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Measuring sustainability of smallholder livestock farming in Yurimaguas, Peruvian Amazon

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Abstract

Sustainability measurement addresses the social, economic, and environmental aspects in order to support policy and decision-making. In the Peruvian Amazon, some smallholder livestock farmers have subsisted through time, partially preserving the ecosystems and demonstrating in practice a certain degree of sustainability. In this regard, this study aims at measuring the sustainability of smallholder livestock farming in the Peruvian Amazon. Sustainability was measured using a multi-criteria method, through the construction of sustainability indicators based on information obtained from field surveys, and soil and macrofauna sampling in the pastures. For this purpose, economic, environmental, and socio-cultural indicators were considered, with a rating scale from 0 to 4, where 0 is the least sustainable category and 4 is the most sustainable one. Smallholder livestock farming was considered sustainable if the general sustainability index (GenSI) was equal to or greater than 2 and, at the same time, if none of the three indicators had a value lower than 2. The socio-cultural indicator was within the sustainability threshold, but the economic and environmental indicators did not fulfill the necessary requirements to consider smallholder livestock farming a sustainable activity in the city of Yurimaguas, Peru. The critical points affecting the sustainability of smallholder livestock farming in Yurimaguas were as follows: degraded soils, lack of silvopastoral systems, inefficient transport system, low annual income, and low levels of associativity. The results suggest the need for mitigating these limitations, as well as promoting associativity and implementing silvopastoral systems for the improvement of the welfare of smallholder livestock farmers.

KEYWORDS
associativity, field surveys, silvopastoral systems, sustainability indicators

1 | INTRODUCTION

Across the tropics, smallholder farmers face numerous threats to agricultural production and their livelihoods (Harvey et al., 2014; Radolf, 2014), and smallholder livestock farmers from the Peruvian Amazon are no exception. These threats are related to poor pasture management practices and vulnerability to climate change, which come both from their predominant location in the tropics and from various socio-economic, demographic, and policy trends limiting their capacity to adapt to changes (Morton, 2007). In addition, small landholdings and financial needs limit some adaptation options (McDowell & Hess, 2012). In Peru, it is estimated that around 824,000 livestock farmers have at least one cattle unit, of which 87% are concentrated in the Andes. Of those farmers, 58% own less than 5 hectares (ha), 30% own between 5 and 49.9 ha, and only 12% own more than 50 ha, evincing that it is the management of small areas that characterizes livestock farming in Peru (MINAGRI, 2017). This scenario, associated with soils susceptible to degradation, poor management practices, poor pasture quality, and weak commercial articulation, affects the sustainability of livestock farming in the Peruvian Amazon (MINAGRI, 2017).

Livestock farming comprises a great variety of productive systems, managed by different social groups and with different patterns of insertion into the market, with a great variation of the systems in biological, technical, economic, and social terms (Murgueitio, 1999). For an agricultural system to be sustainable, it must be sufficiently productive, economically viable, ecologically adequate (i.e., able to conserve the natural resources base and to preserve environmental integrity on the local, regional, and global scales), culturally and socially acceptable and technically possible. In addition to promoting production consistent with the conservation of natural resources, a sustainable system must be compatible with the economic interests of farmers (Sarandón, 2002). In Peru, lately there has been an increasing interest, supported by decision-makers and researchers, in livestock farming systems that optimize productivity and increase income while conserving the soil and protecting the environment.

Many authors have dealt with the design of sustainability indicators of production systems. In such studies, indicators are defined as quantitative or qualitative measurements that allow diagnosing the production systems (Andrieu, Piraux, & Tonneau, 2007). Researchers who have analyzed sustainability agree that indicators should be aligned with the objectives and adapted to the agroecosystems of the relevant region (Costanza & Patten, 1995; Girardin, Bockstaller, & Van der Werf, 1999; Merma & Julca, 2012). A sustainability analysis will be operational if the behavior of an appropriate number of relevant indicators is characterized (Peña, Alegre, & Bardales, 2018). These indicators must: (a) be aligned with the objectives and the scale of analysis, (b) integrate variables, (c) be reliable and simple to understand, and (d) be sensitive to a wide range of conditions and changes in time to be easily measured (Sarandón, 2002).

During the last three decades, population growth, economic development, and a growing demand for natural resources have caused rapid deforestation in the Peruvian Amazon (Barrantes & Glave, 2014; Bax, 2015). Yurimaguas, a district located in the Loreto region, lost 25 thousand hectares of forest cover in the last 15 years, with most of that area being used for grazing pastures and cash crops (Paz, Tello, & Solis, 2015). Although large extensions have been deforested, some smallholder farmers have conserved some patches of forests in their farms, which make Yurimaguas an interesting area for the analysis of sustainability indicators. In this context, this study hypothesizes that the smallholder farmers of Yurimaguas practice sustainable livestock farming.

Several studies have used a multiple criteria method for the analysis of agricultural sustainability, through the construction of sustainability indicators based on laboratory analysis and information collected from field surveys, considering environmental, economic, and socio-cultural indicators (Battaglini, Bovolenta, Gusmeroli, Salvador, & Sturaro, 2014; Márquez-Romero et al., 2016; Otta et al., 2016; Peña et al., 2018; Sarandón & Flores, 2009). These analyses allowed identifying farms that maintain ecological stability and maximize productive efficiency, while improving the livelihoods of the people involved (Otta et al., 2016). In view of the above, this study aims to measure the sustainability of smallholder livestock farming in Yurimaguas, Peruvian Amazon, in an attempt to identify sustainable land-use options that could help those farmers enhance their farms sustainability.

