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Sustainability Assessment of Smallholder Agroforestry Indigenous Farming in the Amazon: A Case Study of Ecuadorian Kichwas

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Abstract: In the Amazon, the Yasuní Biosphere Reserve (YBR) is considered a natural and cultural diversity hotspot. It is populated by several indigenous groups, including the Kichwa, who are characterized by their traditional systems of production, which are a means of subsistence and socio-ecological integration. The objective of this research was to evaluate the sustainability of small farmers who use a traditional agroforestry system (*chakra*) within the buffer, transition, and core zones of the YBR. We conducted 133 interviews with Kichwa heads of households. The socio-demographic structure and distribution were identified, and the response-inducing sustainability evaluation (RISE) methodology was used to evaluate *chakra* sustainability according to social, economic, and ecological dimensions, expressed using 10 indicators from 50 parameters, valued from 0 (worst case) to 100 (best case). The results are expressed in a polygon, defined by the areas: (1) good performance, (2) medium performance, and (3) poor performance. We employed the multivariate classification hierarchical cluster technique and analysis of variance (ANOVA) to identify dissimilarities between groups of *chakras* and the existence of statistical differences, respectively. Among the studied indigenous Kichwas, a pyramidal structure progressive type was identified, which is characteristic of young populations and the nonexistence of significant differences between the RISE indicators and *chakras*. The lowest-scoring indicators using the RISE guidelines were: use of materials and environmental protection, animal production, economic viability and *chakra* administration. We provide suggestions for decision makers who support Kichwa populations in socio-productive management with sustainability goals. We to taking actions on the indicators identified with high priority to improve the sustainability in the *chakras* and sociodemographic dynamics.

Keywords: hotspot; natural resources; sustainable agriculture; Yasuní

1. Introduction

The biological and cultural richness of the tropics is recognized globally. Worldwide, it is estimated that there are approximately 300 million indigenous people who belong to 5000 different cultures,

representing between 80% and 90% of the world's cultural diversity [1]. They are also called tribal, aboriginal, or autochthonous peoples; they are located in various ecosystems, particularly in the tropics [2]. In many cases, national minorities may meet one or more of the following criteria: (a) they are descendants of the original inhabitants of an ancestral territory; (b) they are peoples of the ecosystem, such as cultivators, shepherds, hunter-gatherers, fishers, permanent or itinerant artisans, etc.; (c) they practice a form of small-scale rural production; (d) they organize their lives at a community level; (d) they share common traditional clothing, moral values, and identifying characteristics; (e) they have a custodial and non-materialistic attitude based on a symbolic exchange with nature; (f) some are subjugated by a dominant culture, society, and economy, and others remain isolated from market economies, preserving their culture and social dynamics; and (g) they consist of individuals who subjectively consider themselves to be indigenous [3].

The Western Amazon includes parts of Bolivia, Colombia, Ecuador, Peru, and western Brazil. It is one of the most biodiverse areas on the planet for many taxa, which include plants, insects, amphibians, birds, and mammals [4–9]. The region maintains large areas of intact tropical humid forest and has a high probability of stable climatic conditions in the face of global warming [10]. The Western Amazon is also home to many indigenous ethnic groups, including some of the world's last peoples living in voluntary isolation [11–13]. Ecuador has a cultural heritage with an estimated one million people self-identifying as indigenous [14]. In the Ecuadorian Amazon Region (EAR), there are currently 11 officially identified nationalities, one of which is the Amazonian Kichwa, the most populous ethnic group in this region. The EAR has been inhabited since before the Hispanic conquest by the Kichwa and other indigenous peoples [15,16]. Since the second half of the 19th century, these populations have increased due to rubber plantations [17]. However, their large-scale environmental transformation began in the 1970s with the intensification of oil exploitation, highway expansion, and colonization [18], which led to the division of ancestral lands and the displacement and disintegration of indigenous nationalities [19]. Later, the construction of roads, initially to facilitate oil activities, brought the small-scale agricultural colonization of migrant settlers, who were also pushed by government land tenure policies [20]. These processes transformed the cultural, social, and, to some extent, the agricultural context of the Kichwa populations given their territorial displacement as well as their contact with societies based on the market economy [21]. With this intervention by external agents in the territory, new strategies for living were created such as: participation in salaried jobs, the purchase of manufactured products, the use of government services, and participation in political activism. In the agricultural context, access to markets provoked new agricultural practices [22–24], such as the expansion of monocultures like cacao (*Theobroma bicolor* L.) and especially for the sale of small-scale agricultural and livestock products [25]. This caused the rapid expansion of the agricultural frontier and consequent deforestation [26], diminishing the quantity and quality of ecosystem services [27], which have been used ancestrally as a means of livelihood.

The Amazonian Kichwa populations have also been characterized by their agricultural systems, having practiced the traditional system called *chakra* for thousands of years. This system was initially oriented toward subsistence, integrated with the cultivation of basic foodstuffs, such as manioc (*Manihot esculenta* Crantz), plantain banana (*Musa paradisiaca* L.), peach palm (*Bactris gasipaes* Kunth) etc., as well as medicinal plants [28,29]. It is characterized by its high level of diversity [30] and its ability to provide security and sovereignty in terms of food and health [31–33]. The *chakra* plots in the Northern Ecuadorian Amazon range from 0.05 to 3.0 ha [30,34,35], have high levels of ecological and social integration [36–38], and can mitigate both the impact of population growth in the Amazon [29] and the effects of climate change [39].

The need is urgent for greater agricultural sustainability [40]; comprehensive responses are required to understand the complex dynamics between social, economic, and ecological sustainability [41,42]. In 2015, the United Nations plenary approved the 2030 agenda, converging the development, environment, and climate agendas. The agenda includes 17 sustainable development goals (SDGs) that must be met by 2030, unlike the previous sectorial and regional goals, such as the Millennium

Development Goals for the period 2000–2015, which only directly affected developing countries. This new agenda is for everyone and for a global world. This means that in the coming years, all political actions and business strategies, and especially private ones, must be aligned with the achievement of those objectives. In the field of agriculture, agricultural and environmental policies will be aligned with the agenda, especially in the field of sustainability. The specific related goals include SDG 15: Life of terrestrial ecosystems, in which the Amazon biome is a main exponent; the scope of SDG 1: End poverty in all its forms; and SDG 2: Zero hunger should be allowed, in coexistence with local populations [43]. Assessing agricultural sustainability is one of these responses. Although capturing the systemic complexity of sustainability through assessment is difficult, it is warranted by the attention of policy makers beyond crop productivity to include dimensions of human well-being and ecological soundness [44,45]. Sustainability is a multidimensional concept [46] of a dignified life for the present without compromising a dignified life for future generations or threatening the natural environment and endangering the global ecosystem [47]; its evaluation is an important process in promoting the concept of sustainable agricultural systems [48,49].

To understand the transition toward more sustainable production, a variety of tools have been developed to obtain information on the sustainability performance of production [50,51]. Indicator-based sustainability assessment tools require the management of a wide variety of information types, parameters, and uncertainties [52], and vary in scope (geographic and sectorial), target group (farmers or policy makers), selection of indicators, aggregation, weighting methods, and time required for their execution [50,51,53]. Although many emphasize the importance of integrating social, economic, and environmental issues into sustainability assessment tools, environmental issues and tools generally receive more attention [50,51,54–56]. The results of sustainability assessment tools should be seen as a starting point for discussion, reflection, and learning [57].

Several tools are available for the evaluation of sustainability based on indicators: farm sustainability indicators (IDEA) [58], sustainability assessment of food and agriculture systems (SAFA) [59], response-inducing sustainability evaluation (RISE) [60], and others [61,62]. The IDEA tool was developed in France in 1998. Its analysis is at the farm level and it represents an approach based on principles; methodological indicators can be added [58]. SAFA is an open process methodology. According to the guidelines of the Food and Agriculture Organization of the United Nations (FAO), it is used as a self-assessment tool for food producers and manufacturers [59]. The justifications for the selection of indicators have been documented, and the integration problems between scales have been considered. It is not possible to add indicators, and the validation of the indicators is based on comparison and expert evaluation [63]. RISE is an easy-to-use tool that covers all dimensions of sustainability [57] and uses principles-based approaches; RISE presents both numerical and graphical results [51]. RISE is the best compared to other tools for sustainability assessment in terms of scientific robustness, feasibility, utility, influence, spatial applicability, and adaptability [52]. RISE has been used in various countries such as Poland, Spain, Kenya, and Canada, and in different evaluation scenarios (Table 1).

Table 1. Evaluation of sustainability using the response-inducing sustainability evaluation (RISE) methodology.

Evaluation Scenario	Country	Indigenous Peoples and/or Small Producers	References
Family farming	Sweden	No	[64]
Organic and conventional farms	Poland	No	[65]
Indigenous agriculture	Ecuador	Yes	[66]
Organic farms	Denmark	No	[67]
Agricultural and livestock production	Ethiopia	Yes	[68]
Tea plantation	India	Yes	[69]
Agricultural production	Spain	No	[70]
Coffee cultivation	Brazil	Yes	[71]

Sustainability assessment tools can provide support for decision making in production systems and may, therefore, significantly impact their sustainable development [53,72]. The availability and quality of data, time and budget requirements, as well as factors related to unknown terminology and ease of use of use and accessibility of the tool, influence the perception of small producers about the relevance of the tool and, consequently, whether they decide to use it [53,73,74].

In this study, our aim was to assess the sustainability of small farms using the traditional agroforestry system (chakra) in the Ecuadorian Amazon, with the objective of understanding traditional knowledge about the farming system and to explore and discuss possible improvements.

2. Materials and Methods

2.1. Geographical Location

We focused on the Kichwa populations settled along the Napo River, in the north of the Yasuní Biosphere Reserve (YBR). This indigenous group is the result of inter-ethnic relations with ancestral populations in the area: Quijos, Záparos, Omaguas, Tucanos, Shuar, Achuar, Siona, Secoya, and Highland Kichwas and Peruvian Quechuas [36]. The Kichwa of this region are the most numerous indigenous populations in the EAR (60,000 inhabitants) [37,38]. Those residing in the Yasuní National Park (YNP) present a type of grouping based on associations that cohabit communal territories, associations, and federations [39]. They speak *Runa Shimi*, a dialect based on Kichwa and Spanish. Their identities are complex and overlap with other indigenous and white settler groups.

The study was conducted in two sectors, A and B, located in the YBR, which is considered one of the areas with the greatest biological and cultural biodiversity on the planet [75–78], including the YNP, Waorani Ancestral Territory (WAT), Tagaeri Taromenane Intangible Zone (TTIZ), and the Fringe of Diversity and Life (FDL), located in the EAR. Ecuador is 1 of 17 megadiverse countries [79,80] (Figure 1). The YBR was announced by UNESCO in 1989; it is located in the provinces of Orellana (51.96%), Pastaza (39.40%), and Napo (8.64%), between the Napo and Curaray Rivers [81]. The predominant ecosystem is lowland evergreen forest in the Napo–Curaray (BsTa02) [82], the temperature ranges from 24 to 27 °C, rainfall is 3200 mm/year, relative humidity ranges from 80% to 94%, and the soils are relatively young and are generated by fluvial sediments from the erosion of the Andes [83].

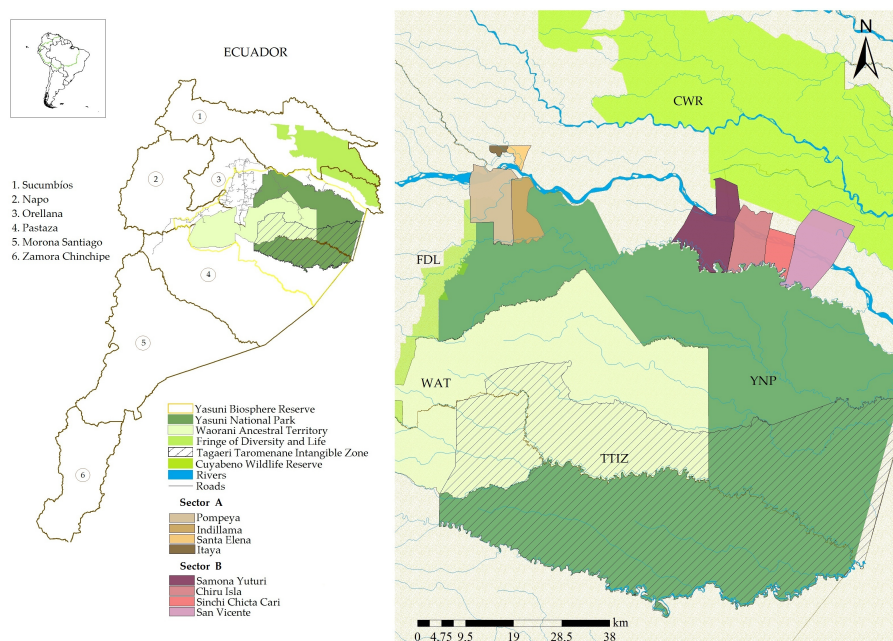


Figure 1. Sectors A and B located in the north of the Yasuní Biosphere Reserve (YBR) in the Ecuadorian Amazon region.

2.2. Sampling and Data Collection

In the sectors identified, sampling was performed using the reference chain or snowball methodology [84], given the difficulty of constructing a sampling frame due to the scarcity of demographic information in the intervention zone and the complex logistics for traveling to and mobilization through the communities. This method begins with one interviewee, who gives the researcher the name of at least one other potential interviewee. This interviewee, in turn, provides the name of at least one other potential interviewee, etc., with the sample growing like a rolling snowball if more than one reference is provided per interviewee [85,86]. In the initial phase of the survey, participants expressed their concern that local and international institutions would cut social and agricultural programs due to participation in the study. In this situation, a signed informed consent form was not used, but with the support of the German Agency for Development Cooperation (GIZ-Ecuador), all approaches were made to producers and the principles of ethical research were explicitly applied [87], discussing the objectives, risks, methodology, and schedule of the study with members of each community. One of the pillars of our positive relationship with the participants was the presentation of the results of the questionnaire. The restitution of results is an ethical duty that is often overlooked when conducting research on human beings, especially when indigenous communities participate [88,89].

