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Using the Main Agroecological Structure (MAS) Indicator for Evaluating the Agroecological Status of Farms Along the Ecuadorian Northern-central Andean Region

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Master Thesis

Using the Main Agroecological Structure (MAS) indicator for evaluating agroecological transition in farms along the Ecuadorian northern-central Andean region

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THESIS APPROVAL

I, Massimo De Marchi as supervisor of the student

Mauricio Gabriel Sáenz Lituma, hereby APPROVE the thesis entitled

Using the Main Agroecological Structure (MAS) indicator for evaluating agroecological transition in farms along the Ecuadorian northern-central Andean region

Place Padova, Date 12/02/2024

Signature [signature]

Declaration of Mobility

This thesis is the result of the Joint Master's degree in Sustainable Territorial Development (STeDe). This program is offered by a consortium made up of the following universities: Università degli Studi di Padova (UNIPD, Italy), The Universidad Andina Simón Bolívar, Sede Ecuador, the University of Johannesburg (South Africa) and Université Joseph Ki Zerbo de Ouagadougou (Burkina Faso).

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"To action alone hast thou a right and never at all to its fruits; let not the fruits of action be thy motive; neither let there be in thee any attachment to inaction."

Bhagavad Gita, Chapter 2, Verse 47

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Contents

ABSTRACT

The Main Agroecological Structure (MAS) methodology aims to measure the degree of development of the ecological structure in an agroecosystem or farm. This structure relies upon 1) the degree of connectivity of the agroecosystem with the surrounding naturally occurring ecosystem, 2) the biodiversity that can be found in the living fences inside the farm and 3) the capacity of the farm administrator to improve or maintain this biodiversity. The MAS measurement will increase with practices favoring biodiversity and conservation within the farm, improving the agroecosystem resilience to natural or anthropogenic-derived disturbances. This comes in handy in the context of the Andean region of Ecuador, where many small-scale producers have transitioned from conventional agriculture to agroecology. However, they face severe challenges derived from environmental, social and political constraints. For this reason, I evaluated the MAS of 20 farms in different degrees of agroecological transition in five locations of the northern-central Andean region of Ecuador. I found that they had a moderately developed structure on average ($\bar{x}$ =71.05), with a maximum of 89.94 and a minimum of 54.75. MAS variation is strongly influenced by the practices employed for production and natural resource conservation and the capacity of farm administrators to sustain this performance in time. In addition, MAS was significantly related to the study site, with significantly higher values of MAS in the locations of Cayambe and La Merced, Pichincha. One of the main differences between the groups was the more extended prevalence of cooperation and development programs. Longer processes of capacity building and leadership formation might directly impact assertive decision-making and an effective agroecological transition. For this reason, I propose that MAS measurements in the study site should be complemented with an analysis of the Cooperation and Networking Potential (CNP). This involves: 1) the quality of the interchange of knowledge between farmers and between farmers and organizations, 2) the time that this interchange has lasted and 3) the level of empowerment that farmers might achieve in their practices. The MAS analysis provides valuable feedback obtained with simple, low-cost methodologies that academics and producers could implement. This study aims to establish a baseline to support farm administrators' assertive decision-making. Hopefully, this practice will scale up to other sites, enabling farmers to adopt practices to sustain production in time while preserving agroecosystem functions, soil health, food sovereignty and appropriate means of subsistence for all.

RESUMEN

La metodología de la Estructura Agroecológica Principal (EAP) busca medir el grado de desarrollo de la estructura ecológica en un agroecosistema o finca. Esta estructura se basa en 1) el grado de conectividad del agroecosistema con el ecosistema natural circundante, 2) la biodiversidad que se puede encontrar en los cercos vivos dentro de la finca y 3) la capacidad del administrador de la finca para mejorar o mantener esta biodiversidad. La EAP aumentará con las prácticas que favorezcan la biodiversidad y la conservación dentro de la granja, mejorando la resiliencia del agroecosistema a las perturbaciones naturales o antropogénicas. Esto resulta útil en el contexto de la región andina de Ecuador, donde muchos pequeños productores han pasado de la agricultura convencional a la agroecología. Sin embargo, se enfrentan a graves problemas derivados de las limitaciones medioambientales, sociales y políticas. Por este motivo, evalué la EAP de 20 fincas en diferentes grados de transición agroecológica en cinco localidades de la región andina del centro-norte de Ecuador. Encontré que tenían una estructura moderadamente desarrollada en promedio ($\bar{x}$ =71,05), con un máximo de 89,94 y un mínimo de 54,75. La variación de la EAP está fuertemente influenciada por las prácticas empleadas para la producción y la conservación de los recursos naturales, y la capacidad de los administradores de las fincas para mantener este rendimiento en el tiempo. Además, la EAP estuvo significativamente relacionada con el sitio de estudio, con valores significativamente más altos en las localidades de Cayambe y La Merced, Pichincha. Una de las principales diferencias entre los grupos fue la prevalencia más extendida de programas de cooperación y desarrollo. Procesos más prolongados de fortalecimiento de capacidades y formación de liderazgos podrían impactar directamente en la toma de decisiones asertivas y en una transición agroecológica efectiva. Por esta razón, propongo que las mediciones del EAP en el sitio de estudio se complementen con un análisis del Potencial de Cooperación y Trabajo en Red (PCTR). Se trata de: 1) la calidad del intercambio de conocimientos entre agricultores y entre éstos y las organizaciones, 2) el tiempo que ha durado este intercambio y 3) el nivel de empoderamiento que los agricultores podrían alcanzar en sus prácticas. El análisis de la EAP proporciona información valiosa obtenida con metodologías sencillas y de bajo coste que podrían aplicar académicos y productores. Este estudio pretende establecer una línea de base para apoyar la toma de decisiones asertivas de los administradores de fincas. Espero que esta práctica se extienda a otros lugares, permitiendo a los agricultores adoptar prácticas para sostener la producción en el tiempo y preservar al mismo tiempo las funciones del agroecosistema, la salud del suelo, la soberanía alimentaria y unos medios de subsistencia adecuados para todos.

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PREFACE

Agriculture is in great peril. Human activities have carried the planet to its limits, causing large-scale changes in land use, soil degradation, biodiversity loss, depletion of natural resources, pollution, and, ultimately, climate change (CC). All these factors threaten how we produce, transport and trade food. However, not all food is produced in the same way. Once recognized as the only alternative for feeding the world population, industrial agriculture is also responsible for pushing natural systems to their boundaries. Practices like converting large extensions of natural ecosystems into croplands, monocultures, intensive tillage and the addition of chemically synthesized inputs, like fertilizers and pesticides, have generated almost a third of the global land degradation and are held accountable for a third of total Greenhouse Gas (GHG) emissions. However, not all food is produced in the same way. Many practices have been the object of recent studies for their potential to minimize the impacts of agriculture in nature, as they reduce the impact and aid in the regeneration of ecosystem functions at different scales of space and time.

One of the most studied alternatives is Agroecology. Agroecology focuses on generating synergies between human and non-human components of "agroecosystems" as it recognizes an agricultural space as part of the ecosystem. This is achieved by applying practices that promote agrobiodiversity and conservation of ecosystem functions over time. In parallel, it incorporates a vital social component that seeks the integral well-being of all human beings around food production and consumption. Furthermore, agroecology can potentially improve agroecosystem resilience, understood as the capacity to tolerate disturbance while conserving its properties. This is critical as nutrient depletion, water scarcity, the enhanced prevalence of pathogens, land conversion from urbanization, pollution and altered climatic patterns due to CC put tremendous pressure on ecosystems, including those destined for agricultural activities. Nevertheless, transitioning from "conventional" to agroecological farming faces many challenges.

The factors that condition the agroecological transition of production systems have been the subject of many studies over the last four decades and have sparked a broad debate on the most accurate indicator to evaluate the state of a farm. Evaluating the state of a farm by studying the transformation of specific characteristics over time allows us to answer how and how far it has progressed in its transition, understanding that this progress is the result of a producer's decisions, conditioned by a context and specific possibilities for each case. These characteristics' direction and magnitude of transformation will also determine their resilience. Greater resilience implies a greater probability that, in the face of a disturbance (which may be natural, economic, political or social), the process remains stable and does not return to the previous state (farm with conventional production) or reaches an alternative state (permanent degradation of the productive space).

The MAS methodology applied in this study measures the degree of connectivity of a farm with the natural ecosystems in the surrounding landscape. This, because a greater degree of connectivity implies higher agrobiodiversity and enhanced agroecosystem performance. It also measures the inner agrobiodiversity arranged in living fences within the farm. Finally, it measures the quality of practices employed by farmers that favor agrobiodiversity and the conservation of natural resources. This allows us to understand farms' resilience or vulnerability as complex systems and reflects how farms support or affect the ecosystems. This is the first application of MAS in the Ecuadorian Andean region, which faces all the aforementioned global threats and others derived from its local context. With this, I hope to contribute to the understanding of the most critical factors conditioning an effective agroecological transition. Also, to test a tool with enormous potential, not only for academics but for producers and members of civil society with a desire to contribute to helping agriculture overcome permanent degradation.

INTRODUCTION

The current agroindustrial model has severely impacted the conservation of natural ecosystems, causing an increasing conversion in land use and extension, fragmentation of ecosystems, soil erosion and loss of biodiversity (Kimbrell, 2002, p. 60). Additionally, agribusiness has influenced national and international policies of privatization of biological (seeds) and natural resources (land and water for crops), free trade agreements, subsidies and monetary restrictions, limiting the participation of small farmers in agricultural trade (McMichael, 2015, p. 59). This, coupled with the increasing accumulation of land by dispossession, has led to acute marginalization and impoverishment of the peasantry, bringing violent land conflicts, forced migrations, and dispossession of their rights to well-being and security, to produce their food and to live in their ways (Fian International, 2018).

Therefore, it is necessary to call for a change in the current food production-distribution-consumption paradigm. Agroecology has been considered the most prominent alternative to address social, economic and environmental asymmetries, as it can provide a balanced environment and sustained yields through the design of diversified agroecosystems and sustainable technologies (Altieri & Toledo, 2011). At the same time, it aims to co-create knowledge between crucial actors, such as producers, government institutions, and cooperation agencies, such as NGOs and academia, through universities (Teixeira et al., 2018). Thus, "dialogues of knowledge" are encouraged between technical knowledge and producers' traditional, practical and local knowledge, enhancing their autonomy and adaptive capacity.

However, in Ecuador, the scaling up of these practices faces severe challenges, such as lack of government support, weak regulatory policies, scarce cooperation programs among key actors and limited access of producers to commercial spaces (Giunta, 2014; Valdivia-Díaz & Le Coq, 2021). This discourages producers from switching from conventional to agroecological practices and threatens those who have already started the process. The transition from complex systems ─such as that of a farm in transition to an agroecological─ production model is a process that depends on multiple factors, biological as well as social, economic and political. This means that the individual decisions of a producer are not the only thing that determines the transition of his or her productive unit, but that these decisions are conditioned by the context and the possibilities of each individual (León-Sicard et al., 2018).

This is equally important considering that, like natural ecosystems, agroecosystems are also under pressure from new conditions, with more extreme and frequent climatic events, due to Climate Change (CC) (IPCC, 2022). Healthier agroecosystems then act as climate buffers by sequestering carbon, managing moisture, recycling nutrients and improving plant health while decreasing dependence on chemical inputs, increasing resilience to CC, droughts, floods and eutrophication of water bodies (Neher et al., 2022). The evaluation of the state of agroecological development of a production unit, measured through indicators at different levels, is essential to understand the impact of the decisions made on the space by the producer and also to maintain high levels of resilience, allowing it to sustain its functions (productivity, ecosystem services) over time (Altieri et al., 2015).

This research aims to evaluate agroecological development on farms in the central-north Andean region of Ecuador through the Main Agroecological Structure (MAS) methodology (T. E. L. León-Sicard, 2021). It permits to perform a multi-scale analysis that integrates the landscape assemblage (macro scale), inside-farm agrobiodiversity, understood as the species arranged in the extension of living fences, and finally, the set of practices that farm administrators employ for managing their production, as well as the capacities for sustaining such practices in time. The measurement of these indicators at different levels will make it possible to understand, in general, the state of the agroecosystem, the degree of development of its MAS and its implications on the farm's level of resilience, and propose concrete actions that can ensure its sustainability.

RESEARCH OBJECTIVES

In response to the presented background, the main objective of this research is to:

- Characterize the Main Agroecological Structure (MAS) of agroecological farms in the northern-central Ecuadorian Andean region

The secondary objectives are to:

- Analyze the landscape features surrounding the farms selected for the study and its change through time
- Identify the type and development of agroecological practices employed in the farm management
- Determine the main factors behind the variation of the MAS between the study sites

THEORETICAL FRAME AND LITERATURE REVIEW

The Development of the Agribusiness Model

After World War II, the need to ensure access to food promoted the modernization of agricultural systems towards an industrialized form that all nations would adopt. Under this premise, the "Green Revolution" took place: a trend towards the technification of agricultural production based on agrochemical inputs, genetic modification of plants and animals, and agricultural machinery and equipment to increase yields and profitability. This strategy led to the development of "agribusiness", whose dynamics consist of increased production and monetary gain and the dynamization of international markets (McMichael, 2015). This development model, aligned with neoliberalism, soon demonstrated that the commodification of food had negative consequences for human beings and the environment at all levels. By operating over vast extensions of territory, agroindustrial production has led to the monopolization of productive land. This process has been especially conflictive in territories with weak land tenure policies, where large industries have used intimidation and explicit violence to force out small farmers (Fian International, 2018).

Agribusiness has influenced national and international policies of privatization of resources (such as seeds) and free trade, subsidies and monetary restrictions, limiting the participation of peasants in agricultural trade. As a consequence, their situation of marginalization and impoverishment has worsened, provoking violent conflicts over land, in addition to forced migrations of the peasantry to marginal areas of neighboring cities and the dispossession of their rights to well-being and security to produce their food and live under their ways (Laterra et al., 2019). Additionally, the level of resource consumption and waste has contributed significantly to the planet reaching the "limits" to sustain life in terms of 1) land conversion, 2) biogeochemical flows, 3) depletion of freshwater sources, 4) loss of biodiversity, 5) chemical pollution and 6) climate change (Richardson et al., 2023). The conversion of large areas of forests into crops, the impact of pesticides on local fauna and flora, contamination with fertilizers that have favored the increase of pathogenic and invasive species, and the diversion of freshwater bodies have left entire populations in situations of scarcity are some of the additional effects of the agroindustrial model.

The prioritization of economic growth as a measure of development, the liberalization of markets and the "homogenization" of territories around the world, including their inhabitants, have established a new system of paradigms and values where the main objective is to supply raw materials to the "machinery of development", with a profit margin that increases every year (Sachs, 2010). This system dates back several decades, and through large transnational corporations and governments, which have placed technological and scientific innovation at their service, has positioned itself as a current of practices and narratives that disregard the ecological limits of the planet and, even more, so the welfare and rights of human groups, large and small, outside the command of the industrialized means of production.

This can be seen clearly when we focus on the "food industry". After the scarcity caused by the armed conflicts of the early and mid-20th century, it became evident how important it was to secure food production and distribution on a global scale. This led to the establishment of "food security", which charged the industry with the mass production of food "for all mankind" and aligned the policies of nations to strengthen its prevalence (Margulis, 2017). The industry privatized food production, and food went from being a right to a commodity affordable to anyone who could pay. Thus, international agencies measured the success of the agro-industrial system in terms of its earnings, instead of the people it was able to fed (McMichael, 2015).

Agribusiness justified its existence as the only way to produce more food for the following decades and feed a rapidly growing population (Rivera-Ferre Marta, 2020). Although this is undeniable, it is also undeniable that it did not take into account the massive food waste, how unbalanced food consumption is in the world, the productive limits of the land and the right of each human group to provide its food. Accordingly, agribusiness continued to expand to meet the unrestrained needs of an economically privileged society and to make nutrient-poor foods more affordable. The productive limits of the land were "stretched" through innovations such as fertilizers, pesticides and transgenic seeds, which could grow with less loss in vast expanses of monocultures. Land that once belonged to small producers and was increasingly deprived of state and private support was sold "voluntarily" (Rivera-Ferre, 2020).

At present, we know that GHG emissions related to industrial food production and mass food consumption, i.e. produced on a large scale, amount to 21-37% of total anthropogenic emissions, of which 14-28% correspond to agriculture and land use and 5-10% to non-crop emissions (transport and marketing) (Crippa et al., 2021). Therefore, it is essential that the different sectors of society - local and central governments, the scientific community, academia, private companies, farmers' collectives, consumers and civil society - work together to raise awareness of the impacts of an agroindustrial food model and move towards systems that are more equitable and fairer to the planet and its inhabitants.

Food Sovereignty, Agroecology and Climate Change

Different movements, discourses, and alternatives have emerged in contrast to this global socioeconomic phenomenon that revolves around food production. They share their intention to restore the right of humans to produce their food through their means and conditions, to have a secure access to land, and to live in a safe environment, without being forced to reproduce the current market-based logics of living (Giraldo, 2021). Much can be summarized when speaking of "food sovereignty". This incorporates practices, knowledge and worldviews preserved through local traditions of predominantly peasant and indigenous groups, which focus on the right of people and nations to control their agricultural and food production systems, including their market, modes of production, environment and food culture (Desmarais, 2015).

This has gained momentum in the last decades, with international movements such as "La Via Campesina", with more scientific and empirical research oriented towards these practices and their importance as a truly "sustainable" alternative, and with the incorporation of local indigenous and local knowledge in the elaboration of local and national policies. Despite this, the road is still long, and it is essential to work in a multidisciplinary and multi-scale manner to highlight how the agro-industrial food production system is rapidly pushing us out of planetary boundaries. Neglect in terms of climate justice has exacerbated social differences, leaving the majority of the population vulnerable to the new atmospheric conditions provided by climate change. Because of this, food sovereignty stands as an alternative: "focusing on food for people, valuing food providers, localizing food systems, placing control at the local level, developing knowledge and skills and working with nature" (Desmarais, 2015).

Agroecology has been the primary vehicle for advancing towards food sovereignty. However, the concept has undergone a profound transformation since it started appearing in agricultural transformation discussions in the late 20th century (Wezel et al., 2009). It can be defined as an integrated approach that applies technical, social and scientific concepts and principles to the design and management of agricultural productive units. In this sense, its main objective is to provide a balanced environment, sustained yield and soil fertility, and natural pest control by designing diversified agroecosystems and using self-sustaining technologies (M. Altieri & Nicholls, 2000). At the same time, it aims to co-create knowledge by combining scientific knowledge with the traditional, practical and local knowledge of producers, enhancing producers’ autonomy and adaptive capacity (Giraldo & Rosset, 2023).

The agroecological approach considers agricultural ecosystems as the fundamental units of study. These systems investigate and analyze mineral cycles, energy transformations, biological processes, and socioeconomic relationships (Gliessman, 2018). However, it goes deeply beyond a set of techniques for enhancing production. A large part of the agroecological practice is political, because it challenges the current power relationships between the actors involved in food production (González de Molina et al., 2021). For example, Agroecology is addressed as a science, practice and social movement. However, in Latin America, a tremendous driving force for the adoption of Agroecology, and therefore for an agroecological transition, relies on the social struggle pushed by indigenous and peasant communities, which inextricably involve historical marginalization, means of living and producing, and the recognition of their rights (Rosset et al., 2022). Considering this heterogeneity of natural ecosystems, productive systems and social dynamics, the study of Agroecology requires highly sensible methodologies that articulate biotic and abiotic interactions and past and current social phenomena at different scales (Côte et al., 2019), in order to understand the processes of use, maintenance, regeneration, and destruction of natural resources related to human activities, going on either simultaneously or sequentially.

In the present, agroecological practices not only represent an "alternative" way but could become one of the few options for food production. This is especially relevant in the context of ecological degradation and Climate Change (CC) (M. A. Altieri et al., 2015). It has been observed that CC is characterized by more frequent extreme climatic events, with peaks of high or low temperatures of greater dimension than in previous years (IPCC, 2022). Agroecological plot's resilience to rapidly changing and extreme climatic conditions depends on 1) the capacity to resist and 2) the capacity to recover from impacts derived from climatic events. Thus, an "agroecosystem" is understood to be resilient if it can withstand these events without losing its productive capacity and if its component elements (biotic and abiotic) can quickly recover their functions (Quintero et al., 2024). Agroecological systems are more resilient to CC because of functional diversity (Wood et al., 2015). In an ecosystem, different species occupy different "ecological niches". This means that each species plays a role that ensures the balance of ecosystems.

A high diversity can be observed in a healthy ecosystem, and with it, a remarkable functional diversity. This implies, for example, multiple nitrogen-fixing plant species, birds and pollinating insects, small mammals that disperse seeds, trees with different behaviors that provide shade for species with less need for sunlight, short life cycle species that contribute with their organic matter, and the great variety of microorganisms such as bacteria and fungi that fulfil the nutrient cycle (Visscher et al., 2023). This diversity has an enormous impact on available water, where the integrity of the forest canopy and the species that compose it maintain a balance that ensures the provision of water to all beings. Trees extract water from the ground or filter it by rainfall and send it back to the air through evapotranspiration, crucial for regulating temperature, precipitation, and water availability at the site (Pershouse, 2017). It has been observed that CC is characterized by more frequent extreme weather events, with peaks of higher or lower temperatures of greater dimension than in previous years (Intergovernmental Panel on Climate Change, 2022). This directly impacts the balance of functional diversity since many species have a narrow "ecological niche": moderate or low tolerance to desiccation, temperature oscillations, or excessive rainfall (Cáceres-Arteaga et al., 2020).

Finally, the possibility of transferring this resilience to communities also depends on complex factors such as their degree of social organization, the integrity of traditional knowledge, socioeconomic conditions, historical context, and biogeographic location, among others (Groot et al., 2016). One key issue is the incorporation of new technologies that might support agroecological transition. The usage of technology in agriculture has supported the development of new “conventional” branches of agriculture, such as precision or organic agriculture. Still, new technologies have an enormous potential for “democratizing” knowledge, putting new tools for crop improvement at the hand of each farmer (De Marchi et al., 2022).Together, these will determine the capacity of societies to react and the quality of their response to extreme events derived from climate change. If these factors are adequate, communities will be highly adaptable to new socio-ecological conditions and can actively reformulate themselves as these changes occur (Oteros-Rozas et al., 2019).

Agroecology in the Ecuadorian context

Since the 1980s, Ecuador has experienced an expansion of agroindustrial production models due to the "Green Revolution". Neoliberal policies adopted in response to international economic, social and political dynamics prioritized exporting products such as cocoa, bananas, flowers and shrimp in large-scale monocultures. In 1990, a package of "structural adjustment" measures introduced by the state led to an increase in private indebtedness, in addition to reducing social welfare spending, and favored the concentration of wealth, tax evasion by large companies and the collapse of the national banking system (Martínez-Valle, 2004).

This generated severe social tensions, leading to protests and mobilizations organized by indigenous and peasant communities. The measures adopted, added to a history of centuries of marginalization and exclusion, placed them in a position where there was no other alternative but social struggle to make their situation visible. Thus, a process was initiated to demand recognition of the cultural identity of the 14 nationalities and 18 ethnic groups within the territory, access to land, legalization and protection of ancestral territories, bilingual education and the plurinationality of the State. The indigenous movement played a crucial role in opposing the neoliberal policy trend and its socially and environmentally irresponsible development proposal. Additionally, it articulated the participation of other actors, such as peasant and Afro-Ecuadorian organizations, women's and human rights associations and public unions, and environmental and ecological activists (Giunta, 2014). This had profound consequences in the country's politics and triggered processes such as the Agrarian Reforms in Ecuador (between 1964 and 1973), which allowed the redistribution of land concentrated in "Haciendas" and the recognition of the indigenous political organization and their rights (López-Sandoval & Maldonado, 2019).

Indigenous and agroecological thinking developed as part of peoples' struggles for identity, political recognition, and equitable access to land and resources (Deaconu et al., 2021). The agroecological movement has continued to develop over the last few decades to overcome many of the problems generated by industrialized agriculture. This struggle allowed multiple advances at the national level, such as the incorporation of one of the axial elements of the Andean Cosmovision, “Sumak Kawsay” or Good Living, in the Constitution of Ecuador, which was reformulated in 2008

(Gobierno del Ecuador, 2008), as well as the creation of the Organic Law of the Food Sovereignty Regime (LORSA) in 2009 (Gobierno del Ecuador, 2009).

One of the main demands at that time was precisely the recognition of their traditional forms of organization, production and subsistence, intimately linked to agriculture (Intriago et al., 2017). For this reason, beginning in 1980, after the agrarian reform processes, academia began to support the revaluation of the traditional management of agricultural systems, as it represented a practical and concrete alternative to counteract the effects of agroindustrial policies. Additionally, professionals and NGOs proposed, for the first time, incorporating practices based on Agroecology after an initial dialogue stage with peasant and indigenous movements (Intriago et al., 2017). These organizational and knowledge-sharing processes allow for defining the principles of agroecology and its integration with ancestral agriculture in Ecuador.

METHODOLOGY & RESEARCH DESIGN

Study areas

Selection of study sites

For this study, I selected farms in Ecuador's northern central Andean region, managed under agroecological practices. This is because one of the main objectives of this research is to understand how alternative practices to the conventional paradigm of agricultural production could contribute to the conservation and restoration of the ecosystems in the surrounding landscape (Perfecto et al., 2009, p. 74). I focused on farms where administrators managed their productive units following at least three agroecological principles and considered themselves agroecological producers. Agroecological principles applied to the management of productive units were described by Altieri & Nicholls (2000, p 17) and are defined as follows (but not limited to):

1. Plant and animal diversification (species or varieties) in time and space.
2. Nutrient and organic matter recycling, optimization of nutrient availability and nutrient flow balances.
3. Provision of optimal soil conditions for crop growth, managing organic matter and stimulating soil biology.
4. Minimizing soil and water losses, maintaining soil cover, controlling erosion and managing the microclimate.
5. Minimize crop affection due to insects, pathogens and weeds through preventive measures and promotion of antagonist agents, allelopathy, parasitism, etc.
6. Exploiting synergies emerging from plant-plant, plant-animal and animal-animal interactions

Most of the producers from the study sites that fell into the selection criteria were already working with Ekorural Foundation: an NGO focused on research, development and cooperation, whose actions are oriented towards local food systems, where Agroecology and Alternative Food Networks are key axes of work (Ekorural, 2023). As a result of a collaboration between the author and the organization, we could link producers from different geographic locations and degrees of development or agroecological practices (considered preliminarily as the number of years of agroecological management of their productive unit) to this study. We selected 20 farms as Experimental Units in 4 provinces: Imbabura, Pichincha, Cotopaxi and Chimborazo. Because of the selection criteria (at least three agroecological principles), logistic constraints (such as accessibility of the author to the study site), and the incompatibility of some farms, Experimental Units were selected unevenly across all provinces, with 5 in Imbabura, 8 in Pichincha, 4 in Cotopaxi and 3 in Chimborazo.

Location of study sites in the northern-central Andean region

The 20 farms considered as Experimental Units for this study were distributed in 7 different locations from the aforementioned provinces (Figure 1). In the following section, I provide a further description of the areas.

Imbabura

The agroecological farms selected in Imbabura were located in the rural parish "La Esperanza" in the Ibarra Canton. The Parish has an altitudinal range from 2400 meters in the sector near the city of Ibarra to 4600 meters in the high areas near the Imbabura Volcano. It has around 7000 inhabitants and a total surface area of 34.76 km^2. Due to its location in the inter-Andean valley, it has an equatorial mesothermal semi-humid and equatorial high mountain weather, with an average annual temperature of 15°C, rainfall ranging between 750mm - 1250 mm and relative humidity of 70%, relatively constant throughout the year (GAD Parroquial Rural “La Esperanza", 2015).

According to the parish's Development and Land Use Plan, 33% of the territory surface (1132.21 Ha) has soils adequate for agricultural activities, whilst the rest have soils with severe limitations or should be included in protected areas. Still, 66.7% of the land (2319.17 Ha) is currently employed in agriculture, with short cycle crops, greenhouse crops, and crops within areas under erosion processes (GAD Parroquial Rural “La Esperanza", 2015). The area has undergone intense land use change from forests to croplands, grazing areas and urban settlements. This has exerted considerable pressure over the 620.20 Ha of land under protection, mainly belonging to montane forests and "páramos" (high Andean mountain ecosystems), which face threats from deforestation and burning practices, as well as an advancing agricultural frontier (GAD Parroquial Rural “La Esperanza", 2015).

Agricultural production focuses mainly on cereals, maize and vegetables. A lesser proportion of land is dedicated to short cycle vegetables. Farmers faces many threats, some naturally occurring and some derived from intensive land use and extensive land conversion. Natural-derived threats are frosts, which are very common in the area, and human-derived threats include soil erosion, biodiversity loss, pollution of water bodies and landslides due to deforestation in areas with high slopes (+70%). In the parish, the total population is 7363 inhabitants, distributed evenly by sex (50.6 male, 49.4 female), with more than 50% of the population in an age range from 0 to 34 years; 70% of the population define their ethnicity as indigenous (*indígena*) and the resting 30% define themselves as “mixed race” (*mestizo/a*).

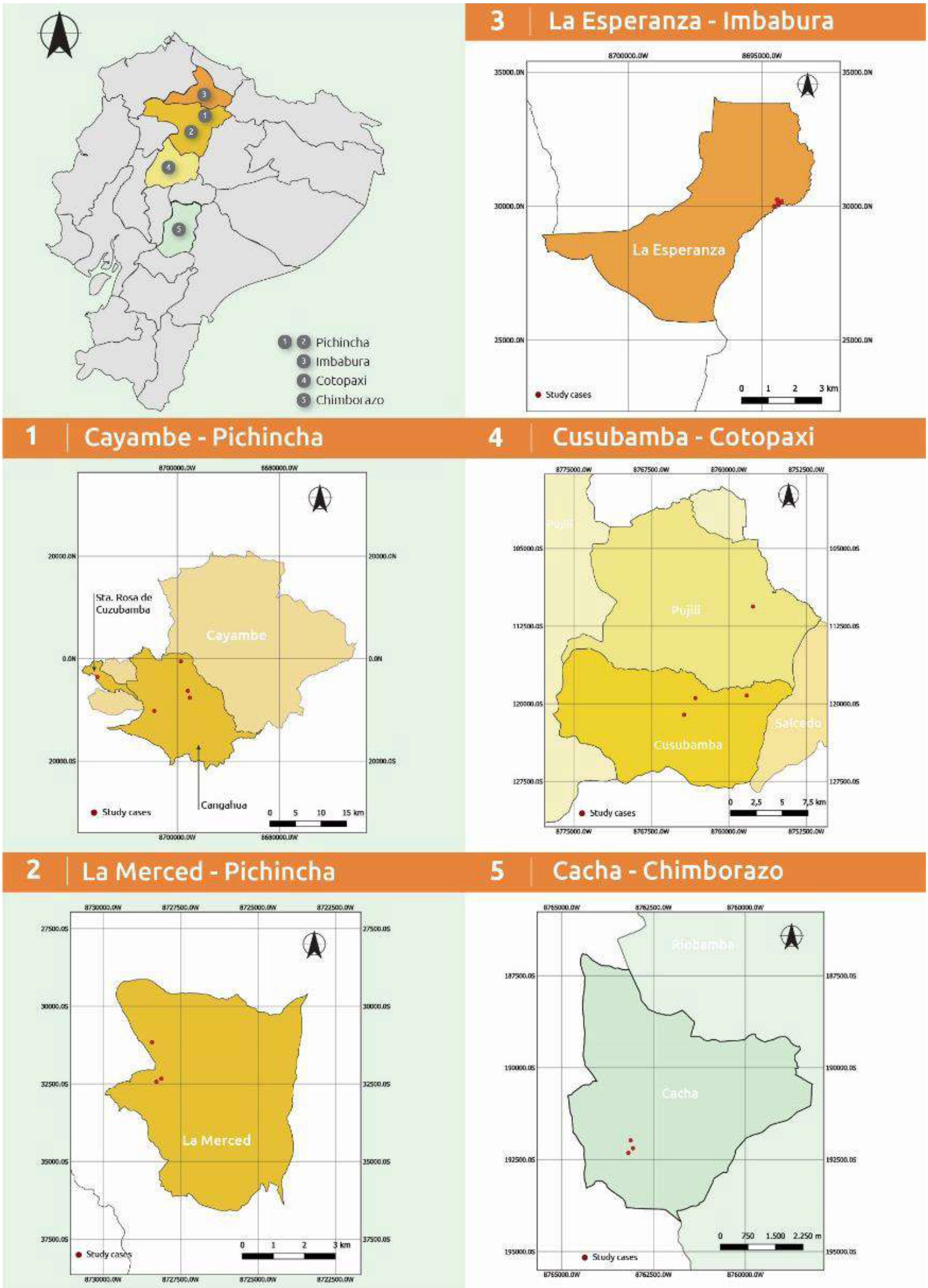

Figure 1. Study Areas.

The map describes the location of farms (red dots) in the parish, and in the country.

Pichincha

In Pichincha, I selected eight agroecological farms in Cayambe and La Merced. Both locations are close to Quito, the capital city of Ecuador. The canton of Cayambe is located in the province of Pichincha, approximately 75 km northeast of Quito, at an altitude of 2700 m. It has a surface area of approximately 1198 km^2, which represents 14.21% of the total surface area of the province of Pichincha. It has a widely variable relief between the inter-Andean zone and the eastern mountain range, with elevations as high as 5970 m in the Cayambe volcano summit, páramos, and plains. To the west, and as it approaches the Pisque River, the terrain becomes dominated by sandy areas (GAD del Municipio de Cayambe, 2020, p 13). Cayambe is formed by six rural parishes, Olmedo, Ayora, Cangahua, Otón, Azcásubi and Cusubamba, and two urban parishes, Cayambe and Juan Montalvo. The study sites (5) were located in Cangahua (4) and Cusubamba (1).

The climate in Cayambe is as variant as its relief. It has two main seasons: dry and rainy. Dry months go from June to September, while rainy months are distributed bimodally, with one season starting in February until May and the other starting in October until December. In January, usually, precipitation decreases. Above 3000 m, in the areas near Cayambe volcano, the mean temperature is 16°C, while in the lower parts, it can be 25°C. Monthly rainfall also varies with altitude and season, with the higher parts having 23 mm during the dry season and as much as 100 mm during the rainy season, and the lower with 21 mm in the dry season and almost 90 mm during the rainy one, for a total of 300-1200 mm annually (GAD del Municipio de Cayambe, 2020, p 24). The main climate hazards are droughts and frosts, because they impact all parishes and are critical for ensuring food access and security, especially in a warming scenario due to Climate Change (CC) (GAD del Municipio de Cayambe, 2020, p 25).

Natural areas in Cayambe canton represent 64.09% of the total land surface, which might or might not be included in protected areas, such as the Parque Nacional Cayambe-Coca. There is an abrupt transition between this type of cover and other productive activities. The advance of the agricultural frontier, the expansion of pastures related to livestock activities and the excessive felling of tree species are leading to a decline in transitional ecosystems. In the southern area of the canton, these ecosystems have entirely disappeared. (GAD del Municipio de Cayambe, 2020, p 18). Natural resources, mainly forests and water, are under tremendous pressure. Forest cover has contracted as a consequence of overexploitation and land conversion. Livestock and commercial agriculture activities have polluted rivers, ditches and streams that flow down from the Cayambe volcano by dumping waste from cattle and chemical products used by the flower industry and conventional agriculture (GAD del Municipio de Cayambe, 2020, p 20).

The following land use in terms of extension belongs to pastures for livestock with 18.38% of the territory, 5.18% for agricultural use and 1.32% of the cantonal land occupied in flower plantations. The urban areas represent 2.12% of the territory, concentrated in Cayambe and Juan Montalvo parishes and the resting 8% of land use is distributed between other productive activities such as mining concessions (3.09 km^2)(GAD del Municipio de Cayambe, 2020, p 15). Land tenure shows significant inequalities in the number and extension of Agricultural Productive Units (APU). There are 18,165 APUs with less than one hectare (Ha), representing 13.9% (7069 Ha) of the land surface destined for this use. On the other side, 87 APUs of more than 50 Ha cover 23.8% (12110 Ha) of the total land surface.

It has 105781 inhabitants, of which 60% (42201) live in rural parishes, and the remaining 40% (63579) live in urban areas, distributed more or less evenly by sex, with 51% of women and 49% of men. A comparison with data from the 2010 census shows that the population has significantly shifted from rural to urban areas. In 2010, the urban population was 39028 inhabitants, showing an increase of 24551, whilst in the rural areas, there were 46767, with a difference of -4566. 60% of the population defines itself as *mestiza*, 33.9 as indigenous, and 7% as white or Afro-descendant. 44% of the population is between 0 and 19 years old, 18% from 20 to 29, 32% from 30 to 69 and 6% from 70 years old and older(GAD del Municipio de Cayambe, 2020, pp 63-67).

The other 3 study sites were located in La Merced, a rural Quito Metropolitan District parish, 25 km southeast of the capital. La Merced has an area of 31.63 km^2, and it belongs to the Zonal Administrative Jurisdiction of Valle de los Chillos, an area of the inter-Andean Valley in the eastern part of the province with a lower altitude, divided by the Ilaló volcano. (GAD Parroquial de La Merced, 2012, p 31). La Merced is located at 2680 m, and this added to its geographic features, gives rise to its characteristic humid inter-Andean equatorial climate. It has an average temperature of 18 degrees Celsius, and precipitation fluctuates between 111 and 128 mm, divided into two most representative rainy periods: the first in March and the second in November. The dry season goes from July to August. (GAD Parroquial de La Merced, 2012, p 44).

La Merced has 8394 inhabitants, of whom men represent 49.1% and women 50.9%. Half of the population is concentrated in the group from 0 to 29 years old. According to the 2010 national census, poverty is a significant issue in La Merced, with as much as 65% of the total population (5071 inhabitants) living in poverty. (GAD Parroquial de La Merced, 2012, p 35). Agriculture is the main economic activity of the families in this parish, followed by raising small animals. The main crops in La Merced are from short-cycle species, followed by maize. Among these are barley, wheat, potatoes, beans, legumes and vegetables, the latter with organic fertilizers.

Cattle raising has been drastically reduced due to the scarcity of grazing land. Women mainly carry out these activities and have become essential income generators for the maintenance of their households. Factors such as the decline in agricultural production due to the generalized degradation of agricultural soils, the lack of adequate spaces for commerce, roads in poor condition and lack of transport have caused men, as heads of families, to migrate to other cities or change their productive activities, most of them looking to work in the construction sector. (GAD Parroquial de La Merced, 2012, p 44).

Most of the production is destined for family consumption, and a part of it is sold in nearby markets and fairs. However, the development of this sector has been affected by the heavy degradation of the soil, the high cost of inputs, as well as an increasingly scarce labor force (GAD Parroquial de La Merced, 2012, p 52). Factors such as rapid population growth, deforestation and land conversion have triggered erosive processes of cultivable land. In addition to the fact that a considerable part of La Merced lies on the slopes of the Ilaló volcano, this adds more significant pressure to the loss of soil and subsoil.

Consequently, there has been an increasing emergence of a typical edaphological formation in the zone: "Cangahua", which in Quichua means "sterile hard land" (Palacios et al., 2021). Cangahua is a rocky geological formation originated from pyroclastic material and ash, that has hardened and "cemented" the soil within many years. It can be found mainly in the northern part of the Inter-Andean valley, but it is present in the central part as well (Palacios et al., 2021). Due to these features, wherever Cangahua has outcropped, means that soil has eroded completely and no agricultural activity remains possible.

Cotopaxi

Cotopaxi is located in the central zone of the Andean region in Ecuador. The study sites (4) were located in the Cusubamba (3) and Pujilí (1) parishes in the Salcedo and Pujilí cantons, respectively, close to the southern border of the province. Due to their proximity, they have similar geographic and demographic characteristics. Cusubamba is located in the southern limit of Cotopaxi, in the eastern part of Salcedo. Its altitude (3100 m) and geographic location give rise to a high Andean mountain climate, with a temperature range that goes from an average of 12 °C to 3 °C, and occasionally, minimums below 0°C, which causes frosts among crop fields (GAD Municipal del Cantón Salcedo, 2014). It has an irregular topography, with abundant ravines an elevations with a slope as high as 50% (GAD Municipal del Cantón Salcedo, 2014).

It has a total extension of 185.5 km2, from which almost 50% correspond to páramo ecosystems that might or might not be included in protected areas. The other half is destined for croplands, grazing pastures and tree plantations (GAD Municipal del Cantón Salcedo, 2014). The soil formation history of this area of the Inter Andean valley gives place to a severe risk of erosion. Most cultivable soils range from 10 to 40 cm deep, covering approximately 20% of the parish surface. This, in addition to solid winds, considerable precipitations (10-15 mm) in the rainy seasons and steep slopes (10-30%), causes natural soil erosive dynamics, which intensify with the loss of vegetation cover, as a consequence of land conversion and deforestation (GAD Municipal del Cantón Salcedo, 2014).

In rural areas, a vast majority of the population is dedicated to agricultural and livestock production, and fruit production in fewer cases. In Cusubamba parish, a total surface of 8.94 km^2 of land is destined to agriculture, with potatoes, barley, maize, *mellocos* and fava beans. Agricultural expansion has been reported as one of the main threats to natural areas due to land conversion and pollution of lakes, streams and rivers (GAD Municipal del Cantón Salcedo, 2014).

Cusubamba has 7200 inhabitants, of which 52% are women and 48% are men, and 57% of the population is under 30 years old. Most of the population (79%) lives in rural areas and is dedicated to agricultural and livestock productive activities as subsistence. However, they face a current situation of scarcity due to a generalized lack of access to essential services (education, health, electricity, drinkable water, sanitation) and poor infrastructure; this affects the population asymmetrically regarding age and gender. In the province, child malnutrition affects 43% of the population. Medical assistance due to morbidity was 41% for men and 59% for women. In terms of education, Cusubamba presents the highest illiteracy (number of people aged 15 and over who cannot read and write) rates of the Cantón, with 20.27%. Amongst men, illiteracy is 14%, whilst in women, it is 26%. Migration in Cusubamba represents 6% of the total migrant population of Cantón, with a lack of labour opportunities being the leading cause. From this, 55% corresponds to men and 45% to women. (GAD Municipal del Cantón Salcedo, 2014).

<u>Chimborazo</u>

The last study sites are in the rural parish Cacha, in the Riobamba canton. It covers a surface of 29.07 km2 and is the highest study site, with an average altitude of 3400 m. In addition to its geographic position and irregular topography, with steep slopes and numerous ravines, this gives rise to an Andean template weather (GAD de la Parroquia Cacha, 2019, p 8). It has variable rainfall patterns, with 410 and 615 mm of annual precipitation distributed in rainy and dry seasons. The highest rainfall is distributed between October and April, while June and September are characterized by low rainfall. The average annual temperature varies between 10-18°C during the day, while at night, temperatures can drop as low as 5°C. Climate hazards are mainly associated with droughts and frosts. In 2015, 18 communities reported droughts distributed unevenly throughout the year, causing the total loss of crops. Frosts have been reported in August, September and December and damage all crops in the parish. (GAD de la Parroquia Cacha, 2019, p 15).

In addition to accelerated land conversion into agricultural and grazing fields, over-exploitation of soils without conservation practices, deforestation, and geological and climatic factors have caused generalized soil erosion in the parish (GAD de la Parroquia Cacha, 2019, p 24) This has resulted in a shrinkage of the land surface suitable for productive activities, and projects aiming to recover soil quality are scarce and have severe limitations (GAD de la Parroquia Cacha, 2019, p 27). There are naturally occurring water sources, such as springs and small rivers, but they have undergone considerable pressure from many directions. Factors that put at risk or modify the water of the parish's springs are the presence of exotic forest species in the watersheds, deterioration of watercourses, contamination due to human-derived polluting discharges, overexploitation and infiltration. (GAD de la Parroquia Cacha, 2019, p 11).

The rural parish of Cacha has 3,376 inhabitants, of whom 47% are men and 53% are women. Most of its population is between 15 and 30 years (12% for men and 14% for women) and 50 years and older (15.4% for men and 17.5% for women) (GAD de la Parroquia Cacha, 2019, p 42). An explanation for this division lies in the complex conditions of the territory, which leaves few productive and labour options for the population and encourages migration, either to other cities in the country or other countries (GAD de la Parroquia Cacha, 2019, p 77). According to the Instituto Ecuatoriano de Estadísticas y Censos (INEC), the percentage of poverty estimated for the parish in 2020 was 78.71%, generated by the unsatisfied basic needs of a person, like lack of food, housing, education, health care, drinking water or electricity, while the percentage of extreme poverty was of 39.96% (GAD de la Parroquia Cacha, 2019, p 45). This reflects a general condition of scarcity aggravated by the degradation of natural resources.

The most important agricultural products are barley, grown on approximately 20 Ha, beans (16 Ha) and maize (15 Ha). Other short-cycle crops are potatoes, cabbage, strawberries, alfalfa, quinoa, wheat, geese and peas. The harvest months are between October and December when the production is distributed and sold in different markets in the canton, but in most cases, it is destined to satisfy the family needs (GAD de la Parroquia Cacha, 2019, p 72).

Methodology

The Main Agroecological Structure (MAS) method

For this study, I applied the Main Agroecological Structure (MAS) methodology as described in León-Sicard (2021). I selected the MAS methodology because of its potential to capture the intrinsic characteristics of a farm in terms of agrobiodiversity and how this is influenced by the practices of the farmer, as well as the integrity of the ecosystems in the surrounding landscape. This allows us to understand farms' resilience or vulnerability as complex systems and reflects how farms support or affect the ecosystems (León-Sicard, 2021, p. 43). It becomes relevant to mention this because the MAS is a relatively new methodology that has been applied in many previous research (Clavijo et al, 2019; Cleves-Leguízamo et al., 2017; Cordoba & León-Sicard, 2013; Daza, 2020; León-Sicard, 2014; León-Sicard et al., 2018; Lozano, 2019; Lucco, 2019; Murgueitio, 2020; Pinzón, 2014; Quintero, 2020) with minor but decisive variations in many of them. This is because "As various experiences in other agro-ecosystems have been conducted, the measurement of the index -and even the formulation of the concepts that distinguish the elements it uses- evolved to be structured under the criteria presented (in the publication above) (León-Sicard, 2021, p. 51).

The MAS has three main objectives: The first is to measure the degree of connectivity of the farm with the surrounding landscape. In this sense, the farm is understood as a unit of the ecosystem where productive activities occur (agroecosystem), and the surrounding landscape corresponds to the coverage of naturally occurring vegetation (forests, bushlands and prairies), which might be continually distributed or in patches. The second objective is to measure the agrobiodiversity of the farm, understood as the diversity of plant species included in the spatial arrangement of the farm, which are not directly related to the productive function but rather exist as a support of the ecological functions that take place within the agroecosystem. This diversity can be found in the internal and external living fences, in internal patches of vegetation intentionally preserved, or if the farm presents agroforestry or silvopastoral arrangement.

The third objective is to characterize the practices employed by farm administrators that support the prevalence of agrobiodiversity and its degree of development within the farm. It measures five ecosystem or biological indicators and five cultural indicators for this. The first five indicators measure the actual situation of the farms in terms of their agrobiodiversity and connectivity with the landscape. The remaining five indicators are cultural because they depend directly on the actions and decisions of farm administrators. These are, in time, conditioned by factors of social and anthropological order, such as educational processes, traditions, the external influence of agricultural policies, and conditions of producers, like family composition, income, market dynamics and labor opportunities, land tenure (T. León-Sicard et al., 2018). The indicators are summarized in Table 1.

Table 1. MAS indicators.

The first five indicators are related to the ecosystem order, whereas the last five, to the cultural order.

Number	Parameter	Acronym	Description
1	Connection with the Main Ecological Landscape Structure	CMELS	Assesses the distance and relationships of the farm to nearby fragments of natural vegetation, mainly vegetation cover and water bodies.
2	Extension of External Connectors	EEC	Determines the percentage of the linear extent of live fences, present on the perimeter of the farm.
3	Extension of Internal Connectors	EIC	Determines the percentage of the linear extent of vegetation rows present within the farm.
4	Diversification of External Connectors	DEC	Assesses the diversity of live fences or hedgerows located on the perimeter of the farm (main agroecosystem)
5	Diversification of Internal Connectors	DIC	Assesses the diversity of internal living fences.
6	Use and Soil Conservation	USC	Determines the percentage distribution of different land use coverages (minor agroecosystems) within the main agroecosystem.
7	Agricultural/Livestock Management Practices	AMP / LMP	Values the ecological or conventional practices of the production systems, whether agricultural or livestock, present on each farm.
8	Conservation Practices	CP	Assesses soil, water or biodiversity conservation practices used on farms
9	Perception-Awareness	PA	Assesses the degree of conceptual clarity and awareness of producers regarding agrobiodiversity.
10	Capacity for Action	CA	Assesses the capacities and possibilities of farmers to establish, maintain or improve their MAS.

Each indicator is scored from 0 to 10 depending on its degree of development, based on the parameters established in the methodology (León-Sicard, 2021). Indicators 1, 2, 3 and 6 can be measured using satellite imagery, such as those provided by Geographic Information Systems (GIS) software like QGIS, ArcGIS or Google Earth Pro (GEP). Indicators 4 and 5 involve the identification of plant diversity in live fences, if present, which might be done through plant fresh material collection and identification or *in situ* identification with taxonomic keys or even with smartphone applications, such as the iNaturalist app (iNaturalist, 2023). Parameters 7 to 10 refer to the practices and perceptions of farm owners/managers, and information is collected through semi-structured direct interviews based on the specific parameters for each indicator.

In addition, the methodology measures some of the spatial features of the farm, like the area and perimeter. Once they have been established, it is necessary to define the bisector, which corresponds to a line that connects the two most distant vertexes of the farm. Then, it is possible to calculate the Area of Influence (AI), which corresponds to the area where the surrounding landscape directly influences the farm, either positively or negatively. The AI is a circle drawn from the center of the farm, whose radius will equal two times the bisector.

Research Design

This research took place from February to December 2023, and I carried it out in three different phases. The first was an extensive literature review of agroecological transition and its relation to ecosystem conservation. This also implied the selection and study of the methodology, a review of study sites that might be interesting and adequate for the research, and the planification of the field phase. The second phase consisted of field data collection, which was carried out from April to October 2023. The field phase included visits to the selected study sites, interviews with the farm administrators and field measurements to fulfil the requirements of the MAS methodology. Finally, the third phase consisted of field data systematization, geographic and statistical analyses and writing.

<u>Field visits</u>

Field visits were carried out after the consent of the farmers was granted. In all cases, this occurred only after a meeting was organized between the participants (myself as the primary researcher and farmer), and I was able to explain what the research consisted of, what was the nature of the information that the MAS methodology required, and what were the possible outcomes of the research project. A single visit of one hour and a half to two hours would be enough to gather all the required information. In some cases, a second visit was necessary to gather any missing information from the first visit. In the case of the Cacha study site, a previous study carried out as a bachelor thesis covered the missing information from the interviews. (Illapa, 2022)

The visit started with a walk around the farm, where the farmer would explain general information about the place and his/her activities. Here, I conducted a semi-structured interview, where I would listen to the explanations freely given by each farmer and infer the information required by the methodology from this conversation (indicators from 7 to 10). I asked specific questions if the farmer did not mention the information in the first instance. I would only interrupt the conversation with further questions if necessary (due to time constraints). This format follows some suggestions made by León-Sicard (2021, p 51), but are largely detailed by Pumisacho & Sherwood (2005, p 51) in their book "Methodological Guide for Farmer Field Schools". Here, the editors explain that this might be a technique employed by a facilitator for having an enriching interview with producers that might generate a genuine interchange of information and allow them to express themselves more freely and accurately.

I designed a questionnaire (Annex 1) for completing the information that the MAS methodology required using the Kobo Toolbox platform, and registered the answers using the Kobo Collect app for smartphone (KoboToolbox, 2023). In parallel, interviews were recorded with a voice recorder (Olympus Imaging America Inc., n.d.) after informing every farmer, to record all the provided information. Once the interview was finished, I walked around the perimeter of the farms taking the coordinates of its vertices with a GPS (Garmin Ltd., 2007), for the geospatial processing (indicator 1).

Meanwhile, I registered the number of species present in the living fences around the farm and the total extension of the living fence (indicators 2 and 4). I did not collect any fresh material for identification but instead defined the name of the species with the farmer (usually a common or local name) and searched for the scientific name using different resources (de la Torre et al., 2008; Missouri Botanical Garden, 2024). When there was no information from the farmer, I took a picture of the unknown species and uploaded it to the iNaturalist platform using the smartphone app. Once uploaded, the platform would suggest an identification for the plant species, and users from the community would corroborate or correct its identity. Finally, I would walk inside the farm to identify and locate (through GPS coordinates) inner living fences and their plant species (indicators 3 and 5), as well as to define the different types and extent of land use coverages (minor agroecosystems) found within (indicator 6). This process was systematically repeated along the 20 experimental units (farms) included in the study.

Data analysis

All the geographic information was processed using Google Earth Pro (GEP) (Google LLC, 2022). Although not a true Geographical Information System (GIS), this free-license software allows users to visualize a digital replica of the planet and incorporates essential but powerful tools for analyzing territories (Google Earth, 2023) One of the main advantages of using GEP was the software's excellent visual resolution when analyzing images using a lower scale, which generally was equivalent to an eye altitude of 5 km. Another great advantage of using GEP is that the user can access recent images of almost any territory. This type of image typically has a cost depending on the resolution, (EOS Data Analytics, 2023), imposing a severe limitation on access and development of research projects. Another good option is orthogonal aerial photographs, ordinarily available from Defense or Environmental public agencies. Here in Ecuador, orthophotos can be requested freely by the Ministry of Agriculture, which conducted a project from 2011 to 2015 to capture orthophotos of the whole country (SIGTIERRAS, 2017). The disadvantage is that all photos were taken in 2014, thus missing any significant changes in the landscape until the present.

The analyses included the elaboration of polygons for calculating farm perimeter, inner area, bisector and external Area of Influence (AI). Once the AI was established, I calculated the CMELS (indicator 1), EEC (indicator 2), EIC (indicator 3) and USC (indicator 6). Then, I elaborated an Excel matrix for all the indicators and their values, either calculated from geographic and biodiversity evaluations (indicators from 1 to 6) or assigned according to the interview results (indicators from 7 to 10). Calculations and practices that build up the cultural components are described in great detail in León-Sicard (2021), so I will not describe them in this section.

Then, I gathered the available orthophotos of the study sites to determine the variation over time of the first MAS indicator, the CMELS, because it is the only indicator that relies solely on landscape visual lecture and interpretation. It considers two components: 1) the distance of vegetation relicts, such as forest or grassland that can be visually recognized on a satellite image, to the center of the farm (DCF), and 2) the density (area) of such vegetation relicts. Orthophotos were used to calculate the variation in the CMELS by comparing its measurements. (taken in 2014, SIGTIERRAS, 2017) vs. the measurements in the most recent images available on GEP.

In the statistical analysis, I elaborated a linear model to determine if the MAS was explained by the location of the study sites, and repeated it with every MAS indicator (Faraday, 2005). I elaborated a Pearson correlation analysis between the area and the bisector of the farm, and a Spearman rank correlation analysis to evaluate if the area of the farms was correlated to the MAS (after a log 10 transformation of area for adjusting it to a normal distribution). Then I further analyzed the existence of a correlation between the MAS indicators. Finally, I performed a Mann-Whitney-Wilcoxon test to assess if variations in the percentages of density of forest patches and its distance to the center of the farm (both parameters of the CMELS) were significant, comparing 2014 vs present (Bruce et al., 2020). All statistical analyses were performed with RStudio (Posit team, 2023).

RESULTS &FINDINGS

Characteristics of the study farms

The 20 farms included in the study presented a wide variation in their physical features (Table 2). The farms, or Experimental Units (EU), were in an altitudinal range of almost 1000 m, from 2584 m to 3615 m. Their area varied considerably, as they went from 580m2 to over 4 hectares (40000 m^2); still, most were at least over 1000 m^2.

Its shape, which in turn affected the result of the bisector, also had great variations due to factors like geographic location, topography and land distribution history, with regular and irregular polygons (Figure 1). Despite this, the area and the bisector of farms were positively correlated ($p<0.01$) (df = 18; $R = 0.85$; *p-value* = 2.3 e-06**), showing that shape does not play a significant role over area in the MAS analysis.

Figure 2. Farm under MAS analysis with Google Earth Pro (Google LLC, 2022).

The typical analysis of the MAS started with the location of the farm coordinates in the GEP map interface. Then, a polygon is drawn over the farm limits (white line), from which perimeter and area are calculated. From here, a line connecting the most distant vertices is drawn (green line), which will be the bisector. From the center of the farm, the Area of Influence (AI) is drawn (yellow line). The radius of the circle equals two times the bisector. Here, in particular, we see the delimitation of forest patches (red lines) within the AI to calculate the CMELS (indicator 1). Farm 01 (in the figure) forms an irregular polygon, which was the case of most of the EU.

aracteristics of farms included in the study.

ribes the unique code for each farm, its physical features and the date of the satellite image provided by GEP (Google Earth Pro) that w be analysis.

nce	Location	Admin gender	Type of crops	Title of property	Altitude (m)	Area (m2)	Bisector (m)	Area of Influen (m2)
cha	Cayambe	Female	Maize (in asc), Andean tubers,short cycle vegetables, seasonal fruits	Own	2840	5341	125	196160
cha	Cayambe	Female	Maize (in asc), Andean tubers, short cycle vegetables, seasonal fruits	Own	2850	3557	86	89384
cha	Cayambe	Female	Maize (in asc), potatoes, Andean tubers, short cycle vegetables, seasonal fruits	Own	2992	1126	47	26633
cha	Cayambe	Female	Maize (in asc), potatoes, Andean tubers, short cycle vegetables, seasonal fruits	Own	2874	580	40	19728
cha	Cayambe	Female	Maize (in asc), Andean tubers, short cycle vegetables, seasonal fruits	Own	2795	41441	426	2239054
orazo	Cacha	Male	Maize (in asc), short cycle vegetables	Own	3420	1769	56	40785
orazo	Cacha	Male	Maize (in asc), short cycle vegetables	Own	3380	11057	142	252488
orazo	Cacha	Male	Maize (in asc), short cycle vegetables	Own	3423	1500	67	56724
paxi	Cusubamba	Female	Maize (in asc), short cycle vegetables, seasonal fruits	Own	3615	3715	193	466756
paxi	Cusubamba	Female	Quinoa, andean lupin	Own	3390	8711	289	1047888
paxi	Cusubamba	Female	Maize (in asc), potatoes, short cycle vegetables, seasonal fruits	Own	3060	5876	245	750822
paxi	Pujilí	Female	Maize (in asc), potatoes, short cycle vegetables, seasonal fruits, flowers	Own	2955	16627	342	1466996

cha	La Merced	Female	Maize (in asc), short cycle vegetables, seasonal fruits	Own	2584	1764	59	43365
cha	La Merced	Female	Maize (in asc), short cycle vegetables, seasonal fruits	Own	2595	1165	53	34554
cha	La Merced	Male	Maize (in asc), andean tubers, short cycle vegetables, seasonal fruits	Own	2735	40583	431	2323506
ura	La Esperanza	Female	Maize (in asc), short cycle vegetables	Own	2617	5228	156	305975
ura	La Esperanza	Male	Maize (in asc), short cycle vegetables	Own	2610	5375	110	152079
ura	La Esperanza	Female	Maize (in asc), short cycle vegetables	Own	2618	15001	172	370435
ura	La Esperanza	Female	Beans, short cycle vegetables	Own	2618	4159	122	186681
ura	La Esperanza	Male	Beans, short cycle vegetables	Own	2630	3398	89	98266
				x̄	2930,05	8898,65	162,5	508413,95
				max	3615	41441	431	2323506
				min	2584	580	40	19728
				SD	338,63	11846,09	122,82	714210,60

maximum value; ,min: minimum value; SD: standard deviation; Maize (in asc), maize sown in association, commonly with beans and local varieties c

In general, the GEP software provided actual images considering the timespan of the field phase (April to October, 2023). There were, however, sites whose images were not as recent, which is the case of F03 (2018), F01 and F05 (2020), and F06, F07 and F08 (2021).

MAS characterization and analysis

Indicators 2 (EEC), 3 (EIC), 4 (DEC), 5 (DIC) and 6 (USC) were calculated from measurements, or species identification, performed during field work. Indicators 7 (AMP), 8 (CP), 9 (PA) and 10 (CA) were calculated from information provided by farmers during the interviews about their management practices, perceptions and current capacities in terms of agricultural production. Finally, Indicator 1 (CMELS) was calculated using satellite imagery from Google Earth Pro. Indicator 7 normally involves agricultural and/or livestock management practices. However, almost all (18 out of 20) had only small animals (chickens, guinea pigs), and in small amounts. For this reason, Livestock Conservation Practices were not measured nor included in the analyses.

In average, the farms included in this study have a strongly developed Agroecological Structure (Table 3). The highest value was found in F15, with a score of 89.94 out of 100 (very strongly developed), whereas the lowest was from F20 with 54.75 (moderately developed). The highest indicator (average) was the EEC (Extension of External Connectors or external living fences) with a score of 8.80 out of 10, followed by the EIC (Extension of Internal Connectors or internal living fences), with 8.50. The lowest indicator (average) was the CMELS, with 2.4 followed by the DIC (Diversity of Internal Corridors), with 4.93. Apart from these differences, indicators were rather homogenously distributed, going from 7.23 (CP, conservation practices) to 8.10 (DEC, diversity of external connectors) (Figure 3).

S analysis.

mpilates the scores of all farms for the 10 different indicators. From these, the first five correspond to the ecological order a

rder. Each indicator is scored out of 10, and the MAS corresponds to the sum of them all, out of 100.

Farm	CMELS	EEC	EIC	DEC	DIC	USC	AMP	CP	PA	CA	MAS
F15	6.00	10.00	10.00	10.00	6.94	8.00	9.00	10.00	10.00	10.00	89.94
F04	3.00	10.00	8.00	10.00	8.00	10.00	8.50	8.00	10.00	9.50	85.00
F01	1.50	10.00	10.00	8.00	6.12	8.00	9.00	8.00	10.00	9.50	80.12
F05	6.00	10.00	10.00	7.00	3.00	10.00	8.50	8.00	9.00	8.50	80.00
F13	3.00	8.00	10.00	9.00	4.52	8.00	8.50	8.00	10.00	9.00	78.02
F11	0.00	10.00	10.00	9.00	6.45	8.00	8.50	8.00	10.00	7.50	77.45
F14	1.50	6.00	10.00	8.34	4.62	8.00	8.50	8.00	10.00	9.00	73.96
F02	1.50	8.00	8.00	7.00	5.29	8.00	8.50	7.33	10.00	9.50	73.12
F07	3.00	8.00	10.00	9.00	7.38	8.00	7.25	6.67	7.00	6.50	72.79
F09	1.50	10.00	6.00	9.00	6.40	10.00	7.25	7.33	7.00	8.00	72.48
F03	1.50	8.00	8.00	8.52	3.83	8.00	8.50	7.33	8.00	9.00	70.68
F19	3.00	10.00	10.00	9.00	5.87	6.00	6.00	6.67	6.00	7.75	70.29
F16	3.00	10.00	10.00	9.00	4.18	6.00	6.00	6.00	6.00	5.00	65.18
F06	1.50	8.00	8.00	6.97	3.72	8.00	8.50	6.67	7.00	6.50	64.86
F12	3.00	6.00	8.00	5.53	5.04	10.00	7.25	6.67	7.00	6.00	64.50
F17	3.00	8.00	8.00	9.00	4.81	6.00	6.00	6.67	6.00	6.75	64.22
F08	1.50	8.00	6.00	6.00	3.00	10.00	7.25	6.67	7.00	6.50	61.92
F18	1.50	10.00	6.00	7.69	4.50	6.00	6.00	6.67	6.00	6.75	61.11
F10	1.50	10.00	8.00	6.00	2.03	6.00	6.00	6.00	7.00	8.00	60.53
F20	1.50	8.00	6.00	8.00	3.00	4.00	6.00	6.00	6.00	6.25	54.75
x̄	2.40	8.80	8.50	8.10	4.93	7.80	7.55	7.23	7.95	7.78	71.05
min	0.00	6.00	6.00	5.53	2.03	4.00	6.00	6.00	6.00	5.00	54.75
max	6.00	10.00	10.00	10.00	8.00	10.00	9.00	10.00	10.00	10.00	89.94
SD	1.49	1.36	1.57	1.31	1.62	1.70	1.17	0.97	1.70	1.44	9.01

maximum value; ,min: minimum value; SD: standard deviation

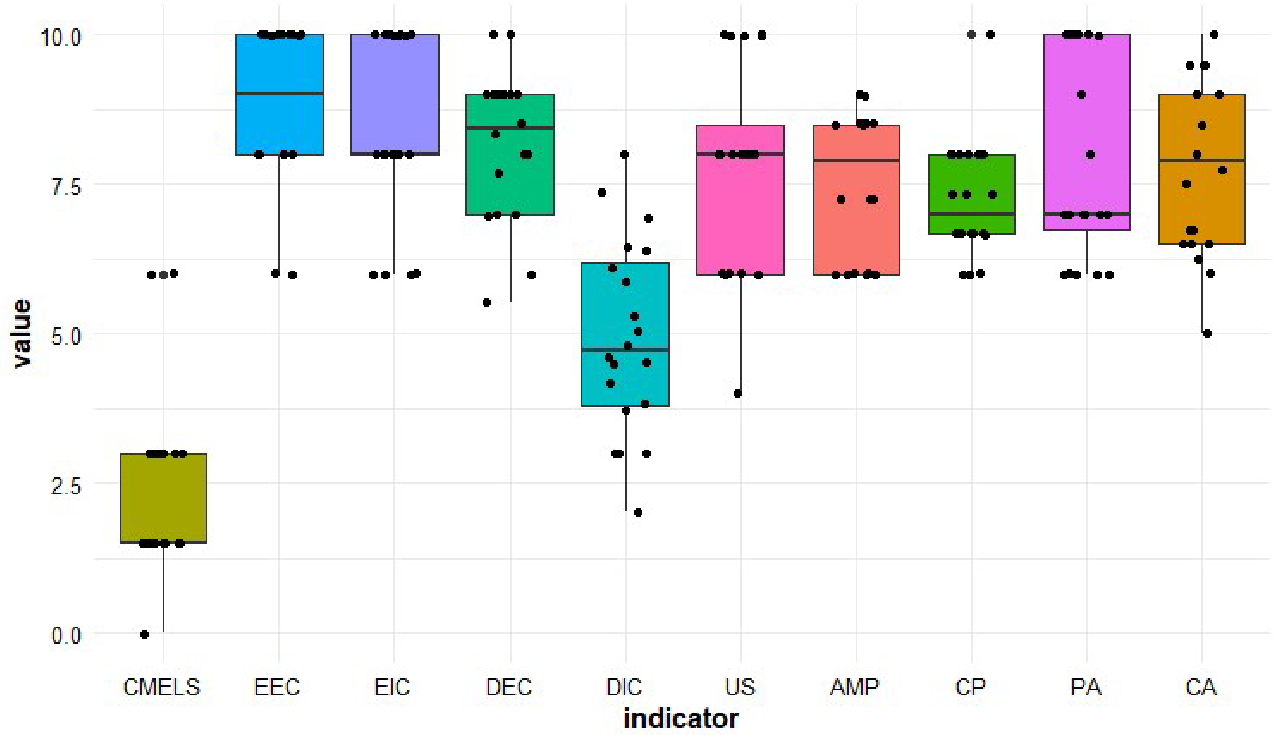

Figure 3. MAS indicators.

The chart shows the distribution of the scores obtained for each farm (black dots), for each indicator (colored boxplot). CMELS (Connectivity with the Main Ecological Landscape Structure) is considerably lower than the rest of the indicators, followed by DIC (Diversity of Internal Connectors). Most of the indicators exhibit a low intrinsic dispersion, with data arranged in well-defined rows, with the exception of DEC (Diversity of External Corridors), DIC and CA (Capacity of Action).

In the correlation matrix (method: Spearman) that evaluates the correlation between MAS indicators, only the extension and diversity of internal living fences (EIC, DIC, respectively) exhibited a positive correlation with agrobiodiversity conservation practices (CP) and perception and awareness (PA) indicators, with significative ($p<0.05$) results for CP

Table 4. Ecological and cultural correlation matrix.

The table shows the correlation coefficient showing positive (1), negative (-1) or no (0) relation between the indicators, as well as the significance level of the correlation.

	CP	**PA**
EIC	*R* = 0,453 *p-value* = 0,044*	*R* = 0,421 *p-value* = 0,065
DIC	*R* = 0,504 *p-value* = 0,023*	*R* = 0,385 *p-value* = 0,093

R = correlation index; *p-value* = significance level, *significative

I analyzed the potential relation between the area of farms and the MAS score obtained. There was a weak positive correlation (*p*<0.01) between farm area and MAS (df = 18; *R* = 0.16; *p-value* = 0.51), with no significant results (Figure 3).

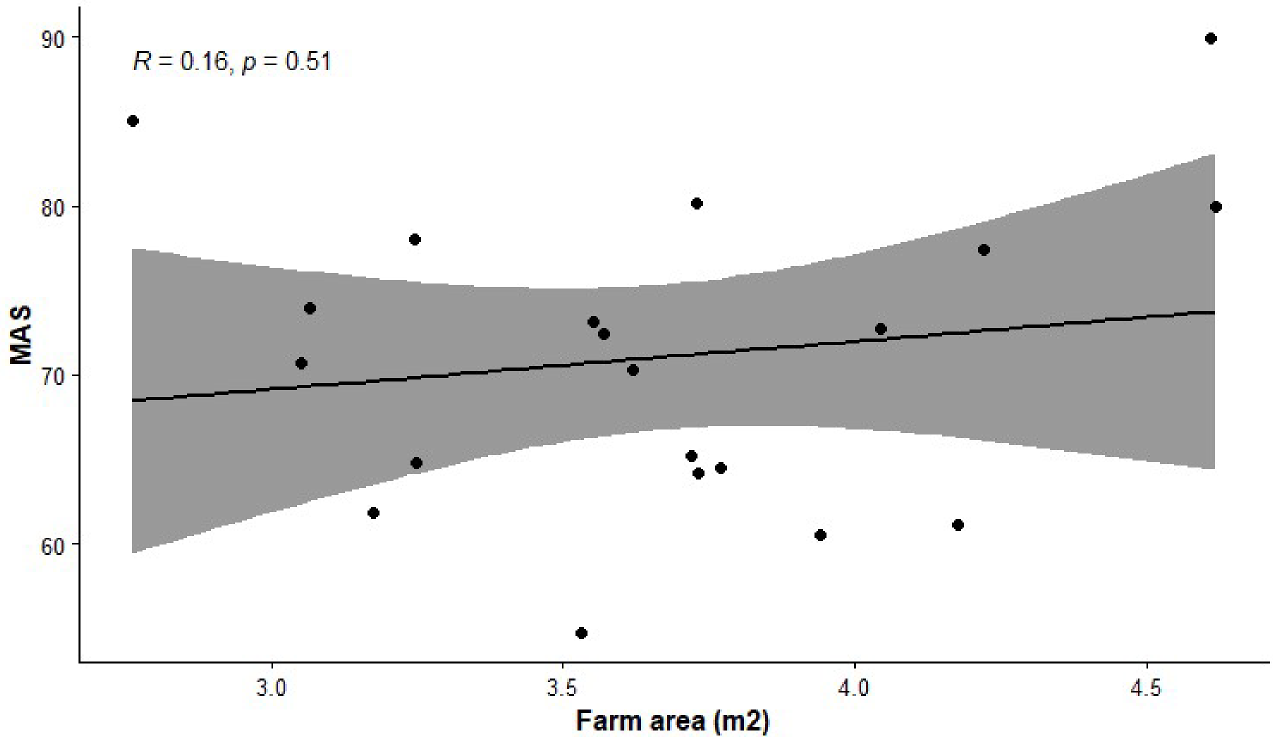

Figure 4. Correlation between farm area and MAS.
The scatterplot shows the relation between farm area (in m^2) and the MAS score obtained by each farm. Data from farm areas (x axis) was log transformed (log 10) to adjust it to a normal distribution. The graphic shows a weak (*R* = 0.16), non-significative (*p-value* = 0.51; *p*<0.01) positive correlation between both variables.

I analyzed the effect of location in MAS. For this, I built a linear model with "site" as the independent variable and "MAS" as the dependent variable. The variable "site" included 5 categories, where I grouped the EU by location: "La Esperanza", "Cayambe", "La Merced", "Cotopaxi" (which groups Cusubamba and Pujili) and "Cacha". The model explained that site influences in a highly significant way (*p*<0.01; *p-value* = 7,504e-03**) the MAS score, and the model explains 47% of the observed variation (Adjusted R-squared: 0.4728) (Table 4).

Table 5. Simple linear regression of MAS by each site.
The linear model explained 47% of the observed variation of MAS, indicating a strong difference of MAS depending on the study site. Cayambe (CY) and La Merced (Me) (left column) showed

significantly higher results (right column).

	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	66.523	3.777	17.611	1.98e-11 **
siteCo	2.217	4.997	0.444	0.6637
siteCY	11.261	4.778	2.357	0.0324 *
siteEs	-3.413	4.778	-0.714	0.4860
siteMe	14.117	5.342	2.643	0.0185 *

Residual standard error: 6.542 on 15 degrees of freedom

Multiple R-squared: 0.5838,   Adjusted R-squared: 0.4728

F-statistic: 5.26 on 4 and 15 DF, p-value: 0.007504 **

*significative; **highly significative

Cayambe and La Merced appeared as the sites with a significantly higher MAS in comparison to the rest, whereas La Esperanza was the site with the lowest values (Figure 4). Farms over 85 (very strongly developed MAS) are F15 (89.94) and F04 (85.00), In La Merced and Cayambe respectively. The only farm under 60 (moderately developed) is F20 (54.75) in La Esperanza.

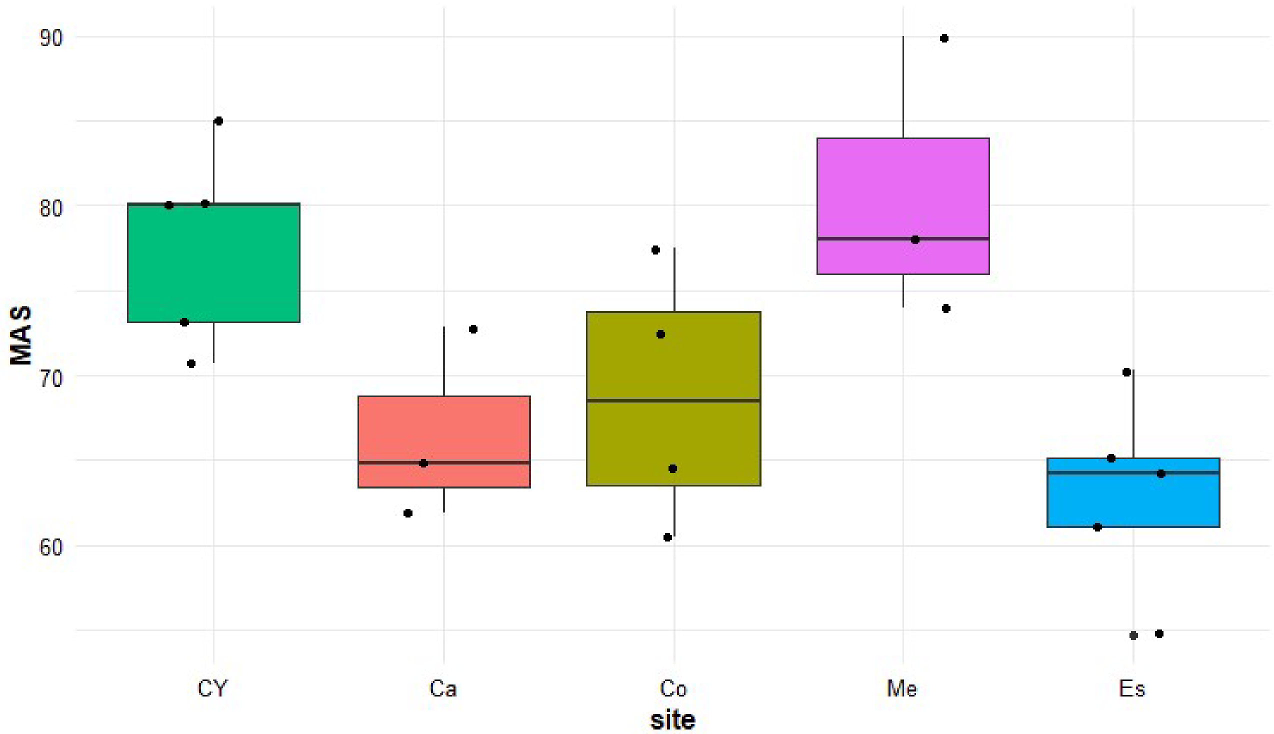

Figure 5. MAS score by site.

The boxplot chart shows the MAS score dispersion for all EU. CY stands for Cayambe; Ca, Cacha; Co, Cotopaxi; Me, La Merced and Es, La Esperanza.

The models elaborated by each indicator showed that Cayambe and La Merced had significantly higher scores in the four last cultural indicators: Agricultural Management Practices (AMP), Conservation Practices (CP), Perception-Awareness (PA) and Capacity of Action (CA).

Table 6. Simple linear regressions of MAS indicators by each site.

The table shows the score of indicators 7, 8, 9 and 10 in the different study sites (CY: Cayambe; CA: Cacha; Co: Cotopaxi; ME: La Merced; ES: La Esperanza). The Pr(>|t|) column shows the significance level (*p-value)* of the difference according to the linear model.

Site	AMP	Pr(>|t|)	CP	Pr(>|t|)	PA	Pr(>|t|)	CA	Pr(>|t|)
CY	8.60	0.03*	7.73	0.03*	9.40	0.001**	9.20	1.54e-4**
CA	7.67	-	6.67	-	7.00	-	6.50	-
CO	7.25	-	7.00	-	7.75	-	7.38	-
ME	8.67	0.04*	8.67	0.001**	10.00	4.14e-4**	9.33	2.81e-4**
ES	6.00	-	6.40	-	6.00	-	6.50	-

*significative; **highly significative

Comparison of CMELS past vs present

Lastly, analysis of the variation in the CMELS (Connectivity with the Main Ecological Landscape Structure) of EU, comparing past (2014 orthophotos) vs present (GEP images), showed no significant variation (Mann-Whitney-Wilcoxon test) (Table 5)

Table 7. CMELS Comparison 2014 vs present.

CMELS is build up with two measurements. The first is DCF (Distance to the Farm Center), which measures the distance of vegetation patches to the center of the farm in proportion to the AI radius. The second is D (Density), which measures the area of vegetation patches as a proportion of the AI. The Mann-Whitney-Wilcoxon (MWW) test showed no significant results in the variation of both measurements. Negative results in the “Difference” column indicate a decrease (in time), meanwhile positive values an increase.

Farm	DCF 2014	DCF Present	Difference	MWW	D 2014	D Present	Difference	MWW
F01	60,81	62,78	1,97		17,17	12,27	-4,90	
F02	65,76	62,06	-3,70		4,16	2,91	-1,25	
F03	72,21	75,59	3,38		41,26	8,92	-32,35	
F04	61,88	47,22	-14,66		0,90	1,26	0,36	
F05	49,82	50,70	0,88		45,57	43,87	-1,70	
F06	67,85	62,66	-5,20		16,33	14,96	-1,37	
F07	64,46	70,00	5,54		27,85	20,11	-7,74	
F08	70,38	71,98	1,60	0.7764	20,71	9,37	-11,34	0.57
F09	56,92	66,32	9,40		5,54	5,23	-0,31	
F10	67,82	67,91	0,09		16,45	15,42	-1,03	
F11	78,81	84,91	6,10		1,19	1,80	0,61	
F12	45,89	48,62	2,73		0,38	0,20	-0,18	
F13	65,75	70,86	5,11		19,85	25,58	5,72	
F14	75,80	69,09	-6,72		11,33	12,42	1,09	
F15	66,53	69,11	2,58		28,31	51,30	22,99	

F16	66,33	55,98	-10,36	12,66	14,06	1,39
F17	67,27	57,82	-9,45	13,83	15,37	1,54
F18	72,98	62,24	-10,74	10,06	12,51	2,45
F19	63,31	56,35	-6,95	15,37	17,09	1,72
F20	56,20	66,59	10,39	16,46	18,28	1,82

DCF, Distance to the Farm Center; D, Density of forest patches; MWW, Mann Wilcoxon-Whitney test

Most EU show small changes in the proportion of the AI covered by vegetation, or the proximity of this coverage to the farm. However, different patterns emerged when looking at every EU in detail (Figures 5 and 6).

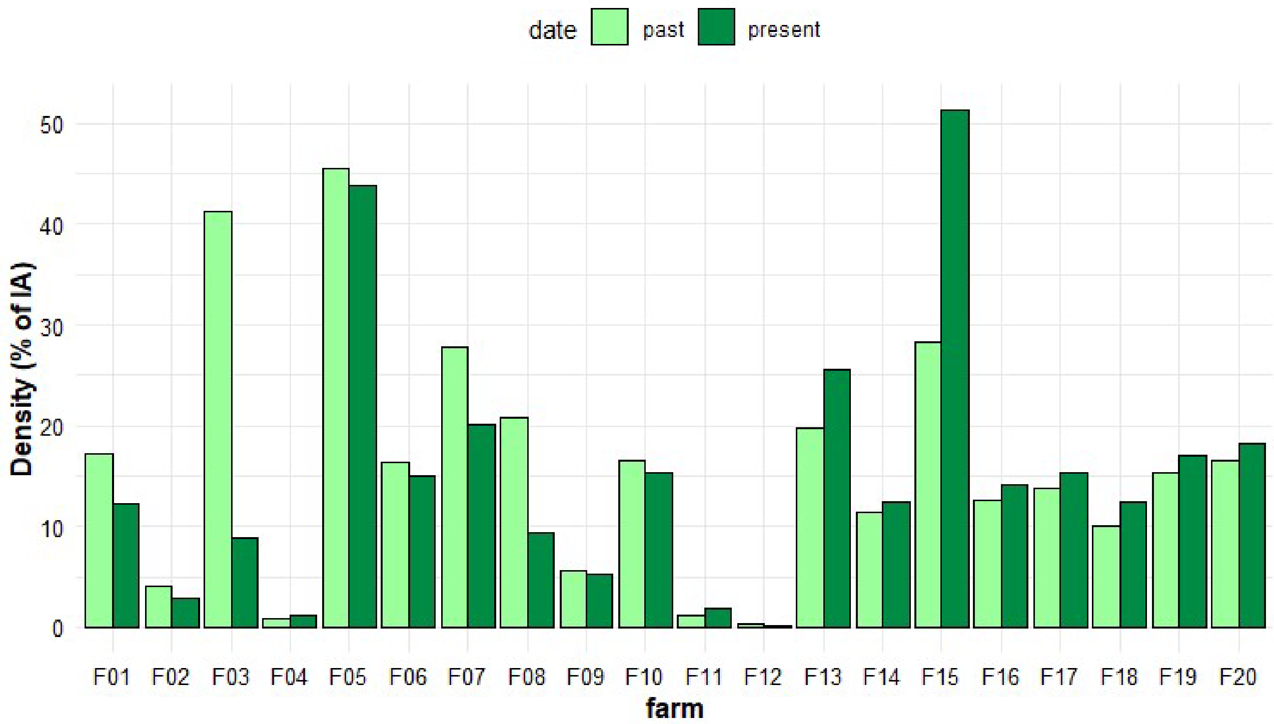

Figure 6. Variation of density of vegetation cover in AI of farms.

The barplot shows the variation of vegetation cover density. Density is calculated as the proportion of the AI of every farm with naturally-occurring vegetation coverage. Clear bars are values calculated through the 2014 orthophotos analysis, whilst dark bars represent present (GEP most recent available image) values.

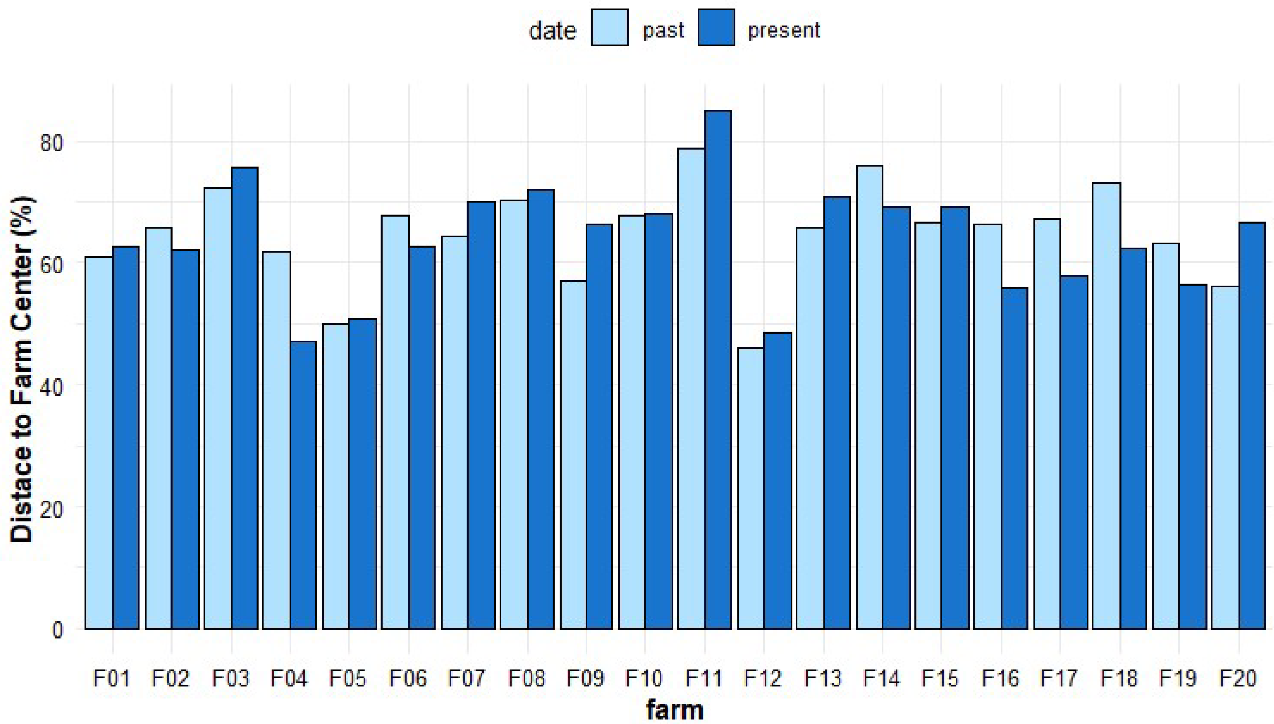

Figure 7. Variation of proximity of vegetation patches in AI of farms.

The barplot shows the variation of vegetation proximity to the center of the farm. DCF is calculated as the proportion of the distance of vegetation patches to the center of the farm, in relation to the AI radius. Clear bars are values calculated through the 2014 orthophotos analysis, whilst dark bars represent present (GEP most recent available image) values.

Density variations were remarkable in F03 and F15. F03 lost more than 30% of its vegetation cover, whereas F15 showed a recovery of more than 20%. The rest of farms showed a low variation (5% or less).

DISCUSSION

Analysis of the landscape features surrounding the farms and its change through time

Assessment of MAS in the different farms was conducted successfully in the study areas. One particularity of the MAS analysis was the generalized low CMELS in all the study areas. All scores were lower than 6, indicating a low ecological structure surrounding farms. All the study sites have an intense history of land use change, where natural ecosystems were transformed into pastures and agricultural lands. This practice was adopted in all the Andean region during the colony, where landlords from Spain or with Spanish ascendance (criollos) appropriated large extensions of lands with productive purposes, under the figure of "*Haciendas"* (Gondard & Mazurek, 2001). Later, with the agrarian reform, the land was given back to indigenous communities which originally inhabited Haciendas in exchange for their labor force and a piece of land for producing food for self-sustaining. This figure was known as "*Huasipungo"* (large state) and implied a form of slavery of indigenous communities for many generations, using mechanisms such as indebtments and coercion. When the agrarian reform entered into action, the largest haciendas were divided, and more minor land extensions were "given back" to people who formerly worked as "*huasipungueros*" (García, 2007).

However, land division was not aleatory. Lands in the worst conditions were given back to people, and lands were subjected to further degradation due to a lack of regenerative practices due to previous use. In addition, the region has generally experienced massive hoarding from many sectors of agroindustry that have grown disproportionately compared to small-scale agricultural and livestock activities, which were what people who claimed back the land aspired to (De Zaldívar, 2008). Land was divided, and in many cases, people chose the option of selling it due to the impossibility of initiating any productive activities. This was taken as an opportunity for more robust productive sectors, like the large dairy producers, large-scale monocultures of export products and flower production, who transformed the landscape (GAD del Municipio de Cayambe, 2020), leaving relicts of natural vegetation in the form of islands with limited surface and poorly connected. In other cases, the disappearance of the original ecological structure obeys urbanization processes, which resulted in a "soil sealing" process as a consequence of urban infrastructure, leaving no room for vegetation to grow.

In addition, there is an intense process of decrease in the size of plots. In Cayambe, 93% of agricultural plots destined to small-scale agriculture are less than 5 ha, and from those, 66% are less than 1 ha (GAD del Municipio de Cayambe, 2020). This responds to many complex socio-economic drives. Land conversion pressure results in conflicts for accessing water sources and pollution derived from pesticides, which motivates landholders to abandon their properties (Froese & Schilling, 2019). In addition, lack of labor opportunities, combined with a scarce access to adequate education and health, mostly due to a generalized state abandonment, have caused massive migrations from rural to urban areas, and even to other countries, where people search for better living opportunities (Gray & Bilsborrow, 2014). This has had a profound impact in the social fabric, eroding familiar relations and value systems in rural communities, and marking a distance between younger generations and rural ways of living. As a consequence, the rural areas have undergone a dramatic process of "aging". The INEC published in 2022 the results of the "Survey of Area and Continuous Agricultural Production" (ESPAC), where it states that 77% of the agricultural and livestock employment has over 45 years, with people over 65 years representing the 31% of this population (INEC, 2022).

In Cayambe, authorities have reported that the lack of a generational turnover compels owners of plots equal or under 5 ha to cut up their properties, to hand them over to their children and grandchildren. Most farmers now have smallholdings of less than one ha, which might pose a limitation of making a living from land exploitation, and might worsen in a near future (GAD del Municipio de Cayambe, 2020, p 42). A similar pattern was observed in the study sites. The internal diversity of living fences (DIC, indicator 5) showed considerably lower results than the external diversity, with a mean value of 4.93. The first and most evident reason for this was observed during the farm visits and interviews: in many cases, producers would mention that they would rather use the space within the plots for sowing productive species rather than non-crop species found in more diverse living fences.

I performed a correlation (method: Spearman) between the farms area (log 10 transformed) and DIC (explain DIC), but found no relation (R = 0.1; *p-value* = 0.67) between the two variables. Studies that analyze the relationship between farms size and their degree of sustainability (or development of agroecological practices) are not conclusive, as some favor smaller size farms (Liebert et al., 2022), but others explain that larger farms could show larger benefits for environmental protection (Ren et al., 2019). Others explain that smaller farms are more sustainable because of their management rather than its size (Ebel, 2020), but in the end, smaller farms could exhibit a greater economic vulnerability in terms of profit and production (Rached et al., 2022).

The correlation matrix (Table 4) shows a general positive relation between internal living fences (EIC, DIC) and conservation (CP) and awareness (PA) indicators, showing that farmers with a higher degree of awareness of the importance of preserving agrobiodiversity within the plot are more likely to "sacrifice" some of the productive space to sustain the performance of living fences, and hence benefit from the ecosystem services that they might provide. It remains to be elucidated whether living fences actually benefit these producers and their plots, but at the same time, the fact that internal fences are more developed, in exchange of not using a valuable resource such as productive space within the plots, responds to a perceived benefit that, even though it has not been measured before, it is evident for the farm administrators.

All these considerations reference current changes in the spatial arrangement of small-scale farms in the study sites. As for the historical changes, the analysis of the CMELS comparing historical orthophotos vs actual satellite images showed no conclusive results. Density variations were considerable in F03 and F15. F03 lost more than 30% of its vegetation cover in 4 years (the most recent GEP image for F03 was in 2018). On the other hand, F15 recovered more than 20% of its cover (from less than 30% to over 50%). The rest of the farms showed a low variation (5% or less). There is a consistent pattern in terms of loss and gain of cover: Cayambe and Cacha (sites 1 and 2) showed a decrease in the density (area) of forest patches within their AI, while Cotopaxi, La Merced and La Esperanza showed an increase. These patterns appear to respond to some intrinsic dynamic of every study site. However, the results did not provide enough information to conclude. Still, it could be a powerful tool to perform a rapid, low-cost analysis to evidence significant changes.

Agroecological practices employed in the farm management and its degree of development

Small-scale agriculture endured despite these conditions through a series of adaptions in the practices of local producers. Some of these practices are a remnant of the traditional practices employed to develop agriculture in the region, which can be traced back to pre-Columbian times. Among these, we find customization of beds and plot preparation, safeguarding native seed varieties, protecting the plot from wind and water erosion, practicing crop rotation, fallow and crop associations, and "feeding" the plot by rejuvenating the soil and other resources (Gallegos-Riofrío et al., 2021). Some of these practices are evaluated in the MAS methodology and cultural indicators, specifically in indicators 7 and 8. Indicator 7, Agricultural Management Practices (AMP), evaluates four different elements: 1) management of seeds, 2) soil preparation practices, 3) fertilizing practices, and 4) management of weeds. Indicator 8, Conservation Practices (CP), evaluates 1) soil, 2) water and 3) biodiversity conservation.

The MAS gives a higher score whenever the farmer includes practices that, in general, avoid the usage of chemical synthesis products, favor the recycling of nutrients and energy through organic inputs coming from the own farm's waste, and applies local and traditional knowledge for the conservation of resources and the generation of synergies between the farm's different elements. As stated by León-Sicard (2021, p 175), when the researcher has identified the primary set of practices (along with the Use and Soil Conservation, USC, indicator 6), he/she can infer the result of indicator 9, Perception-Awareness (PA), which evaluates the degree of clarity that each farmer might have in promoting and conserving agrobiodiversity. The results of cultural indicators (from 6 to 10) were high, on average, with means from 7.23 to 7.95 (over 10). This reflects that agroecological producers in the central northern Ecuadorian Andean region have adopted practices favoring agrobiodiversity within their crops.

According to previous studies, these practices could also enhance their production by giving larger yields, reducing farmers' dependency on chemical inputs that imply an expense, and ensuring better economic benefits due to direct sales or expense savings (Delgado et al., 2019). Aside from that, the benefits of agroecological practices extend beyond production, strengthening the services that agroecosystems deliver in terms of carbon and nitrogen fixation, organic matter cycling, and enhanced water and nutrient retention (Wood et al., 2015). In this line go the benefits that agroecosystems deliver to the general landscape assembly as repositories of genetic diversity and corridors that connect species with larger relicts of natural ecosystems (Perfecto et al., 2009). Finally, but of equal importance, agroecological practices enhance food security amongst local communities in the Andean region, ensuring access to nutritious food and reducing the risk of food scarcity due to diseases and disasters (Bezner Kerr et al., 2021).

Of all the indicators, the ones that obtained the highest scores were EEC and EIC (Extension of External and Internal Connectors), with an average of 8.80 and 8.50, respectively. Living fences are a crucial component of agroecosystems, performing multiple functions favoring their stability. First of all, they act as a barrier to limiting the influence of any physical agent, and this is relevant beyond the human-derived concept of property and the farm administrator's desire to keep trespassers away. Living fences buffer the impact of strong winds, characteristic of the inter-Andean valleys, where most of the study sites are located (Caulfield, 2019). The influence of wind can accelerate soil erosion and water evaporation, especially when soils have no coverage. They can also cause mechanical damage to seedlings and herbs and increase the risk of frost in crops (Winkel et al., 2009).

In addition, living fences are repositories of biodiversity and a stable part of an ecosystem subdued to constant disturbance. For example, they provide a safe habitat for macro and meso invertebrates, which play a vital role in agroecosystem dynamics (Harvey et al., 2005). Invertebrates influence soil properties through the decomposition of organic matter and the cycling of different elements such as carbon and nitrogen, the creation of macropores and the mobilization and redistribution of organic matter in different soil horizons (Bignell et al., 2008). They are also an essential vehicle for the dispersion and colonization of microorganisms, such as fungi and bacteria, from bulk soil to the rhizosphere of plants (Moore & De Ruiter, 2012). Within living fences, invertebrates can endure the severe disturbance to which agricultural soils are subjected, coming from the removal of living soil cover, the alteration of the physical structure of the soil by mechanical ploughing, the gradual reduction of organic matter from leaf litter, and the addition of mineral fertilizers and non-selective pesticides.

Apart from their role as barriers and shelters, living fences are necessary connectors of the biodiversity around and within the agroecosystems. Fences form biodiversity corridors that connect the natural ecosystems surrounding the farms, generally in the form of patches of vegetation (T. León-

Sicard et al., 2018). Depending on the land use conversion background of each site, these can be more or less isolated, but the more isolated, the higher the risk of suffering a disruption in a feature (energy flows, genetic variability) that might imply a severe degradation. Living fences buffer the effects of isolation by enabling the movement of species such as insects, birds, and bats with a broader distribution range (Harvey et al., 2005). These groups are relevant for ecosystems regarding pollination and seed dispersal but also the mobilization of microorganisms, genetic diversity, and predation. Living fences can host and allow the dispersal of natural enemies of organisms that can harm crops, maintaining pathogen populations in equilibrium. Fences benefit natural enemies by providing plants essential for completing their life cycle (reproduction, nesting) and other resources like alternative prey, nectar and pollen (Zamora Pedraza et al., 2022). These benefits are similar to those provided by a crop field with high biodiversity (weeds and cultivated plants).

In practice, all the services provided by living fences improve with their extension and diversity: the larger the extension of live fences, the higher the degree of connectivity of patches of natural and agro ecosystems (T. León-Sicard et al., 2018). However, extension is not the only factor: the quality of interactions within and among species and the quality of ecosystem services that living fences might provide are also determined by the biodiversity they host. This, in turn, will impact the shapes found in the canopy, as different species will define different vegetation strata. This overall functional diversity will condition the performance of the living fence as an ecosystem and the possibility of interactions between the natural and agroecosystems. From the results obtained in indicators 2 and 3 (extension of external and internal living corridors), I conclude that the farm administrators in this study know the importance of maintaining large and diverse living fences. This asseveration is reinforced by the results obtained in indicator 4 (diversity of external corridors), which values species and strata diversity and had a mean value of 8.10.

I found 60 species growing in living fences, either cultivated or occasional (Annex 2). The criteria for selecting species intentionally planted in living fences were growth form and speed. Fast-growing trees, trees and shrubs were preferred, independent of other factors like their ecological role, endemicity status or further use beyond acting as a living barrier. Most farm administrators consider having and maintaining living barriers significant for different reasons. However, a deeper understanding of the ecological role of living barriers leads to a differentiated allocation of resources for conserving their diversity and extension. This is corroborated by the correlation between indicators CP (Conservation Practices) and the extension (EIC) and diversity (DIC) of internal living fences.

Occasional species were mostly pioneer herbs, either native or introduced, that would typically grow in highly intervened areas. This is highly conditioned by the dispersion syndrome of species, where zoochory and anemochory might be favored given the lack of continuity of living fences and direct connection with the natural ecosystems (Zamora Pedraza et al., 2022). However, further studies are required to deepen our understanding of the living fence dynamics in the study sites.

Implications of MAS in the resilience of agroecosystems

The results presented are aligned with previous studies that show how farm management practices can increase its resilience, understood as greater sustainability or, in this case, the degree of development of the main agroecological structure. Ecosystem resilience can be understood as the capacity to return to a determined state of equilibrium (in its functions, performance and diversity) after a disturbance, which can be natural or anthropogenic (Yi & Jackson, 2021). This resilience depends on multiple factors, such as its functional redundancy, response diversity and the presence of dominant, foundational or keystone species (Sasaki et al., 2015). Functional redundancy corresponds to the possibility that, given a population reduction, the functions they perform in the ecosystem might be replaced by other organisms. Response diversity refers to the number of different responses organisms might have under the same disturbance. Foundational, dominant and keystone species enable the adequate functioning of the ecosystem, and are central to the ecosystem through a cascade of relations and effects over different organisms at different scales, like arborescent species in a forest or calcareous-body corals in a reef (Sasaki et al., 2015).

Under a disturb, the type and magnitude of these ecosystem responses will determine that the ecosystem transitions from its initial state, which can be understood as the equilibrium state, into a "temporary state" (Chang & Turner, 2019). From here on, ecosystems will return to equilibrium in a process called "succession". However, if the disturbance was large enough, it could push the ecosystem beyond its possibility of returning to its equilibrium state into an alternative state where some (or many) of its functions would be permanently altered, as well as its overall structure and performance (Caulfield, 2019; McCune et al., 2021).

In nature, only events of a geological scale, such as vast earthquakes or volcanic eruptions, could cause ecosystems to shift to an alternative state. Events like droughts, floods, or fires are disturbances that can move an ecosystem to an early successional state but are not strong enough to cause permanent changes (Scheffer et al., 2001). They have become a part of their dynamics, marking temporal cycles (Prach & Walker, 2011). Agroecosystems are not different from natural ecosystems in terms of these dynamics, but the time scale is absolutely different. Croplands are agroecosystems constantly disturbed by farm administrators, and depending on the agricultural practices employed, they can be pushed into an earlier successional stage (Crews et al., 2016).

One of the most robust indicators of succession in agricultural lands is the soil ecosystem, which comprises a wide range of abiotic and biotic elements interacting in different degrees of complexity in different temporal and spatial scales. Recent research indicates that succession in the soil system can be understood in terms of its diversity of functions, the complexity of life that it hosts and its degree of connectivity with natural ecosystems (Harris et al., 2022). The practices that are currently employed in a large portion of agricultural lands, especially in large-scale production, come from an industrial model that does not take into consideration the soil system or the agroecosystem, as a complex set of actors and interactions, with specific dynamics, limits to anthropogenic use, and degradation thresholds.

Cropland establishment implies the removal of the living plant cover of soil, making it vulnerable to erosion and weakening the microbial communities that make many nutrients bioavailable for plants and play a vital role in the carbon and nitrogen cycle. Mechanized and intensive tillage compacts the soil, destroying its structure and making it harder for plant roots to penetrate and grow, limiting an adequate flow of water and gases. Adding chemical inputs like inorganic fertilizers and pesticides has adversely affected soil health and contributed to soil and freshwater pollution induced by run-off and drainage (FAO, 2021). Due to these practices, it is estimated that 1660 million Ha, which represents 35% of the total agricultural land or 12.6% of the globe's surface, is light to strongly degraded (FAO, 2021).

This is even more worrisome when considering the contribution of agriculture to Greenhouse Gas (GHG) emissions and Climate Change (CC). According to the Sixth Assessment Report of the IPCC, emissions from the agrifood system increased globally by 16% between 1990 and 2019. This includes activities derived not only from agriculture but also those involved in the different stages of industrial processing and transportation. In 2019, the agrifood system contributed 31% of the global anthropogenic GHG emissions or 17 billion tons out of 54 of carbon dioxide equivalent (or CO2-eq). Specifically, it generated 21% of the total CO2 emissions, 53% of methane (CH4) and 78% of nitrous oxide (N2O). Emissions derived strictly from agricultural activities were equivalent to 7 billion tons of CO2-eq; meanwhile, pre and post-production processes generated 6 billion tons, and land use change (e.g., conversion of natural ecosystems into agricultural fields) was 4 billion tons (IPCC, 2021).

Paradoxically, agriculture is severely threatened by increased GHG emissions, temperature, and precipitation patterns due to CC changes. Higher temperatures exert thermal stress over plants, increasing evapotranspiration rates and forcing adaptations that might affect production, such as the abortion of flowers and a decrease in crop yield (Pais et al., 2020). A higher concentration of CO2 has also led to higher plant productivity in certain species due to augmented photosynthesis rates. However, research also shows that zinc, iron, sulfur and protein contents of C3 grains and legumes decrease with higher CO2 levels, negatively impacting human nutrition (Uddling et al., 2018). Warmer temperatures are also causing disruptions in the different growth stages of species, extending or shortening the crop life cycle, depending on the latitude. This alters the synchrony between plant growth and phenology, pollinators' life cycle associated with agricultural plant species, and climatic events, such as the start of rainy seasons (Inouye, 2022).

The new thermal regimes also affect soil microbiota, critical agents in the nitrogen and carbon cycle, accumulation of soil organic carbon and solubilization of nutrients. Higher temperatures triggered varied responses in the enzymatic activity of nitrogen-fixing and phosphorus-solubilizer bacteria; the highest performance was reached near or in the usual average temperature (Kaur et al., 2014). Soil microbiota can aid in buffering the effects of CC over plants like water stress, salinity or persistent pathogens. However, when higher temperatures are coupled with the prevalence of agricultural xenobiotics (pesticides, fertilizers), the plant-microbe interaction is further disrupted, causing a detrimental effect on plants and soil health (Kumar Singh et al., 2019). All these factors raise the need to switch agricultural practices into ones that promote the succession of agroecosystems in order to regenerate their performance and increase their resilience to the current changing conditions. Therefore, it becomes vital to understand the threshold of disturbances that a soil ecosystem can withstand before permanent degradation and the main factors causing such disturbances.

The use of MAS methodology for evaluating agroecological transition

The MAS evaluates how farmers support agrobiodiversity by measuring the degree of development of practices that preserve water, soil health, and plant and animal diversity beyond productive purposes. By doing so, they promote the agroecosystem functional redundancy, response diversity, and presence of dominant, foundational, or keystone species, improving its resilience to disturbances like the ones caused by modern conventional agricultural practices or CC. Moreover, the spatial analysis performed using GIS allows farmers and researchers to assess if this "conservation spot", a farm with a strongly developed MAS, is connected to the natural ecosystem matrix and to what extent. This will directly influence how agroecosystems advance in their ecological succession and increase the complexity of the life they host and the richness of their functions.

A recent study shows that frameworks and methodologies for evaluating agroecological transition could be highly complex, making them impractical and expensive (Van Wijk et al., 2023). In many cases, this endangers transition, as the lack of an effective mechanism for measuring advancements might result in decisions affecting crop yields or, in the worst case, the overall agroecosystem health. Moreover, complex approaches could limit the participation of farmers, generating dependence instead of building capacities and knowledge. In this sense, the MAS successfully assesses agroecological transition while engaging both researchers and farmers, as it allows to make a rapid, wide-focused analysis of a farm and obtain a clear picture of its state.

In addition, the MAS methodology does not consider the natural components of the agroecosystem in isolation but rather as interdependent on the socioeconomic context of the farm administrator (T. León-Sicard et al., 2018). The practices employed for the production and maintenance of the agroecosystem obey multiple factors, such as the possibility of accessing sufficient resources and the knowledge to make the best use of them. Accessing sufficient resources might be largely conditioned by the economic conditions of farm administrators and refer to the possibility of accessing local seeds and plants, materials for maintaining the farm and developing the different stages of production, and logistic capabilities for transporting production from farms to markets.

Nevertheless, knowledge acquisition might be conditioned by multiple factors. One of the first and most effective sources of knowledge comes from the farmer-to-farmer interchange, where information comes from different experiences or teachings shared between neighbors or members of a community (Martini et al., 2023). This powerful practice provides first-hand information about how to improve production or deal with a problematic situation; it is shared horizontally and comes from a reality close to that of the producers in terms of context and even language (Martini et al., 2023).

Even so, the learning processes in rural areas have been influenced mainly by entities outside farmers' reality. A clear example of this comes from agroindustrial companies that offer (often for free) capacity for modern agricultural techniques, offering improvements in yield increase, disease control, and effort reduction. In reality, this "knowledge" aims to teach farmers how to use packages of xenobiotic inputs (or agrochemicals) developed by the same companies. This approach does not address the principles behind agroecosystem performance and soil health. Instead, they offer simplistic solutions conditioned by the usage of agrochemicals, promoting its purchase and further dependence (Staudacher et al., 2021).

On the other hand, some Non-Governmental Organizations (NGOs) working in rural development have focused on supporting a transition from conventional agricultural practices into ones that might improve their production and economies while keeping agroecosystems and farmers healthy. By encouraging grassroots initiatives and providing technical assistance for building capacities and collective knowledge, NGOs became a key stepping stone for shifting towards a more sustainable agriculture (Bernard & Lux, 2017; López-García et al., 2021; Mier Y Terán Giménez Cacho et al., 2018). Practices gathered under "sustainable" agriculture are many, depending on their basic principles, geographic origin, objectives and field of application (Velten et al., 2015). Still, agroecology has been widely studied for its multi dimensionality, necessary to address highly complex backgrounds. The adoption of agroecological practices for transitioning from conventional agriculture, and the scaling-up of this process, appears as one of the most effective ways, at least from agriculture to cope with land degradation, climate change, biodiversity loss, rural impoverishment and hunger (HLPE, 2019).

The widespread adoption of agroecology was evidenced in this study, as all the producers who collaborated in the research conceived themselves as agroecological. In some cases, this identification occurred after receiving technical support from an organization, which indicated that the practices employed by farm administrators at that moment were the same in agroecological production. Producers inherited these practices from their families, who have worked the lands following certain principles derived from Andean Cosmovision. However, all of them included, at some point, or are still employing practices from conventional modern agriculture, reflecting the deep prevalence of agroindustrial influence in the historical background of the study sites. In this sense, is it correct to define a farm as agroecological if it still employs conventional techniques? This question generated an intense debate around the community (other researchers, students and farm administrators) around this study and could have multiple answers.

One of the best examples of how to address this issue comes from the Participatory Guarantee Systems (PGS) developed by some associations of producers. PGS consists of grassroots certifications of a network of farmers, self-regulated by a designed committee of producers, experts and civil society members, that guarantee the quality of agricultural production under standards developed in a participatory way (Loconto & Hatanaka, 2018). These standards might refer to restrictions in the usage of agrochemicals (pesticides, xenobiotic fertilizers), incorporating practices for soil health and natural resources conservation, fair trade, and animal and human wellbeing (FAO, 2018). In some cases, these certifications also come with a scale for classifying farms, depending on the degree of adoption of the required practices. Thus, the transition from conventional to agroecological production is recognized as *a process* rather than a single, isolated event, and even further, the degree of transition is not fixed, meaning that advanced agroecological farms can return to an earlier stage under specific circumstances (e.g., a pathogen that grew out of control in a neighboring farm).

This was evidenced in the Cayambe study site in the northern part of Pichincha Province. Here, the producers who collaborated in this research belonged to the "Movimiento Cantonal de Mujeres de Cayambe" (cantonal movement of women of Cayambe), an association created in 2016 to strengthen agroecological practices, empowerment of women and fair trade (Lang, 2022). Despite its recent creation, all participants started the transition at least ten years ago. Some of them, like administrators of farm F04, have worked following these principles for more than 25 years. At present, all movement members also adhere to a PGS to guarantee the quality of production to consumers. Another example comes from the Ilaló study site in La Merced, Pichincha. Here, farm F15, the lighthouse farm of this study, started its production over a "cangahua" layer 14 years ago (cangahua is a subsoil layer formed by ash and other volcanic materials, which has lost its organic layer due to erosion). This forced farm administrators to incorporate techniques for soil regeneration and resource conservation from the beginning. In this process, he could share these experiences in the format of a peasant school of agriculture (or ECA in Spanish) (Pumisacho & Sherwood, 2005) with other farmers nearby, including administrators of farms F13 and F14.

The other three study sites, Cotopaxi, Cacha and La Esperanza, showed contrasting situations. In Cotopaxi, all the farmer who collaborated in this research participated in an agroecological fair called “De la mata a la olla” (from plant to pot), which also handles a PGS (Hipo, 2023). This PGS establishes a minimum of practices to be incorporated before being able to sell its products at the fair, which takes place in the city of Salcedo (in Cotopaxi province). Despite this, the study sites are located in areas with severe land use pressure and erosive processes and might require more specific and aggressive approaches to achieve an effective transition. A similar situation was observed in Cacha, where agroecological producers are located in zones with advanced erosive processes and the growing emergence of Cangahua outcrops. Factors like steep slopes, deforestation and lack of access to water for irrigation condition agricultural production in all its forms. Aside from that, Cacha producers are not linked to any fair or PGS, and cooperation from private organizations or the local government is scarce.

Finally, La Esperanza producers are part of the association “Sumak Yuyay” (good/beautiful ideas/thoughts in Quechua) that, alongside INIAP (National Institute for Agriculture and Livestock Research in English), have collaborated to improve production through the introduction of improved varieties of seeds and the addition of agrochemical packages. In addition, intensive tillage practices were recorded in the five farms. Still, producers manifested their urge to transition into agroecological practices. For the last five years, they have incorporated living fences, alternate crops, organic fertilizers and agroecological vegetable gardens as experimental plots. For this reason, all experimental units (EU) in this study were treated as farms “in a degree of agroecological transition” rather than agroecological or not, even though all conceive themselves as “agroecological”. There were clear differences amongst every EU; however, this difference was more substantial when analyzing the MAS score by study site (Table 5).

Cayambe and La Merced having significantly higher values than the other three. This pattern was consistent when analyzing the scores of MAS indicators separately (Table 6), specifically in 4 cultural indicators (AMP, CP, PA, CA); the rest did not show a significant difference. This supports the idea that variation by site is not explained by differences in the connectivity with the landscape or by the recorded agrobiodiversity in each farm. It is instead explained by the practices included for agricultural production (AMP), conservation of natural resources (CP), awareness of farm administrators about the importance of agrobiodiversity (PA) and their capacity to take action for sustaining these practices in time (CA).

These practices were, in turn, the direct consequence of cooperation and development processes started by external actors, which were constant over time and evolved to generate grassroots initiatives and networks, according to farm administrators. For this reason, I propose that one of the main drivers for the variation of MAS between sites, and potentially of the agroecosystems resilience, is the Cooperation and Networking Potential (CNP). This notion, proposed by the author of this research, refers to 3 main aspects: 1) the quality of the interchange of knowledge that can occur between farmers and between farmers and organizations, 2) the time that this interchange has lasted and 3) the level of empowerment that farmers might achieve in their practices as a consequence of this interchange.

In the MAS methodology, these aspects are addressed by the indicator CA (Capacity of Action), which measures four different capacities of farmers: 1) logistic (transport and infrastructure), 2) economic and financial, 3) management (institutional and interpersonal relations) and 4) access to agroecological technical assistance. Farm administrators in Cayambe and La Merced state that the first three were built over time. However, technical assistance was vital to *start* with the agroecological transition, as it implied building capacities for agroecological production, assigning fair prices to their production, and organizing fairs or other delivery systems that promoted direct trade, amongst others.

About time, the two sites had the most extended processes of capacity building and cooperation with other organizations, with approximately 10 to 15 years of relatively constant interchange. Finally, and perhaps the most crucial aspect, farmers in both sites now have attained a considerable degree of autonomy because they can generate their learning processes independently from organizations or external agents and have the resources to do so —moreover, some lead processes from communitarian organizations to political and administrative positions.

Although the MAS methodology does not measure these aspects in depth, it is still an excellent tool to understand which could be the main drivers shaping the agroecological structure of farms, understood as agroecosystems. In addition, there are many frameworks and methodologies for measuring CNP, but further research is required to understand how to scale this notion into an indicator and if it is worth assembling a specific methodology instead of simply using something previously defined. CNP could be a powerful tool for determining the impact of capacity-building processes in future research.

CONCLUSIONS

The Main Agroecological Structure (MAS) methodology is a powerful tool for evaluating the assembly of an ecological structure in an agricultural context. This "agroecological" structure relies upon three main components: 1) the degree of connectivity of the agroecosystem (or farm) with the naturally-occurring ecosystem in the landscape and 2) the biodiversity that can be found within and 3) the capacity of farm administrator for maintaining such state. For this, it measures the development of 5 ecological and five cultural indicators. The degree of connectivity relies upon the proximity of patches of forests and their area within an Area of Influence (AI) that is calculated according to the farm's dimensions. However, it does not distinguish the type of forest (plantation of trees, secondary forest) and, therefore, might be overestimating the ecosystem functions provided by such patches.

Concerning biodiversity, it directly measures the diversity of species found in living fences, either inner or outer (that is, in the farm's surroundings), as well as its extension. Indirectly, it evaluates how farm administrators support the proliferation and conservation of biodiversity, either cultivated or occasional. This is achieved by measuring the quality and degree of implementing practices for managing crops and natural resources (organic matter, soil, water). Finally, the capacity of farm administrators is understood as their current degree of knowledge, the possibility of accessing necessary resources (seeds, money, transport, labor force, information), and the strength of their social networking with other farmers, the public and private organizations. This methodology was successfully applied in the Ecuadorian context for the first time, specifically in the northern-central Andean region, along four provinces: Imbabura, Pichincha, Cotopaxi and Chimborazo.

I evaluated the MAS of 20 farms in different degrees of agroecological transition and found that they had a moderately developed structure on average (71.05). The highest score was from farm 15 (F15) in La Merced, Pichincha, which exhibited a strongly developed MAS (89.94). The lowest was from farm 20 (F20) with a slightly developed (54.75) MAS. Further analyses of the results showed that MAS variation is not correlated to the area of farms included in this study. Nevertheless, the area is critical for developing agricultural activities and scaling up agroecological practices. Therefore, a larger sample size could reveal a relation. MAS is also not correlated to the Connectivity of the Main Ecological Landscape Structure (CMELS, indicator 1, which measures proximity and density of forest patches in AI). Values for this indicator were low (3 or less, out of 10, in 18 farms), confirming the tremendous pressure on ecosystems due to land conversion and deforestation stated in the sites' description.

MAS variation is strongly influenced by the practices employed for production and natural resource conservation (indicators 6, 7, 8,9) and the capacity of farm administrators to sustain this performance in time (indicator 10). In addition, MAS was related to the site, with significantly higher values of MAS in the locations of Cayambe and La Merced than in the other sites. One of the most prominent differences between these two locations and the others was the more extended background of cooperation and development programs carried out in the last decade. Longer processes of capacity building, construction of knowledge and leadership formation might directly impact assertive decision-making and eventual improvement of practices for an effective agroecological transition.

For this reason, I propose that MAS measurements in the study site should be complemented with an analysis of the Cooperation and Networking Potential (CNP). This analysis should measure 1) the quality of the interchange of knowledge between farmers and between farmers and organizations, 2) the time that this interchange has lasted and 3) the level of empowerment that farmers might achieve in their practices. It might be possible to obtain this information by applying methodologies of frameworks already developed for this purpose. However, evaluating its suitability in terms of relevance, required resources and compatibility with the local context should be necessary. It is essential to highlight that the MAS methodology does not cover all factors that might be critical to consider for an effective agroecological transition. Thus, it should be complemented with further analysis, for example, socio-cultural, economic and soil health studies.

During the MAS analysis, I used the platform Google Earth Pro (GEP) to access recent satellite images of the farms and measure their dimensions and ecological indicators. In addition, I used orthophotos of the study sites taken in 2014, provided by the Ministry of Agriculture, to evaluate the variation of the CMELS compared to the present. There was no significant variation of CMELS comparing past vs present images. However, some patterns emerged: Cayambe and Cacha (sites 1 and 2) showed a decrease in the density (area) of forest patches within their AI, with F03 showing the highest loss (32%). On the other hand, Cotopaxi, La Merced and La Esperanza showed an increase, and notably, F15 showed an increase of 23%. It is possible that landscape analysis alone, through satellite images, is not sufficient to assess changes in Land Use/Land Cover (LULC). However, it is a rapid, low-cost tool to evidence significant changes.

