Environment for Development

Discussion Paper Series

March 2024 ■ EfD DP 24-03

# Examining the Success of the Tilapia Industry in Huila

## *an Emerging Aquaculture Hub in the Colombian Southwest*

**J. Marco, N. Valbuena, D. Valderrama, M. Vásquez**

**Central America**
Research Program in Economics and Environment for Development in Central America Tropical Agricultural Research and Higher Education Center (CATIE)

**Chile**
Research Nucleus on Environmental and Natural Resource Economics (NENRE)
Universidad de Concepción

**China**
Environmental Economics Program in China (EEPC)
Peking University

**Colombia**
The Research Group on Environmental, Natural Resource and Applied Economics Studies (REES-CEDE), Universidad de los Andes, Colombia

**Ethiopia**
Environment and Climate Research Center (ECRC), Policy Studies Institute, Addis Ababa, Ethiopia

**Ghana**
The Environment and Natural Resource Research Unit, Institute of Statistical, Social and Economic Research, University of Ghana, Accra

**India**
Centre for Research on the Economics of Climate, Food, Energy, and Environment, (CECFEE), at Indian Statistical Institute, New Delhi, India

**Kenya**
School of Economics
University of Nairobi

**Nigeria**
Resource and Environmental Policy Research Centre, University of Nigeria, Nsukka

**South Africa**
Environmental Economics Policy Research Unit (EPRU)
University of Cape Town

**Sweden**
Environmental Economics Unit
University of Gothenburg

**Tanzania**
Environment for Development Tanzania
University of Dar es Salaam

**Uganda**
EfD-Mak, School of Economics and Department of Agribusiness and Natural Resource Economics, Makerere University, Kampala

**USA (Washington, DC)**
Resources for the Future (RFF)

**Vietnam**
University of Economics
Ho Chi Minh City, Vietnam

# Examining the Success of the Tilapia Industry in Huila, an Emerging Aquaculture Hub in the Colombian Southwest

**J. Marco*,[a], N. Valbuena[b], D. Valderrama[c], M. Vásquez[d]**

## Abstract

Reaching a production level of 200,000 tons (live weight) in 2022, the tilapia industry has emerged as the most important finfish farming sector in Colombia. Located in the southwest of the country, the Huila department currently accounts for 40% of total production and 90% of exports. As the industry grew at a remarkable pace over the last two decades, two clearly identifiable sectors emerged, with large-scale producers targeting the export market, and mid- and small-scale producers focusing on the domestic market. This study used the Aquaculture Performance Indicators (API) methodology to examine the economic, environmental, and social performance of both production sectors. The evaluation relied on the input of industry experts and information collected from a number of secondary sources. While the export sector achieved acceptable scores for each sustainability criteria, the economic and social performance of the domestic sector was deficient. Contrasting capacities to cope with a number of production, investment and cost scenarios as well as varying vulnerability to potential risks could further amplify the differences in performance between the two sectors.

**Keywords**: Aquaculture Performance Indicators, Food production systems, Triple bottom line, Sustainable aquaculture, Tilapia.

**JEL Codes**: Q22.

---

[a] Department of Economics, University of Los Andes, Bogotá, Colombia. [b] Faculty of Agricultural Sciences, University of Hohenheim, Stuttgart, Germany. [c] Department of Environmental Science and Policy, George Mason University, USA. [d] Colombian Federation of Fish Farmers (FEDEACUA), Colombia.
[*] Corresponding author: j.marco@uniandes.edu.co

# Examining the Success of the Tilapia Industry in Huila, an Emerging Aquaculture Hub in the Colombian Southwest

J. Marco[a,*], N. Valbuena[b], D. Valderrama[c], M. Vásquez[d]

[a)] Department of Economics, University of Los Andes, Bogotá, Colombia.
[b)] Faculty of Agricultural Sciences, University of Hohenheim, Stuttgart, Germany.
[c)] Department of Environmental Science and Policy, George Mason University, USA.
[d)] Colombian Federation of Fish Farmers (FEDEACUA), Colombia.

## Abstract

Reaching a production level of 200,000 tons (live weight) in 2022, the tilapia industry has emerged as the most important finfish farming sector in Colombia. Located in the southwest of the country, the Huila department currently accounts for 40% of total production and 90% of exports. As the industry grew at a remarkable pace over the last two decades, two clearly identifiable sectors emerged, with large-scale producers targeting the export market, and mid- and small-scale producers focusing on the domestic market. This study used the Aquaculture Performance Indicators (API) methodology to examine the economic, environmental, and social performance of both production sectors. The evaluation relied on the input of industry experts and information collected from a number of secondary sources. While the export sector achieved acceptable scores for each sustainability criteria, the economic and social performance of the domestic sector was deficient. Contrasting capacities to cope with a number of production, investment and cost scenarios as well as varying vulnerability to potential risks could further amplify the differences in performance between the two sectors.

*Keywords*: Aquaculture Performance Indicators, Food production systems, Triple bottom line, Sustainable aquaculture, Tilapia.

*JEL Codes*: Q22.

* *Corresponding author:* j.marco@uniandes.edu.co

## 1. Introduction

Aquaculture accounts for around half of global seafood production and has sustained an average growth rate of 6.7% since 1990, making it the fastest-growing food sector over the last decades (FAO, 2022). This growth contrasts with the comparatively stable harvests of capture fisheries (Garlock et al., 2020). In 2020, global aquaculture production reached a record 122.6 million tons, valued at USD 281.5 billion (FAO, 2022). Aquaculture development is therefore clearly aligned with Sustainable Development Goals 2 (Food Security) and 8 (Economic Growth), and contributes substantially to global well-being (Troell et al., 2023).

However, the rapid expansion and intensification of aquaculture has raised several environmental concerns regarding potential negative externalities such as water pollution, genetic contamination, disease spread, and increased pressure on natural resources due to input demands like feed (Asche et al., 2022). Given the expanding role of aquaculture as a food security and economic growth engine, whether aquaculture can engage in a path of sustainable development is a research question of continued relevance.

While a consensus has emerged on the importance of practicing aquaculture in the most sustainable way, it is equally important to establish a shared understanding of the practices and conditions that guarantee the three pillars of sustainability – economic, environmental, and social (UN, 1992) – in any aquaculture production sector (Pillay, 1997; Naylor et al., 2009, Krause et al., 2020; Naylor et al., 2021; Brugere et al., 2023; Kumar et al., 2023). Assessment and monitoring of aquaculture production are essential steps to improve evidence-based policy making and management (Garlock et al., 2020). Yet, there is a general lack of both qualitative and quantitative information on sustainable aquaculture performance (Valenti et al., 2018).

Building upon the success of the Fishery Performance Indicators (FPIs) as an instrument to evaluate sustainable management of fishery systems (Anderson et al., 2015),[1] the Aquaculture Performance Indicators (API) were developed as an innovative assessment tool[2]

---

[1] Examples of FPI studies include research on tuna in the Pacific (McCluney et al., 2019), queen conch in the Colombian Caribbean (Marco et al., 2021a), industrial deep-sea shrimp in the Colombian Pacific (Marco et al., 2021b), and anchoveta in the Southeastern Pacific (Chávez et al., 2021).

