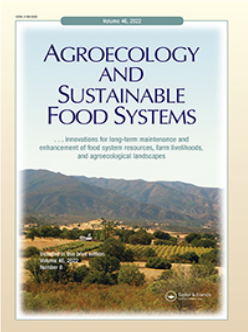

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Terraces and ancestral knowledge in an Andean agroecosystem: a call for inclusiveness in planetary health action

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ABSTRACT
Ancestral knowledge, centered in Mother Nature, is in the indigenous discourse and international forums. Caliata, a resilient community in Ecuador's central highlands faces internal structural problems and external pressures. Nevertheless, it has retained an ancestral knowledge deeply integrated into a pre-Columbian system of cultivation terraces, agrodiversity, native crops, and natural cycles' management, which combine to shape a viable agroecosystem. We describe Caliata's agroecological landscape and community views to explore the sustainability cues that have assured food sovereignty, seemingly from ancient times. Our research provides insights that can be scaled-up from local to programs and policy aligned to planetary health.

KEYWORDS
Sustainable agriculture; participatory research; agroecology; food sovereignty; system dynamics; cultivation terraces; indigenous knowledge

INTRODUCTION

Indigenous people advocate for the recognition of their "ancestral knowledge" (also "ancestral wisdom") in order to tackle sustainability, conservation, food sovereignty and climate change challenges. Their voices have been heard in global forums like the Climate Summit–COP23 (Bonn: 2017) and the 18th session of the United Nations Permanent Forum on Indigenous Issues (New York: 2019). Ancestral knowledge signifies discourses of resistance and resilience, a patent of systems of knowledge and skills that have survived and adapted to historical forms of colonization. Countries of the Andean Community of Nations (CAN), comprised of Colombia, Ecuador, Peru and Bolivia, recognize the importance of ancestral knowledge in their regulatory

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and legal frameworks, often as complementary to science (e.g., Cevallos 2013; Ecuador 2016; Zamudio 2012). South America is home to 30 million indigenous people, and half inhabit the CAN area, mostly living in rural communities at altitudes greater than 2,500 meters above sea level [MASL] (FAO 2014).

Ancestral knowledge is articulated rationally, emotionally, and spiritually in Andean cosmovision, an ecocentric ontological stance that places *Pachamama* or Mother Nature as a central interconnected whole (Gallegos-Riofrío et al. 2021a; Tituaña-Males 2006). In that sense, this knowledge originates in a multidimensional relationship with nature, which Andean societies have developed from pre-Columbian times (e.g., Guerrero-Ureña 2015; Peñaherrera, Costales-Samaniego, and Costales-Peñaherrera 1996). This ancestral knowledge in the Andes includes agrarian and hydraulic technologies that are still effective today. These include raised beds (*warus-warus*), water recharge systems from micro-basins (*qochas*) or terracing cultivation, as well as robust native crops and genetic variability, which help to ensure food sovereignty, the vitality of ecosystems, and respond to climate change (Carrasco-Torrontegui et al. 2020).

The ecocentric ontology implicit in ancestral knowledge is expressed through the creation of agroecosystems that result from heterogeneous spaces, like family-based polycultures, such as the biodiverse *chakra* with its regional variations (e.g., Gallegos-Riofrío et al. 2021b; Perreault 2005; Rhoades 2006). Agroecosystems may be viewed as landscapes with identifiable borders shaped by agency, architectural knowledge (e.g., cultivation and irrigation systems), and close links among geographical, biochemical, social and individual factors (Altieri 2018). Andean agroecological space is also epistemological, a learning space where children interrelate with elders (Nieto Gómez, Valencia Trujillo, and Giraldo Díaz 2013). Consistently, it is the backbone of the traditional health system, which is preventive, reciprocity-based, and centered in balance with *Pachamama*, seeking to procure access to food and medicinal plants (Gallegos and Jara 2007).

Andean agroecosystems are characterized by verticality and climatic interactions of ocean currents, mountainous winds, and rainforest humidity, forming microclimates and a variety of habitats (Murra 2002). Colombia, Ecuador, and Peru are among the world's seventeen most megadiverse countries (Mittermeier, Robles-Gil, and Mittermeier 1999). The Andean region is, consequently, central to planetary health––representing exceptional biological and cultural richness, both of which are critical for securing ecological functions like climate regulation, soil health, providing water and humidity, and CO2 sequestration. Furthermore, the Andean mountains are inexorably linked to the Amazon jungle and its ecological services (FAO 2014; Mathez-Stiefel et al. 2017).

Planetary Health (or Biosphere's Homeostasis from geophysical theory) can be viewed as the self-stabilizing physical and biochemical conditions that generate favorable conditions for life. The concept is, as a matter of fact, a constitutive element of indigenous' cosmovisions, like the Andean *Pachamama* (Gallegos and Jara 2007), echoing scientific discourses broadly defined from Lovelock and Margulis (1974) and in Earth System Analysis (Schellnhuber and Wenzel 2012). More recently planetary health has gained attention through the reports of two collaborations substantiating how human health and food-systems depend on nature's health: Rockefeller-Lancet (Whitmee et al. 2015) & EAT-Lancet (Willett et al. 2019).

The objective of this research was to test a mixed-methods characterization of an indigenous-based landscape, which would be able to capture both scientific and indigenous information that could yield a more accurate socio-ecological representation. The case may contribute to a narrative that inclusiveness with self-determination is fundamental for the major transformation required to stay within the planet's generative capacity and ecological boundaries (Rhoades 2006).

Case study

Seven percent of Ecuador's population self-identifies as indigenous, representing 14 different nations with distinctive languages and customs (INEC, 2010). The Kichwa nation, composed of Kichwa speakers, is the largest indigenous group in Ecuador; it is concentrated mainly in the highland provinces, with 38% living in Chimborazo province (INEC, 2010). This exploratory study describes and analyzes the Andean agroecological space of the indigenous community of Caliata located at an average altitude of 3,150 MASL in the rural parish of Flores (Riobamba canton, Chimborazo province), near the city of Riobamba, the provincial capital (Figure 1).

Caliata is home to 57 families and 144 residents who are dedicated principally to subsistence agriculture. While crop production is largely rainfed, it also interacts with surrounding forests, creeks, and nearby high montane forest and high Andean meadows (*paramo*) habitats. For example, *paramos*, located above 3,500 MASL, are fundamental for high-altitude agroecosystem because the *pajonal* (*Calamagrostis effuse*) captures moisture from the environment and acts as a water retention mechanism (Sarmiento 2012). Caliata has retained its indigenous Kichwa-Puruwá identity and Kichwa is the common language. Using historical narratives, people in Caliata recognize a mixed heritage as descendants of the Puruwá people (500–1480 AD) (Freire 2005) and the Incas (1438–1533 AD) (Costales 1963). They often wear their traditional clothing, and many social norms are still in place, such as the *minga* (reciprocal communal work) and *raymis* (feasts). Moreover, the community is affiliated to local, regional, and national indigenous organizations (Gallegos-Riofrío et al. 2021b).

The inhabitants of Caliata experience various structural problems like material poverty, acculturation, outmigration, and population aging (Gallegos-Riofrío et al. 2021a, 2021b). While the agroecosystem is threatened

Figure 1. Maps of Ecuador, Chimborazo Province and Riobamba Canton.

by modern agriculture in the form of mechanized plowing, agrochemicals, and monocultures, as well as structural social problems, land is still managed mostly using ancestral knowledge. Caliata is notably resilient and a positive deviance. The concept positive deviance denotes uncommon advantageous collective behaviors that lead to better outcomes in comparison to neighboring communities and, in particular, the case provides opportunities to learn about sustainable diets and food sovereignty as well as clues to tackle unhealthy dietary patterns and chronic diseases (Gallegos-Riofrío et al. 2021a).

METHODS

We conducted participatory agroecology-based site analysis, qualitative techniques and community-based system dynamics (CBSD). The research team included two indigenous colleagues from Caliata, with applied research experience, and a community elder who provided advice. Fieldwork was conducted between April and December 2018. Preliminary findings and refined findings were assessed with community members using a participatory evaluation method, following an experience in an intercultural study with Kichwa speakers in Ecuador's highlands (Gallegos, Waters, and Kuhlmann 2017). Finally, we employed systematic member checking, including in the making of this manuscript, in order to maximize validity (Creswell and Miller 2000). Results are presented by interspersing the voice of community actors, codified to keep confidentiality (*see* Table 1).

This study was approved by two institutional review boards (IRBs) in Universidad San Francisco de Quito (Ecuador) and Washington University in St. Louis (United States). Study participants gave their verbal informed consent.

Table 1. Testimonials' Coding Schema.

	Code		Code
Research Activity		*Research Activity*	
Focus group	G	Interview	I
Biological sex		*Biological sex*	
Female/ Male	F/ M	Female/ Male	F/ M
Focus groups' age cluster		*Interviewed position*	
18–29 yrs.	T	Endogenous perspective/key informer	K
30–39 yrs.	Y	Exogenous perspective/external informant	E
40–64 yrs.	A	*Order of the interview*	1–10
≥ 65 yrs.	O		
Participants' initial	A-Z		

Notes: **1**. Examples of coding mechanism: (a) "Victoria" [fictional name] has 31 years is a focus group participant, her code is "GFYV." (b) "Juan" [fictional name] was the third informer interviewed, his code is "IMK3."
2. The six additional follow-up interviews were aggregated in a single file, as an extended interview, for the following codes: IFK2 (x2); IFK4 (x1); & IMK1 (x3).