2 | MATERIAL AND METHODS

The study area corresponds to a total area of 720 km^2, located in Yurimaguas, Loreto, Peru. The climate that extends over most of the research area is warm with a rainy season from November to May. The mean annual temperature is 26°C, and the total annual precipitation ranges from 3,000 to 4,000 mm.

2.1 | Selection of farmers

The study area comprises of 35 rural communities and approximately 1,559 families. The distribution of inhabitants per rural community was variable, and the amount depends mainly on its proximity to a main road. The communities far from the main road had the smallest number of families: Las Palmeras, Yanayacu and San Ramón, with 3, 5, and 5 families, respectively, whereas the communities near to the main road had the largest number of families: Munichis, Miguel

Grau, and Santo Tomás, with 327, 190, and 138 families respectively.

2.2 | Questionnaires administration and soil analysis

The present study was carried out within the framework of the Sustainable Amazonian Landscapes (SAL) project, led by the International Center for Tropical Agriculture. The SAL project interviewed 417 families, approximately 25% of the total, in 2016. The surveys were carried out randomly, and an important criterion for selecting respondents was that they must own at least one farm located in the study area. The surveys were organized into modules: general data, socio-demographic aspects, durable goods, subjective welfare, food security, productive activities and natural resources, associativity, income outside the farm, farm characterization, crops characterization, pastures characterization, livestock characterization, and perception of climate change. The farm owner, or spouse, was requested to answer the survey questions. The questions were related to the history of the communities, associations of farmers, opportunities for development, main problems, perception of authorities' performance, and perception of climate change effects (Quintero et al., 2019). In addition, elderly people and authorities of the communities were interviewed. The questions were related to the history of the communities, associativity, working conditions, opportunities for development, main problems, and perception of climate change effects. This study focused on cattle farming because it is the most important type of livestock farming in the study area.

Soil analysis was performed in 10 pasture plots randomly selected from the households that practiced livestock farming. Soil samples were collected from plots of 30 × 30 m (900 m^2), with a central soil pit of 1 × 1 m, and three lateral soil pits located at 10 m from the central point in the 0°, 120°, and 240° directions, at three depths (0–10, 10–20, and 20–50 cm). In each soil pit, undisturbed samples for determination of soil bulk density were collected (in metal rings of 100 cm^3) at the three depths. In addition, disturbed samples were collected from the same depth intervals in each sampling point for physicochemical characterization. In total, 120 soil samples (10 farms × 4 sampling points × 3 depths) were collected within the study area for analysis.

Soil samples were placed in plastic bags and transported to the Soil Laboratory of Universidad Nacional Agraria La Molina (UNALM), air-dried at room temperature, crushed, pooled into one homogenous group considering the same depth intervals of the sampling points, and finally were passed through a 2 mm sieve before analysis. The soil quality variables considered in this study were pH, organic matter, available potassium (K), available phosphorus (P), and percentage of aluminum (%Al) saturation. Soil pH was measured using a pH meter, soil organic matter was determined by the Walkley and Black method (1934), the available P content was analyzed by colorimetry, and available K content was measured by ammonium acetate extraction using atomic absorption equipment (Anderson & Ingram, 1993). Comparisons related to soil analysis were based on the nutrients content and their availability for plants.

Likewise, soil macrofauna was evaluated in the same plots to construct the soil macroinvertebrates diversity indicator, for which macrofauna was identified and quantified according to the standard ISO-TSBF method (Tropical Soil Biology and Fertility Program; Anderson & Ingram, 1993). Three 30 × 30 cm soil monoliths were taken from each plot on regular transects. The fauna was sampled and sorted in the litter layer before soil blocks were excavated. Each monolith was cut from three horizontal layers (0–10, 10–20, and 20–30 cm). Soil invertebrate macrofauna specimens were extracted and stored in a 70% alcohol solution. Earthworms were preserved in 4% formaldehyde. All individuals were counted and identified at the morphospecies levels (i.e., morphologically identical groups of individuals) (Marchão et al., 2009).

2.3 | Construction of sustainability indicators

The general sustainability evaluation was carried out using the multi-criteria method proposed by Sarandón and Flores (2009), in order to detect the current critical points in the sustainability of smallholder livestock systems and to propose management alternatives based on the results. As a first step for the construction of indicators, the authors analyzed the available bibliographic information and statistical data from local institutions. Then, three discussion groups that included at least one researcher, one local specialist and one farmer determined the factors that influenced in the sustainability of smallholder livestock farming in Yurimaguas. Based on the information collected, the present study chose indicators that were easy to obtain and interpret, that provided relevant information, and that allowed detecting trends on the farms (Sarandón et al., 2006).

The indicators were expressed in different units: weight, length, area, number, farmers' attitudes, and economic gain. The data were standardized by being transformed into a scale for each indicator. The scale comprises values from 0 to 4, where 0 is the least sustainable category and 4 is the most sustainable one (Sarandón & Flores, 2009; Sarandón et al., 2006). Regardless of the original units of each indicator, they were expressed at some value on the scale as represented in Tables 1–3.