[2] Early attempts to assess aquaculture sustainability focused on ecological and carbon footprints (Folke et al., 1998; Madin and Macreadie, 2015), life cycle assessments (Gronroos et al., 2006; Medeiros et al., 2017), and

to address the sustainability concerns associated with fast aquaculture development (Anderson et al., 2020). The API methodology assesses the sustainability of an aquaculture sector through the Triple Bottom Line (TBL) perspective (Asche et al., 2018), that is, environmental stewardship, economic viability, and social responsibility. The methodology is adaptable to the often limited data contexts of transitional countries[3], and it is powerful enough to address a variety of research questions such as comparisons of aquaculture production sectors and in-depth analyses of specific dimensions of sustainability. As with FPIs, API assessments may serve as benchmarks for monitoring progress in aquaculture sectors over time (Chu et al., 2017; Marco et al., 2021b).

Located in the southwest of the country, the Huila department has emerged as a leading aquaculture hub and the most important producer of farmed tilapia in Colombia. Growing at an average rate of 10% since 2012, tilapia production in Colombia reached approximately 200,000 tons in 2022, with the Huila and Meta departments accounting for 40% and 11%, respectively (FEDEACUA, 2023).[4] In 2022, Huila exported approximately 16,000 tons of the 84,000 tons it produced, representing 90% of Colombian tilapia exports (FEDEACUA, 2023). Two distinct production sectors can therefore be identified in Huila: (i) large-scale producers who export over 80% of their output, and (ii) mid- and small-scale producers who predominantly cater to the domestic market and have minimal export activity (less than 15% of output). The two sectors are characterized by dissimilar production, investment, cost, risk, and vulnerability profiles.

The major goal of this study is to develop a comprehensive understanding of the practices and conditions affecting sustainability in both tilapia production sectors in Huila. The API instrument was applied to address two major research questions: First, is tilapia production

---

energy analyses (Cavalett et al., 2006; Garcia et al., 2014; Williamson et al., 2015), but were predominantly biased toward the environmental pillar of sustainability. Recent years have seen new approaches proposed for assessing aquaculture performance (FAO, 1998; Boyd et al., 2007; Pullin et al., 2007; Valenti, 2008; FAO, 2011; Fletcher, 2012; Hofherr et al., 2012; Fezzardi et al., 2013), yet only a few of these techniques have been widely disseminated in scientific journals, prompting concerns regarding their global applicability across diverse production sectors. Certifying institutions like Best Aquaculture Practices (BAP) and Aquaculture Stewardship Council (ASC) have developed methodologies for assessing compliance, but obtaining necessary indicators for aquaculture performance assessment remains challenging, often relying on hard-to-obtain secondary data.

[3] Notice that aquaculture production growth has exhibited an uneven distribution, with transitioning countries taking the lead in global production (Garlock et al., 2020).

[4] The reference (FEDEACUA, 2023) pertains to information obtained from the Colombian Federation of Fish Farmers (FEDEACUA) in the year 2023.

in Huila a sustainable endeavor from the TBL perspective? Second, are there any significant differences in TBL performance between the export- and domestically oriented sectors?

The article is organized as follows. The case study is introduced in Section 2 while Section 3 provides a brief description of the API methodology and its application to the two production sectors. Results are summarized and discussed in Section 4. Finally, Section 5 presents the major conclusions and recommendations.

## 2. Case study

Both red (*Oreochromis sp.*) and Nile (*Oreochromis niloticus*) tilapia were introduced in Colombia in the late 1970s as part of government programs aimed at restocking local water bodies and fostering aquaculture throughout the country (Merino et al., 2013; Parrado, 2016; Carrera-Quintana et al., 2022). Native to northern Africa, tilapia proved to be quite adaptable to the local environment and eventually emerged as the most important finfish aquaculture species, exceeding production of native and other non-native species such as cachama (*Piaractus brachypomus*) and rainbow trout (*Oncorhynchus mykiss*) (Ministry of Agriculture and Rural Development, 2022). The growth of the industry in the Huila region has been remarkable considering that other departments had a longer fish-farming tradition (e.g., Valle del Cauca) or enjoyed greater public support for this activity (e.g., Meta; Parrado, 2016). Currently, more than 40% of Colombian tilapia production takes place in Huila (Figure 1).

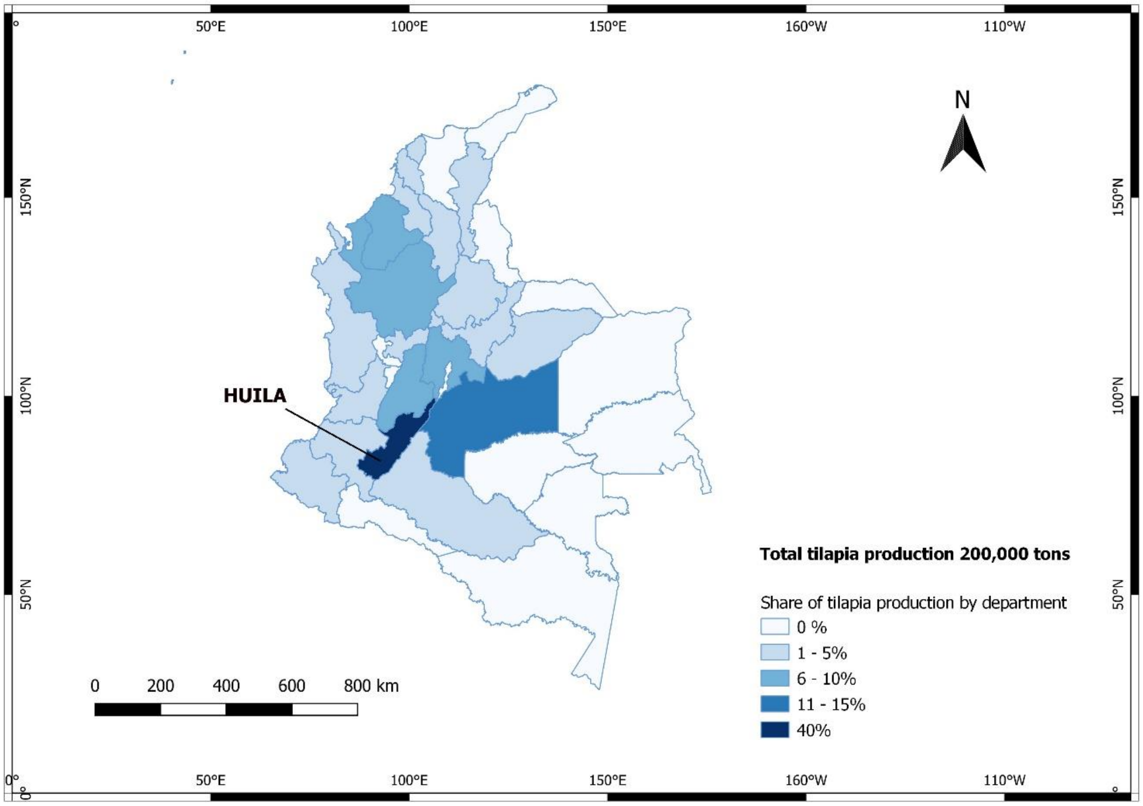

**Figure 1.** 2022 tilapia production in Colombia, by department (shares of total harvest). Source: Ministry of Agriculture and Rural Development (2022).

The fast growth of tilapia production in Huila can be explained by two closely interlinked factors: (i) the entrepreneurship abilities and tenacity deployed primarily by large-scale producers in the region, and (ii) the signing of the Free Trade Agreement (FTA) between Colombia and the US in 2007. To benefit from the positive effects of economic liberalization, local agricultural enterprises must be able to adapt to more competitive environments by building up a substantial level of capabilities and infrastructure (Feola et al., 2015). The construction of the Betania reservoir in the upper Magdalena River basin in the late 1980s and the entrepreneurial drive shown by early tilapia producers enabled the industry to capture the benefits associated with the opening of the US market (Figure 2). Shortly after the construction of the reservoir, a few pioneers began growing tilapia on precarious arrays of floating cages. In tandem with these developments, demand for tilapia in both domestic and international markets increased sharply. Tilapia production in Huila experienced significant growth as a result, achieving annual growth rates in excess of 15% (Castillo, 2012). This early success allowed producers to ramp up operations through improved culture technologies and to target international markets following the approval of the FTA in 2007. Exports were also enabled by an adequate transportation infrastructure connecting Huila with Bogota, the country's capital. As a result, fresh tilapia harvested in Huila is able to reach US warehouses in less than one day through air transport.

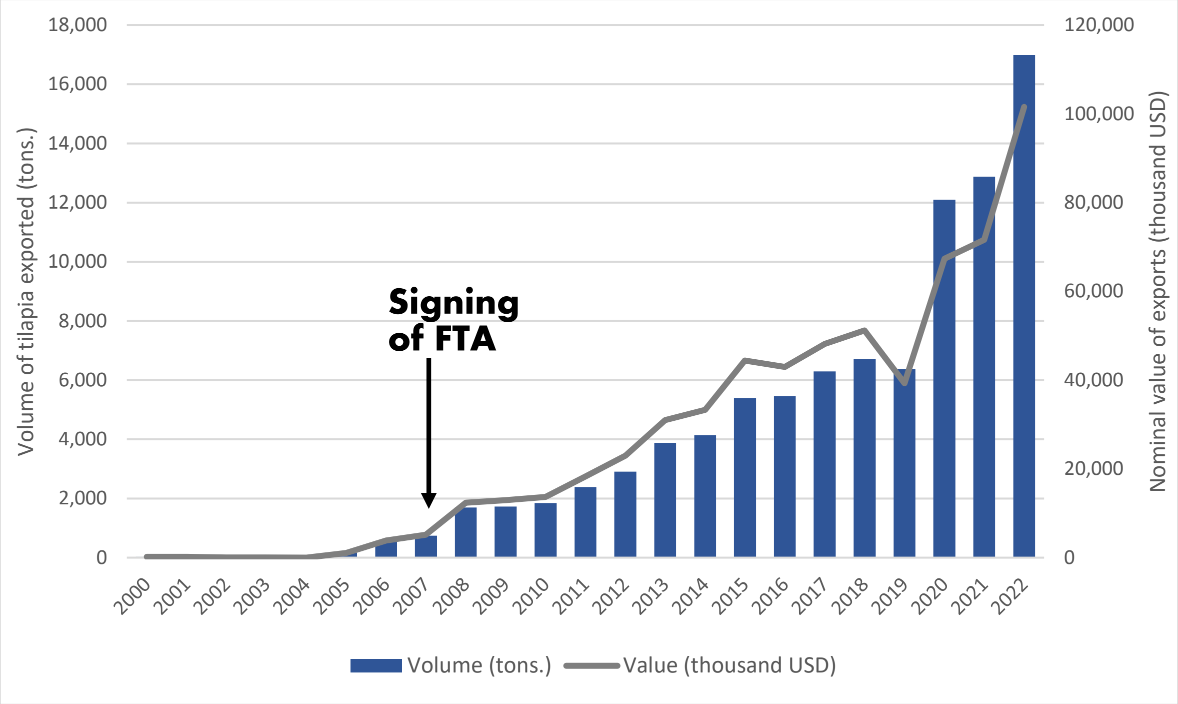

**Figure 2.** Colombian tilapia exports to the U.S market. Source: NOAA Fisheries (2022).

The tilapia industry in Huila currently comprises 1,230 registered producers, with nearly 100 of them (8%) focusing primarily on exports – the remaining producers cater primarily to the domestic market. The National Aquaculture and Fisheries Authority (known by its Spanish acronym, AUNAP) classifies producers into small, medium, and large (or industrial) categories according to production volume and levels of technological innovation and integration of intermediate activities (AUNAP, 2016). The latter group consists of large-scale, highly integrated firms that usually produce over 800 tons per year and focus mainly on exports to the high-value US and European markets. Due to increasing demand from export markets, large firms have recently outsourced production to small and mid-sized farmers who benefit from access to superior transportation, cooling, and processing facilities as well as international certification schemes. These arrangements substantially improve the competitiveness of this group of farmers, relative to other small-scale producers.

As mentioned previously, this study assumes that large firms (and the farmers producing for them) are export-oriented while small and mid-sized producers are domestically oriented. This assumption is nevertheless not entirely accurate as some of the output (around 15%) from the former group is destined for the domestic market, while small- and mid-sized producers export some tilapia (around 20% of output) to Peru, Central America, and even the US. For the purposes of this study, however, it is useful to place the two producer groups in separate categories.

Table 1 summarizes general production parameters for export-oriented producers in Huila[5]. On average, 1.6 growout cycles per year are obtained. Mortality rates are moderate, ranging from one quarter to one third of the stock. Production costs are estimated around USD 1.50/Kg, with feed, energy, and vaccinated fingerlings accounting for 75%, 7%, and 5% of costs, respectively. It should be noted that energy costs are highly subsidized (up to 50% of actual costs). Farm-gate prices hover around USD 2.00/Kg, which translates into profit margins ranging from 20% to 30%, (a net gain of around USD 0.50/Kg). Wholesale prices range from USD 2.90 to USD 4.50/Kg. Although tilapia prices in the US market vary depending on factors such as product type and quality, Colombian tilapia prices range from USD 5.40 to USD 7.40/Kg.

**Table 1.** Production parameters for tilapia aquaculture in Huila, 2023. The exchange rate in July 2023 was approximately 4,166 COP (Colombian Pesos): USD 1.00.

| **Tilapia production in Huila** | |
|---|---|
| Final average weight (g) | 420-500 |
| Length of growout cycle (days) | 180-220 |
| Feed Conversion Ratio (FCR) | 1.5-1.8 |
| Number of animals to produce 1 Kg | 2-2.4 |
| Cycles per year | 1.6 |
| Mortality | 25-33% |
| Production Costs | USD 1.44 – 1.55/Kg |
| | 75% Feed |
| | 7% Energy |

---

[5] Production parameters for small- and mid-sized farmers are not presented because of a lack of reliable and representative data. In addition, this group of farmers is known to be highly heterogeneous.

| | |
|---|---|
| | 5% fingerlings (vaccinated) |
| | 13% Other (including labor costs) |
| Farm-gate price | USD 1.9 – 2.05/Kg |
| Net benefit | USD 0.41 – 0.6/Kg |
| | Profit margin: 20-30% |

Source: FEDEACUA (2023), Ministry of Agriculture and Rural Development (2022), calculations by the authors.

Tilapia is currently farmed under four major systems in Huila: (1) floating cage systems in Betania and El Quimbo reservoirs, (2) pond culture, (3) Recirculating Aquaculture Systems (RAS) for fingerlings, and (4) Intensive Pond Aquaculture (IPA) achieved through innovative In-Pond Raceway Systems (IPRS). Traditional floating cage culture is still the predominant method with around 70% of the total output in the region. Although estimates for the other methods are imprecise, production through IPRS is steadily increasing. IPRS is a highly energy-intensive, state-of-the-art growout system that increases productivity by approximately 30-50% by shortening the production cycle to four months. The system emerged as a strategic response by large-scale producers to meet the growing demand from the US market. Export-oriented firms currently produce tilapia under the four systems whereas small- and mid-sized farmers rely primarily on earthen ponds.

The entrepreneurial drive of the early producers enabled them to grow their operations into the large-scale export firms that currently dominate the market. These firms have assumed control of all processing and transportation functions, including product distribution within the US market. For example, a single buyer – RedFishCo, which is partially owned by the large aquaculture firms of the region – dominates purchases of Colombian tilapia in the US. Family firms such as Piscícola Botero and Piscícola New York, which began operating no more than 30 years ago, have now emerged as leading export firms in the industry (FEDEACUA, 2023). The success of these firms allowed Colombia to emerge as the primary exporter of fresh tilapia to the US market since 2020 (Figure 3). Colombia currently accounts for approximately 92% of US imports in the whole fresh segment (FEDEACUA, 2023). The industry is expected to see even further growth in the near term.

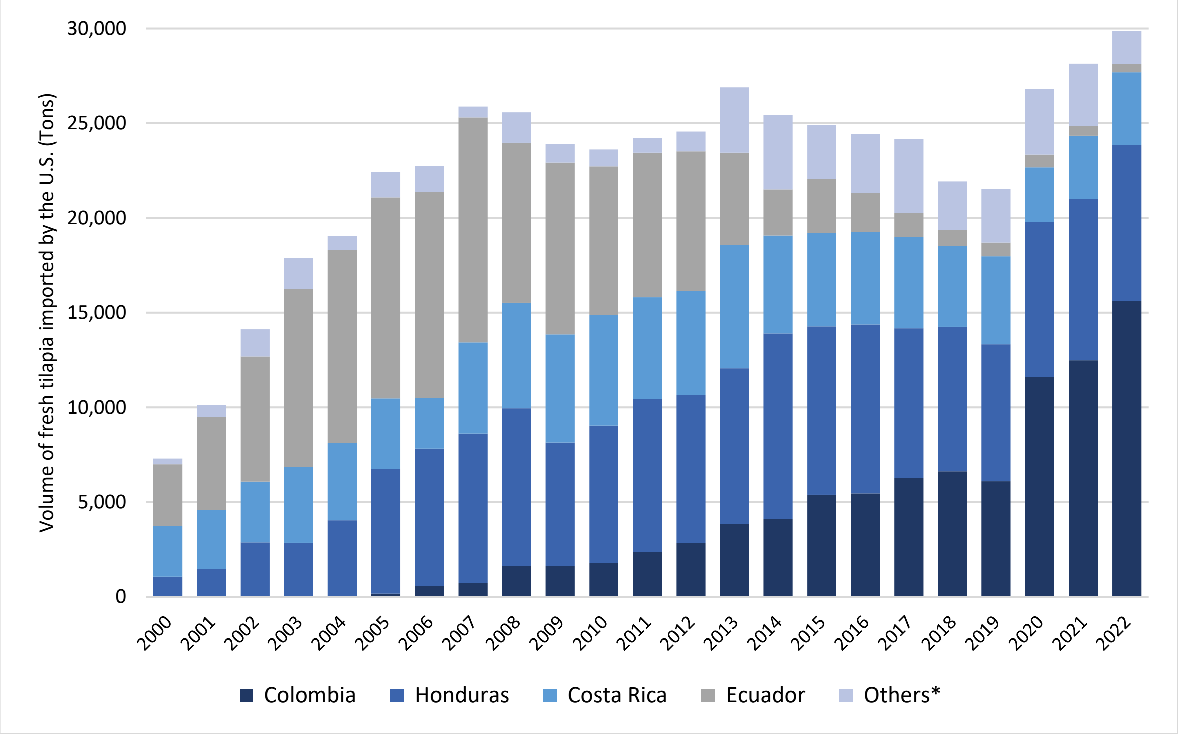

**Figure 3.** US imports of fresh tilapia by country of origin. Source: NOAA Fisheries (2022). (*) The "Others" category includes Brazil, Mexico, Taiwan, Panama, Vietnam, Uganda, Guyana, and Nicaragua.

While the expansion of aquaculture has benefited both large- and small-scale producers, current and emerging economic and environmental challenges have led to disparities between the two sectors that may widen in the future. As aquaculture expanded in the Huila region, much agricultural activity shifted from traditional crops, e.g. rice, to tilapia culture in search of larger profit margins. In contrast to the somewhat stable growth achieved by the early producers, many small- and mid-sized operations are more vulnerable to external economic shocks. Moreover, the increasing adoption of energy-intensive systems by large-scale producers may enhance the economic and market-power disparity between the sectors. Environmental challenges resulting from increasing atmospheric emissions and pressure for land and habitat conversion may also constrain future growth. These challenges are further discussed in the Results section.

## 3. Methodology

The APIs were designed to capture expert assessments of aquaculture performance through a set of 154 output and input metrics. The 88-output metrics (*Outputs*) identify and measure whether the examined aquaculture production sector delivers economically viable and socio-ecologically sustainable results. Output metrics are aggregated into the economic, environmental, and social dimensions of sustainability (TBL perspective) or into sectorial dimensions (*Environment*, *Production* and *Post-Production*), but can also be aggregated into 15 different components (e.g., *Risk*, *Trade*, *Certification*, *Environmental Compliance*). The 66-input metrics (*Inputs*) identify the enabling conditions that incentivize profitable and socio-ecologically sustainable aquaculture sectors, leading to the creation of sustainable livelihoods and upkeep of ecosystems. Input metrics are aggregated into six dimensions (*Macro Factors*, *Property Rights*, *Co-Management*, *Management*, *Supply Chain* and *Production*), but can also be aggregated into 17 different components (e.g., *Gender*, *Land Rights*, *Governance*). Analyzing the scores from these metrics provides insights into successful and sustainable aquaculture policy and practice.

### 3.1. Scoring methodology

As with FPIs, the 154 metrics are assigned both quantitative and qualitative scores by one or more experts. Quantitative scores range from 1 to 5, with 5 indicating excellent performance and 1 denoting very poor performance. In addition, quantitative scores are assigned quality ratings (A, B, or C) to indicate varying levels of confidence: B and C ratings suggest the need for clarifications and adjustments. Overall performance in an output (or input) dimension or component is assessed by averaging the scores within that dimension or component. A benchmark of 3.5 and higher indicates good performance (Anderson et al., 2015). Importantly, input metrics are designed without assuming that higher scores lead to better performance. Discrete bins address the lack of standardized data in data-poor aquaculture sectors, allowing imprecise but reasonably accurate scoring of metrics when precise underlying data are unavailable (Anderson et al., 2015). Combining multiple metrics into output or input components in these cases enables robust evaluation and a holistic interpretation of success.

### 3.2. The evaluation process

Data were collected through 13 expert interviews conducted between March and July 2023. The group of experts included local producers, firm employees, and directors of farm cooperatives. Six of the interviews were conducted in-person exclusively, four of them via virtual meetings while the other four were conducted both in-person and virtually. Questionnaires were adapted and translated to Spanish for the interviews. Experts assigned scores to sectors and metrics according to their domain of expertise, enhancing score quality. Throughout the assessments, experts were encouraged to explain their chosen scores, including expressing any uncertainty about their scores. Following the interviews, secondary sources of information were consulted for additional quality control of scores and explanations. These sources included official statistics and reports, data proxies, and unpublished reports.

## 4. Results and discussion

This section presents the results obtained from the API assessments and conducts a comparison of the two production sectors – export vs. domestically oriented – according to aggregated performance (section 4.1), and performance for Outputs (section 4.2) and Inputs (section 4.3). The scores varied slightly between aquaculture production sectors. For the exporting sector, 38% of the scores were rated as A, 56% as B, and 6% as C. For the domestic sector, 32% of the scores were rated as A, 67% as B, and 1% as C. A complete listing of scores is presented in Appendix A. Differences between sectors were analyzed using the Mann-Whitney U test under the assumption that each metric carries equal weight. Under the null hypothesis, performance across sectors does not differ significantly.

### 4.1. Aggregated performance

Table 2 presents the aggregated performance of export-oriented and domestically oriented tilapia production in Huila. Aggregate performance is assessed through the simple mean of metrics, considering both Output and Input metrics (*All*), Output metrics only (*Outputs*), and Input metrics only (*Inputs*). Statistical analysis reveals a higher aggregate performance score in all three categories for the export-oriented sector compared to the domestic sector. Specifically, the export-oriented sector exhibits mean values of 3.56 (*All*), 3.86 (*Outputs*), and 3.23 (*Inputs*), while the corresponding mean values for the domestic sector are 2.88, 3.11, and 2.58, respectively.

**Table 2.** Aggregate performance assessments of export-oriented versus domestically oriented tilapia production sectors in Huila, 2023.

|  | **Export-oriented** | **Domestically oriented** | **Mann-Whitney U test** |  |  |  |
|---|---|---|---|---|---|---|
| **All** |  |  | W | p-value | significance | effect size |
| Median | 4 | 3 | 7802 | $p < 0.001$ | *** | $r = 0.30$ (moderate) |
| IQR | 2 | 1 |  |  |  |  |
| Mean | 3.56 | 2.88 |  |  |  |  |
| SD | 1.1 | 1.17 |  |  |  |  |
| # Metrics | 154 | 154 |  |  |  |  |
| **Outputs** |  |  | W | p-value | significance | effect size |
| Median | 4 | 3 | 2498 | $p < 0.001$ | *** | $r = 0.32$ (moderate) |
| IQR | 2 | 2 |  |  |  |  |
| Mean | 3.86 | 3.11 |  |  |  |  |
| SD | 0.96 | 1.21 |  |  |  |  |
| # Metrics | 88 | 88 |  |  |  |  |
| **Inputs** |  |  | W | p-value | significance | effect size |
| Median | 3 | 2 | 1370 | $p < 0.001$ | *** | $r = 0.29$ (small) |
| IQR | 2 | 1 |  |  |  |  |
| Mean | 3.23 | 2.58 |  |  |  |  |
| SD | 1.17 | 1.04 |  |  |  |  |
| # Metrics | 66 | 66 |  |  |  |  |

Note: *, **, and *** indicate significance in mean differences at 10%, 5%, and 1% levels, respectively. Wilcoxon test statistic (W), Interquartile range (IQR), and Standard Deviation (SD).

In the export-oriented sector, scores for overall performance (*All*) and the *Outputs* category surpassed the benchmark of 3.5 for good performance. However, there is room for improvement in the *Inputs* category. In contrast, performance in the domestic sector fell somewhat short as none of the categories in this sector surpassed the 3.5 benchmark. Note that aggregated performance assessments may mask differences in the environmental, economic, and social dimensions of sustainability, as well as differences in the Input components, both within and across the production sectors under study. For instance, overall performance (*All*) results exhibited greater variability in the domestic sector than the export sector.

Although the aggregated results shed light on the existing disparity between sectors, more detailed insights are provided in the disaggregated analysis of output and input score metrics.

### 4.2. Output performance

The 88 output indicators were grouped into the three TBL dimensions: *Environmental*, *Economic* and *Community*. Export-oriented producers outperformed domestic producers in the *Economic* (4.0 vs. 3.33) and *Community* (3.73 vs. 2.6) dimensions; however, no significant difference was found for the *Environmental* (3.73 vs. 3.53) dimension (Table 3).

Environmental and economic performance scores for the export-oriented sector are both higher than the global average (3.48 and 3.60, respectively) while the score for social performance is slightly above the average (3.71). The environmental performance score for the domestically oriented sector is slightly above the global average (3.48), while economic and community performance scores are below the average (3.60 and 3.71, respectively) (Garlock et al., under review).

**Table 3.** Comparison of output scores by TBL dimensions reported for export- and domestically oriented tilapia production sectors in Huila, 2023.

| | **Export-oriented** | **Domestically oriented** | **Mann-Whitney U test** | | | |
|---|---|---|---|---|---|---|
| **Environmental** | | | W | p-value | significance | effect size |
| Median | 4 | 3 | 99.5 | $p = 0.59$ | no | r = 0.11 (small) |
| IQR | 2 | 1 | | | | |
| Mean | 3.73 | 3.53 | | | | |
| SD | 1.16 | 0.99 | | | | |
| # Metrics | 15 | 15 | | | | |
| **Economics** | | | W | p-value | significance | effect size |
| Median | 4 | 3 | 635 | $p < 0.001$ | *** | r = 0.27 (small) |
| IQR | 1.5 | 2 | | | | |
| Mean | 4 | 3.33 | | | | |
| SD | 0.95 | 1.23 | | | | |
| # Metrics | 43 | 43 | | | | |
| **Community** | | | W | p-value | significance | effect size |
| Median | 3 | 2 | 195 | $p < 0.001$ | *** | r = 0.51 (large) |
| IQR | 1.75 | 1 | | | | |
| Mean | 3.73 | 2.6 | | | | |
| SD | 0.87 | 1.13 | | | | |
| # Metrics | 30 | 30 | | | | |

Note: *, **, and *** indicate significance in mean differences at 10%, 5%, and 1% levels, respectively. Wilcoxon test statistic (W), Interquartile range (IQR), and Standard Deviation (SD).

The assessment indicates that there is no significant difference in *Environmental* performance scores between export and domestically oriented producers, with both sectors scoring above the 3.5 threshold score (3.73 vs. 3.53). The few indicators with contrasting scores between the sectors (Table 4) are reflective of the major environmental challenges faced by tilapia producers in the region.

Domestic-oriented producers achieve higher scores for the indicators *Wildlife Mortality* (2 vs. 3), *Ecological impacts of escaped fish* (2 vs. 3), *Land use* (2 vs. 4), and *GHG emissions* (2 vs. 4). This difference is driven by the larger environmental externalities associated with the large-scale operations. The Betania reservoir, where the larger farms have traditionally been located, has lost many of its native fish species due to the introduction of the non-native tilapia. Additionally, in response to the growing international demand for tilapia, large-scale producers have expanded earthen pond acreage for both traditional culture and energy-intensive systems (IPRS), which has substantially altered land use, benthic habitats, vegetation, and hydrological regimes in the region (these impacts are captured by the *Land Use* indicator). Lastly, the *GHG Emissions* indicator reflects both the higher emissions associated with large-scale production and growing concerns about the adoption of energy-intensive systems in the region. According to several interviewees, this development has emerged as the most pressing environmental issue in the industry, given the large energy subsidies for agricultural production in the region.

On the other hand, large-scale producers achieve higher scores for the indicators *Freshwater Use* (5 vs. 4), *Sustainability of Non-marine Feed Ingredients* (5 vs. 4), *Compliance with Environmental Law* (4 vs. 2), and *Proportion of Production with 3rd Party Certification* (5 vs. 2). *Freshwater Use* performance scores are higher because a larger share of tilapia production in the export-oriented sector relies on water-efficient methods like floating cages or IPRS, while small and mid-sized producers rely mostly on earthen ponds with little or no water circulation. The higher scores for the other three indicators result from the requirement to certify production to access international markets, which leads to greater compliance with environmental law and the use of improved feed sources.

In conclusion, though, the greater share of certified producers in the export-oriented sector does not lead to better performance in the *Environmental* dimension because of the scale of their operations. From the beginning of the tilapia boom in Huila more than a decade ago, large firms have intensified production by constructing new facilities on converted land and by relying increasingly on energy-intensive systems such as the IPRS. Large-scale producers comply with the environmental requirements of certifying organizations related to water quality, feed sources, waste management, and implementation of impact assessments, but these gains are offset by the larger footprint of their operations.

**Table 4**. Environmental scores for export- and domestic-oriented sectors.

| **Metric** | **Export-oriented** | **Domestic market** | **Difference (%)** |
|---|---|---|---|
| Sustainability of aquatic feed sources | 5 | 5 | 0 (0%) |
| Sustainability of non-marine feed ingredients | 5 | 4 | 1 (20%) |
| Impact of discharge (nutrient emissions) | 4 | 4 | 0 (0%) |
| Non-nutrient emissions | 3 | 3 | 0 (0%) |
| Freshwater use | 4 | 3 | 1 (25%) |
| Wildlife mortality | 2 | 3 | -1 (-50%) |
| Benefits to wildlife | 2 | 2 | 0 (0%) |
| Ecological impacts of escaped fish | 2 | 3 | -1 (-50%) |
| Genetic impacts of escaped fish | 3 | 3 | 0 (0%) |
| Parasite and disease transmission | 5 | 5 | 0 (0%) |
| Site use | 5 | 5 | 0 (0%) |
| Land Use | 2 | 4 | -2 (-100%) |
| GHG emissions | 2 | 4 | -2 (-100%) |
| Compliance with environmental law | 4 | 2 | 2 (50%) |
| Proportion of production with 3rd party certification | 5 | 2 | 3 (60%) |

In the *Community* dimension, the performance gap between the export- and domestic-oriented sectors is larger due to improved working conditions in the former sector, which is reflected in the significantly higher scores achieved for the components *Managerial returns* (4.33 vs. 2), *Labor returns* (3 vs. 1.5), *Career* (3.33 vs. 2.67), and *Community Services* (3.8 vs. 2.6) (Figure 4). Because large-scale tilapia producers have historically captured higher economic rents through international trade, they are in a better position to provide benefits to their employees and families such as higher salaries and access to superior health and education services (as captured by the *Community Services* component). Regarding the

*Career* component, export-oriented producers rely more on experienced workers with specialized knowledge, while the smaller producers are more reliant on seasonal or family labor.

The export-oriented sector achieves consistently higher scores for a number of components under the *Economic* (Table 3) dimensions of *Production Performance* (4 vs. 3.15), *Production Assets* (3.83 vs. 3.17), *Trade* (4.5 vs. 2), *Product Form* (4.13 vs. 3.38), and *Post-harvest Assets* (4 vs. 2.67) (Figure 4). These results reflect the superior economic standing export-oriented companies have achieved through the years by pioneering tilapia aquaculture in the region, having access to wider markets, investing in more productive facilities and, ultimately, becoming more resilient to external shocks that have pushed smaller competitors out of business. However, the *Risk* component score of the *Economic* dimension does not show that small and mid-sized producers are more vulnerable to shocks, since they perform slightly better than the large export-oriented companies in this dimension (4.67 vs. 4.17). A plausible explanation is that country-level data on wholesale prices and production in Huila was used for the indicators related to this component. This assumes smaller producers are the only ones supplying the domestic market, which is not the case. Lack of data, and difficulty in collecting, reliable data on farm-gate prices and production for small and mid-sized farmers limits the accuracy of the API tool on this matter.

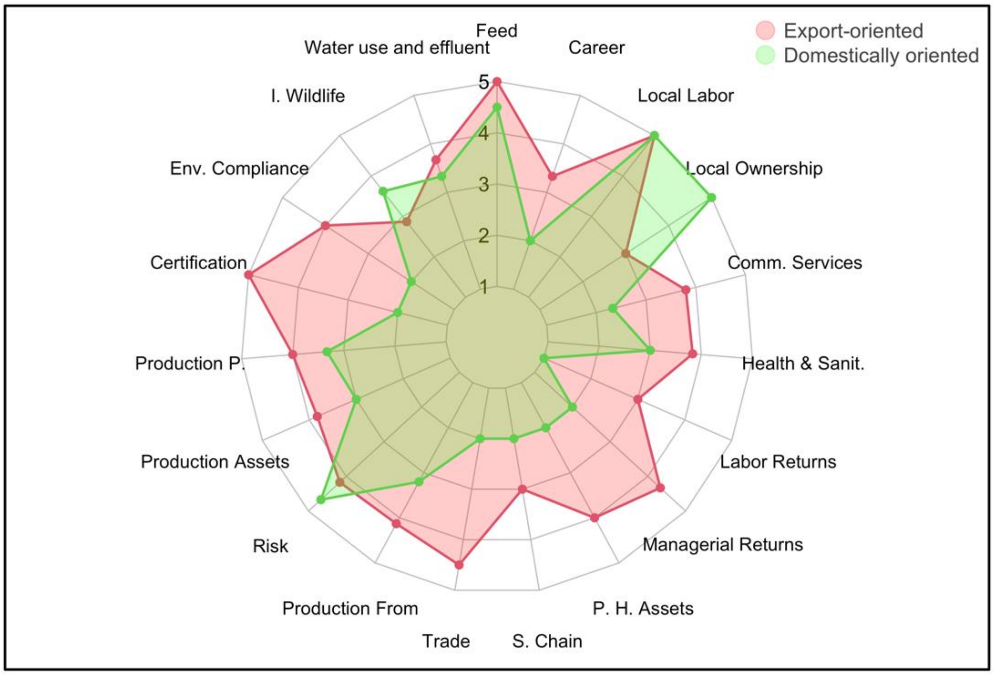

**Figure 4.** Output scores by component for the tilapia aquaculture industry in Huila, Colombia, 2023.

### 4.3. Input performance

The export-oriented sector achieved higher scores than the domestic sector in five dimensions related to Inputs (Tables B.3 and B.4, Appendix B): *Property Rights* (3.17 vs. 1.83), *Co-Management* (3.36 vs. 2.27), *Management* (2.82 vs. 2.41), *Supply Chain* (3.64 vs. 2.93) and *Production* (3.33 vs. 2). However, a statistically significant difference was only observed for the *Co-Management* dimension. Note that both sectors are assigned the same scores under the *Macro Factors* dimension (3.4) as these metrics refer to external economic, environmental, and political factors faced by the two sectors.

Important differences were observed for the components measuring social cohesion in the *Co-Management* dimension (Figure 5): *Collective Action* (4.33 vs. 2), *Participation and Support* (4 vs. 2), *Leadership and Cohesion* (4 vs. 2.5), and *Gender* (2 vs. 2.5). Producers in the export sector collaborate on a much more frequent basis compared to domestic producers. Producers for the domestic market have organized themselves in cooperatives or associations fostering their interests at the local level, but the level of inter-firm engagement is not as high as that of export-oriented producers. As a result, the influence of mid- and small-scale producers on sectorial management and marketing decisions is marginal compared to that of large producers. However, women have less influence in managing exporting businesses, with less participation in decision-making, ownership, and financing.

Marked differences were also observed for metrics related to the *Property Rights* dimension (e.g., *Transferability Index*, *Exclusivity Index*) measuring land and water usage rights conditions (Figure 5). Legal access to water resources is a major issue for small- and medium-scale producers in Huila as it lack of access obstructs formalization of economic activities. Experts – including the leader of a producer association – highlighted the high costs incurred to gain legal access to water resources, even when farms are located on private land. Informal access to water resources creates negative impacts in terms of the type of certifications available to farmers, their access to markets, and the share of production commercialized via contract farming. This disparity between the two sectors may widen in the future with increased international demand for tilapia products and more entry barriers for new farmers.

Lasty, export-oriented producers achieve somewhat higher scores for the components *Scale* (5 vs. 2), *Infrastructure* (3.17 vs. 2.71) and *Contract farming* (4 vs. 2) (Figure 5). This suggests that large-scale producers are capitalizing on factors such as lower per-unit production and transportation costs, improved access to capital, advanced technology adoption in the processing sector, and yield-boosting contract farming arrangements.

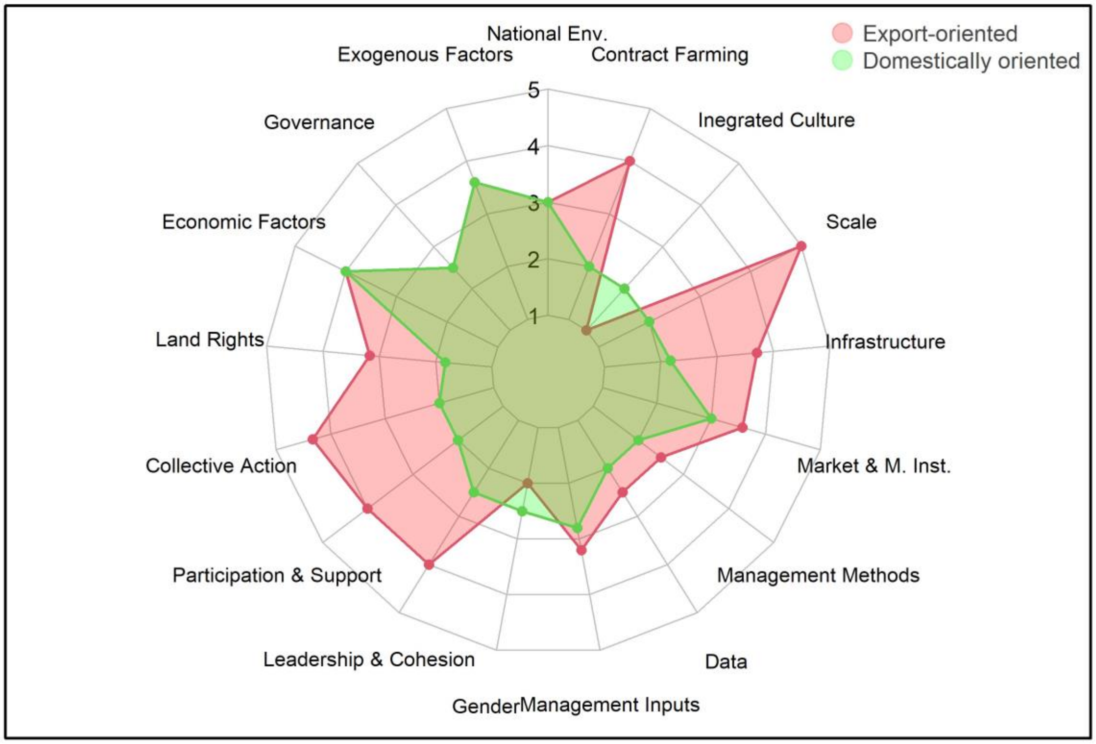

**Figure 5.** Input scores by component for the Tilapia aquaculture industry in Huila, Colombia, 2023.

## 5. Conclusions

This study used the API methodology as an assessment framework to evaluate the sustainability and compare the performance of export-oriented versus domestically oriented tilapia production sectors in the Huila department, an emerging aquaculture hub in the Colombian Southwest. Results show that the export sector exceeds performance benchmarks for the three TBL dimensions while the domestic sector reaches the benchmark for only one dimension (*Environment*). The assessment revealed that the two production sectors are characterized by different production and investment capabilities as well as divergent cost, risk, and vulnerability profiles. The difference in performance scores between the two sectors related to *Economics* and *Community* dimensions is statistically significant. Notable differences were also observed for the *Post-Production* dimension. No significant differences were detected for the Input metric scores, with some minor exceptions (the *Co-Management* dimension and some *Property Rights* metrics).

The economies of scale and other economic advantages enjoyed by large firms provide them with a greater capacity to withstand and recover from environmental and economic shocks. The same shocks could lead to the exit of small- and mid-sized producers. This distinction is particularly relevant in the context of challenges arising from changing climatic conditions, fluctuations in feed supply, and escalating energy costs. To improve the future performance of firms in the industry, efforts by policymakers should be oriented towards improving firm performance related to the Input components of *Governance*, *Land Rights*, *Gender*, *Data*, *Management Methods*, and *Integrated Culture*.

## References

1. Anderson, J.L., Asche, F., Garlock, T. and Eggert, H. 2020. Aquaculture Performance Indicators Manual (version 1.0).
2. Anderson, J.L., C. M. Anderson, J. Chu, J. Meredith, F. Asche, G. Sylvia, M. Smith, D. Anggraeni, R. Arthur, A. Guttormsen, J. McCluney, T. Ward, W. Akpalu, H. Eggert, J. Flores, M. Freeman, D. Holland, G. Knapp, M. Kobayashi, S. Larkin, K. MacLauchlin, K. Schnier, M. Soboil, S. Tveteras, H. Uchida, D. Valderrama, 2015. The Fishery Performance Indicators: A Management Tool for Triple Bottom Line Outcomes, PLOS ONE, 10:5. https://doi.org/10.1371/journal.pone.0122809.
3. Asche, F., Garlock, T.M., Anderson, J.L., Bush, S., Smith, M., Anderson, C.M., Chu, J., Garrett, K., Lem, A., Lorenzen, K., Oglend, A., Tveteras, S., Vannuccini, S., 2018. The three pillars of sustainability in fisheries. Proceedings of the National Academy of Sciences, 115(44): 11221-11225. https://doi.org/10.1073/pnas.1807677115.
4. Asche, F., Eggert, H., Oglend, A., Roheim, C. A., and Smith., M. D., 2022. Aquaculture: Externalities and Policy Options, Review of Environmental Economics and Policy 16(2): 282-305.
5. AUNAP, 2016. [In Spanish]. Resolución Número 00001352 de 18 de agosto de 2016 “Por la cual se establece la clasificación de los acuicultores comerciales en Colombia de acuerdo con la actividad, el sistema y el volumen de producción”.
6. Belton, B., Little, D., Grady, K., 2009. Is Responsible Aquaculture Sustainable Aquaculture? WWF and the Eco-Certification of Tilapia', Society & Natural Resources 22 (9), 840–855.
7. Boyd, C.E., 2003. Guidelines for aquaculture effluent management at the farm-levels. Aquaculture 226, 101–112.
8. Boyd, C.E., Tucker, C., Mcnevin, A., Bostick, K., Clay, J., 2007. Indicators of resource use efficiency and environmental performance in fish and crustacean aquaculture. Rev. Fish. Sci. 15, 27–360.
9. Brugere, C., Bansal, T., Kruijssen, F., and Williams, M., 2023. Humanizing aquaculture development: Putting social and human concerns at the center of future aquaculture development. Journal of the World Aquaculture Society, 54(2), 482–526. https://doi.org/10.1111/jwas.12959.

10. Carrera-Quintana, S. C., Gentile, P., and Girón-Hernández, J., 2022. An overview on the aquaculture development in Colombia: Current status, opportunities and challenges. Aquaculture, 738583
11. Castillo, L. F., 2012. [In Spanish]. Tilapia Roja 2011: Una evolución de 29 años, de la incertidumbre al éxito. Editorial Académica Española. ISBN13: 978-3-8473-5533-5.
12. Cavalett, O., de Queiroz, J.F., Ortega, E., 2006. Emergy assessment of integrated production systems of grains, pig and fish in small farms in the South Brazil. Ecol. Model. 193, 205–224.
13. Chávez, C., Dresdner, J., González, N., Leiva, M., Quiroga, M., 2021. The performance of shared fish stock fisheries under varying institutional and socioeconomic conditions: Evidence from the South Eastern Pacific Anchoveta Fishery, Marine Policy, Volume 125, 104262, ISSN 0308-597X, https://doi.org/10.1016/j.marpol.2020.104262.
14. Chu, J., T. M. Garlock, P. Sayon, F. Asche and J. L. Anderson, 2017. Impact evaluation of a fisheries development project, Marine Policy, Volume 85, Pages 141-149, ISSN 0308-597X, https://doi.org/10.1016/j.marpol.2017.08.024.
15. FAO, 1998. Report of the ad hoc expert meeting on indicators and criteria of sustainable shrimp culture. In: Fisheries Report, 582. FAO, Rome, p. 86.
16. FAO, 1999. Indicators for sustainable development of marine capture fisheries. Technical Guidelines for Responsible Fisheries No. 8. FAO, Rome, p. 68.
17. FAO, 2011. General Fisheries Commission for the Mediterranean Studies and Reviews Indicators for the Sustainable Development of Finfish Mediterranean Aquaculture: Highlights from the Dam Project. No. 90. FAO, Rome, p. 234.
18. FAO. 2022. The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. FAO, Rome, p. 266. https://doi.org/10.4060/cc0461en.
19. Fletcher, W.J., 2012. National Application of Sustainability Indicators for Australian Fisheries – Part 2: Ecosystem based frameworks for aquaculture, multi-fishery and international applications. FRDC Report – Project 2000/145 Part 2. Fisheries Research Report No 235 Department of Fisheries, Western Australia.
20. Feola, G., Agudelo Vanegas, L. A., and Contesse Bamón, B. P., 2015. Colombian agriculture under multiple exposures: a review and research agenda. Climate and Development, 7(3), 278-292.

21. Fezzardi, D., Massa, F., Àvila-Zaragoza, P., Rad, F., Yücel-Gier, G., Deniz, H., Hadj Ali Salem, M., Hamza, H.A., Ben Salem, S., 2013. Indicators for sustainable aquaculture in Mediterranean and Black Sea countries. Guide for the use of indicators to monitor sustainable development of aquaculture. Studies and Reviews. General Fisheries Commission for the Mediterranean No 93. FAO, Rome, p. 60.
22. Folke, C., Kautsky, N., Berg, H., Jansson, A., Troell, M., 1998. The ecological footprint concept for sustainable seafood production: a review. Ecol. Appl. 8, 563–571.
23. Garcia, F., Kimpara, J.M., Valenti, W.C., Ambrosio, L.A., 2014. Energy assessment of tilapia cage farming in a hydroelectric reservoir. Ecol. Eng. 68, 72–79.
24. Garlock, T., F. Asche, J. L. Anderson, T. Bjørndal, G. Kumar, K. Lorenzen, A. Ropicki, M. D. Smith, and R. Tveterås, 2020. A Global Blue Revolution: Aquaculture Growth across Regions, Species, and Countries. Reviews in Fisheries Science and Aquaculture 28 (1): 107–16.
25. Garlock, T., Anderson, J.L., Asche, F., Smith, M. D., Camp, E., Chu, J., Lorenzen, K., Vannuccini, S., 2022. Global insights on managing fishery systems for the three pillars of sustainability. Fish and Fisheries, 23(4), 899-909. https://doi.org/10.1111/faf.12660.
26. Garlock, T., & et al. (under review). Environmental, Economic and Social Sustainability in Aquaculture.
27. Gronroos, J., Seppala, J., Silvenius, F., Makinen, T., 2006. Life cycle assessment of Finnish cultivated rainbow trout. Boreal Environ. Res. 11, 401–414.
28. Hofherr, J., Natale, F., Fiore, G., 2012. An Approach Towards European Aquaculture Performance Indicators. Indicators for Sustainable Aquaculture in the European Union, JRC Technical Reports.
29. Krause, G., Billing, S. L., Dennis, J., Grant, J., Fanning, L., Filgueira, R., Miller, M., Agúndez, J. A. P., Stybel, N., Stead, S. M., Wawrzynski, W., 2020. Visualizing the social in aquaculture: How social dimension components illustrate the effects of aquaculture across geographic scales, Marine Policy, Volume 118, 103985, ISSN 0308-597X, https://doi.org/10.1016/j.marpol.2020.103985.
30. Kumar, G., Engle, C., van Senten, J., Sun, L., Hegde, S., Richardson, B. M., 2023. Resource productivity and costs of aquaculture practices: Economic-sustainability

perspectives from U.S. catfish farming. Aquaculture, Volume 574, 739715, ISSN 0044-8486, https://doi.org/10.1016/j.aquaculture.2023.739715.

31. Madin, E.M.P., Macreadie, P.I., 2015. Incorporating carbon footprints into seafood sustainability certification and eco-labels. Marine Policy 57, 178–181.
32. Marco, J., Valderrama, D., Rueda, M., 2021a. Triple bottom line assessment for the historically underperforming Colombian queen conch fishery, Marine Policy, Volume 125, 104257, ISSN 0308-597X, https://doi.org/10.1016/j.marpol.2020.104257.
33. Marco, J., Valderrama, D., Rueda, M., 2021b. Evaluating management reforms in a Colombian shrimp fishery using fisheries performance indicators, Marine Policy, Volume 125, 104258, ISSN 0308-597X, https://doi.org/10.1016/j.marpol.2020.104258.
34. McCluney, J.K., Anderson, C.M., Anderson, J.L., 2019. The fishery performance indicators for global tuna fisheries. Nature Communications, 10: 1641. https://doi.org/10.1038/s41467-019-09466-6.
35. Merino, M. C., Bonilla, S. P., Bages, F., 2013. [In Spanish]. Diagnóstico del estado de la acuicultura en Colombia. Plan Nacional de Desarrollo de la Acuicultura Sostenible en Colombia AUNAP-FAO. Bogotá, Colombia: Ministerio de Agricultura y Desarrollo Rural.
36. Ministerio de Agricultura y Desarrollo Rural, 2022. [In Spanish]. Acuicultura en Colombia, Cadena de la Acuicultura. Dirección de Cadenas Pecuarias, Pesqueras y Acuícolas. Septiembre 2022, p. 12.
37. Medeiros, M.V., Aubin, J., Camargo, A.F.M., 2017. Life cycle assessment of fish and prawn production: Comparison of monoculture and polyculture freshwater systems in Brazil. J. Cleaner Prod. 156, 528–537.
38. Naylor, R. L., Hardy, R. W., Buschmann, A. H., