors in climate risk management and territorial resilience building.

Rather than emerging as an external normative model, the proposal represents an analytical synthesis of empirical lessons identified in the municipality of La Montañita, where climate vulnerability is expressed differently depending on the biophysical, productive, and institutional configuration of the territory.

Table 2 explicitly links the main vulnerabilities identified in the study with proposed adaptation strategies, allowing for a clear traceability between diagnosis and action. Its construction was guided by four analytical variables: 1) type of predominant vulnerability (exposure, sensitivity, or adaptive capacity); 2) empirical evidence from field data and spatial analysis; 3) adaptation strategy emerging from local practices; 4) predominant scale of intervention.

Community-based adaptation is framed as a *situated response* that seeks to reduce vulnerability not only through technical practices, but also through organizational and territorial transformations. This approach recognizes that climate change impacts are experienced differently depending on the local context, and that effective adaptation must go beyond infrastructure or technology. It must also strengthen: 1) Collective organization and governance, 2) Territorial planning and land use management, 3) Local knowledge and social learning, 4) Community empowerment and autonomy.

Table 2. Link between identified vulnerabilities and community-based adaptation strategies

Identified Vulnerability (Findings)	Empirical Evidence from the Study	Proposed Adaptation Strategy	Scale
High productive sensitivity to droughts	68% initial failure in sacha inchi; early-stage losses	Integrated agroecological package (vegetative cover, organic management, artisanal irrigation)	Farm-level
Differential exposure to extreme events	Risk maps show concentration in foothills and slopes	Farm planning with risk management approach	Farm–Community
Reactive post-event adaptation	Lack of emergency plans and early warning systems	Community-based early warning systems	Community
Fragmented governance	Disconnection between JAC–state–cooperation actors	Organizational strengthening through Agrosolidaria	Community
Pressure on remaining forest cover	Cattle expansion + loss of landscape connectivity	Zero-deforestation agreements + ecological restoration	Territorial

Source: Authors' elaboration

In short, it's about building resilience *from the ground up*, by empowering local actors to lead the design and implementation of solutions that are context-specific, socially inclusive, and ecologically sustainable.

Table 3 organizes the adaptation strategies by scale of intervention, identifying the main actors, the type of action implemented, and its adaptive function within the broader socio-ecological system. The variables used for its construction include:

1. Spatial scale of action (farm-level, community, territorial, and multiscale)
2. Key actors involved at each level
3. Type of intervention (productive, organizational, institutional, or ecosystem-based)
4. Primary adaptive function (reducing exposure, decreasing sensitivity, or strengthening adaptive capacity)

Table 3. Community-based adaptation strategies by scale of intervention

Scale	Main Actor	Type of Action	Adaptive Function
Farm-level	Farming families	Agroforestry with *sacha inchi*, passive restoration, soil management	Reduces climate sensitivity
Community	Agrosolidaria / JAC	Early warning systems, collective landscape management	Reduces exposure
Territorial	Municipality / cooperation	Ecosystem service incentives, farm-level land-use planning	Increases adaptive capacity
Multiscale	Hybrid networks	Social learning and technical support	Facilitates transformative adaptation

Source: Authors' elaboration

This approach demonstrates that climate adaptation does not occur exclusively at the farm level. Instead, it depends on the integration of household practices, community organization, and broader institutional arrangements. Notably, organizational strengthening through Agrosolidaria emerges as a key pillar for coordinating technical assistance, managing resources collectively, and facilitating institutional dialogue. At the territorial level, there are clear opportunities to integrate mechanisms such as ecosystem service incentives, community-led land-use planning, and conservation agreements, which can support and scale up local initiatives.

Finally, Table 4 presents an interpretive framework for understanding the transition from current reactive and incremental adaptation responses to more robust, transformative adaptation processes. Its construction is based on five analytical dimensions: 1) timing of the response, 2) type of intervention, 3) governance configuration, 4) scale of action, 5) sustainability of adopted measures.

Table 4. Transition from reactive responses to transformative adaptation in La Montañita

Dimension	Current situation (diagnosis)	Bottom-up proposal
Temporal scope	Post-event response	Anticipation and prevention
Type of action	Isolated technical measures	Integrated system of practices
Governance	Fragmented	Polycentric and coordinated
Scale	Individual farm level	Landscape and territorial scale
Sustainability	Project-dependent	Anchored in local capacities

Source: Authors' elaboration

While multiple adaptive practices are already underway in La Montañita, they remain largely anchored in reactive, post-event responses, with limited anticipation and a strong dependence on external projects. In contrast, the community-based adaptation approach seeks to consolidate long-term processes grounded in local capacities, social learning, polycentric governance, and integrated landscape management. Although the territory reflects a strong narrative of conservation and restoration, the field visit shows that environmental stability depends on turning that intention into basic ecological infrastructure and on-farm management routines (water, ground cover, erosion control) that can sustain progress in the face of climate extremes.

This case confirms that climate change adaptation in highly transformed Amazonian territories cannot be reduced to isolated technical interventions or farm-level actions disconnected from broader systems. On the contrary, it requires territorial innovation systems that combine agroecology, ecological restoration, smallholder land-use planning, risk management, and multilevel governance.

The bottom-up scaling approach proposed here demonstrates how existing local practices can become pillars of more robust adaptation—as long as the institutional, organizational, and territorial conditions needed to support them are strengthened. Infrastructure, seed banks, post-harvest zones, and market access remain the main bottlenecks. The key opportunity lies in prioritizing collective and scalable initiatives, aligned with the technical needs identified in the field, such as water management, implementation of vegetative cover, strengthening of seed systems, and improvement of ecological connectivity.

6.3. Building a community research route

The implementation of the participatory tools helped identify significant gaps between technical-institutional knowledge and local knowledge regarding the configuration and use of the territory. These gaps were evident in inconsistencies in vereda (rural district) boundaries, missing information about the presence and territoriality of Indigenous communities, and the lack of land-use planning criteria at both the family and community levels. These gaps not only limit territorial planning but also directly impact productive decision-making and contribute to the continuation of environmental degradation.

During the workshops, participants expressed concern that technical blind spots often lead to poor investment decisions, especially when attempting to replicate seemingly successful crops without understanding the biophysical conditions or required investments for proper establishment.

A participant's testimony illustrates this issue clearly:

> *Campesinos, our producers, since they don't have land-use planning, they clear a space, and when they see it doesn't produce much, they go and cut down forest to make a new space to keep farming* (Workshop participant, November 13, 2025 – La Montañita)

This practice – linked to the absence of on-farm planning – reinforces the expansion of the agricultural frontier, deforestation, and the loss of socio-ecological resilience, as it favors short-term reactive responses over long-term sustainable land management strategies. In this regard, the literature on territorial planning and climate change adaptation emphasizes that systematically integrating local knowledge into territorial diagnostics and public policy design is essential for the effectiveness of adaptation and mitigation strategies. It also plays a key role in strengthening socio-ecological resilience and adaptive governance, particularly in complex rural contexts (World Resources Institute, 2025).

The identified threats to local adaptation stem from both external drivers—such as climate variability, increased rainfall (which reduces the effectiveness of chemical pest control), and extreme events—and recurrent biological pressures. The frequency of these events and the producers' perception of risk directly influence decision-making and the adoption of management practices. This confirms the importance of integrating both local and scientific knowledge into climate change adaptation strategies (IPBES, 2019; IPCC, 2022).

One of the key potentials in building a community-based research pathway lies in the codesigned of a farm planning protocol and a permanent monitoring process, using the agroecological resilience assessment tool proposed in this study. This could include a practical implementation manual and a capacity-building process with interested farmers, enabling them to evaluate their own farms and those of their peers. The results, compiled with academic support, can serve as a foundation for participatory action research by identifying necessary actions, existing gaps, and barriers to achieving a successful sustainable transition—both at the farm and territorial levels. The systematic documentation of this information can, in turn, inform local policy and decision-making processes.

A central strategic component to develop a local research-action process is to create a Community Research Committee (CRC), made up primarily of young people from the territory, as a mechanism for sustainability and generational support for the processes. The CRC is not proposed as a new organization competing with existing ones, but rather as a community body for learning, monitoring, and prioritization. It would be connected to Agrosolidaria and engages in dialogue with partners (academia, CIAT, SINCHI, UMATA), with the capacity to turn diagnosis into a living research-action agenda. The CCI responds to a structural need: to institutionalize community-based monitoring —logbooks, photo-monitoring, indicator reviews, annual prioritization— and to safeguard the technical memory of the territory, which is currently threatened by discontinuity, economic pressure, and youth migration.

The overall purpose of the CCI is to build and sustain a Community Research Agenda focused on strengthening the resilience and sustainability of production and restoration systems. This agenda is rooted in local territorial knowledge and developed in coordination with organizational processes and partners. Based on the current stage in the transition process, it can be structured into five initial lines of action research:

1. *Water and climate:* securing water at the farm level, harvesting rainwater, protecting springs, and community-based monitoring of droughts and rainfall.
2. *Seeds, autonomy and food safety and sovereignty:* creating and managing family and community seed banks and seed houses, registering native varieties, fostering local exchange, and recovering agri-food heritage.
3. *Living soils and cover crops:* implementing legume rotations and green manures, reducing bare soil, adopting contouring practices on slopes, and improving runoff control.
4. *Ecological connectivity and restoration:* establishing biological corridors, enrichment planting with native species, early management of invasive species, planned maintenance, and setting survival targets.
5. Social support: farms planning, community agreements (on fire use, livestock, logging), clear role definitions, and indicator-based monitoring.

To prevent the CCI from remaining a mere intention, concrete and minimal outputs are proposed for its first year of operation. The first is a community monitoring log, developed farm by farm, with detailed records of tasks, dates, mortality, replacements, and organized photographic evidence. The second is a traffic light system of indicators—both biophysical and social—reviewed quarterly to support adaptive management and ensure comparability over time. The third is an annual community learning report, focused on what worked, what didn't, what needs adjustment, and what should be prioritized. The fourth is a living map of allies and opportunities, aimed at translating coordination into concrete actions and reducing dependence on local political circumstances.

7. Conclusions

The results of this study show that climate change adaptation in the rural socio-ecological systems of La Montañita is deeply shaped by structural vulnerabilities that go far beyond the isolated occurrence of extreme weather events. Key challenges such as fragmented territorial governance, the absence of systematic smallholder land-use planning, the weakness of local risk management systems, and high dependency on temporary external interventions create a scenario where climate exposure interacts with limited adaptive capacity, leading to persistent pathways of vulnerability. In this context, climate vulnerability emerges as a socio-ecological phenomenon, where climate impacts are amplified by fragile institutional arrangements and historical processes of landscape transformation in the Amazon

Spatial analysis and participatory mapping reveal that climate threats – particularly prolonged droughts linked to El Niño, landslides, flash floods, and slow-onset floods – do not impact the territory uniformly. Instead, they are concentrated in areas where biophysical factors (such as steep slopes, water-saturated soils, and loss of forest cover) intersect with land-use decisions, especially those related to the expansion of extensive cattle ranching. This spatial configuration of risk is far from accidental, but it reflects a disconnect between formal territorial planning and the actual land-use and management practices, and the absence of effective tools that integrate climate information into productive and community-level decision-making.

The results of the participatory workshops show that the territory of Montañita has made less progress in structural terms and more in processual and cognitive aspects. The emerging strengths are not yet reflected in increased income or productivity, but rather in a greater capacity to understand the agroecosystem, motivation for change, and on-farm experimentation. This shift in the SWOT analysis —from structural to process-oriented— suggests that the territory is in an **early phase of agroecological transition**, where the main challenge is no longer to identify *what* to transform, but rather *how* to support, scale up, and sustain the changes that have already begun.

Although producers in La Montañita have developed a significant set of adaptive practices – including agroforestry systems, organic soil management, passive and assisted ecological restoration, productive diversification, and traditional management strategies – these actions function mostly as reactive and incremental responses, triggered *after* damage has occurred, with limited capacity for anticipation or prevention. Field data shows that, while these practices are valuable, they are insufficient to confront projected scenarios of climate intensification in the Colombian Amazon. This is especially true when such practices lack the support of stable institutional mechanisms, continuous funding, and collective learning processes.

The case of sacha inchi clearly illustrates these tensions. The high initial failure rate of the crop, which required multiple replantings, highlights the extreme sensitivity of productive systems to climate variability, especially during early establishment phases. However, the better performance observed on farms with greater forest cover, agroecological management, and sustained technical support shows that productive vulnerability is not solely due to biophysical conditions. Instead, it results from the interaction between environmental, social, organizational, and institutional factors. Empirical evidence confirms that productive and ecological resilience depends less on isolated technical innovations and more on social learning, consistent technical support, and strong collective coordination.

Likewise, the absence of community emergency plans, early warning systems, and local risk management protocols reveals an adaptation model focused more on disaster response than on prevention and anticipation. This reactive approach increases the likelihood of cumulative losses, leads to abandonment of farmland, and contributes to climate-induced displacement – all of which remain largely invisible in public policy and continue to reinforce territorial inequalities. Moreover, the lack of coordination between state actors, community organizations, and international cooperation limits the potential to consolidate institutional learning and scale up successful practices beyond isolated projects. This highlights the urgent need for integrated, multilevel governance and long-term support mechanisms that empower local communities as key actors in climate adaptation.

Our findings indicate that the socio-ecological system of La Montañita is in a transitional phase, where trajectories of environmental degradation and increasing vulnerability coexist with emerging pockets of resilience linked to agroecological practices, ecological restoration, and community organization. However, without significant changes in territorial governance and multilevel coordination mechanisms, these emerging niches are unlikely to consolidate as dominant alternatives in the face of the structural pressures the territory is facing.

While in the case of La Montañita there is a real social and technical foundation to support processes of agroecological transition, restoration, and diversification - Agrosolidaria, with 350 member families, provides an important organized base and is seen as a platform for managing collective solutions. On the other hand, structural bottlenecks persist which, if not addressed through agroecological strategies, community agreements, continuous follow-up, and intergenerational learning, could slow down —or even reverse— the progress achieved. There is a cross-cutting threat: the discontinuity of technical support and the absence of simple monitoring routines, which weakens the accumulation of learning and the permanence of changes.

In this context, the identified socio-ecological threats reaffirm the need for a strategy that goes beyond the territorial level. Environmental and climate-related risks such as climate variability, post-agreement deforestation, and severe soil degradation due to extensive cattle ranching are documented, alongside social and security threats including the presence of armed groups, the killing of community leaders, threats, and forced recruitment. Youth migration is also noted as a particularly sensitive issue, posing a direct risk to generational renewal. All of this confirms that resilience does not rely solely on “improving practices,” but rather on building community structures of continuity: who cares, who monitors, who learns, who passes knowledge on. When transmission is broken, processes become fragile; when sustained, they become long-term trajectories. For this reason, moving forward with a locally grounded research-action agenda, led by a **Community Research Committee**, is one of the core proposals set forth in this report.

Moving toward transformative adaptation requires overcoming short-term, project-based approaches and shifting toward territorial innovation systems that integrate sustainable production, ecological restoration, smallholder land-use planning, and adaptive, multilevel governance. Only through the simultaneous strengthening of natural capital (ecological connectivity and landscape functionality), social capital (community organization, collective learning, and local networks), and institutional capital (clear rules, inter-institutional coordination, and policy continuity), will it be possible to reduce climate vulnerability, enhance adaptive capacity, and build long-term socio-ecological resilience in highly transformed and climate-exposed Amazonian territories.

The resilience and sustainability of the processes implemented in La Montañita do not rely solely on the arrival of new projects, but on greater continuity. This continuity rests on two inseparable pillars: technical practices that stabilize water, soil, biodiversity, and production; and social practices that strengthen agreements, roles, monitoring, and learning. In both areas, youth participation is strategic—not only because of their capacity to document and systematize, but also due to their potential to inhabit the future of the territory and sustain it with memory and purpose. In a context where climate threats, forest pressure, insecurity, and youth migration are real challenges, the creation of a Community Research Committee is not just another component; it is the organizational foundation for ensuring that progress is not lost but, rather, becomes a cumulative trajectory of knowledge and action, built by the community and for the community.

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