Weighting of indicators was carried out multiplying the obtained value on the scale by a coefficient determined by

TABLE 1 Indicators and rating scale of the economic dimension

Economic dimension	Rating scale 0	1	2	3	4
A. Level of farm capitalization					
A1. Total area of the farm (ha)	Area ≤ 10	10 < Area ≤ 15	15 < Area ≤ 20	20 < Area ≤ 30	Area > 30
A2. Area of pasture (ha)	Area ≤ 5	5 < Area ≤ 10	10 < Area ≤ 15	15 < Area ≤ 20	Area > 20
A3. Number of cattle units	No cows	1 ≤ Cows ≤ 10	11 ≤ Cows ≤ 20	21 ≤ Cows ≤ 25	>25 cows
A4. Technological goods on the farm	0	1	2	3	>3
B. Economic risk					
B1. Diversification of the income from the farm	No economic activity	1 economic activity	2 economic activities	3 economic activities	> 3 economic activities
B2. Access road to the farm	Without access	River	Bridle path	Unpaved road	Paved road
C. Net income					
C1. Annual net income in 2016 (US dollars)	I ≤ 1,200	1,200 < I ≤ 2,400	2,400 < I ≤ 3,600	3,600 < I ≤ 4,800	I > 4,800

TABLE 2 Indicators and rating scale of the environmental dimension

Environmental dimension	Rating scale 0	1	2	3	4
A. Soil quality					
A1. pH	pH ≤ 3.5	3.5 < pH ≤ 4	4 < pH ≤ 4.5	4.5 < pH ≤ 5	pH > 5
A2. Organic matter—OM (%)	OM ≤ 1	1 < OM ≤ 2	2 < OM ≤ 3	3 < OM ≤ 4	OM > 4
A3. Potassium—K (ppm)	K ≤ 70	70 < K ≤ 100	100 < K ≤ 130	130 < K ≤ 160	K > 160
A4. Phosphorus—P (ppm)	P ≤ 4	4 < P ≤ 6	6 < P ≤ 8	8 < P ≤ 12	P > 12
B. Resilience capacity					
B1. Silvopastoral systems (SPS)	No SPS	Scattered shrubs	Fodder banks	Live fences	Scattered trees
B2. Proportion of forest on the farm (%)	No forest	F ≤ 10	10 < F ≤ 20	20 < F ≤ 30	F > 30
B3. Current conflicts related to natural resources	>3	3	2	1	0
B4. Problems on the farm	>3	3	2	1	0
C. Soil macroinvertebrates diversity					
C1. Soil macroinvertebrates diversity (Shannon Index – SI)	SI ≤ 1	1 < SI ≤ 1.5	1.5 < SI ≤ 2	2 < SI ≤ 2.5	SI > 2.5

consensus between the researchers who participated in this study, considering the importance of the indicators, the farmer's opinions, the analysis of local conditions, and previous studies (Lefroy, Bechstedt, & Rais, 2000; Merma & Julca, 2012; Sarandón & Flores, 2009). The weight of each indicator reflects its importance in the sustainability of the activity. For the calculation of the economic, environmental and socio-cultural sustainability indicators (KI, EI, and SCI, respectively) and the calculation of the general sustainability index (GenSI), the formulas presented in Table 4 were applied. Sarandón et al. (2006) established the middle value of the scale as the minimum sustainability threshold. According to this, farms were considered sustainable if GenSI > 2 and if none of the three indicators (KI, EI, and SCI) had a value <2 (Sarandón & Flores, 2009).

3 | RESULTS

3.1 | Description and weighting of the chosen indicators

The application of the multi-criteria methodology for the construction of indicators allowed us to obtain a series of standardized and weighted indicators for the three dimensions analyzed.

TABLE 3 Indicators and rating scale of the socio-cultural dimension

	Rating scale				
Socio-cultural dimension	**0**	**1**	**2**	**3**	**4**
A. Satisfaction of basic needs in the community					
A1. Housing	Hut	Wooden or brick walls, no floor, and roof of palm leaves	Wooden or brick walls, no floor, and roof of corrugated iron	Wooden or brick walls, with a floor, and roof of palm leaves	Wooden or brick walls, with a floor, and roof of corrugated iron
A2. Education	No education	Incomplete primary	Complete primary	Complete secondary	Higher
A3. Health care	No access to health care	Healer	Community medical center	Yurimaguas public hospital	Private hospital
A4. Drinking water	Rainwater	River	Water tanker	Water well	Aqueduct
A5. Transport	Walking	Horse or donkey	Canoe	Motorcycle	Car
B. Knowledge and ecological awareness					
B1. Training and qualification	No training and no education	No training and access to primary school	No training and access to secondary school	Training and access to primary school	Training and access to secondary school
B2. Reasons to protect forests	No forest	Source of wood or firewood	Source of food or medicine	Protection of water sources	Protection of the environment
C. Social integration					
C1. Membership in organizations	Independent	1 organization	2 organizations	3 organizations	>3 organizations
C2. Satisfaction with social life and coexistence	Very unsatisfied	Unsatisfied	Neither satisfied nor unsatisfied	Satisfied	Very satisfied
C3. Satisfaction with the work performed by local government	Very unsatisfied	Unsatisfied	Neither satisfied nor unsatisfied	Satisfied	Very satisfied
D. Working conditions					
D1. Time spent going from home to farm (hours)	$T \geq 1$	$0.5 \leq T < 1$	$0.25 \leq T < 0.5$	$0 < T < 0.25$	Live on the farm
D2. Satisfaction with the current job	Very unsatisfied	Unsatisfied	Neither satisfied nor unsatisfied	Satisfied	Very satisfied

3.2 | Economic dimension

Table 1 shows the indicators chosen to assess the economic sustainability of livestock systems.

