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Integrating Assessment of Characterization, Sustainability and Efficiency for the Production of Rainbow Trout (*Oncorhynchus mykiss*): A Case Study in the Amazonas Region of Peru

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Abstract: In this research, aspects of sustainability and efficiency were evaluated to provide information to decision makers. First, 39 rainbow trout farms were characterized, sustainability indices were determined for 36 production units using Sarandon's methodology, and technical efficiency was evaluated using input-oriented Data Envelopment Analysis (DEA). The production units studied were grouped into three clusters, and the most determining variables were associated with total annual production. In addition, a medium-level general index was obtained with a total of 60 sub-indicators, divided into four social indicators (with 10 sub-indicators), four economic indicators (with 34 sub-indicators) and three environmental indicators (totaling 16 sub-indicators). Of 33 production units evaluated, 14 were identified as efficient; the Amazonas region's trout farmers were found to operate at 83.87% technical efficiency on average. All resources showed room for improvement and thus can be further adjusted. The most underutilized resources were land (area), feed and seed (fry), which could be reduced to increase technical efficiency. In conclusion, the trout farming units in northeastern Peru are differentiated into three groups by production volume and operate at a medium level of sustainability, with most at levels of technical inefficiency.

Keywords: characterization; sustainability; efficiency; rainbow trout

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1. Introduction

Ensuring food security in the world population is one of the major contemporary priorities and concerns. Despite the remarkable growth in food production, there remain about 900 million people without access to sufficient protein, carbohydrates and lipids in their diets [1]. In response, aquaculture makes an outstanding contribution to food security and the world economy [2,3]. It is the fastest growing sector in agriculture, with an annual growth rate close to 6%; according to the Food and Agriculture Organization (FAO), fish and fishery products are a fundamental source of protein worldwide, especially in low-income countries [4]. In fact, it has been the main source of fish for human consumption, providing 53% of fish, which is expected to increase in the long term as part of the solution to provide sufficient food and protein for the projected global population of more than nine billion people by 2050 [5].

Rainbow trout is an exotic species in Peru. It was introduced from the United States in 1925. The development of the culture during the last three decades involved a large number of egg and fish imports as well as adaptation of the sanitary conditions of Peruvian aquaculture facilities [6].

Designing, implementing and evaluating an aquaculture system involves, among other issues, water quality and quantity, fish growth performance and water saving [7]. Resource efficiency, involving the ratio of inputs to outputs, is essential for profitability and production impact [8]. The success of this industry is highly dependent on aquafeeds, and nutritional composition is an important factor for the quality, productivity and profitability of aquaculture species [2]. However, due to its high dependence on agricultural and fishery resources, its growth is constantly constrained by environmental impacts beyond aquacultural production systems [3]. In this scenario, capture fisheries have declined rapidly due to the reduction of available fish stocks, while aquaculture has increased in the last 20 to 30 years, representing a huge potential to alleviate pressure on natural populations [9].

The development of aquaculture depends largely on the implementation of technologies focused on achieving better production while increasing sustainability [10]. Accordingly, the aquaculture sector needs to invest in assessing water quality in real time, recording production data, and implementing platforms that facilitate communication among actors representing the technological, institutional social, and environmental aspects of the value chain [11,12]. Environmental sustainability indicators identified in the scientific literature for fish aquaculture operations include the amount of resources used (e.g., water, energy, space, feed, amount of raw marine ingredients), waste discharges (nitrogen, phosphorus, organic particulate matter, greenhouse gases, metals), chemical use (e.g., antibiotics, pesticides, hormones), disease incidence, escaped fish, genetic interactions, and impacts on biodiversity [13]. Economic sustainability indicators for aquaculture generally measure the employment characteristics of the industry (e.g., full- and part-time employment, wage levels, female participation, layoff rates) and the economic viability or financial performance of the sector (e.g., profitability, capital efficiency, revenue investment rate, internal rate of return) [14]. The social dimensions of sustainability are associated with issues of poverty, education, health, culture, governance, equity and social cohesion, with some dimensions (e.g., employment, education) being easier to measure than others (e.g., culture, social cohesion) [15].

The present research aims to evaluate the sustainability index and relative efficiency of rainbow trout (*Oncorhynchus mykiss*) production, a topic not yet explored in the Amazonas Region of Peru.

2. Materials and Methods

2.1. Place of Study

Of 60 trout production units in Amazonas registered in the Peruvian aquaculture cadastre (http://catastroacuicola.produce.gob.pe/web/ accessed on 20 November 2020), a total of 37 were evaluated, as these were in operation at the time of the study (see distribution of the production units in Figure 1).

2.2. Characterization of Trout Production Units

In the characterization of trout production, a diagnosis of the production units was carried out with the objective of recognizing the capability of the management system that will allow the assessment, evaluation and analysis of variables, causes, effects and trends of the Trout Production Units (TPUs) [16]. The information from the TPUs was collected from a survey related to socioeconomic aspects of the producer and environmental factors, which were used as the basis for the preparation of a questionnaire with indicators that were easily understood by the producers [17]. A total of 39 questions distributed in 3 dimensions were used. In the case of the social dimension, 12 questions were asked; for the economic dimension, 18 questions were asked; and finally, in the environmental dimension, 9 questions were coded for the respective processing and analysis. The TPUs were analyzed as production systems with social, economic and environmental variables that allowed the classification of production systems and the classification of homogeneous groups of trout producers in the Amazonas region. Multivariate analysis was also used to summarize and classify the data obtained from the surveys [18]. The information was tabulated in a spreadsheet (Excel). For the 39 variables evaluated, the coefficients of variation were calculated to discard those variables with low discriminatory power (<40%) and to take into consideration those variables that contribute to the multivariate analysis [19,20]. Similarly, 23 variables were used for the greatest discriminatory power for the principal component analysis, using the ggbiplot package. In addition, orthogonal rotation of the components (Varimax rotation) was used for a better interpretation of the variables. For the cluster analysis, Ward's method was used, which allowed obtaining homogeneous groups of systems with similar characteristics (typologies), with minimum intra-group variability and maximum inter-group variability, for a better understanding of the analysis of the complexity of trout production systems [21].