Agroecology-based site analysis

We designed a structured observation tool with three modules. Module 1 collected data on seasonality, site characteristics such as access to irrigation water, land management, borders, site architecture, and geographic positioning system (GPS) measurements with a Garmin (64sx), including geographical coordinates, plot size, altitude, and angle of the slope. Module 2 consisted of a biodiversity assessment in parcels and at borders, including the common names of natives and introduced plants, varieties, use, and estimated abundance with quadrats at random locations. Module 3 was a training for soil health analysis in terms of physical and biochemical parameters, using MO-DIRT protocols; a user-friendly method that allows community members to obtain on-site test results (Arango-Caro and Woodford-Thomas 2015).

Using modules 1 and 2, we assessed ten sites following a purposive selection rationale (Patton 2014) that responded to community perspectives about variability. We assessed parcels, traditional pedestrian paths, and borders or edges. Variability criteria included different heights of terrace systems (high, medium, or low), cultivation practices/stages (e.g., monoculture, polyculture, plowed), presence or absence of irrigation systems, and anthropogenic biomes (cropland, woodland, mixed cropland-woodland, rangelands).

These criteria were attained by applying participatory depictions of the landscape using the talking map technique (Catley et al. 2007), with four groups of community members (48 participants) in order to understand members' notions of space (Figure 2). Participants were asked to describe their maps, characteristics of different terrains, and rationales for its perceived importance. Descriptions were note recorded, systematized, and discussed with the elder and the two local collaborators to select the sites. Landscape assessment was carried out with the two collaborators and with local key informants (IFK4, IFK6 & IMK1 codes in Table 1), who identified species with broad uses to the community (i.e., agroecologically useful to their food sovereignty and resilience), like horticultural and agricultural, trees, medicinal plants, and edible fungi. Afterward, we developed a comprehensive biodiversity list in the first participatory evaluation meeting (25 participants).

Data from site biodiversity assessment served to calculate ecological richness using Margelef's index (DMg), with the formula proposed in Moreno (2001), where S is the total number of different species on site, Ln is the natural logarithm, and N the total number of individuals of each species. Similar to a study in five rural indigenous communities in Chimborazo (Oyarzun et al. 2013), we included agroecological diversity and evenness using Shannon's index (H^1); considering ni = abundance, where p_i is proportional abundance of species ($p_i = ni/N$).

Margelef's index:

$$DMg = \frac{(S-1)}{Ln(N)}$$

Shannon's index:

$$H^1 = \sum_{n=1}^{S} (p_i \ln p_i)$$

Figure 2. Youth and young adults participating in talking maps.

Margelef's index formula was also used by Oyarzun et al. (2013), with the difference where they considered "*Ln N*" as the natural logarithm of the farm area (m^2). We corroborated results with a Menhinick's index (*DMn*) because "like the Margalef index, it is based on the relationship between the number of species and the total number of individuals observed, which grows when increasing sample size" ([*trans.*] Moreno 2001, 27). Incorporating the methodology of a relevant study in rural indigenous communities in Chimborazo allowed us to better understand agrodiversity in Caliata.

Menhinick's index:

$$DMn = \frac{S}{\sqrt{N}}$$

Module 3 tested soil health in a subset of five of the ten sites due to the limited number of portable tests (Luster Leaf's Rapitest Soil Test Kit ™) that are not available in Ecuador. We conducted several trials and were successful in conducting four full tests with MO-DIRT protocols. One sample was re-tested in the laboratory along with a sample not tested with MO-DIRT, both at *Agrocalidad* (Ecuadorian Agency for Phytosanitary and Animal Health Regulation and Control), mainly in response to the request of community members that wanted to see laboratory results of a polyculture and a monoculture in similar geographic conditions. Results were contextualized with data from the area. Recognizing major limitations, the primary purpose in applying this module was to promote local collaborators' capacities and participation in order to conduct a larger study in the future.

Qualitative techniques

As presented in Table 1, using previously tested protocols (e.g., Gallegos, Waters, and Kuhlmann 2017), we conducted nine focus groups (39 participants), proportionately distributed in different age groups, and ten individual key informant interviews (females = 5/ males = 5) with six additional follow-ups. The interviews gathered insights from four external informants (exogenous view or from the perspective of the observer/etic) who work in relevant areas in indigenous communities in Chimborazo. The other six informants live in the community and together represent knowledge based on leadership, status as elders, detailed knowledge of agrarian practices, and traditional and intercultural health.

We triangulated the information gathered in focus groups and interviews (Creswell 2014) with a desk study of records found in the community. As reported in greater detail elsewhere (Gallegos-Riofrío et al. 2021b) and based on previous research in the rural Ecuadorian highlands (Gallegos, Waters, and

Kuhlmann 2017), we performed qualitative analysis simultaneously conducted by two researchers. Categories obtained separately were compared before and after participatory assessment and the unified categories received systematic input through member checking.

Community-based system dynamics

We conducted four workshops using CBSD with sixteen participants (females = 9/ males = 7), considering two principles (*see*: Hovmand 2014; Richardson 2011). First, systems thinking requires defined boundaries; we consider Caliata an ecological community. Second, group model-building (GMB) conducted with an endogenous perspective, assuring that a potential intervention will be implemented from a community perspective (emic). CBSD conventions allow for transferring perceptions in the form of mental representations, models, of interconnected variables (cause-effect relationships) and for identifying leverage points or areas of intervention (Meadows 1999). We are cognizant of the challenges of interpreting CBSD models (*see*: Trani et al. 2016 for another applied experience), in response we offer some guidelines in the sections pertaining to this methodology.

In a previous experience using CBSD, twelve Ecuadorian indigenous students participated in five workshops at Universidad San Francisco de Quito to tailor a culturally appropriate GMB manual, which included the scripts (procedures) applied in Caliata (detail about System Dynamics' scripts in: https://en.wikibooks.org/wiki/Scriptapedia). We used three different scripts to explore with community members the agri-food system: (i) variable elucidation with rankings; (ii) connection circles; and (iii) causal loop diagram (CLD). Participants rationalized causal relationships that, through our team facilitation (including the two local collaborators), were conveyed in an agreed-upon models.

RESULTS

The most salient feature of the community's landscape is that houses are located on a system of cultivation terraces (Figure 3), each segment corresponding to individual smallholdings. This system is described by residents as pre-Columbian, which speaks to the historical memory of both the Incan period of colonization in the early 15th century and the prior Puruwá epoch. As can be seen in the satellite image, the architecture of the agroecosystem, consisting of the cultivation terraces themselves as well as ditches, contention walls, traditional paths, agrodiversity and ecological associations, as well as its structure and its functions, which are the backbone of Caliata's agrifood system.

Figure 3. Google satellite image of a portion of Caliata's terracing system.

Sites' characterization

With local informants, we assessed a total of ten sites. Table 2 presents information on six parcels (T) and two edges or borders (B). We include geographic coordinates in order to make our work accessible. We use local names, recognizing meanings and Kichwa-Puruwá customs for labeling land characteristics. The table includes *Hucu Wayco* (T03) which is a parcel belonging to a Caliata resident that is located in an adjacent community (a blackberry monoculture). It was included to present a contrast with agricultural practices in Caliata, while having comparable geographical conditions.

We assessed two traditional pedestrian paths (Table 3), typically referred to as *chaquiñan* ("*chaqui*" foot and "*ñan*" path/road). These paths function as circuits that connect various points within Caliata. Paths are lined with trees

Table 2. Parcels and edges.

Code [a]	Local Name	Area (m^2) [b]	Latitude	Longitude	Altitude (MASL) [c]
TO1	*Jahua Huichi*	1935	078°38′309″	01°48′977″	3217
TO2	*Chuglin*	877	078°38′102″	01°48′901″	3131
TO4	*Bosque Pata*	1200	078°38′401″	01°48′606″	3143
TO5	*Jahua Pamba*	3395	078°38′102″	01°49′024″	3182
TO6	*Ashpamama Tukuiman Karaj*	6158	078°38′354″	01°48′784″	3150
BO1	*Jahua Huichi*	260	078°38′288″	01°48′977″	3225
BO6	*Chimba Pamba*	6	078°37′960″	01°48′835″	3138
TO3	*Hucu Wayco*	789	078°38′182″	01°48′296″	3008

[a]"T" stands for *terreno* (field) & "B" for border/edge (adjacent to the field) | [b] Square meter | [c] Meters above sea level

Table 3. Pedestrian paths/*chaquiñanes*.

Code [a]	*Local Name*	*Length (m)/Approx. area (m²)* [f]	*Latitude (start/end)*	*Longitude (start/end)*	*Altitude (start/end: MALS)*
CO4	*Camino Viejo* (Old Road)	540/1620	078°38′309″/ 078° 38′277″	01°48′498″/ 01° 48′787″	3161/3122
CO7	*Huarug path*	300/900	078°38′304″/ 078° 38′481″	01°48′830″/ 01° 48′747″	3164/3128

[a]"C" stands for *chaquiñan* |[f] Approximate area: calculated with length and a conservative estimate for wide (3 m. average).

and bushes, so they also act as wind barriers that protect fields and pedestrians and also provide materials, food and medicine. In Figure 3 it is possible to note the network of roads and traditional paths intersecting the terrace system.

The characterization of selected sites reflects the heterogeneity of agroecological space (Table 4). A key element of variability was the categorization of areas "inside" the terrace system and those "outside." The two pedestrian paths cross the terrace system and extend beyond its limits ("interspersed"). The other key characteristic of areas inside the terrace system was whether these were considered high, middle or low grounds; the "top edge" (B01) represents the highest point we measured.

Land use is an important factor in the characterization of land. For example, *Jahua Huichi* (TO1), a freshly plowed terrain occupies former terrace segments that were purposively destroyed to get a larger and even parcel, but it is adjacent to terraced plots where polyculture cultivation is practiced.

Most fields are rainfed. In contrast, *Chuglin* (T02), a mixed biome, is one of the few parcels that has access to a small irrigation system that takes water from an underground source from which it takes its name. Parcels T02 and TO4 (*Bosque Pata*) are eucalyptus forests (an introduced species to Ecuador), combined with native fruit trees like *tocte* (*Juglans neotropica*), a walnut, and *capuli* (*Prunus serotina*), a native cherry. There are also native bushes such as chilca (*Phlebodium aureum*).

Table 4. On site characterization.

Code	Terraces system	Terraces system location	Principal land use	Water access for cultivation	Anthropogenic biomes
TO1	Inside	High ground	Plowed	Rainwater	Cropland
TO2	Outside	Alongside	Polyculture, timber	Irrigation	Mixed cropland-woodland
TO4	Outside	Alongside	Timber		Woodland
TO5	Inside	Middle ground	Polyculture	Rainwater	Cropland
TO6	Inside	Low ground	Polyculture, grasses	Rainwater	Mixed cropland-rangeland
BO1	Inside	Top edge	Grasses	Rainwater	Rangeland
BO6	Outside	Alongside	Polyculture	Rainwater	Cropland
C04	Interspersed	Middle to low	Path		Hedgerow
C07	Interspersed	Middle to low	Path		Hedgerow
*TO3	Outside	Not in proximity	Monoculture	Irrigation	Cropland

*Represents "intended" for monoculture, however reality showed otherwise (see: Table 5).

Table 5. Crop varieties.

Crop	Local use names
Potatoes	*Puña; uvilla; papafri; puka chauca; killu chaucha; gabriela; maría; chuco*
Beans	*Canario; muru huagra; cholo; chili puka*
Corn	*Igchug sara; puka sara; yana sara; morocho; chaso; moro; shushi* [g]*; urubaca* [h]
Barley	*Cuchi chupa; fransciscana; common; runa*
Wheat	*Turco; apricano; morocho; trigo 150*
Oca [i]	*Candonga; yurak oca*
Melloco [j]	*Puka; killu*
Quinoa	*Ancient purple; common*

Cross pollination: morocho-puka [g] & Igchug-yana [h] | *Oxalis tuberosa* [i] | *Ullucus tuberosus* [j]

Chimba Pamba (B06) takes its name from the sector; it is one of many patches of land that are scattered around the community, especially next to the roads. An essential function of these patches is household food production, which supports dietary diversity. Finally, *Hucu Wayco* (T03*) that as mentioned above is a parcel dedicated to irrigated production of blackberries.

Pachamama's symbolic space

Ancestral knowledge is transmitted through the "doing" (*rurai*), from the elders to the rest of the family, and learning takes place in the field. The Kichwa-Puruwá language supports Caliata's ancestral knowledge because it defines the landscape, how people relate to elders, and how land is managed. For example, a Puruwá word is *tzacmana* (to move soil with a tool), which is a decompaction technique that causes minimal soil disturbance. Most parcels are referred as *chuzafundio or wachifundio* (small parcel), which shows that people in Caliata are smallholders who rely on subsistence agriculture. In the words of some of the farmers we interviewed:

> IFK2A: I am a Kichwa-Puruwá woman . . . Our roots are ancestral, so to speak; there was a Puruwá language that was older than Kichwa. The Incas brought the Kichwa language but before, there was the Puruwá language. Here, we have words that come from Puruwá. An anthropological researcher found that, for example, the word *Punin* [a neighboring parish] is not Kichwa; it means "seed of fire." *Tulabug*, the big mountain in front of Caliata, is another Puruwá word. When you go to the top, there is a large esplanade, a sort of stadium.

> IMK5: [It is different] if one lives in the city. Despite being indigenous, Puruwá blood, if one does not have the tradition, knowing the culture, the value of our land, the knowledge transmitted by our grandparents, even though they may say that they are indigenous, that does not count at all . . . I am proud to be Puruwá from here, especially because Caliata is a blessed land [. . .] If I am in the city, I use the Spanish language and likewise with my people, when I go to visit the elders, I use my own mother tongue.

Paths acquire further relevance when using the lenses of the symbolic. Both local records and testimonials mentioned that Caliata has several ancient paths, potentially connected to the Alausi segment, which is known as part the *Capacñan* or *Qhapaq Ñan* (which literally means "main roads" of the network that constituted the Inca Trail). These ancient paths have spiritual and customary dimensions, particularly as a part of Caliata's historical memory, as detailed in a tourism degree thesis:

> In addition to the terraces, there are sacred places such as the crosses. A cross is the space where two ancient roads intersect. It is said that these are transverse paths of the Inca Trail. People come to these points considered since ancient times as places of power, where energy accumulates, in order to ask for health, abundance of crops and animals, and for wisdom, knowledge, patience, and harmony.

Land, field, parcel, and soil are all referred using the same word, both in Spanish (*tierra*) and Kichwa (*allpa* or *ashpa*). However, Kichwa language is highly contextual, for example in referring to "*yapuna allpa*" (plowing or preparing soil) or "*saywa allpapak*" (boundary between two fields). Used alone, the word *Pacha* refers to the landscape, while *ashpamama* and *pachamama* are interchangeably used. *Pachamama* (Mother Nature or Mother Earth) is polysemic: it refers to the parcel (particularly the *chakra*), which provides conditions for life and also to the cosmos, time, and all existence.

> GMTA: The *chakra* is the *Pachamama* … The *chakra* itself is the mother; we say the Mother Nature or Mother Earth, and *Pachamama* in Kichwa because she feeds us. We grow food from *Pachamama*. We live and we have where to stand and walk.

A community member defined her parcel (T06) as "*ashpamama tukuiman karaj;" ashpamama* refers to field or soil, while *Tukuiman* signifies all, including plants, animals, people, and spirits, while *karaj* means "that feeds." The direct translation then is "field that feeds all," but the semantic meaning, in our view, is "agroecological farm." Although this example may seem particular, it illustrates how a symbolic force, the cosmovision, is instilled through language, defining life as interconnected and relational, with *Pachamama* at the center. It is an expression of an ecocentric view, in which the symbolic has direct implications in the way people participate in the agroecosystem.

Agrodiversity

Each family has a *chakra* that produces much of what is needed. The *chakra* represents agrodiversity, food variety, access, and freshness, local production, and minimal dependence on cities. The *chakra* provides resources other than food, including medicines and materials. For example, the thorns of the fique plant (*Furcraea andina*) are used to secure the harvest load on a donkey's back. The *chakra* is also connected to public spaces like roads and the community meeting hall. In the event of illness, it becomes, along with *chaquiñanes*, nature's pharmacy, providing medicine that is accessible and available for all.

> GMAC: The chakra is a source of life: it, is like a mother who cares, who puts the mind at peace, that bears fruit, and serves for all, the ecosystem. It not only provides food, but sustains the plant and animal realms, like the birds. Without this diversity, one cannot say that the field is beautiful. This also affects both the body and the mind, and that is all . . . along with the ecosystem, it is the water, the air.

Starting from the *chakra*, agroecologically useful species in Caliata include domestic animals and plants that are edible, medicinal, or useful for construction or other household needs. Native species include fique, sigse or siksi (*Cortadeira nitida*), and chilca. We excluded pollinators, wildlife, and those species locally considered "weeds" (*hierba mala*). Like Oyarzun et al. (2013), we used a single taxonomical category for species included in the analysis while acknowledging intra-species diversity that is the basis for saving seeds of native varieties––part of Caliata's ancestral knowledge. Table 5 provides an overview of some of the varieties of main crops found in the community.

In the ten assessed parcels, with a total area of (17,140 m^2) we counted, on-site, 108 different agroecologically useful species (Table 6). The number of agroecologically useful species per parcel ranged from 11 (T01) to 67 (T06) species (Mean = 29.6; Mdn = 23.5). For example, *Jahua Huichi* (T01) was freshly plowed at the moment of the assessment: different species were found in its margins, while *Ashpamama Tukuiman Karaj* (T06) represents the *chakra*––as biodiverse space. *Hucu Wayco* (T03), was intended for monoculture, so that one species (blackberries) dominated; nonetheless other edible plants, medicinal herbs, and other useful species were also present. Our biodiversity list was expanded during participatory evaluation and monitoring to 165 useful species.

Table 7 contrasts Caliata with the five communities, in the altitude range between 2,800 and 3,400 MASL, studied by Oyarzun et al. (2013). Differences in ecological richness and species evenness reflect unique characteristics of each agroecological space, but also include effects of methodological nuances in selecting sites and identifying and including species. We address some of these nuances in the discussion section.

Cycles in customary life

Information from the parish indicates that annual rainfall is between 400 to 500 mm, while median temperatures fluctuate from 8 to 16 °C (averaging 12.4 °C). We registered temperatures that fluctuated from 7 to 15 °C (averaging 10.8 °C). Combining testimonials and local records, we deducted an overall picture of variation across the year. Frosts are most common during the months of May, August, and December, while strong winds are experienced in August, fog in April, and droughts from June to December. Lower temperatures are experienced during hailstorms or when frost takes place. The first rains generally begin in November or December.

Table 6. Ecological richness, relative abundance, and evenness for selected sites.

	B01	B04	B06	B07	T01	T02	T03	T04	T05	T06	TOTAL
Area (m^2)	260	1620	6	900	1934	877	789	1200	3395	6158	17140
N	2432	29300	375	7820	8560	4309	1060	6415	20575	53357	134203
S	18	26	18	42	11	43	13	21	36	68	108
pi (average)	0.06	0.04	0.06	0.02	0.09	0.02	0.08	0.05	0.03	0.02	0.05
H^1	2.12	2.84	2.54	3.15	1.63	3.30	2.29	2.32	3.00	1.97	2.52
DMg	2.18	2.43	2.87	4.57	1.10	5.02	1.72	2.28	3.52	6.06	9.06
DMn	0.36	0.15	0.93	0.47	0.12	0.66	0.40	0.26	0.25	0.29	0.29

Table 7. Agrodiversity relative contrast.

Community	No. sites	Mean site size (m^2)	No. sp/ site	No. sp/ community	Ecological richness (DMg)	Evenness (H^1)
Paquibug	12	2 959	23	58	2.72	2.03
Vaquería	13	18 197	26	62	2.68	1.64
Tzimbuto	14	3 675	21	37	1.95	1.45
Monjas	6	18 567	12	28	1.23	1.26
Guangopud	6	5 880	14	32	1.49	1.37
Caliata	**10**	**1 714**	**108**	**165**	**9.06**	**2.52**

The table shows the five communities studied by (Oyarzun et al. 2013) (p. 522) and Caliata. *No. sites* is the number of areas assessed. *No. sp/site* is the number of species found during the site analysis. *No. sp/community* is the number of species found at each community. *DMg* is Margelef's index for ecological richness for assessed sites. H^1 is Shannon's index for agrodiversity and evenness.

Instilled by Caliata's ecocentric cosmovision, the *minga* (reciprocal communal work) and *raymis* (feasts) are two social norms (customary institutions) relevant to the agroecosystem. Seasons are intertwined with crop rotation systems, and each system represents a cycle from soil preparation to planting and harvesting. Seasons define the agrarian calendar. Conversely *raymis*, synchronic with the Gregorian calendar, are associated with seasons. The feast pays respect to elders and ancestors and, most importantly, are a ritual of gratitude for *Pachamama*. For example, the Harvest (a *raymi)* takes place throughout August to collect the corn, a laborious task that relies on multiple *mingas*. While soil preparation starts in September, in anticipation to the first rains, this agrarian phase is marked by the Day of the Death (2nd November), which is fundamental in the indigenous tradition because it is a celebration unifying the living and the ancestors, where food and seeds are shared.

GMJC: The *minga* [also a collective work party] here, my colleagues know, the purpose of the *minga* is to mediate conflicts because not everything in the community is a honeymoon. There are ups and downs. With a *minga*–how nice it is when it happens–it is based on human relationships. Here you make friends, you play; we share food, we go out and form a group . . . We build deep and strong, lasting relationships.

IME1: Religious holidays are synchronized with the *raymis* in the indigenous tradition [. . .]. Here it is still important; festivities are a big thing. They are what bind people together, even those who have migrated come back for the festivities.

The rationale of cycles is also related to female essence. The concepts of *Ashpamama* and *Pachamama* convey the sense of an entity; the termination "mama" refers to mother, who is capable of experiencing emotions, which are related to productivity. Hence, unproductive or abandoned parcels are said to be "sad." Smallholders ask permission to work the land and, to symbolize attaining a healthy soil, parcels are adorned with flowering plants, and offerings to the land, so that fertilization strategies are literally expressed as "feeding the parcel" and "rejuvenating the topsoil."

> GMTK: The chakra is Mother Earth. To sow, first you must ask permission from Mother Earth. Can I sow you? And if she accepts, we sow. Because she has life, we communicate. If we sow without saying anything, she feels pain when we shove in the hoe. You must ask permission to sow; otherwise, she gets angry. She doesn't produce as she should produce; the corn will grow small.

> IFK4: Our *Ashpamamita* is the land. The *Pachamama* is all the environment that surrounds us; heaven and earth is included. . . . We use the plants, but to get the plants we also have to make offerings to the land. In this case, such offerings become fertilizer. Also, we were taught that, for example, we should make the offering with fruits and flowers in a corner of the land, because there the *Ashpamama* feels happy for the rich things received.

> IMK2: This is the first requirement: to give a good diet to our Mother Earth, so that she is well fed, fertile, and fruitful, and to provide the best fruit to feed all living beings.

A community *Yachag* (healer or wise person) explained that Andean cosmovision sees existence as cycles, which are manifested in many ways, including, management of the agroecosystem in that everything begins and ends in land, the fields, and the soil. Fundamentally, for people in Caliata, being indigenous means, to a large extent, knowing about how to treat the land, which then makes this person a "*chacarero*" (one who knows about the *chakra*), like reflected by residents:

> IMK1: A good farmer knows at what time of the year his/her land asks to feed her with organic fertilizer. When the he/she moves the soil, the farmer knows; you can see a whitish soil that indicates that the plot needs to be fertilized.

> GMTK: To be indigenous is to know how to respect what I have learned here: the Kichwa language, ancestral clothing, and ancestral knowledge such as the terraces. What is the terrace for? Why the black soil? Why do the soil layers have different colors? What is the best soil? Being indigenous is knowing the ancestral and practicing, not losing . . . Knowing how to really sow and the best days to sow; to maintain the soil using an ancient celestial calendar, to see which days crops can be sown, the day that is good for the roots, the day that is bad for sowing. See the moon, as in the past, the day to sow, and likewise, the day to harvest.

Land management

People in Caliata closely monitor lunar phases and cues from nature. For example, residents report that the arrival of a certain bird, between September and December, determines the beginning of an agrarian season, which starts the time for preparing the soil. Informants describe this bird as of gray color, known in Kichwa-Puruwá as *tulig* (or *lig-lig* in Incan-Kichwa), which we identified as the Stout-billed cinclodes (*Cinclodes excelsior*). The news about the appearance of this bird is spread among families, then mobilizing the work necessary for planting.

Land management practices aligned to natural cycles also reflect community values such as interpersonal relationships, reciprocity, and redistribution, which lead to nutrient feedback loops: land-plants-animals-people-land. In this sense, a cycle starts with the preparation of the field because as expressed by a community member: "the soil must be well fertilized so that nutrients are not lacking." People in Caliata employ different techniques of soil fertilization, including a variety of mixtures of compost and bio-fertilizer (*biol*). Soil preparation measures can be seen as anthropogenically induced bottom-up trophic processes, an important element to understand the viability of the agroecosystem.

> IMK1: First, love the land or parcel, we say: How to use organic fertilizer? Precisely from the animals, including cattle, donkeys, Guinea pigs, chickens, rabbits, sheep, ducks, and turkeys. For what reason? The fertilizer of each animal serves according to the land, according to the need. This organic fertilizer is processed, dried in the sun and piled up for a certain time. When it is seen that the fertilizer has decomposed, then it is taken to the parcel. We never use raw compost.

> GMTM: The *biol* [bio-fertilizer] is made with the waste of the animals. It is mixed with molasses and natural plants such as alfalfa and clover, mixed all together, and left to sit for about fifteen days.

Along with fertilization strategies, people in Caliata practice crop rotation systems, periods of fallow, associated cropping schemes, and the use of hedgerows between parcels and along roads. The association of crops, in principle an ecological mutualism, also has symbolic elements; as a community elder commented, "corn is sad when there is no quinoa." The two principal crop association schemes practiced in Caliata are: corn scheme, which corresponds to corn-beans-squash-quinoa-lentejilla (*Lepidium virginicum*)-vicia (*Vicia sativa*)-and-lupini beans (see Figure 4); followed by one of potatoes, which is potatoes-ocas-melloco-fava beans-and-lupini beans. The lupini beans is present in both systems as a food, and also as a wind break, nitrogen fixation and to prevent the growth of unwanted species.

During the potato scheme, people in Caliata have an ancestral technique to "cure" the potato before planting, consisting of using Guinea pig bones nailed to the seed. This is, the family and sharecroppers in the cultivation area in the past, would eat roasted Guinea pigs, separating the bones, which would be pinned to the potato seed (like a "toothpick appetizers") during sowing. The idea of the "cure," a remedy, speaks to well stablished notions of preventive health from the Andean cosmovision––this is "cure in healthy" so that the plague does not enter and so that the plant grows strong. A testimonial from a community elder indicated that he consulted once about this technique with an agricultural specialist, who speculated that this may have to do with the nitrogen cycle.

Figure 4. Illustration of corn cycle.

GFOR: Our parents knew that potatoes produce best when one takes the roasted Guinea pig to the planting . . . When they sat down for lunch, they said that they should keep the Guinea pig bones . . . Grabbing a handful [of bones], my mother would stick each tiny bone into a seed potato . . . It was true; this way, the harvest would be plentiful. Up on the hill, my late father would take the donkey to spread the straw from high pasture in order to keep the moisture and the (organic) fertilizer in the soil . . . They prepared the field so that they could eat during Carnival. Now things have changed; we sow in the months of May or June . . .

GFOBe: On the day potatoes were sown, my mother would roast the Guinea pig . . . She knew how to send the *Tonga* (lunchbox) to those participating in the planting . . . To sow the potatoes, one must keep the bones so the potatoes will grow to the size of a Guinea pig.

Other crop associations in Caliata are the combination of peas-vicia-and-lentejilla, and also of peas-barley-and-wheat; both are planted throughout the year in scattered patches in parcels. In addition, hedgerows, which serve as barriers to wind and pests, also have combinations of useful plants. One combination provides both medicinal plants and species used for a variety of household uses: chilca, valeriana (*Valeriana pilosa*), calaguala (*Campyloneurum angustifolium*), and fique. Another combination found in hedgerows consists of taxo (fruit vine, genus *Passiflora*) that climbs the capuli tree (an Andean cherry); two native species that enrich the diet and also have medicinal properties.

IMK1A: Back then, the elders said that in associated cropping, the plants have a *minga* in defense of the harmful predators and plagues: the plants take care of each other.

Fallow periods should follow a full crop rotation of corn and potatoes schemes so that, as a community elder explained, "the land is fertilized and does not tire of producing." However, for smallholders this is a challenge. Depending on the amount of land that the family has available, the fallow period can last up to three years, which corresponds to the maximum length seeds of legumes and cereals can be stored. During the fallow periods, cover crops are typically planted with a twofold purpose. First, they protect the topsoil from wind and water erosion. Second, animals are allowed to temporally graze in parcels, which provides fertilizer.

In addition, clothing is an integral part of Caliata's identity and the traditional health system, and is also relevant to the agroecosystem management because it combines the symbolic with practical elements of everyday life. The traditional woven belt women wear, for example, is said to help carry heavy loads by protecting the hip and back during the physically demanding tasks. Similarly, the thick wool poncho protects the body from the cold and rain and the traditional broad-brimmed hat protects the wearer from intense UV radiation experienced at high altitude and protects from the rain.

> IMK3: The *cushma* is something like a poncho; it is not very long and made here. They wear the *cushma* with a white sash. This is special, from our ancestors. So, when it rained, they would stand along the wall where it was dripping, and with that hat she would sit there and she would squat when it rained, and when the rain fell on her hat, she did not get wet. The water fell behind her. These are things that our ancestors left to us.

> GFA2M: I believe in improving self-esteem; I liked the anaco (wrap-around skirt) but when I understood, when the elders explained to me the meaning of what our anaco, our bayeta (shawl), our sash, and our hat means. Then I accepted this with much more joy. The natural materials protect us from diseases.

Building capacity on soil health

An outcome of agroecological assessment was that two local collaborators were familiarized with MO-DIRT protocols and language about physical and biochemical factors, and in doing so, we gained a sense of soil health in Caliata.

Data on nutrients present in soil (Table 8), were obtained with the Rapitest Soil Test Kit and validated with results from the government *Agrocalidad* laboratory for TO6, our reference lot tested by both methodologies. Testing revealed that the soil had a neutral pH of 6,5 and levels that were low for

Table 8. Results of capacity building for on-site soil health assessment.

Code	pH	Nitrogen	Potassium	Phosphorus	Soil texture
TO5	7,2	N 0	K 3	P 4	Clay
TO1	6,8	N 0	K 2	P 4	Sandy Loam
TO2	6,2	N 0	K 2	P 2	Silty Clay Loam
TO6	6,5	N 0	K 1	P 3	Silty Clay

Rapitest values: 0 = depleted; 1 = deficient; 2 = adequate; 3 = sufficient; 4 = surplus nitrogen (N0), mid-low for potassium (K1), and high for phosphorus (P3). Laboratory results provided comparable values: pH 7,26; N = 0,14%; K = 0,73 cmol/kg; and P = 40,3 mg/kg, which according to lab reference tables are considered pH neutral (6,5–7,5); N low level (0–0,15); K high level (>0,4) and P high level (>21). Except for potassium, all other results were similar using the two methods. This finding suggests the potential of MO-DIRT as a feasible on-site methodology.

The soil test of two samples in the *Agrocalidad* lab revealed adequate organic matter levels but with important differences. Although more research is required, the sample from T06 (in terracing system) was in the high range with 2,86 of volumetric content compared to T03 (located outside Caliata, and intended blackberry monoculture that received agrochemical inputs), which was in the mid-level range of 1,97 for the lab reference (protocol: PEE/SFA/09).

Compared to reference values found in local records for five local communities (Baaquitay Quillincocha; Guantul Central; Shungubug Chico; Flores Centro; & Tumbug Lliushirun), it was notable that land in Caliata has generally higher organic matter values, lower nitrogen, and similar pH levels. Also, from local records, it was derived that in the Flores Parish approximately 20.16% of the total soils are *cangahuas* (indurated borizoiis, sedimentary rock) and also that approximately half of cultivable soils need to be reclaimed.

Figure 5 shows a causal loop diagram (CLD) pertinent to soil health; this model building was preceded by two other Community-Based System Dynamics' (CBSD) experiences: Variable Elucidation with Rankings and Connection Circles. A CLD uses the conventions described in the box below.

Based on Hovmand (2014: 2–3)

Arrows = variable's causal relationships, either as conjectures or evidence based

Plus (+) & **minus** (–) **signs** indicate the influence direction

With everything else held constant:

(+) = increasing a variable increases the effect of another or decreasing a variable decreases the effect of another

(–) = increasing a variable decreases the effect of another or decreasing a variable increases the effect of another

CBSD's workshop participants unanimously concurred that healthy soils assure a sustained production of food for the community. In the same fashion, participants expressed consistently that polyculture agriculture has kept soils in Caliata fairly healthy, acknowledging that this practice has been preserved from generations ago. The maintenance of the *chakra*, representing intense small-scale agriculture, assures agrodiversity. If these elements are maintained, the system is seen as resilient. Furthermore, people in Caliata have a good sense of the micro-biome present in soil, and they know well that the system resilience depends substantially on these organisms.

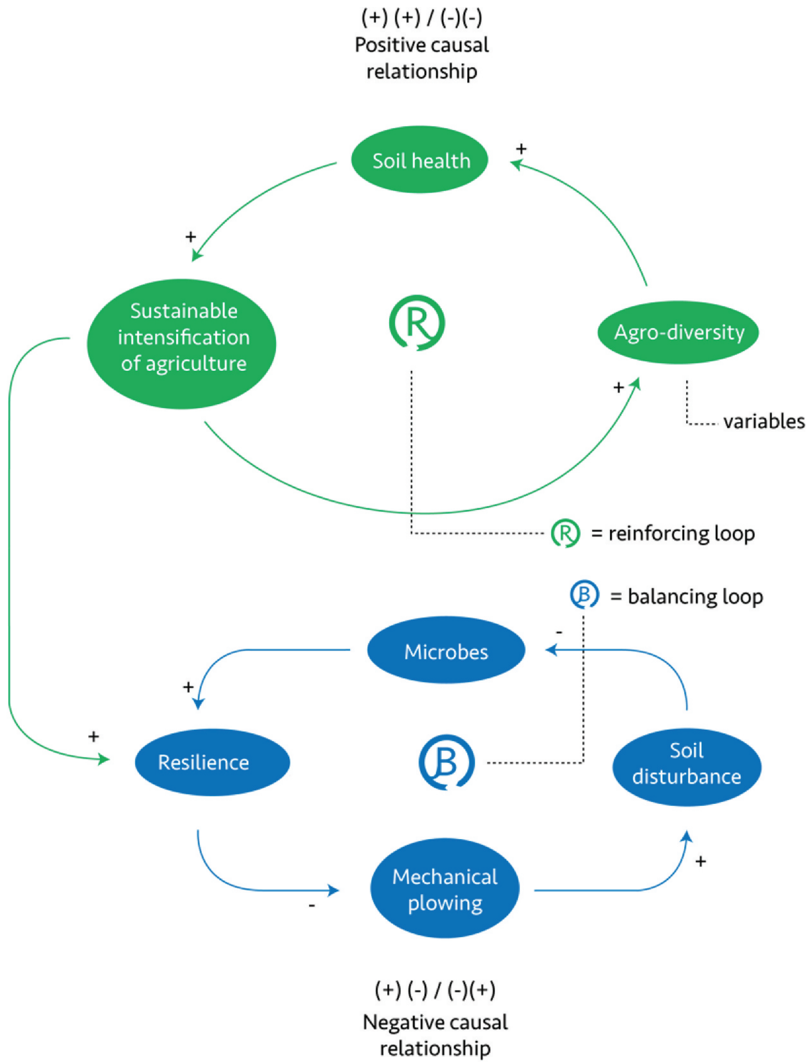


Figure 5. CLD for a soil health view in Caliata.

However, participants also recognized that modern practices, particularly mechanized plowing, are a threat to this resilience because of the disturbance of the soil, which directly affects the populations of microbes, compromising the resilience of the system. In this rationale, unhealthy soils cannot sustain food production nor the biodiverse environment that secure the traditional diet.

An ancient architecture

Whereas a satellite image of the terracing system shows individual smallholdings (Figure 3), on the ground it becomes more evident that there are a variety of ecological niches and microclimates that support the richness of species found in Caliata. Terrace segments vary in area and the height of the walls;

Figure 6. Simplified illustration of Caliata's terracing system.

however, it seems that each represent a piece of a purposive design. Figure 6 is an overly simplified representation of a terrace segment in Caliata to portray structure and functions.

Terraces are aligned with sun patterns procuring maximum sunlight exposure throughout the year. This structural element is fundamental for the growth of C4 plants like corn. Moreover, if not for this design, including the microclimates promoted by the terraces, it would not be possible to grow corn with yields in the high-altitude cold weather of the area. Walls are covered with moss, and the presence of different plants that absorb water. Ditches at the foot of each terrace wall are also important because they retain energy within the system, particularly as nutrient traps: water runoff drags nutrients from higher parcels and mountain ecosystems. In that sense, another ancestral technique practiced in Caliata is "soil harvesting," which consists of collecting the sediments deposited in the ditches after each rainy season and spreading it typically in the adjacent parcels, rarely soil harvested is carried uphill. The ditches also have an additional traditional function. Upon observing where toads lay their eggs, smallholders predicted how much water will be available in the rainy season.

An important function of terracing in Caliata is that it reduces the degree of slope. For example, in three sites (T05; T06; B01), the average slope was 7%, whereas where land was no longer terraced (*Jahua Huichi*; T01) the average slope was 40%. In contrast, on two terraced parcels adjacent to T01, the average slope was 8%. An agricultural engineering thesis from our local records presented similar findings about slopes in the Flores Parish, showing that the slope on terraces ranged from 5 to 9%, compared to 40–60% in non-terraced areas. A report of the council of the Flores parish, analyzed in our desk study, confirms these results in that slopes range from 5% to a pronounced 40%, again reflecting the difference between terraced and non-terraced areas.

A few segments of the terrace system have been destroyed, because a contradictory development is that larger plots provide for more efficient production. The rationale is that they require less labor and more intensive agricultural practices, such as mechanized plowing and monoculture of commercial crops, with the use of agrochemicals. The case of *Jahua Huichi* is striking as it becomes a natural experiment that allows to have a sense not only of variation between terraced and non-terraced systems but also of change when segments of the terrace system are modified or destroyed.

Despite some deterioration, community members report that the terrace system keeps sustaining a steady biodiverse agri-food system that ensures crop survival and protection against pests and frequent strong weather fluctuations (e.g., frost, hailstorms, and heavy rainfall). In the desk study, a local record reported: "The presence of the pre-Incan terraces has been essential for agriculture since this ancient technique has allowed the inhabitants of Caliata to never suffer losses in their crops." This is plausible in the light of the structural and functional factors evidenced, such as wind and pest barriers, heterogeneous segments with microclimates, ecological associations, reduced slope and soils systematically fertilized, and the overall effectiveness of the system as energy traps (i.e., agrodiversity, sun, water, nutrients).

GFA2M: I am a Puruwá woman who is very happy to be from Caliata [. . .] In October, everyone plants corn. In other places, there is always frost, and they hardly have any corn production like us. Here, there is never frost: that's nice, it's a blessing

IMK5: when you work in plots [in the terraces] you can take advantage of irrigation ditches for soil harvesting Also, [working in terraces] is not like a large area of land where you cannot work by yourself. Instead, in the terraces, you go parcel by parcel. This makes the work easier, from my point of view, while also working carefully to avoid erosion and the influences of the weather. For example, the terraces protect the land from excessive wind and frost, because I have analyzed the terraces in this sector, the frost does not affect them from eroding and on the other hand, in other places further back where there are no terraces, there is land that are just exposed. They do not have terraces; that is why the frost kills the crops. It hits them and the plants are burned. The terrace has something––some kind of protection—that inhibits certain climatic problems. I believe that the ancestors worked with a strategy while also thinking about the future: in the future I think, thinking about us . . . .

Challenge and opportunities

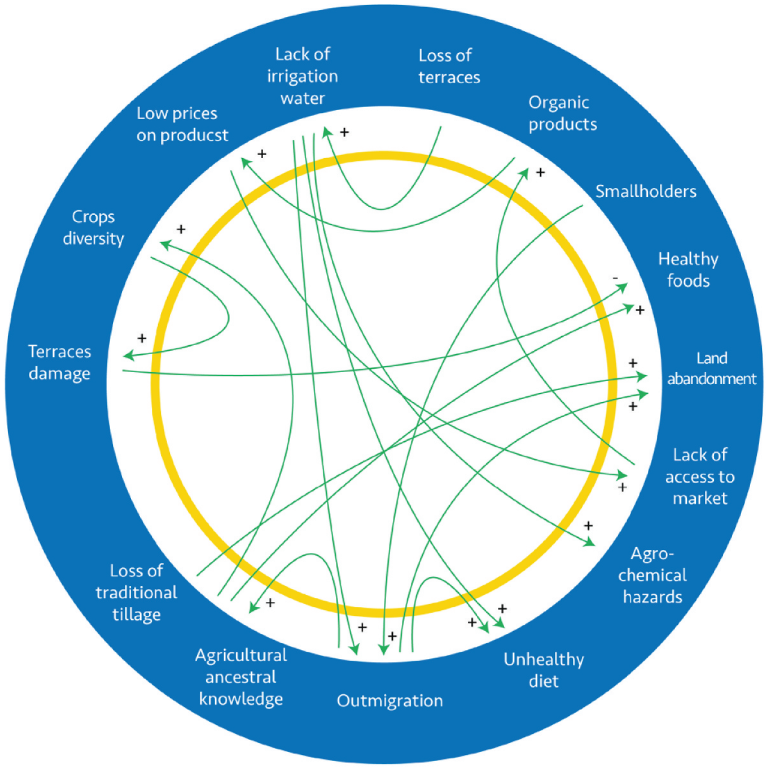
While the beliefs and practices discussed above suggest that community members are dedicated to taking care of *Pachamama*, there is also a sense of loss and depletion (including the soil itself), perceived as threatening for the community. The sense of loss is related in part to developments around Caliata. Along the highway from Caliata to the provincial capital of Riobamba, in the parish of Punin, located only eight kilometers away, one observes dozens of agribusinesses. The presence of agribusinesses indicates their dependence on the use of pesticides to produce cash crops like tomatoes and broccoli, which have raised health concerns in Caliata: in particular, residents worry about their neighbors related to rumors about high rates of stomach and lung cancers.

GMTA: A comparison: down here in Punin, the people spray the tomatoes, onions, carrots; all that is infected. We can make biol; we can fumigate with natural [ingredients]. Instead, down there, they use chemicals that kill themselves and other people . . . I have some colleagues who work there; they say that through infection and by fumigation they contaminate the body and cause cancer of the intestine and lungs.

GFA2B: Because we are eating our grains, it seems that we are still holding on. Those deadly diseases still do not affect us, we still do not hear, in what is below [in Punin and other places with irrigation and fumigation] people are decaying.

To better appreciate challenges and opportunities from the endogenous perspective in Caliata, conducting a CBSD, such as the one done with soil health, allowed us to explore causal-effect relationships in the agroecosystem. These relationships were created from variables that workshop participants previously proposed and ranked according to importance (Script: Variable Elucidation with Rankings). For this purpose, we used a culturally validated script (procedure) to build a Connection Circles models, which is effective for defining initial cause-effect relationships. Figure 7 shows the results of this workshop, where participants were divided in two groups of eight people, and where we facilitated separate model building with each group. The model follows the rationale and conventions described in the textbox that accompanied Figure 5.

Results from the Connection Circles are self-explanatory. For example, in model A, agricultural ancestral knowledge was related to less use of agrochemicals and in model B terrace damage means less healthy foods. Interestingly, and despite the activity was conducted with two separated groups, the resulting models are remarkably similar in the messages they



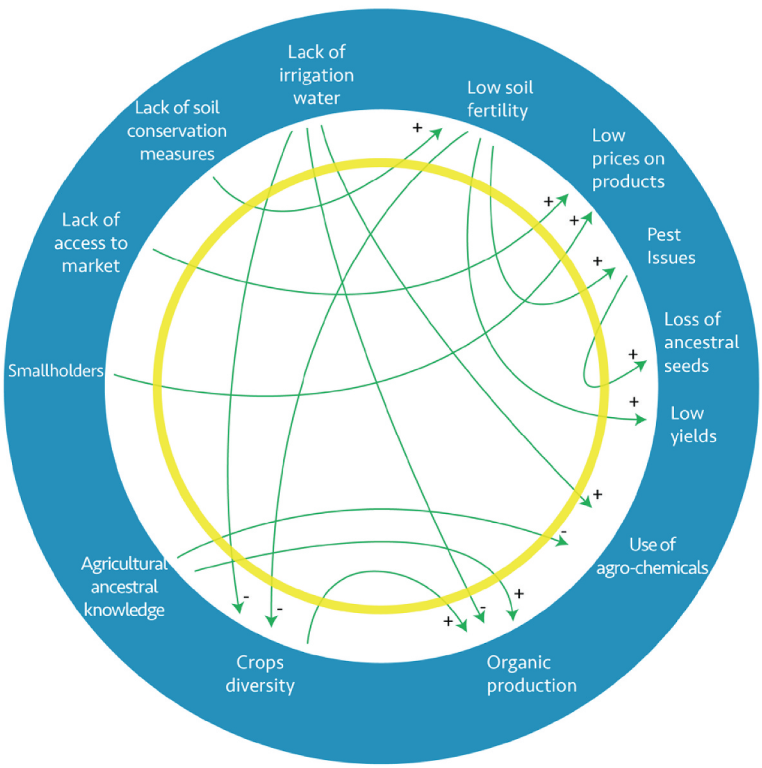


Figure 7. Connection Circles in the agroecosystem: groups A (top) and B.