1. Level of farm capitalization—A farm is sustainable if it is capitalized in a way that allows farmers to improve production efficiency, and get sufficient income to cover production costs and to meet their basic needs. It includes the following indicators:
   a. Total area of the farm: The farm area must be large enough to install the necessary pasture area that allows farmers to improve livestock management and diversify productive activities.
   b. Pasture area: The farm is sustainable if the area used for pastures and food production is adequate in relation to the members of the family group.
   c. Livestock units: According to interviews with farmers, 10 is the minimum number of livestock units that allows them to generate enough income to support the family under local conditions.
   d. Number of technological goods in the farm: Farmers increase the value of their farms when they acquire technological goods, such as the use of machinery, equipment, and electronic communication systems that allow them to improve productivity and increase income to support the family.
2. Economic risk—The farm is sustainable if the economic risk is minimized and production stability is ensured. It includes the following indicators:
   a. Diversification of income from the farm: The farm is sustainable if farmers can diversify their sources of income and/or sell more than one agricultural product, since if the main product suffered any damage or loss, other products could compensate it. Diversified production will allow meeting nutritional requirements and satisfying the basic needs of the family.
   b. Access road to the farm: Access roads to the farms in good conditions will allow farmers to transport input into the systems, and to reduce the risks of damage or loss of products during transport to the market, reducing the economic risk.
3. Net income—The farm is sustainable if income meets the basic needs of the family group. The indicator evaluated was annual net income in 2016 (US dollars).

3.3 | Environmental dimension

Table 2 shows the indicators chosen to assess the environmental sustainability of livestock systems.

TABLE 4 Formulas for the calculation of the sustainability index

Indicator	Formula
Economic (KI)	$\frac{\frac{A1+A2+A3+A4}{4}+\frac{(2*B1)+B2}{3}+(2*C1)}{4}$
Environmental (EI)	$\frac{\frac{A1+A2+A3+(2*A4)}{5}+\frac{B1+B2+B3+B4}{4}+C1}{3}$
Socio-cultural (SCI)	$\frac{\frac{A1+A2+A3+A4+A5}{5}+\frac{(2*B1)+B2}{3}+\frac{C1+C2+C3}{3}+\frac{D1+D2}{2}}{4}$
General sustainability index (GenSI)	$\frac{KI+EI+SCI}{3}$

1. Soil quality—Soil quality is a measure of soils capacity to function adequately in relation to a specific use. The following indicators were evaluated:
   a. pH: The pH is a measure of acidity or alkalinity in soils. It defines the chemical and biological activities in soils. The pH in soils of the Peruvian Amazon is acidic and ranges from 3.5 to 5.5.
   b. Organic matter: It explains the potential supply of nitrogen (N) and available nutrients for plants, besides it is a productivity indicator. Alegre, Lao, Silva, and Schrevens (2017) reported that in soils of the Peruvian Amazon, the N content in soil samples corresponds to 5% of the total organic matter.
   c. Potassium: It is a productivity indicator and explains the available nutrients for plants.
   d. Phosphorus: It is a productivity indicator and explains the available nutrients for plants.
2. Resilience capacity—Sustainable soil management contributes to the resilience of livestock systems. The following indicators were evaluated:
   a. Silvopastoral systems: Silvopastoral systems are a combination of trees, forage shrubs, and pastures with livestock production on the farm. The installation of silvopastoral systems influences in the improvement of pasture quality and livestock productivity. Besides, they are important for conserving biodiversity, increasing the carbon stock, and strengthening the provision of ecosystem services.
   b. Proportion of forest in the farm: A system is sustainable if it maintains at least 10% of the total farm as forest, conserving biodiversity and improving life in the soils.
   c. Number of current conflicts related to natural resources: Conflicts related to natural resources occur due to disagreements about access, control, and use of natural resources.
   d. Number of environmental problems in the farm: The problems were mainly related to changes in temperature and frequency of rainfall.
3. Soil macroinvertebrates diversity (Shannon index—SI)—These macroinvertebrates include so-called soil engineers (termites, ants, and earthworms), in addition to a few species of diplopods and beetles that modify the soil structure and the distribution of soil resources (especially organic matter).

3.4 | Socio-cultural dimension

Table 3 shows the indicators chosen to assess the socio-cultural sustainability of livestock systems.

1. Satisfaction of basic needs in the community—A system is sustainable if farmers ensure that their basic needs are met in the community. It includes the following indicators:
   a. House
   b. Education
   c. Health care
   d. Water
   e. Transport
2. Knowledge and ecological awareness—They are important for farmers to better manage ecosystems, integrating production systems and forests in a balanced way. It includes the following indicators:
   a. Training and qualification: The training and qualification of farmers include basic education and technical knowledge of livestock farming.
   b. Reasons to protect forests: The farmers conserve the forest mainly because they are source of firewood, food, and medicine. Moreover, some farmers conserve forest patches for the conservation of biodiversity and for climate regulation.
3. Social integration—Social integration is the process by which the inclusion in society of all farmers is facilitated. The indicators evaluated were as follows:
   a. Membership in organizations: The relationship with other members of the community through social organizations allows to improve the productive systems and increases the negotiation capacity.
   b. Satisfaction with social life: This indicator is related to the interaction of farmers with other people from local communities.
   c. Satisfaction with the work performed by local government
4. Working conditions—This emphasizes the quality of worker's job and their working environment. The indicators evaluated were as follows:
   a. Time spent going from home to farm (hours)
   b. Satisfaction with the current job