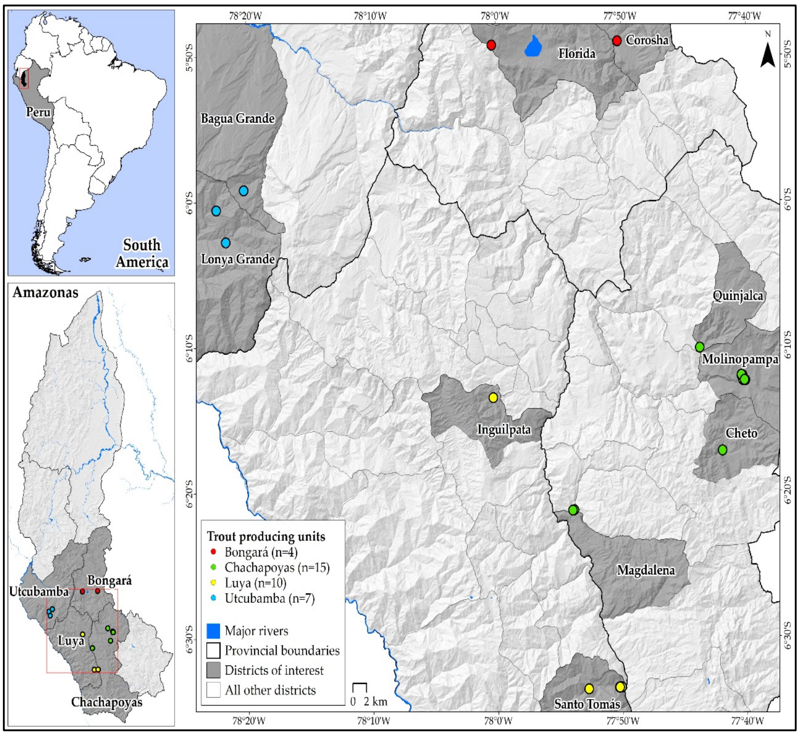

Figure 1. Location of the production units studied.

2.3. Evaluation of the Sustainability Index

For the evaluation of the sustainability index, field data was collected from 36 TPUs, since the remaining three could not be located at the time of data collection. The Principle-Criteria-Indicator (PCI) technique was used [22]. Likewise, the criteria for choosing the indicators were defined as SMART: Specific, Measurable, Achievable, Relevant and Time-bound [23]. To collect data, a survey was used, consisting of 60 questions, divided into three dimensions. The social dimension included the sub-dimension of human resources (3 questions), labor conditions and safety at work (2 questions), and corporate social responsibility and transparency (5 questions). The economic dimension included the following sub-dimensions: level of economic performance (5 questions), operations and production (16 questions), technology, research and development (5 questions), and marketing and sales (8 questions). Finally, the environmental dimension had the following sub-dimensions: carbon footprint level (7 questions), ecological footprint level (3 questions), and water quality (6 questions). Each sub-indicator was assigned a scale from 1 to 4, with 4 being the highest value and 1 the lowest sustainability value. The ranges of values were adapted as follows: 0–1 very low, 1.1–2 low, 2.1–3 medium and 3.1–4 high [24,25]. The sub-indicators were readjusted according to the results generated in the diagnosis of the trout producing units derived in the previous section.

In order to determine the level of association between sustainability dimensions, Pearson's correlation was applied [26].

2.4. Technical Efficiency Analysis

The efficiency index was calculated from the information collected in the field for all the production units (TPU) under study. Through previous runs, the number of TPUs was reduced to 33, eliminating oversized units and those that were not in production.

Data Envelopment Analysis (DEA) was used to determine the frontier TPUs, and the clearances and references for the efficient units were calculated. An input-oriented model (Table 1) was used, with constant scale returns Banker–Charnes–Cooper (BCC) [27,28] convex structure, radial distance and blocking of super efficiencies.

Table 1. DEA model used to calculate efficiency.

Inputs {I}			**Output {o}**
Description	**Abbreviation**	**Unit**	
Number of employees	Empl.	Person	Gross fish production per season
Quantity of fry seed used per season	Alev.	Millar	
Number of seasons per year	Camp.	Unit	
Area of the farm	Area	m^2	
Pre-start feed	Al_prei	kg	
Starter feed	Al_i	kg	
Growth feed	Al_c	kg	
Feed for fattening	Al_e	kg	
Finishing feed	Al_a	kg	
Amount of water used	Agua	m^3/s	

The Efficiency Measurement System V 1.3.0 downloaded from http://www.holger-scheel.de/ems/ (accessed on 05 April 2022) was used for the calculation.

3. Results

3.1. Characterization of Trout Production Units

The information collected from the socioeconomic aspects of the producer and environmental factors of the TPU survey was comprised of 39 variables. Using the CV < 40%, 23 variables were selected, with a variability coefficient range of 42.8%, I-25 (sales price per kilo of trout) and 155.9%, I-9 (participates or belongs to a productive association). In addition, these variables corresponded to the social aspect, 11 to the economic aspect and 6 to the environmental aspect (Table 2).