2.3. Characterization and Sociodemographic Indices

Surveys were conducted with 133 Kichwa households with chakras. They were distributed by sector. In sector A (61), the surveys occurred in the communities of Pompeya (35), Indillama (10), Santa Elena (4), and Itaya (12). In sector B (72), they were conducted in the communities of Samona Yuturi (14), Chiru Isla (31), Sinchi Chicta Cari (15), and San Vicente (12). The average area of the chakras was 0.5 ha in 60 ha of titled land per household.

We studied the Kichwa population structure and its distribution by sex and age from a population pyramid (statistical representation) [90] to examine its implications with traditional production systems [91]. We calculated the following indices: (1) proportion of young population (<14 years) ($P_{young\ people}$); (2) proportion of adult population (between 15 and 64 years, P_{adults}); (3) ratio of children to women, defined as the number of children under 5 years of age for each woman of reproductive age (R); (4) the ratio of men, consisting of the ratio of men for every 100 women in a given population, considered as the first indicator for analyzing the distribution by sex in the population ($R.M.$); (5) youth dependency ratio, which is the relationship between the potentially dependent age population (<15 years) and the potentially active age population (between 15 and 64 years, I_{dj}^t); (6) the structure index of the active age population, which is the relationship between the population from 40 to 64 years and the population from 15 to 39 years (I_r); and (7) the rate of change of the active age population (I_r^t), which is the relationship between the population from 60 to 64 years and the population from 15 to 19 years [90–94], as follows:

$$P_{young\ people} = \frac{P_{0-14}}{P} \times 100 \quad (1)$$

$$P_{adults} = \frac{P_{15-64}}{P} \times 100 \quad (2)$$

$$R = \frac{P_{0-4}}{P_{M. 15-49}} \text{ children per woman} \quad (3)$$

$$R.M. = \frac{P_{men}}{P} \times 100 \quad (4)$$

$$I_{dj}^t = \frac{P_{<15}^t}{P_{15-64}^t} \times 100 \quad (5)$$

$$I_r = \frac{P_{15-64}^t}{P_{15-39}^t} \times 100 \quad (6)$$

$$I_r^t = \frac{P_{60-64}^t}{P_{15-19}^t} \times 100 \quad (7)$$

2.4. Assessment of Agricultural Sustainability

The RISE methodology was applied to holistically evaluate the sustainability of the traditional agroforestry system (chakra). The dimensions considered were economic, social, and ecological [95–99], which allowed us to analyze and compare the degree of sustainability between the chakras. This methodological tool is characterized by the balance between the simplicity of the analysis, the complexity of reality and the transparency of the results [60,97]. RISE seeks to create a tangible evaluation based on science that allows for the beginning of the creation of measures to improve sustainability [98,99] and to initiate a constructive dialogue between producers and processors to spread the philosophy of sustainable production [96–98]. The methodological process began with an interview of the owner of a chakra. The RISE questionnaire was designed with three types of questions: open, drop-down list, and Boolean. The structural index of the questionnaire was divided into three stages: (A) preparation of the field visit to the chakras, containing general questions; (B) questions for the field visit, containing questions with qualitative and quantitative data that were collected during the RISE interview; and (C) comments, a space where notes can be transcribed about the questions or observations during the visit to the chakra. The duration of the questionnaire was 95 min [98].

For the systematization and analysis of the data of the conglomerate of the communities and the holistic evaluation, we used RISE 3.0 Software [99], developed by the Swiss College of Agriculture (SHL), based on the 10 standard indicators according to 50 parameters (Table 2), valued from 0 (worst case) to 100 (best case). As a result, a sustainability polygon was issued, defined by the following areas: (1) good yield, green coloration (66.66–100); (2) average yield, yellow coloration (33.34–66.65); and (3) bad yield, red coloration (0–33.33). The qualification values in the RISE method are fixed and cannot be changed. The red line superimposed on the polygon indicates the degree of sustainability per indicator, which is based on the arithmetic average of four to seven parameters that have the same weight [98].

Table 2. Indicators and parameters used in this study based on response-inducing sustainability evaluation (RISE) 3.0 methodology.

Indicators	Subtopics
1. Land use	1.1. Land management 1.2 Crop productivity 1.3 Soil organic matter 1.4 Soil reaction 1.5 Soil contamination 1.6 Soil erosion 1.7 Soil compaction
2. Livestock production	2.1 Cattle management 2.2 Cattle productivity 2.3 Behavioral opportunity according to species 2.4 Quality of animal housing 2.5 Animal health
3. Use of materials and environmental protection	3.1 Nitrogen balance 3.2 Phosphorous balance 3.3 Self-sufficiency of nitrogen and phosphorus 3.4 Ammonia emissions (risk) 3.5 Waste management
4. Water use	4.1 Water management 4.2 Water supply 4.3 Intensity of water use 4.4 Risks to water quality
5. Energy and climate	5.1 Energy management 5.2 Intensity of energy used in agricultural production 5.3 Balance of greenhouse gases
6. Biodiversity	6.1 Management of crop protection 6.2 Areas of ecological priority 6.3 Intensity of agricultural production 6.4 Quality of landscape 6.5 Diversity of agricultural production

Table 2. Cont.

Indicators	Subtopics	
7. Working conditions	7.1 Staff management 7.2 Working hours	7.3 Health and safety 7.4 Salary and income levels
8. Quality of life	8.1 Occupation and education 8.2 Financial situation 8.3 Social relations	8.4 Personal freedom and values 8.5 Health
9. Economic viability	9.1 Liquidity reserve 9.2 Level of debt 9.3 Economic vulnerability 9.4 Secureness of household livelihoods	9.5 Cash flow, sales volume ratio 9.7 Exhaustion of the capacity to serve the capital of others (payment of interest and amortization)
10. Administration	10.1 Strategies and planning 10.2 Guarantee of supply and performance	10.3 Tools for planning and documenting 10.4 Administration of quality 10.5 Cooperation with others

2.5. The State and Driving Force for Calculating the Degree of Sustainability

Each indicator contains parameters that describe the state of the system (S) and the driving force (D) within the system, leading it in a certain direction of development. S indicates the current condition of each specific indicator, and D is a measure of estimated pressure exerted by the agricultural system on the specific indicator [60]. The state parameters have a value between 0 (worst case) and 100 (best case). The driving force parameters are also calculated using a range of 0 to 100, but since they are valued as a negative pressure in the system, 0 represents the best case and 100 the worst case (the highest pressure).

The degree of sustainability (DS) is calculated as the difference between the state (S) and the driving force (D); $DS = S - D$ (Figure 2). Considering the S and D parameters not only allows for the creation of a static picture of the current situation; it reveals the development trends of the system. Therefore, the RISE evaluation provided an analytical snapshot of the chakra situation while describing some aspects of the dynamics that change the system over time. The assessment of the driving force allowed us to understand and highlight the trends and threats that can be decisive for the concept of operational sustainability.