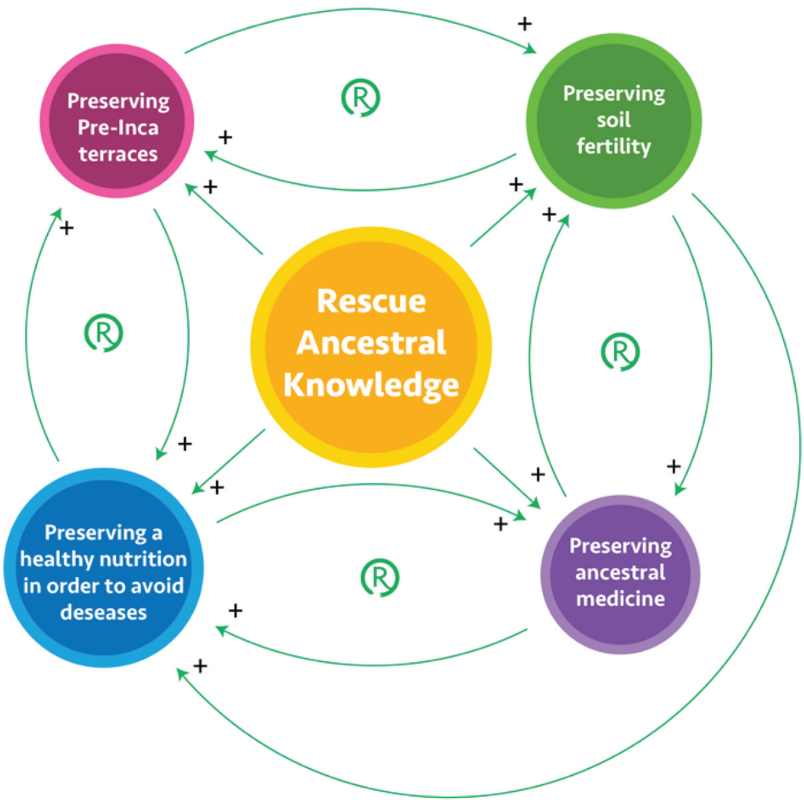


Figure 8. CLD for leverage points.

convey. For instance, the variable "lack of irrigation water:" in model A it is connected to less "organic production" (which stands for crops free of agro-chemicals) and also less "diversity of crops," whereas in model B it is linked to "unhealthy diets" and "outmigration." In both models, "lack of irrigation" is also connected to agrochemicals. However, counterintuitively, this situation is an important issue that has allowed Caliata to preserve their ancestral agroecological space, along with their land management strategies and an associated cosmovision that integrates space, indigenous identity, language and culture. This unexpected element is reasoned by an exogenous key informant:

> IME1: In productive terms, there is a trend by which the market defines what needs to be produced. It's not the family with its autonomy that defines what should be produced. This market orientation means links with wholesalers or circuits of intermediaries, which determine food distribution, obviously speculating with information on where the demands are. For example, we are here in Riobamba, and you will that see all the nearby areas are very productive, Chambo, from San Luis to Punin, which all have irrigation; everything is tied into the circuit defined by monocultures, especially tomatoes, and some vegetables that are very intensively produced. These farmers are totally at the whim of the intermediation of wholesalers, and they can't have any influence. This

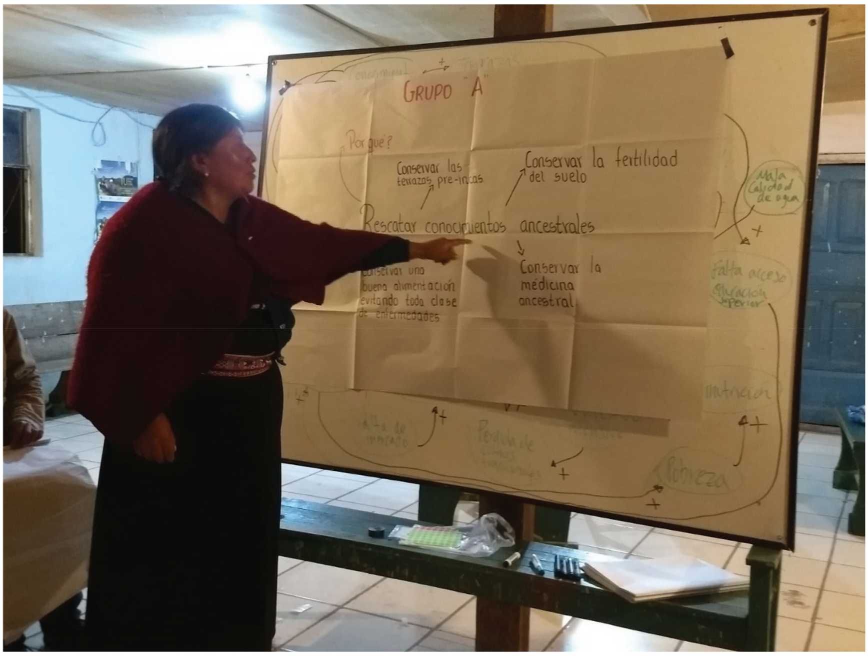


Figure 9. A community member is facilitating the CLD modeling.

> implies giving up your land to the service of the market, so if you used to have land available for your own food for household production and supply, it is now very limited because most of the space is allocated to produce for the market.

Despite a generalized lack of irrigation to water the crops, among other internal and external pressures to the system, including a growing presence of crop pests and marginal participation in the capital economy, it is clear that Caliata has remained a resilient community; a positive deviance in terms of the health of both people and ecosystem, which contrasts with neighboring communities. Figure 8 (a CLD model like Figure 5) could be seen as the final outcome toward the end of the fourth workshop (n = 16); here community participants identified in CBSD language the "leverage points," which are the variables with the greatest potential to produce the greatest change in the community; in other words, areas of intervention. In sum, the model below shows that the ancestral knowledge interconnects biological, physical and psychosocial factors, acting as a central factor for the agroecosystem. Fundamental to understanding this model is that the rescue of the ancestral knowledge, rather than being a future plan for an ongoing process of resistance, is Caliata's strategy to face current challenges (*see* also Figure 9).

Through the above CLD participants expressed their rationale. A reinvigoration of the ancestral knowledge is seen as the mechanism for strengthening the current agricultural system, fundamentally to preserve the fertility of the soils, which in turn leads to secure adequate nutrition and therefore to maintain community health. Ancestral knowledge also represents the production of agroecological, healthy products through ancestral farming techniques and technologies. The pre-Inca terracing system achieves crops for a healthier diet while preserving soil fertility. Ancestral medicine is part of agrodiversity, they are also plants that protect the system, while maintaining people's health. Health is also part of the virtuous circle, of the relationship between people and life, because health, from the Andean optic, is based more on prevention than on the cure of the disease.

GMYV: The *chakra*, the field, and the soil are the fundamental parts for life. Without our soil we would not have life. It is where we can plant our crops. It gives us food; it is where we receive everything in order to survive, in order to exist. In short, to develop ourselves as indigenous people, as peasants. It is essential; so, we must take care of the land, our Mother Earth, and, in this way, treat her well.

GFA1RM: For a fever, I ask someone to bring *tipo* flowers (*Minthostachys mollis/Kunth*), also the taxo (*Passiflora tarminiana*). "Please bring me," I say. After peeling the taxo, I crush it the with the seeds with a small stone. With that, if you have a cold fever, with a little piece of *panela* (raw sugar), they give (the sick person) the liquid in a cup.

DISCUSSION

Based on systems thinking, we have analyzed a space where nature and human agency represent an integrated whole. In that sense, the agroecosystem is physically and conceptually circumscribed within the community territorial borders. Biochemical factors in the form of agrodiversity and soil health parameters are paramount for Caliata's ecological agriculture. Caliata's agri-food system represents a contrast with neighboring communities, which do not have the benefit of the terrace system, which, among other things, is an efficient architecture, an energy trap, to reduce the slope, create segmentation, and respond to environmental shocks (Carrasco-Torrontegui et al. 2020). These factors interact with psychosocial factors, like the social norms (*mingas* and *raymis*) and the symbolic and pragmatic elements of the ancestral knowledge along the cosmovision, working as a virtuous circle that strengthens the system, maintaining its resilience.

Elsewhere, we reported that Caliata's residents are smallholders; 74.8% have less than one hectare (Gallegos-Riofrío et al. 2021a), which represents the *chuzafundio or wachifundio*. We also reported that the 57 families grow an average of 18 main crops, which besides being used for consumption, serve for exchange and sale. They produce a variety of Andean crops, including corn, beans, squash, lupini beans, quinoa, oca, mashua, and potatoes, as well as crops introduced by the Spanish, which are now regarded as traditional, including barley, wheat, broad beans, and peas. In addition, animal husbandry is practiced by 82% of families in Caliata. An adjusted agrodiversity metric was significantly associated with the variety of healthy foods consumed within the household ($p < .05$; $\beta = 1.01$) (Gallegos-Riofrío et al. 2021a). Here we observed 108 different agroecologically useful species in the field, and with input from community members, the list grew to 165 species. With the Kichwa-Puruwá ancestral knowledge merged with the landscape, a sense of diversity is coherently reflected in what we encountered in the field, what families reported (crops produced and diet), social organization and how space is conceptualized and managed.