Table 2. Use of the CV for the selection of variables in the TPU, Amazonas region, Peru.

Item No.	**Variable**	**Mean**	**Standard Deviation**	**CV (%)**
	Social Aspect			
I-5	Basic service not provided	1.89	0.99	52.5
I-8	District/village/village/hamlet has public transportation	0.78	0.42	53.2
I-9	Participates or belongs to a productive association	0.30	0.46	155.9
I-10	Monthly income	3.76	2.02	53.8
I-11	Has access to credit for production	0.35	0.48	137.7
I-12	Receives training in trout farming	0.68	0.47	70.2

Table 2. *Cont.*

Item No.	Variable	Mean	Standard Deviation	CV (%)
	Economic aspect			
I-13	Trout harvests per year	2.24	1.16	51.9
I-14	Volume of production per harvest in tons	2.62	1.21	46.2
I-18	Activity other than trout farming	2.81	1.85	65.9
I-19	Owns title deed to fish farm	0.46	0.51	110.0
I-21	Average density per m^2 of trout in fattening stage	2.92	1.67	57.3
I-24	How trout is sold	2.11	1.49	70.5
I-25	Selling price per kilo of trout	1.89	0.81	42.8
I-27	To whom you sell your production	2.49	1.26	50.7
I-28	Where you sell your production	2.92	1.38	47.3
I-29	Number of people working in your production center	1.35	0.63	46.9
I-30	Years of experience in fish farming	2.65	1.16	43.8
	Environmental aspect			
I-32	Water flow	0.65	0.48	74.6
I-34	Final waste disposal	0.84	0.37	44.6
I-35	Has other type of authorization apart from DIREPRO	0.73	0.45	61.7
I-36	Antibiotics are used in production	0.35	0.48	137.7
I-37	Main problems at UPT	2.65	1.16	43.8
I-39	Adequate management of ordinary solid waste	0.54	0.51	93.5

The principal component analysis recorded nine principal components that explain 72.8% of the total variance (Table 3). The first three principal components explain 35.4% of the total variance in the data. CP1, CP2 and CP3 explain 13.8%, 11.3% and 10.4% of the data, respectively.

Table 3. Principal component analysis of the variables evaluated in the TPUs.

Principal Components	Component Variance	Proportion of Variance	Proportion of Cumulative Variance
CP1	1.334	13.76	13.76
CP2	1.269	11.28	25.04
CP3	1.242	10.35	35.40
CP4	1.159	7.84	43.24
CP5	1.138	7.30	50.54
CP6	1.112	6.65	57.19
CP7	1.096	6.27	63.45
CP8	1.036	5.01	68.47
CP9	0.999	4.33	72.80

The varimax rotation of the factors made it possible to generate three synthetic variables (Table 4), assigning these names: income generation of the TPU (I-10, I-11 and I-37), socio-environmental reality of the TPU (I-9, I-29, I-34 and I-35) and production of the TPU (I-21 and I-28). In the three-dimensional space of the principal components, the variables monthly economic income (I-10) and access to credit for production (I-11) are directly correlated with each other, while the variable main problems that occur in the TPU is inversely correlated with these variables (Figure 2). This would represent the synthetic variable income generation of the TPU (Table 4).

Table 4. Factor loadings of the rotated factors (Varimax) with the generation of new synthetic variables in the TPUs.

Item	Item Code	Component/Factor Loadings C1	C2	C3	Generation of Synthetic Variable
▪ Monthly income	I-10	0.814	0.000	0.131	TPU revenue generation
▪ They have access to credit for their production	I-11	0.528	0.000	0.000	
▪ Main problems presented in the TPU	I-37	−0.534	0.000	0.000	
▪ Participates or belongs to a productive association	I-9	−0.233	0.572	−0.254	Socio-environmental reality of the TPU
▪ Number of people working in the production center	I-29	0.425	0.641	0.000	
▪ Has final disposal of its waste	I-34	0.000	−0.577	−0.143	
▪ Has another type of authorization apart from DIREPRO	I-35	0.000	−0.540	0.000	
▪ Average density per m^2 of trout at fattening stage	I-21	0.000	0.132	0.949	TPU production
▪ Where production is sold	I-28	0.000	0.136	0.500	

The variable participates or belongs to a productive association (I-9) is inversely correlated with the variable has another type of authorization apart from DIREPRO. Likewise, the variable number of people working in its productive center (I-29) is inversely correlated with the variable final disposal of its waste (I-34) (Figure 2), which would represent the synthetic variable socio-environmental reality of the TPU (Table 4). The variable average density per m^2 of trout in the fattening stage (I-21) is correlated with the variable where production is sold (I-28) (Figure 1), which would represent the synthetic variable production of the TPU (Table 4).

The cluster analysis through the dendrogram identifies three groups of trout production systems from the synthetic variables of the new factors established from the principal component analysis (Figure 3). There are three TPU clusters, of which clusters 2 and 3 had the highest number of TPU (41.7%), while cluster 1 had the lowest number of TPU (16.7%) (Figure 3). On the other hand, cluster 3 (group 3) comprised the mini-trout producer, cluster 2 (group 2) comprised the small producers and cluster 3 (group 3) comprised the medium producer. The typification variables that gave rise to the clusters were trout harvests per year (I-13) and production volume per harvest in tons (I-14).

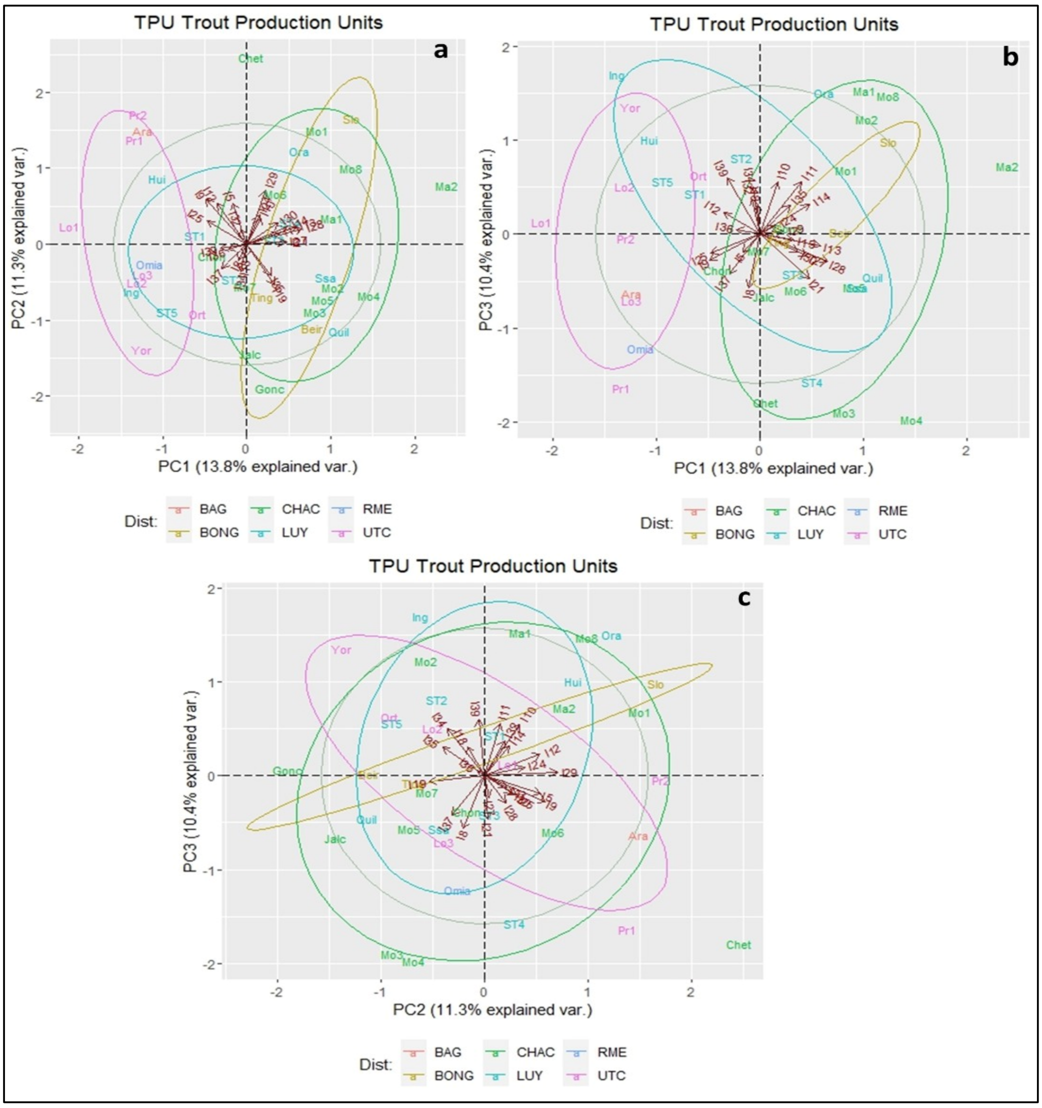

Figure 2. Two-dimensional projections: (**a**) the first (PC1) and second (PC2), (**b**) the first (PC1) and third (PC3), (**c**) the second (PC2) and third (PC2).

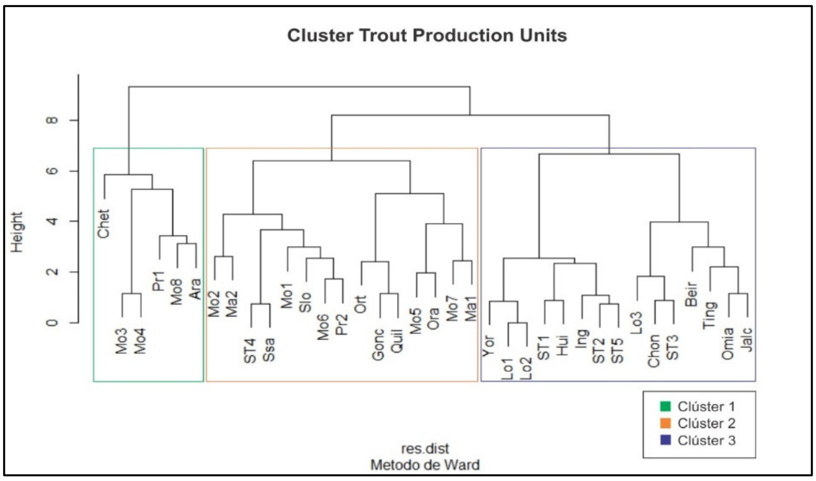

Figure 3. Dendrogram of 23 TPUs resulting from cluster analysis (Ward's method, cut-off distance 7) based on three new factors.

3.2. Evaluation of the Sustainability Index

A total of 60 sub-indicators were determined, divided into four social aspect indicators (with 10 sub-indicators), four economic aspect indicators (with 34 sub-indicators) and three environmental aspect indicators (totaling 16 sub-indicators).

The sub-indicators that contributed the most were those corresponding to the environmental aspect, which averaged a sustainability index of 2.7. The marketing and sales (2.5), carbon footprint (2.5), and ecological footprint (2.3) indicators averaged medium indexes, while water quality estimated a high sustainability index (3.5) (Figure 4, Table 5). Meanwhile, indicators of low sustainability performance should be given more attention and refer to labor conditions (1.3) and aspects of technology, research and development (1.4).

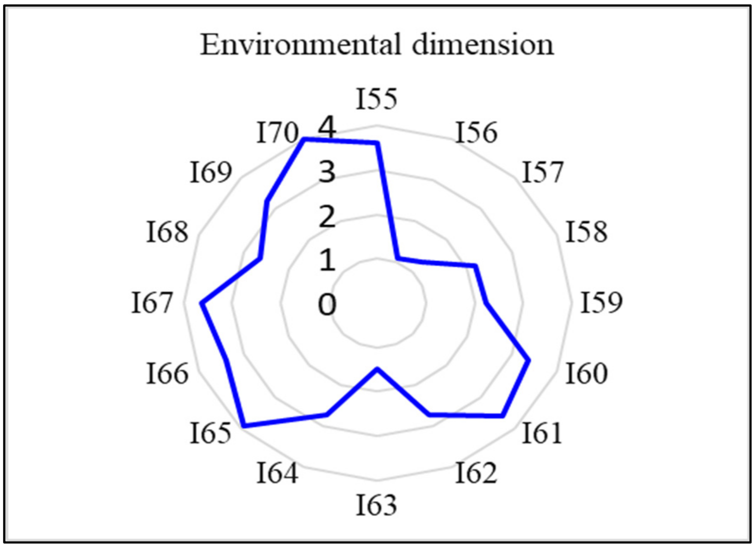

Figure 4. Levels of sustainability for sub-indicators of the environmental dimension in trout producing units in the Amazonas region. The blue line indicates the average level of sustainability per item (I) of the questionnaire.

Table 5. Social, economic and environmental sustainability index values, according to indicators.

Dimensions	Indicators	Value *	General Index *
Social	Human Resources	2.1	1.9
	Working Conditions	1.3	
	Social Responsibility	2.5	
Economic	Economic Performance Level	2.6	2.1
	Operations and Production	2.3	
	Tech. Research and Development	1.4	
	Marketing and Sales	2.5	
Environmental	Carbon Footprint	2.5	2.7
	Ecological Footprint	2.3	
	Water Quality	3.5	

* The values of the indicators and the general index were evaluated by assigning a scale from 1 to 4, with 4 being the highest value and 1 being the lowest sustainability value.

Regarding the economic sub-indicators, they represented a medium level of sustainability (2.1) with the following index values (from highest to lowest): economic performance level (2.6), operations and production (2.3), technical, research and development (1.4) (Figure 5, Table 5).

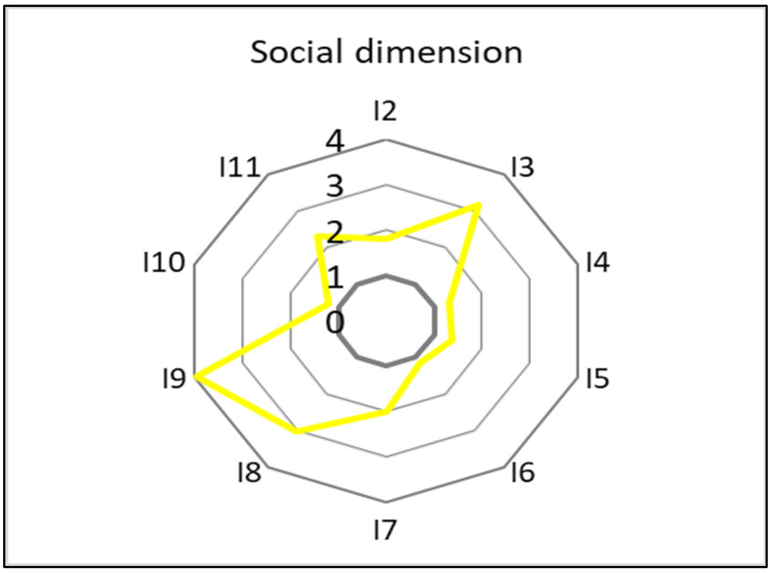

Figure 5. Sustainability levels for sub-indicators of the social dimension in trout production units in the Amazonas region. The yellow line indicates the average level of sustainability per item (I) of the questionnaire.

In the same sense, the lowest average values of the indexes correspond to the sub-indicators of the social aspect with 1.9, which represents a low index of sustainability. From highest to lowest, indices of 2.5 for social responsibility, 2.1 for human resources and 1.3 for working conditions were rated (Figure 6, Table 5). Using the resulting indicators, an overall index of 2.3 was obtained, corresponding to the medium level (Figure 7, Table 5).