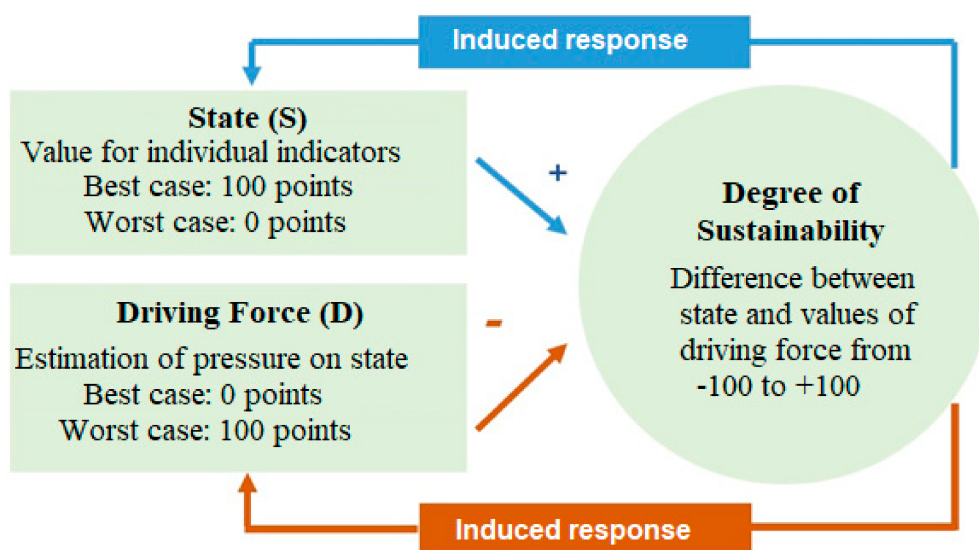


Figure 2. Methodology for calculating the degree of sustainability according to the RISE methodology.

2.6. Hierarchical Cluster Analysis

The statistical analysis was conducted using the multivariate classification hierarchical cluster technique. This is a mathematical method that is included in multivariate statistics. Multivariate analysis is the branch of statistical analysis that studies, analyzes, represents, and interprets the data resulting from the observation of $p > 1$ statistical variables on a sample of n individuals. It focuses on the simultaneous investigation of two or more characteristics (variables), measured on a set of individuals [100]. Hierarchical cluster analysis is mainly used for the formation of groups starting with the basic unit of the objective (BUO), according to the similar characteristics from the similarities or dissimilarities that are presented between pairs of these BUOs in the evaluated characteristics [101]. The hierarchical methodology deals with the grouping of clusters to form a new group, starting with groups as existing individuals in the study and grouping them to form all the cases in the same group [102].

All the sustainability variables defined by the RISE evaluation framework were used, applying the Euclidean squared distance as a similarity criterion, which is a measurement that is affected by the differences in metrics between the variables [100]. It is a measurement of dissimilarity: its minimum value is 0, but it has no maximum value [101]. We also employed the Ward grouping method for hierarchically forming the groups and agglomerates by minimizing the intra-group variation. It tends to generate small but very balanced conglomerates [103] and, at each step of the agglomeration process, uses the distance between classes that meets the objective of joining [104,105].

The data were organized in an Excel spreadsheet (version 19.0, Microsoft, Redmond, United States), using the SPSS version 22 statistical software (IBM, Armonk, United States) [106] to evidence the history of clusters, where the groups to be formed were selected according to the dissimilarity index. The resulting dendrograms are presented for analysis of the sectors in an individual and united way according to the owner of the chakra and analysis of variance (ANOVA) was used to identify the existence of significant differences (0.05) between groups of means.

3. Results

3.1. Sociodemographic and Agricultural Characterization

The Kichwa population in the study area was 48.5% men and 51.5% women (726 total). The average age for men was 27 years and the average for women was 29. The proportion of young men was 17.7% and women, 22.8%; adult men comprised 30.7% and women, 28.6% (Figure 3). The ratio of children to women was 0.45%, while the ratio of men was 48%. The youth dependency index was 68%, the structural index of the working age population was 40%, and the rate of change of the working age population was 4%.

The following pattern was found in the evaluated sites: in sector A, the household composition varied between four and six people. In this sector, the Pompeya and Itaya communities reported at least one household with 10 individuals. In sector B, the household composition ranged from four to seven (Table 3) and the Sinchi Chicta Cari community reported a household with 11 individuals. The average household size in the communities studied was five individuals.

The average age of the heads of household was 42 years. The youngest head of the household (25 years) lived in the Sinchi Chicta Cari community. The youngest age range was between 25 and 34 years. In the communities of Pompeya, Chiru Isla, and San Vicente resides, the oldest head of the household was 60 years. The oldest age ranged from 44 to 60 years.

In the communities of Pompeya and Chiru Isla 8.57% and 3.23%, respectively, completed the third level of education. In Itaya and San Vicente, 8.33% of the heads of household entered the third level of education but had not finished it. In sectors A and B, 19 (31.31%) and 28 (38.24%) heads of household had completed secondary education, respectively; in sectors A and B, 43 and 32 heads of household had completed basic education, respectively.

With regards to land tenure, of the 133 heads of household surveyed, 88% (117 Kichwa indigenous) had deeds (legal land tenure) to their chakras. In the community of Santa Elena (sector A), all had deeds, whereas in the Chiru Isla community (sector B), 23% did not have legal documentation for their land. On average in sectors A and B, 4% and 8% of the chakra owners, respectively, did not have deeds to their lands.

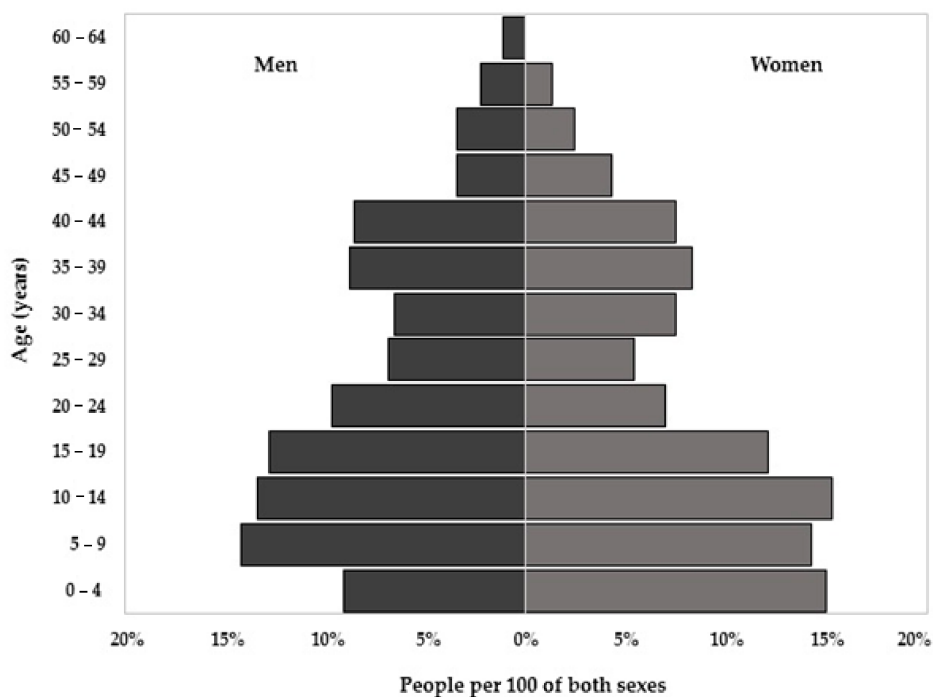


Figure 3. Population pyramid (progressive type) of Kichwas superimposed in the YBR in January 2018.