3.5 | Analysis of the livestock farming sustainability

3.5.1 | Economic sustainability

In the Yurimaguas areas, according to the structured surveys, smallholder livestock farmers presented variations regarding to the total area of their farms: 11.7% of the respondents had less than 10 hectares, 34.2% had between 10 and 20 ha, 24.3% had between 20 and 30 ha, and finally 29.8% had more than 30 ha. At the same time, 96.1% of the respondents had property titles and 3.9% of them had land ownership documents. The management of small pasture areas characterized livestock farming, and 63.1% of the respondents had less than 10 ha of pastures, 29.1% had between 10 and 20 ha, and only 7.8% had more than 20 ha of pastures. The remainder of their farms consisted of croplands, fallows, small areas of peatlands and patches of intervened primary forests, favoring the diversification of their income from the farm and guaranteeing their food security. Thirty-four percent of the respondents reported having between 1 and 10 cattle units, 29.1% reported having between 10 and 20 cattle units, and 19.4% had between 20 and 25 livestock units. Only 17.5% reported having more than 25 cattle units. The respondents indicated that most livestock farmers did not have a defined market to sell their products. Only a small number of them sell milk to public institutions and to small companies that produce dairy products such as yogurt and cheese. Therefore, most farmers were forced to sell their cows to merchants who visited the communities and offered low prices.

Indicators regarding pasture areas, livestock units, annual net income, and technological goods on the farm were below the minimum sustainability threshold with values equal to 1.39, 1.94, 1.17, and 0.83, respectively. The access road to the farm was just above the minimum sustainability threshold, with a value of indicator equal to 2.09. Another important issue worth noting is that farmers practiced different economic activities and diversified their income, with a value equal to 2.67 (Figure 1). Most of the local livestock farmers had diversified their productive activities. The main crops identified through the surveys were as follows: papaya (*Carica papaya*), cassava (*Manihot esculenta*), plantain (*Musa* sp.), beans (*Vigna unguiculata*), and maize (*Zea mays*). Moreover, some of them had installed small-scale crops of rice (*Oriza sativa*), oil palm (*Elaeis guineensis*), and cocoa (*Theobroma cacao*).

The economy of livestock farmers in Yurimaguas is subsistence, even for those farmers who have more than 30 hectares of land, since they lack financial resources and adequate technology. The average net annual income per farm in 2016 was 4,982.2 US dollars per year and 415.2 US dollars per month. However, that income value consisted of 19.4% of farmers who had an income above 3,600 US dollars per year, while 10.7% had incomes between 2,400 and 3,600 US dollars, and finally 69.9% had incomes below 2,400 US dollars per year, confirming an economic inequality among farmers. Farmers living near the main city of Yurimaguas had higher annual income because, sold their products more easily and had more possibilities to generate income outside the farms (Figure 1). Results showed that the smallholder livestock farming in Yurimaguas had an index equal to 1.62 in the

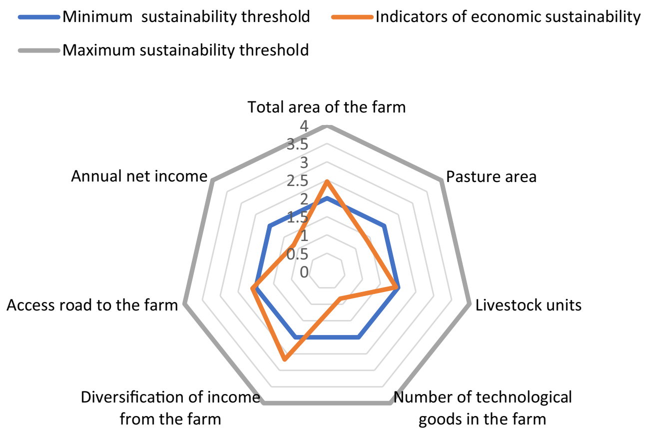

FIGURE 1 Indicators of economic sustainability

TABLE 5 Indicators of sustainability of smallholder livestock farming in Yurimaguas, the Peruvian Amazon

Sustainability Index	Average	Coefficient of variation
KI	1.62	0.53
EI	1.41	0.15
SCI	2.16	0.15
GenSI	1.72	0.22

Abbreviations: EI, environmental indicator; KI, economic indicator; SCI, socio-cultural indicator.

economic dimension, while the coefficient of variation was 0.53 (Table 5).

3.5.2 | Environmental sustainability

Local farmers lack technical knowledge and only 6.8% of the respondents reported having installed silvopastoral systems (SPS) on their farms, showing the lowest index value (0.19). In Yurimaguas, few farmers use electric fences to divide the paddocks into smaller areas and efficiently use the pastures, in addition to establishing forage banks and/or planting trees in the fringes between the paddocks. Farmers reported that they have not installed electric fences or not mechanized the farm due to lack financial resources. Moreover, 93% of local farmers did not practice rotation of paddocks and spend little time on livestock activities; thus, they can carry out other agricultural activities.

Other indicators that were below the minimum sustainability threshold were the soil macroinvertebrates diversity and organic matter stocks, pH, and K and P contents, with indices equal to 1.4, 1.6, 1.6, 0.8, and 0.3, respectively. Proportion of forests on the farm, current conflicts related to natural resources, and environmental problems in the farm were within the sustainability range, with indices equal to 2.2, 2.9, and 2.3, respectively. The pasture plots evaluated in the different farms presented an average soil pH of 4.7 being very acid, and the aluminum saturation on the topsoil was medium (41.9%).

According to local farmers, the main environmental problem was soil degradation due to overgrazing, which was directly associated with low animal productivity. The main causes of conflicts related to natural resources comprised: soil degradation due to increased rate of deforestation; water pollution due to the lack of a waste management system; and increased agriculture frontier due to new oil palm plantations. Despite that, it is worth mentioning that 63.1% of the livestock farmers still conserve more than 10% of the total area of their farms as forests (Figure 2). In the present study, the average Shannon index of macroinvertebrates communities in pasture soils was 1.36; in addition, oligochaetas constituted 36% of the macrofauna population. Another group of importance was ants, which represented 32.6% of the population. Based on the results obtained through different indicators from Table 2, we found that livestock farming in Yurimaguas had an index of environmental sustainability equal to 1.41 and a coefficient of variation equal to 0.15 (Table 5).

3.5.3 | Socio-cultural sustainability

Training and qualification, mobility and transport, and participation in local associations were indicators that were below to the minimum sustainability threshold, with indices equal to 1.86, 0.72, and 0.33, respectively. On average, 23.3% of livestock farmers participated in at least one social organization. On the other hand, we identified nine variables that were within the sustainability range. Access to services of housing, education, water, and healthcare was above to the minimum sustainability threshold, with indices equal to 2.43, 2.11, 2.74, and 2.07, respectively. Most farmers were very

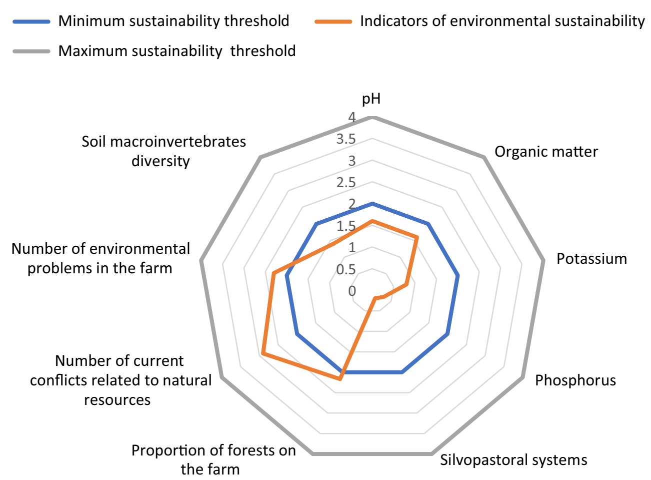

FIGURE 2 Indicators of environmental sustainability

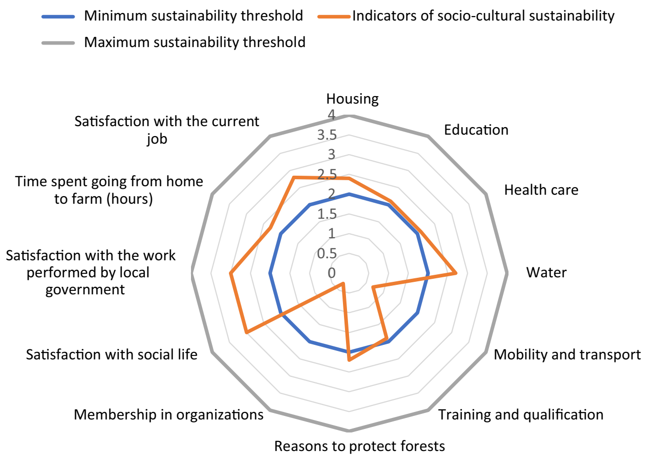

FIGURE 3 Indicators of socio-cultural sustainability

conscious about the reasons for protecting forests and, in addition, they were satisfied with their social life and coexistence and with the work performed by local government. The indices found in these indicators were 2.22, 2.96, and 3.03, respectively. Moreover, time spent going from home to farm and satisfaction with the current job, indicators related to the working conditions, were within the sustainability range with indices equal to 2.25 and 2.81, respectively. On average, farmers spent 0.3 hr for going from home to farm (Figure 3).

The distribution of work varied between the farms. The workforce was essentially family-based. Thirty-eight percent of the respondents reported hiring workers for working, not only in livestock farming, but also in different agricultural activities. Most workers start the workday at 5.00 or 6.00 a.m. and work until 11.00 a.m., working 5–6 hr on average during the morning. Due to the high temperatures during the midday and afternoon, people take a rest and recommence the workday at 3.00 p.m., for 2 or 3 more hours. According to the interviews with elderly people and local authorities, the cattle raised for farmers is like "saving money," mainly for farmers with few cattle units, since they sell the animals when they have no money or have health problems. Lastly, based on the results obtained through different indicators, the smallholder livestock farming had a sustainability index of 2.16 and a coefficient of variation equal to 0.15 in the socio-cultural dimension (Table 5).

3.5.4 | General sustainability

Based on the general analysis, the socio-cultural indicator was slightly above to the minimum sustainability threshold, but the economic and environmental indicators did not fulfill the necessary conditions to consider that a sustainable management of the smallholder livestock farming is practiced in Yurimaguas. The GenSI was equal to 1.72 and the coefficient of variation equal to 0.22 (Table 5).