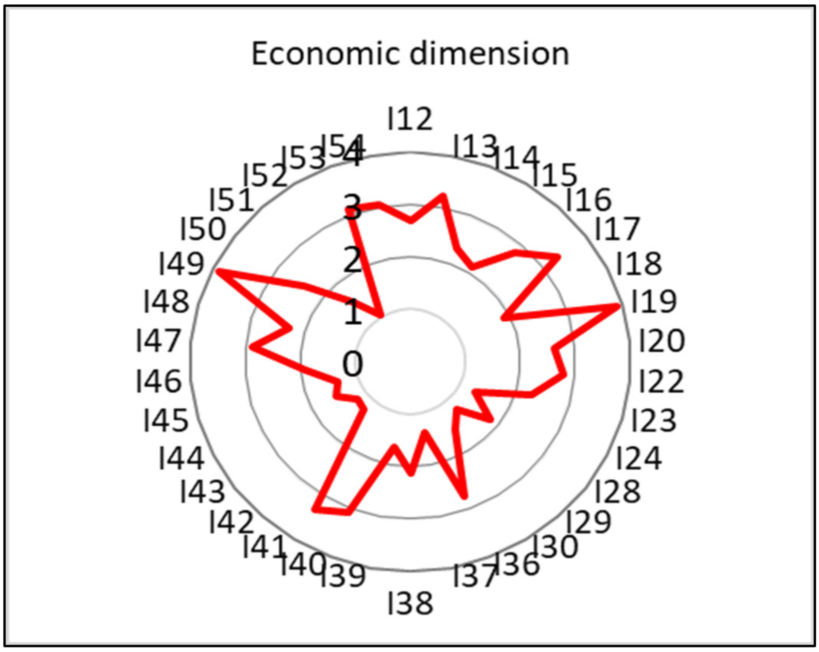

Figure 6. Levels of sustainability for sub-indicators of the economic dimension in trout producing units in the Amazonas region.- The red line indicates the average level of sustainability per item (I) of the questionnaire.

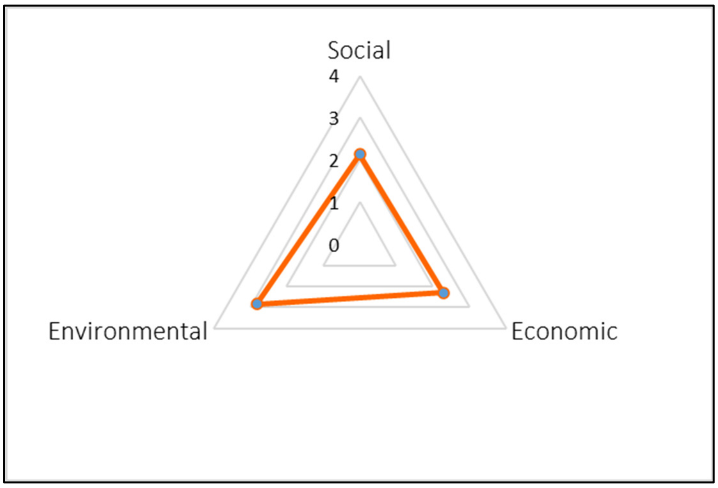

Figure 7. Sustainability levels for the environmental, social and economic dimensions in the trout producing units in the Amazonas region. The orange line indicates the average level of sustainability per dimension.

When we correlated the sustainability dimensions, none of the cases (social with environmental, social with economic, and environmental with economic) showed a moderate, high or very high correlation. On the contrary, there was a low positive correlation between the social and economic dimensions (0.30) and a low negative correlation between the economic and environmental dimensions. There was a small or negligible relationship between the social and environmental dimensions (Figure 8).

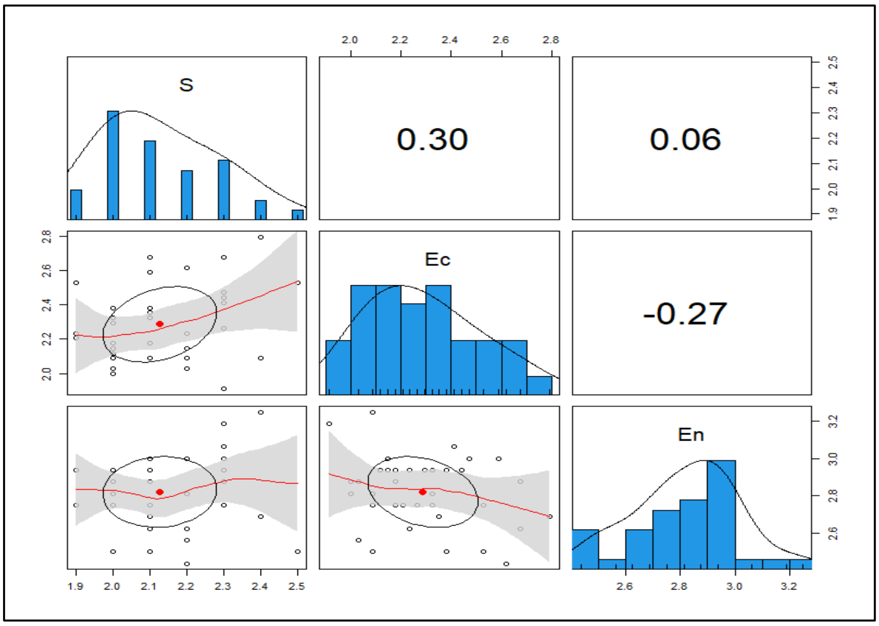

Figure 8. Plot correlation for the dimensions of sustainability in trout production units in Amazonas region. The black line above the bars indicates the distribution of the data and the red lines the relationship between the dimensions.

3.3. Technical Efficiency Analysis

According to the constant scale efficiency index, of the 33 TPUs, 14 showed efficiency (Table 6) and 19 were inefficient, of which 2 TPUs were more than 50% inefficient.

Table 6. Achievement of goals by tranches (averages).