In sum, the MAS methodology allows researchers to define the degree of development of a farm's agroecological structure. However, this can also provide a clear picture of how farm administrators are promoting an advance in the succession of agroecosystems. A more advanced succession could imply a higher degree of resilience of a specific farm. However, to understand how the employed farming practices contribute to this, it would be necessary to complement MAS application with other studies, like soil health assessments. Still, the MAS analysis provides valuable feedback obtained with simple, low-cost methodologies that academics and producers could implement. This study aims to establish a baseline to support farm administrators' assertive decision-making. Hopefully, this practice will scale up to other sites, enabling farmers to adopt practices to sustain production in time while preserving agroecosystem functions, soil health, food sovereignty and an appropriate means of subsistence.

RECOMMENDATIONS FOR THE FUTURE RESEARCH

The application of MAS in the study sites opened a discussion for several issues. One of the most relevant questions was: How do practices that received a high score in the methodology support agrobiodiversity? Understanding that agrobiodiversity goes well beyond plant diversity, one of the first recommendations would be to complement MAS with studies of soil macro and meso invertebrates and fungal and bacterial abundance, understood as microbiomes and diversity if possible. As discussed above, these groups play an essential role in soil health and, therefore, in agroecosystem functions. They are susceptible to changes in the agroecosystem dynamic, coming from intensive tillage and the addition of toxic xenobiotic inputs. Numerous well-documented methods exist for studying soil macro and mesofauna; most require easy-to-access equipment. In what concerns microbiomes, there is an increasing number of methods for quantitative and qualitative analyses. However, many have severe limitations, so assessing any potential drawback in their application is highly recommended before conducting further research.

Another important topic of discussion amongst the collaborators of this research was: What is the importance of the quality of the natural ecosystem remnants surrounding the farms? This question departed from the fact that the MAS does not consider the *type* of vegetation found in forest patches but focuses on its extension. The author of the MAS methodology warns that forest patches differ depending on further studies that were to be carried out in an agroecosystem. In this sense, it is necessary to make a deeper analysis of their flora and fauna, as well as their dynamics and functions. Regarding the inner diversity, the MAS accounts only for plant species arranged in external and internal corridors of vegetation or living fences. However, it does not consider the plant species *within* the productive spaces, except for an indicator that analyzes the percentage of farm cover used for alternating or mixed crops. Crop species will remain for a shorter period and, thus, will impact less on the biodiversity assemblage of the agroecosystem. Still, they are the central part of the farm's arrangement. They will drive the administrator's decisions, so it is strongly recommended that this study be complemented with an analysis of the species cultivated for productive purposes and their possible influence over agroecosystem performance.

Finally, and the most crucial recommendation, is to generate a discussion of the obtained results with the farm administrators. The MAS is a straightforward methodology that could be applied by academic researchers and farmers interested in evaluating the current state of their farms, how it changes year after year, or comparing the MAS of different farms. This demands the interest of farmer collaborators and a strategic effort from researchers and organizations to complement these studies with workshops designed to match each farmer’s context, knowledge gaps and potentialities.

GLOSSARY

Main Agroecological Structure: Environmental index that measures degree of development of the ecological structure in an agroecosystem or farm. This structure relies upon 1) the degree of connectivity of the agroecosystem with the surrounding naturally occurring ecosystem, 2) the biodiversity that can be found in the living fences inside the farm and 3) the capacity of the farm administrator to improve or maintain this biodiversity. The MAS measurement will increase with practices favoring biodiversity and conservation within the farm, improving the agroecosystem resilience to natural or anthropogenic-derived disturbances

Agroecosystem: Agroecosystems can be understood as parts of the ecosystems under an specific regime of human-conducted management. As a natural ecosystem, it is composed of abiotic and biotic elements that interact with each other and the surrounding landscape. Agroecosystems, in addition, build-up by interdependent social, economic and ecological components, and are part of flows (energy, water) and mechanisms (nutrient cycles, pests and diseases biological control, pollen transfer, etc.). For this reason, they have a structural and dynamic complexity given by its inputs and outputs, which also favor the appearance of emergent properties

Agroecology: Agroecology is at the same time a science, a practice and a social movement. It focuses on generating synergies between human and non-human components of "agroecosystems" as it recognizes an agricultural space as part of the ecosystem. This is achieved by applying practices that promote agrobiodiversity and conservation of ecosystem functions over time. In parallel, it incorporates a vital social component that seeks the integral well-being of all human beings around food production and consumption. Furthermore, agroecology can potentially improve agroecosystem resilience, understood as the capacity to tolerate disturbance while conserving its properties. This is critical as nutrient depletion, water scarcity, the enhanced prevalence of pathogens, land conversion from urbanization, pollution and altered climatic patterns due to climate change.

Agroecological transition: Agroecological transition can be understood as the transition from a specific agricultural productive system, commonly a conventional system, into one managed under agricultural practices. Agroecological transition has been a wide subject of debate, as it has been promoted by many scholars and grassroots organizations, but faces severe challenges that demand a wide set of actions from many different actors.

Resilience: Ecosystem resilience can be understood as the capacity to return to a determined state of equilibrium (in its functions, performance and diversity) after a disturbance, which can be natural or anthropogenic. This resilience depends on multiple factors, such as its functional redundancy, response diversity and the presence of dominant, foundational or keystone species

Succession: ecological succession can be understood as the study of how biological communities re-assemble following natural or anthropogenic disturbance. An example of succession could be the dynamics that take place in the soil ecosystem after an anthropic disturb, such as intense plowing or addition of pesticides.

Cangahua: “Cangahua” means in local Quechua “sterile hard land”. Cangahua is a rocky geological formation originated from pyroclastic material and ash, that has hardened and “cemented” the soil within many years. It can be found mainly in the northern part of the Inter-Andean valley, but it is present in the central part as well

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ANNEXES

Annex 1. Battery of questions for interviews with producers. The questionnaire compiles information for completing indicators 7, 8, 9 and 10 to be evaluated within the Main Agroecological Structure (MAS) methodology. Each indicator includes a series of questions aimed at collecting information on the different parameters of the indicators.

7. Agricultural management practices (AMP)

- Where do the seeds used for planting come from?
- Are they conserved in any way? How?
- Is any type of tillage performed on the crop and what does it consist of?
- Are fertilizers used? Are they chemical or organic? Are they purchased or produced?
- How are the plants managed when growing in association with the crops (weeds)?

8. Conservation Practices (CP)

Water conservation

- Are there water bodies on the farm?
- What practices are used for their conservation?
- Are tests or indicators used to measure water quality?

Biodiversity Conservation

- Are areas on the farm set aside for the recovery of natural habitat?
- Are native species planting or reforestation practices in place?
- Are areas set aside for the conservation of wild animals?

9. Perception Awareness Knowledge (PA)

- Do you consider biodiversity on your farm to be important? Why?
- Have you participated in any knowledge sharing on the importance of biodiversity?

10. Capacity for Action (CA)

Financial Capacity

Do you have any of the following financing options?

- financial income
- money savings
- access to credit
- access to government or NGO support programs

Logistical capacity

Do you have enough manpower to work on the farm?

- Always
- Almost always

- Sometimes
- Rarely
- No

What do you consider to be the condition of the roads/trails connecting your farm?

- Excellent
- Good
- More or less good
- Bad
- Poor

Do you own your own means of transportation?

- Yes
- No
- Other (occasional rental/collaboration)

Do you consider that you have the necessary tools for the maintenance of the farm?

- Yes
- No
- Other (occasional rental/collaboration)

Are there plant nurseries nearby where you can easily acquire seeds/seedlings of what you need?

- Yes
- No
- Other (exchange with other producers)

<u>Management capacity and access to technical assistance</u>

Do you maintain links with public (state) or private (NGO) institutions?

- Yes
- No

How would you rate your relationship with these organizations?

- Excellent
- Good
- More or less good
- Bad
- Poor

Have they provided technical assistance on issues important to you?

- Yes
- No

How would you rate this assistance? In terms of quality and frequency.

- Excellent
- Good

- Fairly good
- Poor
- Poor

Are you part of any producer alliances or organizations?

- Yes
- No

If yes, how would you rate your participation in them?

- Excellent
- Good
- More or less good
- Poor
- Very bad

Have you been able to form your own alliances?

- Yes
- No
- Why?

Annex 2. Diversity of species found in living fences. A complete list of the species found in the assessment of DEC and DIC. The list details the botanical family, genus and species, its common name (which might be in Spanish, Quechua or both), its endemical status if they are either native or introduced) and the habit (herb, vine, shrub, treelet or tree)

Family	Common name	Scientific name	Status	Habit
Alstroemeriaceae	Escoba de bruja	*Bomarea multiflora*	Native	Herb or vine
Anacardiaceae	Molle	*Schinus molle*	Introduced and cultivated	Treelet or tree
Araliaceae	Pumamaqui	*Oreopanax ecuadoriensis*	Endemic	Treelet or tree
Asparagaceae	Penco	*Agave americana*	Introduced and cultivated	Herb
Asteraceae	Diente de león	*Taraxacum officinale*	Introduced	Herb
Asteraceae	Rama negra	*Conyza bonariensis*	Introduced	Herb
Asteraceae	Botoncillo	*Galinsoga parviflora*	Native	Herb
Asteraceae	Ñachag	*Bidens andicola*	Native	Herb
Asteraceae	Amor seco	*Bidens pilosa*	Native	Herb
Asteraceae	Chilca	*Baccharis latifolia*	Native	Shrub or tree
Asteraceae	Marco	*Ambrosia arborescens*	Native	Shrub, or treelet
Balsaminaceae	China gigante	*Impatiens sodenii*	Introduced and cultivated	Shrub
Betulaceae	Aliso	*Alnus acuminata*	Native	Tree
Bignoniaceae	Yalomán	*Delostoma integrifolium*	Native	Tree
Bignoniaceae	Cholán	*Tecoma stans*	Native and cultivated	Shrub or tree
Boraginaceae	Borraja	*Borago officinalis*	Introduced and cultivated	Herb
Brassicaceae	Carraspique	*Thlaspi* cf. *arvense*	Introduced	Herb
Cactaceae	Tuna	*Opuntia ficus-indica*	Introduced	Shrub or tree
Calceolariaceae	Zapatito	*Calceolaria crenata*	Native	Herb or subshrub
Cupressaceae	Ciprés	*Cupressus sp.*	Introduced and cultivated	Treelet or tree
Euphorbiaceae	Higuerilla roja	*Ricinus communis*	Introduced and cultivated	Shrub, or treelet
Euphorbiaceae	Lechero	*Euphorbia laurifolia*	Native	Shrub or tree
Fabaceae	Trébol	*Trifolium repens*	Introduced and cultivated	Herb
Fabaceae	Retamilla	*Genista monspessulana*	Introduced and cultivated	Shrub
Fabaceae	Acacia	*Acacia melanoxylon*	Introduced and cultivated	Tree
Fabaceae	Guaba	*Inga edulis*	Native and cultivated	Tree
Geraniaceae	Geranio	*Pelargonium* sp.	Cultivated	Herb
Iridaceae	Gladiolo	*Gladiolus sp.*	Introduced and cultivated	Herb
Juglandaceae	Tocte	*Juglans neotropica*	Native and cultivated	Tree
Lamiaceae	Romero	*Rosmarinus officinalis*	Cultivated	Shrub
Lamiaceae	Bola de rey	*Leonotis nepetifolia*	Introduced	Herb
Lamiaceae	Hierba buena de monte	*Salvia misella*	Native	Herb
Lamiaceae	Quinde tzungana	*Salvia tortuosa*	Native	Shrub
Lauraceae	Aguacate	*Persea americana*	Cultivated	Tree
Malvaceae	Malva morada	*Lavatera arborea*	Introduced and cultivated	Herb or subshrub
Malvaceae	Cucardas	*Hibiscus rosa-sinensis*	Introduced and cultivated	Shrub
Myricaceae	Laurel de cera	*Myrica pubescens*	Native	Treelet, or tree
Myrtaceae	Guayabilla	*Feijoa sellowiana*	Introduced	Treelet or tree
Myrtaceae	Eucalipto	*Eucalyptus globulus*	Introduced and cultivated	Tree
Nyctaginaceae	Buganvilla	*Bougainvillea* sp.	Cultivated	Shrub or vine
Pinaceae	Pino	*Pinus* sp.	Introduced and cultivated	Tree

Plantaginaceae	Llantén	*Plantago major*	Introduced	Herb
Poaceae	Rabo de gato	*Cenchrus setaceus*	Introduced	Herb
Poaceae	Sigse	*Cortaderia nitida*	Native	Herb
Poaceae	Pajonal	*Calamagrostis intermedia*	Native	Herb
Poaceae	Kikuyo	*Pennisetum clandestinum*	Introduced and cultivated	Herb
Polygalaceae	Monina	*Monnina* sp	Native	Tree
Rosaceae	Níspero	*Eriobotrya japonica*	Introduced and cultivated	Shrub or tree
Rosaceae	Capulí	*Prunus serotina subsp. capuli*	Native	Tree
Rosaceae	Rosa	*Rosa sp.*	Introduced and cultivated	Herb
Rosaceae	Yagual	*Polylepis cf. Racemosa*	Introduced and cultivated	Tree
Rosaceae	Mora (de monte)	*Rubus sp.*	Cultivated	Shrub
Salicaceae	Sauce	*Salix* sp.	Introduced and cultivated	Tree
Scrophulariaceae	Verónica	*Veronica persica*	Introduced	Herb
Solanaceae	Floripondio	*Brugmansia arborea*	Native	Shrub or treelet
Solanaceae	Tabaquillo	*Nicotiana glauca*	Introduced	Shrub or treelet
Solanaceae	Hierbamora	*Solanum americanum*	Native	Herb
Verbenaceae	Tupirosa	*Lantana camara*	Introduced and cultivated	Herb or shrub
Verbenaceae	Verbena	*Verbena litoralis*	Native	Herb or shrub
Verbenaceae	Mote-casha	*Duranta tricantha*	Native	Shrub
Viburnaceae	Tilo	*Sambucus nigra*	Cultivated	Treelet, or tree

Annex 3. Photographic record. Photos taken during the elaboration of this research.

Spatial assembly of an agroecological farm. Agroecological farms, or major agroecosystems, typically include plots or "minor agroecosystems" that conform them. These minor agroecosystems can have different uses, like mixed and associated crops, fallow lands with or without integration of animals, living fences, and the prevalence of weeds (either occasional or sown) destined to cover the soil. In the photograph, we can see fallow lands called "barbechos" in Spanish, intentionally left without sowing for promoting soil recovery. In this case, we can also ser the integration of sheep in a practice known as "sogueo" ("roping"), where animals are tied to a rope and moved every once in a while to generate an input of manure. This improves soil organic matter content while preventing soil compaction derived from trampling. Photo taken in farm F01, Cayambe, Pichincha. Author: Gabriel Sáenz Lituma.

Participatory Mapping in La Esperanza. In the picture, Julio (Ekorural) locates a farm in a satellite image along with its administrator in La Esperanza, Imbabura. Esteban and Erick, students from the Universidad Técnica del Norte, also participated in the process. The participatory mapping was part of a diagnose, which served as an introduction for the MAS measurements in the area. Author: Gabriel Sáenz Lituma.

Doña Hilda shares her knowledge with us. One of the most valuable teachings of the whole internship was to learn how to listen. Dona Hilda has led many processes for teaching other women dedicated to agriculture how to incorporate agroecological practices into their production. Photo taken in her farm in Cayambe, Pichincha. Author: Gabriel Sáenz Lituma.

Inti Raymi celebrated in Universidad Andina Simón Bolívar (UASB). During the month of June, it takes place one of the most important festivities in the Andean cosmovision (under which many indigenous nationalities are aligned to): the "Inti Raymi" or Sun Festival. It is celebrated on June 22nd, along with the summer solstice for the north hemisphere, and winter solstice for south hemisphere. The festivity, which celebrates the presence of the Sun as the force that sustains all life on the "Pachamama" (the Earth), included thousands of participants, traditional dances, food and parades. Depending on the location, the festivities can extend up to August. This, and other festivities, are of great importance for indigenous communities, and could imply a delay in any research project during this period. Photo taken in the UASB Campus in La Floresta, Quito, Ecuador. Author: Gabriel Sáenz Lituma

Biodiversity, Seeds and Traditional Foods Fair. During the study, I was able to participate in the Fair which took place in Salcedo, Cotopaxi. Here, farmers from different places of the Ecuadorian Andes gathered to sell their production, but also, to meet other producers, interchange experiences and recover seeds from any species or local varieties that might have been lost for some reason. Spaces for meeting each other are crucial in "campesino a campesino" (farmer to farmer) learning processes. In the photo, we see more than 30 varieties of Andean tubers, like potatoes (*Solanum tuberosum)*, mashuas *(Tropaeolum tuberosum*), ocas *(Oxalis tuberosa)* and mellocos *(Ullucus tuberosus)*. Author: Gabriel Sáenz Lituma

Evaluating soil health along farm administrators. Here, Vicente, professor from the Escuela Politécnica de Chimborazo (ESPOCH), takes soil samples with Don Pedro, owner of a farm in Cacha, Chimborazo. The characterization of the Main Agroecological Structure was embedded within a larger project, that aimed to measure soil health in the study sites along with farmers. This project is currently ongoing, and will be running until mid-2024. Author: Gabriel Sáenz Lituma.

Doña Mercedes and Don Antonio at their farm. Both have worked in their plot for at least 40 years, incorporating many principles of Agroecology and obtaining a robust and healthy production, like the "taxos" (*Passiflora tripartita*) shown in her hand. Photo taken in Cayambe, Pichincha. Author: Gabriel Sáenz Lituma.