Table 3. Socio-demographic and agricultural characteristics of the Kichwa population by sector and communities in the north of the Yasuní Biosphere Reserve in the Ecuadorian Amazon region.

Variables	Sector A					Sector B			
	Pompeya	Indillama	Santa Elena	Itaya	Samona Yuturi	Chiru Isla	Sinchi Chicta Cari	San Vicente	
Household Size	Average (SD)	5 (2.18)	4 (2.37)	4 (2.16)	6 (2.20)	6 (2.16)	5 (2.17)	4 (2.91)	7 (2.47)
	Max	10	9	7	10	9	9	11	9
	Min	2	1	2	3	3	2	1	2
Age of head of the household (years)	Average (SD)	43 (10.80)	45 (11.67)	47 (10.24)	35 (4.98)	41 (11.69)	44 (9.34)	39 (8.04)	44 (11.83)
	Max	60	57	56	44	64	60	56	60
	Min	29	26	34	28	29	27	25	27
Education of head of the household (%)	Higher education	8.57	0.00	0.00	8.33	0.00	3.23	0.00	8.33
	High school	48.57	60.00	0.00	16.67	35.71	32.26	60.00	25.00
	To middle school	17.14	0.00	100.00	50.00	42.86	29.03	40.00	50.00
	None	25.71	40.00	0.00	25.00	21.43	35.48	0.00	16.67
Literate?	% (Yes)	83	90	100	92	93	77	87	83
Existing species in the chakras	Cacao (<i>Theobroma bicolor</i> L.), coffee (<i>Coffea</i> sp.), manioc (<i>Manihot esculenta</i>), plantain banana (<i>Musa paradisiaca</i>), corn (<i>Zea mays</i>), sugar cane (<i>Saccharum officinarum</i>), annatto (<i>Bixa orellana</i>) and pacay (<i>Inga</i> spp.)								
Animals	Poultry (laying hens, broilers, ducks)								

Sector, Community set; SD, Standard deviation; Max, Maximum; Min, Minimum.

3.2. Cluster Analysis and Sustainability Indicators

3.2.1. Values in Sector A

Using the indicators resulting from the evaluation of the sustainability of traditional agroforestry systems (chakra) in sector A using hierarchical cluster analysis, three groups were obtained in a dendrogram (Figure 4) with a Euclidean distance (measurement of association): in groups 1 and 2, we gathered 24 chakras; in group 3, there were 13 chakras.

In the three groups (Table 4), the indicators identified by level of importance (highest to lowest average scores) were: energy and climate (86.82), working conditions (77.89), water use (74.97), and land use (72.62). The quality of life indicator in groups 2 and 3 had a difference of 17.77. The indicators that scored medium performance were biodiversity and use of materials and environmental protection, with average values of 64.52 and 41.94, respectively. In groups 1 and 3, the indicator animal production had a difference of 3.56 and the quality of life in group 1 has a score of 64.25. The lowest performing indicators were: economic viability and administration, presenting averages of 29.19 and 23.66, respectively; and in group 2, the indicator animal production was 30.38.

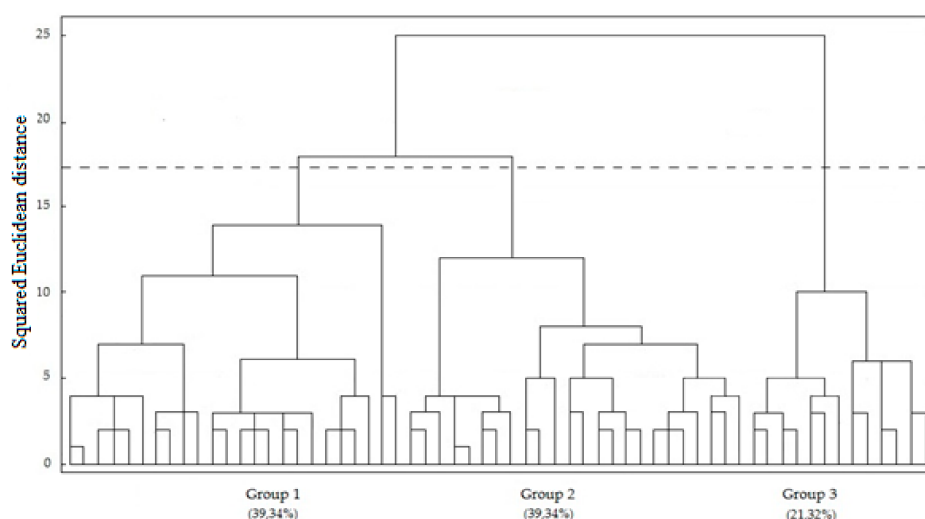


Figure 4. Dendrogram using a Ward linkage to establish three groups within the Kichwa communities in sector A (Pompeii, Indillama, Santa Elena, and Itaya) in the northern Yasuní Biosphere Reserve (YBR) of the Ecuadorian Amazon (percentage of *chakras* in each group).

Table 4. Means and standard deviation of sustainability indicators among clusters (groups) of the chakra systems in sector A in the north of the Yasuní Biosphere Reserve in the Ecuadorian Amazon region.

Indicators	Groups **						Overall Mean of Sector A
	Group 1 (24)		Group 2 (24)		Group 3 (13)		
	Mean	SD	Mean	SD	Mean	SD	
Land use	70.83	4.07	73.50	5.48	73.54	3.04	72.62
Animal production	38.25	4.41	30.38	10.38	34.69	7.27	34.44
Use of materials and environmental protection	36.54	7.60	46.58	7.15	42.69	9.68	41.94
Water use	75.08	3.83	74.67	4.24	75.15	4.22	74.97
Energy and climate	87.00	0.00	86.46	2.65	87.00	0.00	86.82
Biodiversity	65.54	5.45	64.71	4.27	63.31	4.44	64.52
Working conditions	76.83	4.95	80.46	2.06	76.38	5.41	77.89
Quality of life	64.25	6.35	69.08	5.45	86.85	4.88	73.39
Economic viability	29.79	6.95	28.71	3.70	29.08	6.74	29.19
Administration of the chakra	24.33	2.76	22.79	2.48	23.85	2.88	23.66
Global indicator of sustainability	56.84		57.73		59.25		57.94

** There were no significant statistical differences between the evaluated groups.

The overall sustainability indicator in the three groups was medium. The best score was obtained in group 3, whose differences between group 2 and group 1 were 1.52 and 2.41, respectively. Sustainability dynamics by group and color were blue for group 1, orange for group 2, and red for group 3 (Figure 5).

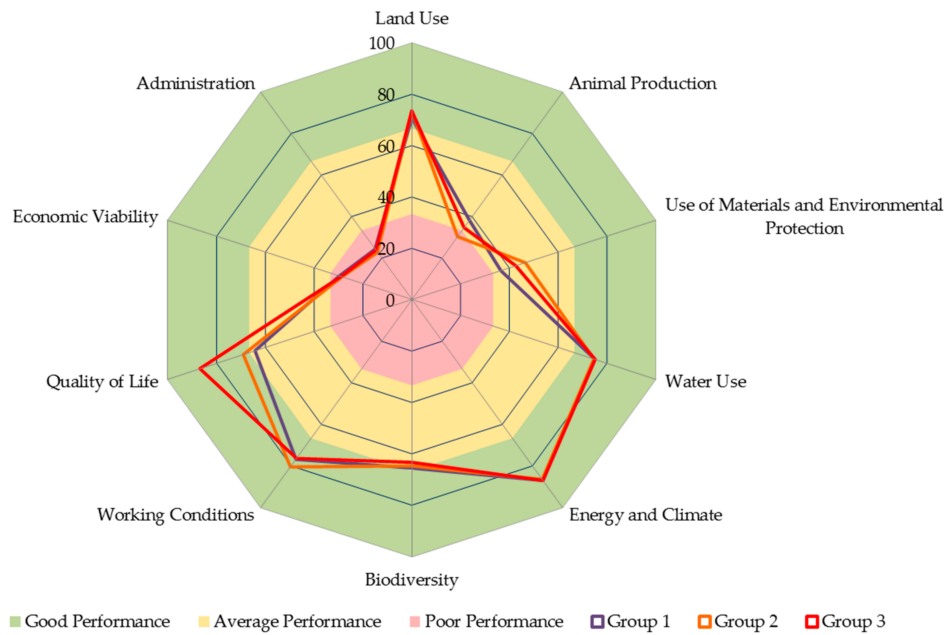


Figure 5. Degree of sustainability of the Kichwa indigenous communities for groups 1, 2, and 3 of sector A in the north of the Yasuni Biosphere Reserve in the Ecuadorian Amazon region.

3.2.2. Values in Sector B

Similarly, the results of the chakras in sector B were obtained and grouped into a dendrogram (Figure 6) with a Euclidean distance (measurement of association) of 14. Three groups were obtained: in group 1, there were 21 chakras; group 2 had 24; and group 3 had 27.

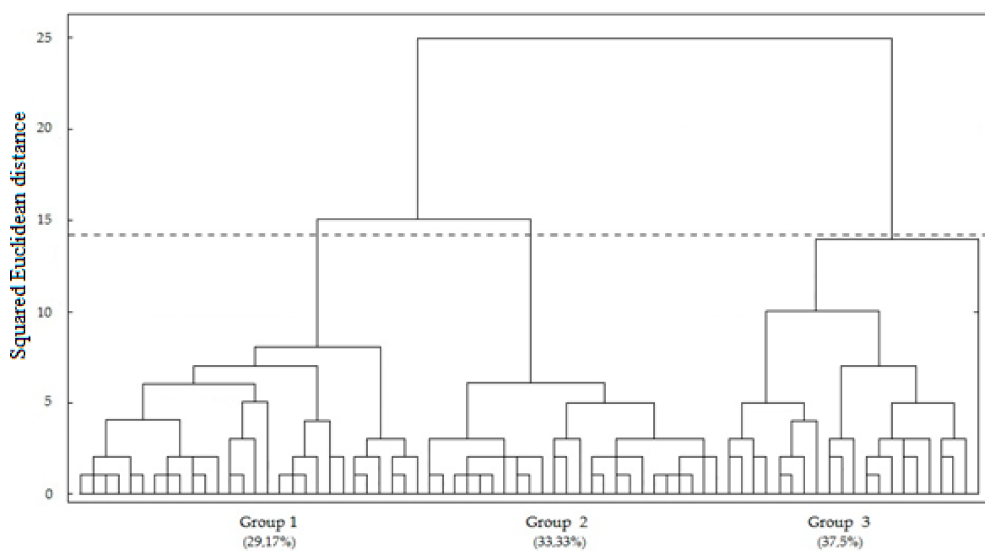


Figure 6. Dendrogram using Ward’s linkage: Communities in sector B (Samona Yuturi, Chiru Isla, Sinchi Chicta Cari, and San Vicente) in the north of the Yasuni Biosphere Reserve in the Ecuadorian Amazon region (percentage of *chakras* in each group).

The indicators with good performance (Table 5) from highest to lowest average scores in the three groups were: energy and climate (92.39), water use (80.18), working conditions (75.57), and land use

(67.23). The Biodiversity indicator in group 1 had 2.68 points more than in group 2; the quality of life indicator in group 3 had 12.52 and 7.9 points more than groups 1 and 2, respectively. The indicators with medium performance were: Animal production, which had an average of 37.90 in the three groups; use of materials and environmental protection in group 1 was 15.78 and 14.17 points higher than groups 2 and 3, respectively. In group 3, biodiversity had 4.53 and 1.85 fewer points than groups 1 and 2, respectively. The quality of life indicator in group 2 was 4.62 points higher than group 1, and in management, group 3 had the best score with a difference of 8.48 and 6.12 from groups 1 and 2, respectively. The lowest performing indicators were: economic viability in all three groups, having an average of 29.81. Group 1 had the best score with 5.05 and 2.82 more points than groups 2 and 3, respectively. Materials use and environmental protection was 1.61 points higher in group 3 than in group 2, and management was higher in group 2 than group 1 by 2.36 points.

Table 5. Means and SDs of sustainability indicators among clusters (groups) of the chakra systems in sector B in the north of the Yasuní Biosphere Reserve in the Ecuadorian Amazon region.

Indicators	Groups **						Overall Mean of Sector B
	Group 1 (21)		Group 2 (24)		Group 3 (27)		
	Mean	SD	Mean	SD	Mean	SD	
Land use	67.38	3.22	67.13	2.11	67.18	4.99	67.23
Animal production	41.00	9.23	38.58	3.11	34.11	5.93	37.90
Use of materials and environmental protection	43.24	10.47	27.46	3.15	29.07	5.74	33.26
Water use	80.29	3.89	80.83	2.55	79.43	2.6	80.18
Energy and climate	92.14	2.15	92.04	3.00	93.00	0.00	92.39
Biodiversity	70.10	5.58	67.42	3.48	65.57	3.49	67.70
Working conditions	74.95	3.07	72.58	5.04	79.18	2.68	75.57
Quality of life	61.05	14.68	65.67	3.42	73.57	6.47	66.76
Economic viability	32.43	8.58	27.38	3.55	29.61	3.65	29.81
Administration of the chakra	27.52	7.39	29.88	5.07	36.00	5.93	31.13
Global indicator of sustainability	59.01		56.90		58.67		58.19

** There were no significant statistical differences between the evaluated groups.

The overall sustainability indicator in all three groups was medium, with the best score being in group 1, which was 2.11 and 0.34 higher than in groups 2 and 3, respectively. The dynamics of the degree of sustainability by groups and color were blue for group 1, orange for group 2, and red for group 3 (Figure 7).