4 | DISCUSSION

Sustainability assessment is a key step in supporting the development of sustainable farming systems (Sadok et al., 2009). Sustainable livestock systems should indeed be environmentally friendly, economically viable for farmers, and socially acceptable, notably for animal welfare (Lebacq, Baret, & Stilmant, 2013). For a considerable long time, agricultural/livestock policies have focused only on productive or economic aspects. Interventions aiming to improve farmers' income or promote modernization have resulted in several negative side effects, such as increased pollution, landscape degradation, and deepening of regional disparities (Andreoli & Tellarini, 2000). Consequently, there is a need to assess sustainability with a more comprehensive approach. Sarandón (2002) and Sarandón and Flores (2009) proposed the use of economic, environmental, and socio-cultural indicators to assess sustainability of farming systems. This method was used in this study to assess sustainability of smallholder livestock farming in Yurimaguas, Peru. The main challenge is using a transparent selection process of indicators to avoid assessment subjectivity (Lebacq et al., 2013).

4.1 | Analysis of the sustainability of livestock farming

4.1.1 | Economic sustainability

Our findings indicated that livestock farming practiced in Yurimaguas by smallholder farmers is not economically sustainable. A livestock farming system is economically sustainable if it guarantees a benefit that allows it to maintain itself over time, while maintaining or improving productive efficiency and decreasing economic risk (Otta et al., 2016). The information obtained locally for the purpose of this study is in line with the national information thereof (MINAGRI, 2017), which reported that the majority of livestock farmers of remote areas in Peru have few cattle, are not articulated with a defined market, and sell their products at low prices. In this study, 97.1% of livestock farmers reported that they practice at least one additional economic activity, that is, a diversified income source, thus the indicator "diversification of income from the farm" was the one with the highest value. In the same line, Mathios, Alegre, and Aguilar (2018) reported that livestock farmers from the lower Shanushi River basin in Yurimaguas practice additional agricultural activities with some working in commerce and in the public sector, which shows a diversification in their income sources. The diversification of income by rural households has the potential to spread economic risk, smooth consumption, and enhance the efficiency of use of natural resources (Caviglia-Harris & Sills, 2005).

The practice of different productive activities and the obtaining of food products from agriculture allowed the subsistence of these farmers, who deem that their basic needs are met, even though this study identified that most of them live in poverty and that income was not distributed equally between farmers. In the same line, the study on farms in Alto Urubamba, Cuzco, carried out by Merma and Julca (2012) reported that local farmers were in conditions of poverty. On the other hand, technological development, such as the use of machinery, equipment, and electronic communication systems, has introduced radical changes to the agricultural working environment in recent years (Pivoto et al., 2018). The acquisitions of such technological goods by farmers can positively influence living standards (Stabile et al., 2020). For example, the use of electric fences led to better management of pastures and to increase in cattle weight and daily milk production. Lamentably, very few farmers have implemented electric fences or other technological goods on their farms. Therefore, government plans for rural development should aim mainly at increasing the resilience of agricultural activities among farmers who live far away from the main cities, by means of agroforestry systems and sustainable use of non-timber forest products.

In addition, the access roads to most of the farms are unpaved, but some of the farmers go to their farms through bridle paths or navigating the rivers. Lamentably, the local authorities do not keep the unpaved roads in good conditions, thus hindering the transport of inputs into the system and agricultural products to the market and affecting the living standards.

4.1.2 | Environmental sustainability

Environmental sustainability is related to the protection, maintenance, and enhancement of natural resources (water, soil, and forests), biodiversity (species and habitat), and landscapes (Passeri et al., 2016). Yurimaguas registered a loss of forest cover of approximately 25 thousand hectares in the last 15 years. The deforested area was used for increasing the extent of cropland and pastures (Paz et al., 2015). These disturbances are considered the main drivers of biodiversity loss and are affecting the soil physicochemical properties (Battaglini et al., 2014; Hiernaux, Bielders, Valentin, Bationo, & Fernández-Rivera, 1999; Melo, Orrutéa, Motta, & Testoni, 2017). Therefore, measuring the extent of environmental degradation in livestock systems is essential for developing strategies to reduce the effects of such human disturbances.

Soils in tropical regions are acid (Liao et al., 2006) and, in such soils, aluminum ions are toxic for most crop plants (Carreño & Chaparro-Giraldo, 2013; Kochian, Piñeros, & Hoekenga, 2005); however, one way to neutralize acidity is the application of limestone amendments. According to Teitzel and Wilson (1991), pasture productivity is always a function of grazing management and fertilization, regardless of the initial soil fertility status. Most grass species in Yurimaguas (*Axonopus compresus*, *Brachiaria decumbens*, *Brachiaria brizantha* etc.) are tolerant to acidity and low levels of soil nutrients. The results showed that poor pasture management leads to negative changes in some of the soil properties that are important for long-term soil fertility. In this sense, the burning and overgrazing of pastures contributed to soil degradation affecting the existing macroinvertebrates diversity and the soil physicochemical properties, placing these environmental indicators below to the minimum sustainability threshold. Hence, soil degradation is a serious threat to the functioning of pastures, the diversity of macrofauna species, and the provision of ecosystem services (Kayser, Müller, & Isselstein, 2018; Pashanasi, 2001).

In Yurimaguas, only 6.8% of the respondents reported having implemented SPS on their farms, and this was the environmental indicator with the lowest value. Alegre et al. (2017) indicated that one option to recover degraded lands affected by overgrazed pastures is the implementation of sustainable agroforestry systems. Pastures combined with shrubs and/or trees, which may have edible leaves, improve livestock production systems by mitigating the negative environmental effects generated by traditional systems, providing animals with shade and improving their welfare, in addition to increased animal productivity (Broom, 2017; Guerci et al., 2013; Navas-Panadero, 2010). Moreover, these systems provide ecosystem services such as carbon sequestration, biodiversity conservation, and soil enrichment (Jose, 2009), highlighting the need to implement SPS in smallholder livestock farming in the Peruvian Amazon.

The environmental sustainability values, mainly results related to the conservation of the forest patches, confirm a certain environmental rationality on the part of farmers. Lamentably, soil degradation, loss of soil biodiversity, and lack of silvopastoral systems showed indices below the minimum sustainability threshold and influenced to our results. Moreover, the agrobiodiversity can play as a source of ecosystem services in fragmented landscapes, especially for smallholder livestock farmers. En este sentido, el mantenimiento de niveles mínimos de biodiversidad es importante (Sarandón et al., 2006).

4.1.3 | Socio-cultural sustainability

Social themes are difficult to assess without collecting additional data on the farm. In fact, social indicators often depend on qualitative estimations. Consequently, only data such as working conditions, associativity, education, and some indicators with a low degree of aggregation could be used as social indicators (Lebacq et al., 2013; Merma & Julca, 2012). The socio-cultural aspects of sustainability have been studied far less than the economic and ecological ones (Boogaard, Oosting, Bock, & Wiskerke, 2011). Within the social aspect, this study investigated important indicators such as satisfaction of basic needs in the community, knowledge and ecological awareness, and social integration. In Yurimaguas, the smallholder livestock farmers satisfied their basic needs within the community, except for the transport. An efficient transport system is essential to facilitate the marketing of products and enable farmers to travel to their farms. The lack of some type of transport is a latent problem and affects the local economy and the standard of living.

Most respondents just have access to primary school and no technical training; thus, the training and qualification of farmers were another indicator that was below the minimum sustainability threshold, making difficult the adoption of new technologies. A study conducted in the peasant communities of Cusco, Peru, showed that the improvement of farmers' agricultural technological skills had positive effects on their livelihoods and allowed them to guarantee food security (Solís-Mora, 2016). Therefore, education should be a priority of programs aimed at promoting rural development and economic growth.

The participation of livestock farmers in social organizations directly involved in production systems (farmers associations, cooperatives, development societies etc.) and in other social groups (civil associations, entities etc.) improves the management capacity of the systems, contributing to productive improvements and the marketing of meat and milk. Sixty-three percent of farmers reported having 20 or fewer cattle units, and the raising is basically for beef cattle, so they consider that the benefits would be minimal if they are associated, requiring local governments to promote both economic development programs and associativity. Previous studies reported that social integration of farmers at various levels improves productive systems, increases negotiation capacity, and contributes to improving their living standards (Merma & Julca, 2012; Otta et al., 2016). Therefore, it is necessary to promote social integration of livestock farmers into society.

Although some socio-cultural indicators were below the minimum sustainability threshold, livestock farmers were satisfied with their social life and coexistence, and with the management of the community by local authorities. An adequate process of implementation of rural development projects focused on livestock and SPS, led by government authorities and researchers, will meet basic needs in the community, promote social integration, and improve technical training. This will allow livestock farmers to have a greater degree of satisfaction regarding their welfare and will facilitate environmental awareness processes, which can lead to a positive effect on the conservation of remnant forest patches and the sustainable use of natural resources.

4.1.4 | General sustainability

Many documents have analyzed sustainability using indicators at the farm level (Márquez-Romero et al., 2016; Merma & Julca, 2012) and at the regional level (Sarandón, 2002; Viglizzo, Pordomingo, Castro, & Lertora, 2003), but there are no pre-established indicators that could be used universally (Flores & Sarandón, 2015). Differences in the scale of analysis (farm, farm, region), type of establishment, desired objectives, productive activity, characteristics of farmers make its generalization impossible (Sarandón & Flores, 2009). In this line, the development of the indicators must be carried out considering previous information, local characteristics of the agroecosystems, and the objectives of the analysis.

The present study identified indicators affecting the sustainability of smallholder livestock farming and provided information for managing agricultural landscapes and decision-making regarding land-use policies to increase the resilience of productive systems. The economic and environmental indicators were below of the sustainability thresholds. Aligned with our study, Otta et al. (2016) identified that the economic indicator was one of the main constraints on the sustainability of agricultural systems in a study performed in Mendoza (Argentina).

Alegre et al. (2017) reported that degraded lands with low fertility, affected by overgrazing in the humid tropics of Yurimaguas, can be recovered for sustainable production with leguminous cover crops and Multistrata Agroforestry Systems (MAS) because in a short time soil, compaction is reduced and organic matter level increased after the establishment of cover crops and trees. Furthermore, the use of leguminous cover crops influences in the increase of tropical crops yield (Solis et al., 2019).

5 | CONCLUSIONS

The studied livestock farms showed that the socio-cultural indicator was within the range of sustainability, but the economic and environmental indicators did not fulfill the necessary requirements for the management of livestock farming in Yurimaguas to be considered sustainable. The critical points affecting the sustainability of smallholder livestock farming in Yurimaguas were as follows: degraded soils by overgrazing, small pasture areas with poor management practices, lack of silvopastoral systems, inefficient transport system, low annual income, and low levels of associativity. In this vein, it is necessary that government rural development programs be targeted at improving productive infrastructure, promoting associativity, and providing financial support and technical assistance to optimize the livestock farming activity in the region and improve the welfare of farmers.

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CONFLICT OF INTEREST

None declared.

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