Biodiversity in Caliata is relatively high in comparison to the communities studied by Oyarzun et al. (2013) in Chimborazo – who were participating, since 2008, in an action-research project focused on agrodiversity intensification and local management. Agrodiversity is also higher than that from communities involved in on-farm diversity conservation projects in the highlands of Peru and Bolivia, and at lower altitudes in the northern inter-Andean valleys of Ecuador (Cotacachi canton, Imbabura province) (Bellon, Gotor, and Caracciolo 2015). In the Cotacachi project, Bellon, Gotor, and Caracciolo (2015) reported 137 species of crops, fruit trees, herbs, and collected wild species; these are communities located in altitudes between 2,300 to 2,800 MASL, with a reported precipitation of 625 mm/year and mean temperature of 15°C. Authors cautioned, however, that there were "problems of endogeneity and selection bias due to the fact that the projects built on the farmers' interests and motivations to maintain crop diversity" (Bellon, Gotor, and Caracciolo 2015, 173).

The examples above contrast with Caliata, a non-intervened community, and also in the exploratory nature of our study, conducted without *a priori* categories, hypothesis and expectations for what we found in the field. However, in our view, absolute comparisons between Caliata and other communities risks several potential biases. This because in participatory agroecological assessments, informants' perceptions play a key role and are clearly subject to different interpretations. For example, the definition and understanding of what a weed is can vary between communities and individuals; what is considered a weed (*mala hierba*) in one place may be a medicinal herb, food or household material in another. Considering the long-standing anthropogenic imprint in Andean mountainous ecosystems (Sarmiento 2012), cultural dimensions, and that Caliata is an ancient human settlement (Costales 1963), what is wild and what is (or was) disseminated by people may not be easy to discern. The category of wild vegetation should be considered along with ethnobotanical and archeological records.

Another limitation of strict comparisons is related to the inclusion of different kinds of spaces in a study. For example, Oyarzun et al. (2013) were interested in farms, whereas in this study the agroecosystem includes other land uses and margins. Finally, there is an array of issues in methodological differences, scope of interventions and lack of enough information––like knowing the interaction between preexisting and/or implemented practices [through action-research/conservation projects] in agrodiversity outcomes, and the contribution of each type. In the same manner, we are unaware if these communities are determined by a complex agroecological architecture, associated to long modeled human behaviors, like the system of terraces and Kichwa-Puruwá knowledge described here. These considerations are fundamental in the light of recognizing the benefits of other systems of knowledge, such as the Andean pre-colonial knowledge in Caliata, which calls for the need of further research. More specifically, a systematic-participatory study of their terracing system, combining archeology and ecology––so it is possible to effectively determine the behavior of the system and for how long it has assured food sovereignty.

Moreover, there are other elements of the ancestral knowledge worthy of future consideration. For instance, it would be illuminating to study the use of Guinea pig bones in the seed potatoes and their potential in promoting the growth of supposed bacteria that transforms atmospheric nitrogen into fixed nitrogen, as well as the use of Caliata's natural cues (e.g., bird arrival and where toads lay their eggs), and to gain more information about ecological associations known in Caliata.

In the context of ecological efficiency, soil health parameters––which we started to explore––suggest that Caliata functions as a viable ecosystem (Arango-Caro and Woodford-Thomas 2015). This is largely due to the presence of high levels of organic material and minerals, reflecting the effectiveness of land management practices, combined with the agroecological architecture of a pre-Columbian system of terraces, which through the generations have continued to be a pillar of the agri-food system. Caliata's system is also similar to other experiences involving pre-Columbian terraces in active use, soil quality and system resiliency in other latitudes of the Andes (Goodman-Elgar 2008) and in Mesoamerica (Mountjoy and Gliessman 1988) as well as to those long abandoned but that nonetheless offer insights about erosion patterns (Londoño, Williams, and Hart 2017). Low nitrogen levels actually reflect the benefits of agricultural techniques used in Caliata, because higher levels usually represent usage of chemical fertilizers, typically intended for monocultures to maximize crop yields (Edwards 2001; Fonte et al. 2012). In this context, the true importance of agrodiversity may be its long-term result in achieving a system that is constantly replenishing soil nutrients and maintaining soil microorganisms, while increasing the resilience of the entire system (Swan and Kominoski 2012).

The terracing system is also part of a long collective memory, a cosmovision instilled in the web of meanings that is culture (Geertz 2008). Cultural expressions are linked to the localized indigenous identity, including language, clothing, the health system, customary governance, respect of tradition and elders, attachment and reciprocity. In the cosmovision, *Pachamama* is a multidimensional feminine entity, a mother, each family's *chakra*, fields, fertile soil, everything above and below, an inclusive and inseparable whole. Meaning resides in functions to sustain the community physically, emotionally and spiritually. Consequently, this ecocentric ontological stance, a way of living that incorporates people into an ecological community, prompts an epistemology that provides the means to ends. Ancestral knowledge is a foundation of contemporary practices that align the agrarian calendar with natural cycles, including lunar phases and ecological signs. These elements provide the basis for nutrient loops in that Caliata smallholders are facilitators of biochemical processes and trophic chains.

During the four CBSD workshops, it was possible to integrate, from an endogenous perspective (community view), learnings from psychosocial and agroecological dimensions. The agroecosystem's salient elements were the cultivation terraces, irrigation channels, contention walls, and paths. But that includes functional elements such as an agrodiversity characterized by richness, evenness, ecological associations, native crops, and healthy soils. This agroecosystem is the signature of the Kichwa-Puruwá's ancestral knowledge; an efficient energy trap to retain solar radiation, water, and nutrients, and also divides the landscape into many small parcels providing microenvironments, where species are thriving, and that serve as effective mechanisms against the impact of pests and environmental events like frosts and hailstorms. Together, this system permits the persistence of an intensive yet ecological form of agriculture that promotes food sovereignty.

This agroecosystem is, however, increasingly confronted by internal and external pressures, including encroaching urbanization, changes in land use, and environmental challenges. Intensive farming based not on traditional practices, but the use of agrochemicals, mechanized plowing, and erosion of terraces threaten the agroecosystem in physical, biological, and cultural terms. As noted elsewhere (Gallegos-Riofrío et al. 2021a, 2021b), these threats are accompanied by population aging, the feminization of agriculture, acculturation, and intergenerational breaches, which also affect the stability of the system.

Nevertheless, evidence from the field along with testimonials, suggest that the community and the agroecosystem are still very resilient. Paramount reasons are that their heterarchical social organization has the ability to respond to pressing needs with very limited resources and particular behaviors (Gallegos-Riofrío et al. 2021b). For example, the residents' preference for healthy diet and corresponding limited consumption of ultra-processed industrialized foods, is a positive deviance comparatively (Gallegos-Riofrío et al. 2021a)––the concept of positive deviance has also been noted in the context of agrobiodiversity, diet, and smallholder family farming in Chimborazo (Oyarzun et al. 2013). Considering the climatic conditions experienced by many Andean communities living above 3,000 MASL and that in Ecuador the range for high-altitude corn is 2,200 to 2,800 MALS (Yánez et al. 2010), annual corn yields in Caliata already represent a notable agroecological feature (note: crop yields were appraised in a participatory ranking and scoring activity (see: Catley et al. 2007) not reported here).

As a globalized awareness about sustainability reaches Caliata, there is a growing recognition among community members of the importance of their ancestral knowledge, which they well understand should be preserved, promoted and, used as a tool for confronting global challenges.

For many indigenous populations that are economically, politically, and physically marginalized the adoption of "modern" forms of agriculture have failed to lift up communities out of a vicious circle of chronic malnutrition, poverty and environmental degradation (Montenegro and Stephens 2006; Tittonell 2013). Caliata, in contrast, has successfully retained its traditional agroecosystems characterized by ecological richness and evenness, the presence of native crops, and interspecies variety, the efficient usage of environmental niches, energy traps, and nutrient loops, soil health, ecological interactions, effective pest control, and mechanisms for mitigating adverse environmental events. Altogether, it is evident that the agroecological system of Caliata offers a view for rethinking and redesigning farming systems in indigenous communities in the Andean mountainous territories, particularly as the current landscape is increasingly defined by modern agriculture.

More broadly, in the Andean region, agroecosystems also represent political space, which through peasant and indigenous organizations, has implications beyond the borders of communities (Altieri & Toledo, 2011). The local level is the foundation of indigenous mobilization (Gallegos-Riofrío et al. 2021b), which has impacted public policy. For example, indigenous communities and organizations in the Andean region champion proposals voiced at the international level, such as the recognition of the rights of nature and *sumak kawsay* or the "good way of living" (Gallegos-Riofrío et al. 2021a). Consequently, planetary health is *Pachamama*'s health. The convergence of mobilization capacity, ecocentric views and ancestral knowledge represent a social force that can be pivotal to global actions needed to redesign the food system within the carrying capacity of the biosphere.

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