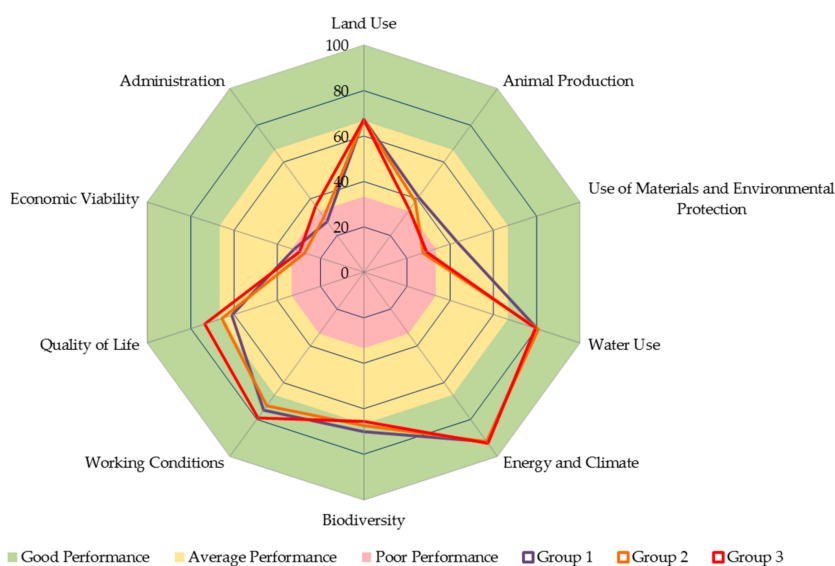


Figure 7. Degree of sustainability of the Kichwa indigenous communities for groups 1, 2, and 3 of sector B in the north of the Yasuní Biosphere Reserve in the Ecuadorian Amazon region.

4. Discussion

The two aspects that were studied in this research: (1) the population and agricultural dynamics of the Kichwa population, and (2) the indicators of the evaluation of sustainability in the chakras. The maximum size per Kichwa household was 11 people, and of the heads of households, approximately 21% had no educational. In terms of sustainability, the chakras did not present significant differences, although only 5 of the 10 analyzed indicators showed good performance, and the economic viability and administration indicators were performing poorly.

4.1. Socio-Demographic and Agricultural Characterization of the Indigenous Kichwa Population

Currently, defining who counts as a resident of the communities is difficult because many young people often come into and out of the study area, mainly for education and marriage, which is a typical dynamic of indigenous people in the north of the Ecuadorian Amazon [107]. Therefore, we describe the socio-demographic characteristics of the population interviewed in 2018.

Figure 3 shows that there was little difference (3.03%) in the population proportion of Kichwa men and women (48.48 and 51.51%, respectively). The proportions of youth and adults were 40.63% and 59.37%, respectively. The ratio of Kichwa children to women (0.45%) was much lower than that of Waorani (0.91%) and Shuar (0.98%) indigenous women [108]. The youth dependency population was 28% higher than the working age population, which corroborates the high birth rates in indigenous populations [109]. In the 40–64-year age range (birth year from 1978 to 1958), only 17.1% of the indigenous Kichwa population is of working age; this value may be influenced by migratory processes [107].

The maximum number of people per household (Table 3) ranged between 7 and 11 members including two parents, which is probably related to higher fertility rates [80] driven by the lack of access to family planning and reproductive health services among indigenous peoples in the Amazon [110–112]. Although it has been debated whether the high fertility among indigenous populations is linked to pronatalism and the desire to repopulate indigenous lands [113–115], the rapid changes in the northern Amazon region have had profound impacts on the demographic dynamics of local indigenous people, including changing patterns of settlement and livelihood strategies, and increasing interactions with markets [116–122].

The heads of household did not complete higher education, despite starting their higher studies; 35.34% (sector A) and 56.39% (sector B) of the heads of household had completed secondary and basic education, respectively. In the Northern Amazon region of Ecuador, the most educated households are likely to have higher non-agricultural incomes than the least educated households in mostly migrant settler populations [120,121]. Participation in non-agricultural employment may be driven by *push factors* such as declining soil fertility, low yields, small production areas, and isolation from markets, which negatively affect farm income [122,123].

4.2. Evaluation of Sustainability Based on the RISE Methodology

According to the ANOVA using the results of the RISE, we found no significant differences between groups and sectors evaluated in the northeast of the YBR. The RISE tool, compared with other frameworks for the evaluation of sustainability, produced the best results in some categories such as scientific soundness, usefulness, adaptability, etc. [52], but it lacks a cultural approach based on the location, which can be detrimental to the communities under evaluation [123,124]. Biocultural approaches are those that start explicitly with and are based on cultural perspectives on the basis of the place and the embodied values, knowledge and needs, and recognize the feedback between the ecological state and human well-being [125,126]. These approaches, in combination with the guidelines of the different sustainability assessment tools, can be used to develop indicators to more accurately depict reality [127]. The exchange between in situ and ex situ actors facilitates the identification

of crucial problems and solutions that are currently lacking in many regional and international sustainability tools [126,128,129].

The indigenous populations in this zone are associated with sustainable agricultural practices [130] that have little environmental impact and are compatible with resource conservation [47,131]. This is corroborated by the excellent scores for land use and water use within the Kichwa chakra dynamics, similar to the Shumahuani people (Peruvian Amazon), who keep most of their land in the forest and use sustainable management practices in contrast to the migrant settlers who cut down the forest to establish pastures [132]. In the Ecuadorian Amazon Region, most soils are not suitable for agriculture [133,134] and the settlers tended to compensate for the low fertility by clearing more land for cultivation. As a consequence, deforestation rates in the Ecuadorian Amazon Region are considered one of the highest in the world [135].

Chakras are complex systems that adapt to and resist the effects of climate change and development [104,105], have high structural complexity [136,137], and present high levels of carbon sequestration [28] and tree diversity [30] compared with other forms of land use. Chakras also allow for the sustainable use of forests by combining the cultivation of fine and aromatic Ecuadorian cocoa, controlled wood extraction, production of basic food items, and the conservation of medicinal plants. In Amazonian communities, chakras contribute to food security as well as to the well-being and conservation of the region's high biodiversity [28]. The adequate management of the chakras increases their potential to recover part of the carbon released into the atmosphere due to deforestation [138]. This is contrary to the circumstances in the evaluated chakras, since the indicator for use of materials and environmental protection had critical and average scores, influenced by the poor management of the chakra: (1) nitrogen and phosphorus balance, (2) ammonia emissions, and (3) waste management [63,100,101], as the sustainability objective of the indicator is the use of natural cycles [97]. Inadequate waste management can endanger human, animal, and environmental health. Inherited pollution from oil activity can also harm future generations and, therefore, violates the principle of sustainability [139], which is influenced by the non-agricultural income received from providing unskilled labor services to oil companies, as well as external assistance from the government and international non-governmental organizations (NGOs). All this results in the chakras not being adequately cared for [140].

The Kichwa people obtain their livelihood mainly from subsistence agriculture, collection of forestry products, hunting, and fishing [141,142], all of which are related to the diversity of species in the chakras, but it had a critical score within the biodiversity indicator [56,57]. Scientific evidence shows that some Kichwa have adopted migrant-settler-style agricultural systems and engage in commercial agriculture, such as cattle ranching, logging, and off-farm wage employment in areas near roads and urban centers [23–25,143,144]. The integration of Kichwas into the market economy has received attention in the literature because of its implications for both human well-being and ecological viability. Animal production has often been driven by oil companies and embodied in livestock breeding projects [145], which justifies the low values in the animal production indicator, since it is not part of the socio-productive dynamics of the Kichwa people.

In terms of quality of life, the studied Kichwa population received outstanding and medium scores; the best scores were expressed in the parameters of social relations and personal freedom and values; the worst score was in the parameter of health [95–97]. Notably, the studied Kichwa population lives in an area overlapped by oil blocks, and in the period from 2001 to 2011, 464 accidental oil spills were registered [146], resulting in a high level of environmental contamination [147]. In 2018, the presence of 1-hydroxypyrene (1-OHP) and creatinine (chemical products from oil activities) was confirmed in the urine of Kichwa indigenous people (inhabitants of the banks of the Napo River) due to the consumption of contaminated food. In addition, the toxicity of drinking water has been revealed, which has caused health problems ranging from dizziness to cancer [148–150]. Within the excellent scores of the working conditions indicator in the chakras, an average score was received for the staff management parameter. An important variable of this parameter is child and adolescent work in the

RISE methodology, as established by the Universal Declaration of Human Rights [151], understanding that the RISE guidelines do not consider underage work. This stands in opposition to the Kichwa cultural dynamics in the management of the chakras since, from a social perspective, it is the result of a set of values, deeply ingrained in the Kichwa cosmovision [51], where ancestral knowledge is transmitted from generation to generation through harmonious relationships, based on solidarity and reciprocity [152]. The contributions of indigenous and local knowledge (ILK) to research is increasingly considered in the science of sustainability [153,154]. ILK is defined as a cumulative body of knowledge, practices, and beliefs that have evolved through processes of adaptation and are transmitted from generation to generation by cultural transmission, through the relationship of living beings (including humans) with each other and with their environment [155–157]. The precarious economic viability and management of the chakras, which have both been obtained, make it more likely that timber will be sold illegally and that income will be earned outside the farm [158]. Given the dynamic evidence for each group in each sector, there is a need to integrate and promote new economic models and reconfigurations of the territory, which may involve changes in governance systems that generate an integration of essential indigenous rules that positively influence chakra management [159].

The sustainability assessments in the Kichwa *chakras* showed certain problems related to the dimensions of the RISE methodology, which must be resolved to improve the level of sustainability. There are priorities (high, medium, and low) for the management of the territory that could be adopted by local political agents to support the Kichwa populations and to strengthen the studied indicators (Table 6).

Table 6. Recommendations to strengthen the indicators resulting from the evaluation of sustainability.

Indicators	Recommendation	Examples	Priority
Land use	<ol style="list-style-type: none"> 1. Increase species biodiversity in the chakras. 2. Incorporate species to increase nitrogen fixation and prevent soil erosion. 	[160,161]	Medium
Animal production	<ol style="list-style-type: none"> 1. Seek advice on the proper handling of poultry and animals. 	[162]	High
Use of materials and environmental protection	<ol style="list-style-type: none"> 1. Improve weed management. 2. Use more organic fertilizers to improve the balance of nutrients. 3. Use cover crops. 4. Use certified seeds. 	[163–165]	Medium
Water use	<ol style="list-style-type: none"> 1. Incorporate technologies to save water and make an inventory of good practices. 	[166]	Low
Energy and climate	<ol style="list-style-type: none"> 1. Strengthen the governance system of natural resources. 2. Incorporate solar panels for electrical use and a solar water heating. 3. Evaluate the perception of the changing climate at the rural, academic, and local public policy levels. 	[167–170]	Low
Biodiversity	<ol style="list-style-type: none"> 1. Disseminate knowledge about ecological infrastructure. 2. Tools for capacity building. 3. Promote the use of local varieties. 	[171–174]	Medium
Working conditions	<ol style="list-style-type: none"> 1. Training to maintain or improve working conditions. 	[175]	Low
Quality of life	<ol style="list-style-type: none"> 1. Improve education and training levels. 2. Promote talks and courses to improve health conditions in the family. 3. Promote sustainable behavior workshop based on scientific evidence. 	[176–178]	Medium

Table 6. Cont.

Indicators	Recommendation	Examples	Priority
Economic viability	<ol style="list-style-type: none"> 1. Develop revenues from projects for reducing emissions from deforestation and degradation (REDD+). 2. Generate opportunities to create marketing chains 3. Promote the diversification of economic income. 	[143,177,179]	High
Administration of the traditional agroforestry system (<i>Chakra</i>)	<ol style="list-style-type: none"> 1. Encourage the strengthening of field schools for potential of the traditional agroforestry system (<i>chakra</i>) administration. 2. Identify model <i>chakras</i> for training processes 3. Help Kichwa people access information 4. Strengthen capacities to increase strategic alliances among Kichwa people 5. Identify opportunities for proposing biodiversity conservation areas to generate another type of economic income, e.g., sustainable agro-ecotourism 6. Identify the change in land use, according to existing classes or categories 	[180–185]	High

5. Conclusions

The average degree of sustainability of the studied Kichwa *chakras* had a medium score for both sectors. In general terms, we argue that the Kichwa *chakras* located along the banks of the Napo River have certain weaknesses for the following indicators based on the RISE guidelines: use of materials and environmental protection, animal production, economic viability, and administration of the traditional *chakra* system. Given the very low values for the economic indicators and for administration in the traditional agroforestry system (*chakras*), losses are generated compared to the neocolonial models belonging to the migrant settlers and potential structural changes in the landscape agroforestry. However, we also identified strengths in the following indicators: energy and climate, water use, working conditions, biodiversity, land use, and quality of life.

The holistic evaluation of the *chakras*' sustainability using the RISE tool provides a system of early warning and can be used to help identify potential measures to improve the situation of the indigenous Kichwa people in the Yasuní Biosphere Reserve. In addition, the results provide a scientific basis for the people in charge of formulating public policies to improve strategies for the rescue and management of the *chakras*. Consequently, this would improve quality of life, strengthen food security and sovereignty, bolster self-employment, and increase the production of sustainable products among Kichwa populations in the Ecuadorian Amazon region.

Although the RISE methodology was not designed to be used as an instrument of certification, it could offer additional value for some process of certification, for example, organic certification of the *chakras*, conservation of the biodiversity of species in productive spaces, and so on.

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