Efficiency (%)	TPU	F	Empl. {I}	Alev. {I}	Camp {I}	Area {I}	Al_prei {I}	Al_i {I}	Al_c{I}	Al_e {I}	Al_a {I}	Water {I}	Meta Production {O}
100	2CHCH, 5CHM, 6CHM, 7CHM, 11CHM, 21CHJ, 22CHJ, 23CHJ, 25LST, 26LST, 27LST, 31LST, 33LST, 41LOR, 48BET, 53UPB, 55UNY, 56ULG, 58UP, 59BA	14	2	27	4	234	73	92	671	1584	1814	92	3371
90–100	2CHCH, 23CHJ, 31LST, 58UP	4	3	9	4	76	21	169	378	1525	1875	59	1325
70–90	11CHM, 21CHJ, 22CHJ, 26LST, 27LST, 59BA	6	3	34	3	94	107	100	756	1280	1540	84	1640
50–70	5CHM, 6CHM, 7CHM, 33LST, 41LOR, 48BET, 53UPB, 55UNY	8	2	19	4	310	53	86	475	938	1225	75	1325
45–50	25LST, 56ULG	2	1	7	4	83	63	175	700	1100	1400	70	750

In general, the trout production units in the Amazonas region operate with 83.87% efficiency at a constant scale.

The goals for the inefficient TPUs have different meanings. For example, only two groups (70–90 and 90–100) should reduce the number of employees (Empl.); the group whose index was between 70–90 should reduce the number of fry (Alev.) planted and should increase their campaigns per year (from 3 to 4). The other TPUs should increase or maintain the levels of these factors used. On the other hand, most of the inefficient TPUs should increase their area dedicated to aquaculture (Area), which indicates that their inefficiency may be due to the size of their farm (scale). The amount of feed used in the different stages can also be optimized. Most of the TPUs should increase the amount of feed.

As can be seen in Table 6, the efficient TPUs are very dispersed, with farms ranging from 60 to 600 m^2 of water surface, with 2 to 100 thousand fingerlings. In addition to the wide range in the amount of feed used and the amount of water, production volumes are between 1500 and 7000 kg of fish per season. This indicates a great heterogeneity in the aquaculture TPUs studied.

On the other hand, the TPUs that proved to be inefficient are smaller. The maximum production volume is 3000 kg of fish per season; however, the facilities occupy a larger area than the efficient TPUs (1000 m^2 versus 600 m^2, as maximum values for both groups; see Tables 7 and 8). In addition, similar to the efficient TPUs, the inefficient farms are very heterogeneous.

Table 7. Efficient trout production units.

Criteria	Empl. {I}	Alev. {I}	Camp {I}	Area {I}	Al_prei {I}	Al_i {I}	Al_c {I}	Al_e {I}	Al_a {I}	Water {I}	Target Production {O}
Minimum	1	2	2	60	3	40	100	680	1000	60	1500
Average	2	27	4	234	73	92	671	1584	1814	92	3371
Maximum	4	100	6	600	500	250	3000	4000	6000	261	7000
Std. dev.	1	33	1	153	133	58	709	939	1280	52	1951

Table 8. Inefficient trout productive units.

Criteria	Empl. {I}	Alev. {I}	Camp {I}	Area {I}	Al_prei {I}	Al_i {I}	Al_c {I}	Al_e {I}	Al_a {I}	Water {I}	Target Production {O}
Minimum	1	3	2	46	5	25	250	600	1000	15	500
Average	2	19	4	194	59	113	543	1180	1465	74	1335
Maximum	4	150	5	1000	450	500	2300	3200	3600	120	3000
Std. dev.	1	34	1	222	103	122	445	613	558	23	525

When analyzing the targets for inefficient TPUs (Tables 5 and 6), the changes that must be made in the amount of resources employed to produce the same amount are heterogeneous. With the exception of the number of employees and the number of campaigns per year, all factors can be adjusted to increase efficiency (Table 9).

Table 9. Achievement of goals.

Criteria	Empl. {I}	Alev. {I}	Camp {I}	Area {I}	Al_prei {I}	Al_i {I}	Al_c {I}	Al_e {I}	Al_a {I}	Water {I}	Target Production {O}
Minimum	0	1	0	22	3	15	90	297	365	11	500
Average	1	6	2	78	15	34	230	631	852	39	1335
Maximum	3	17	3	181	48	90	405	1501	1767	67	3000
Std. dev.	1	4	1	36	11	17	91	249	318	15	525

The adjustments that can be made in the amount of resources employed are more than 40% (Table 10). There is evidence that systems are wasting feed at all stages of the process (from 41.82% in finishing feed to 74.73% of pre-start feed). The 19 inefficient farms can also optimize water use by 46.54% and should reduce their production area by 59.66% (Table 10).

Table 10. Differences between inefficient DMUs and targets.

Criteria	Empl. {I}	Alev. {I}	Camp {I}	Área {I}	Al_prei {I}	Al_i {I}	Al_c {I}	Al_e {I}	Al_a {I}	Water {I}
Inefficient	2	19	4	194	59	113	543	1180	1465	74
Target	1	6	2	78	15	34	230	631	852	39
Improvement	47.26%	69.26%	55.45%	59.66%	74.73%	69.71%	57.62%	46.49%	41.82%	46.54%

4. Discussion

4.1. Characterization of the TPU

The principal component analysis allowed selecting 23 of 39 variables and defining nine new components that explain 72.8% of the total variance (Table 3). The authors of [29] studied the typification of Creole hens in peasant agroecosystems, identifying nine principal components from 25 variables, with a higher degree of discrimination and the absence of correlation between them, explaining 71% of the total variance. In the characterization of agricultural farms (cattle raising, sugarcane and blackberry cultivation) one study used 43 variables to characterize the agricultural units [30].

The typology of the TPUs makes it possible to establish and generate groupings based on the characteristics recorded in the data collection [31]. Grouping the producer units is of utmost importance, because in each group, actions can be carried out jointly and not individually [32]. The use of principal component analysis and varimax rotation with factor loadings greater than 0.5 (Table 4) was considered for the analysis of the variables [30,33], allowing the generation of three synthetic variables through principal component analysis [31,34]: income generation of the TPU (I-10, I-11 and I-37), socio-environmental reality of the TPU (I-9, I-29, I-34 and I-35) and production of the TPU (I-21 and I-28). The cluster analysis (Figure 3) with a Euclidean distance of 10 allowed for identification of three groups of TPUs, where 83.4% of the TPU comprised small and medium trout producers.

These results are important because the high Andean areas of the Amazonas region have hydrological potential, including riverbeds where trout farming is practiced. Thus, in the district of Molinopampa, moderately suitable and marginally suitable areas represent 93% of the total area of the district and are recommended for trout farming [16], which would indicate the potential for trout production in this area of the country. However, the criteria for sustainability must be taken into account. The constant increase in the volume of trout production can affect sustainability, particularly the production of food, as is the case with salmon [35]. There may be alternatives for sustainable trout production, depending on the efficiency in the cultural use of energy (diet, general management, transport and machinery, equipment and construction), a good indicator of sustainability, because as the projected annual production capacity increases the cultural energy expended per kg of carcass and trout fillet marketed decreases [36]. Another alternative could be ecosystem services, as in the case of salmon [37], which can be gradually adapted to trout farming.

4.2. Evaluation of the Sustainability Index

Thanks to the Bruntland Commission, one of the best-known definitions of sustainability was established by Michael Redclift in 2005; it is now common to establish a multidimensional approach [38,39]. It is possible, then, to consider economic, social and environmental criteria to study the sustainability of a territory [40,41], in this case, trout production units in the Amazonas region of Peru.

Despite methodological efforts, capturing the systemic complexity of sustainability through evaluation is difficult [42,43] and has become a constant challenge that seeks to integrate aspects from various approaches (for example, in this research, characterizing and searching for indices as well as evaluating production efficiency in fish farming). However, it is justified by the attention of policy makers beyond productivity to include dimensions of human welfare and ecological soundness [41].

The methodological tools integrated to obtain the sustainability index in this research made it possible to determine problems in a simple way and within the reach of farmers, thanks to the Principle-Criteria-Indicator (PCI) (Ruiz Cabello), the SMART approach (Specific, Measurable, Achievable, Relevant and Time-bound) [44,45], sustainability scales (Sarandón) and correlation analysis. New approaches can be integrated with new dimensions, such as ecological, cultural and political-institutional [46]. Likewise, new indicators and sub-indicators can be developed to represent reality more accurately. This will allow new research in fish culture to be strengthened with respect to commonly used indicators [47,48].

Despite the low correlations between the dimensions of sustainability, higher values between sub-indicators are possible, since in our sample of subjects there are subgroups, and the relationships found can differ greatly when calculated in each group or in all subjects. In these cases, we can obtain future proof by calculating the correlations that interest us in each subgroup and in each subsample [14].

4.3. Technical Efficiency

In the 33 trout production units evaluated, a high average efficiency index was found (83.87%), which indicates that production operates with higher technical efficiency levels than aquaculture operations in Asia, Africa and the United States, and with comparable levels to European aquaculture farms, as reported in previous studies [49]. However, it should be noted that the technique used, being a deterministic method, tends to present overestimations in the calculations [23], and average efficiency may not be an accurate indicator, so a range analysis is necessary.

Farm size is a determinant of the level of efficiency observed, suggesting that, as in other studies, aquaculture units could be more efficient when they increase in size [50].

Although all resources had room for improvement, feed underutilization requires special care, because it has the highest cost of production [49,51]. This opens the possibility that the local industry may seek to improve feed supply efficiency through pond modifications or adjustments in the feed formulations used. An alternative could be the implementation of polyculture systems that make more efficient use of the feed supplied [52].

However, as recommended by other researchers [53], studies of allocative and economic efficiency would be necessary for a better understanding of decision making.

Data envelopment analysis is one of the most widely used tools to measure efficiency in aquaculture production units [54]. Therefore, the results found could be very useful for decision makers and policy makers to help improve competitiveness and efficiency in the TPUs studied.

5. Conclusions

Three groups of trout production units were found in the Amazonas region of Peru, grouped according to total annual fish production.

When we calculate the sustainability index in which the trout production units of the Amazonas region, Peru, operate, we obtained a general index of a medium level, with a total of 60 sub-indicators, divided into four social indicators (with 10 sub-indicators), four economic indicators (with 34 sub-indicators) and three environmental indicators (totaling 16 sub-indicators).

On the other hand, out of 33 production units finally evaluated, 14 were identified as efficient; in general, the Amazonas region's trout farmers operate at 83.87% technical efficiency. All of the resources had slack; therefore, all can be adjusted, with the most underutilized resources being land (area), feed and seed (fry).

Finally, it can be affirmed that the trout farming units in northeastern Peru can be assigned to three groups differentiated by production volume, operate at a medium level of sustainability and are largely operating at levels of technical inefficiency.

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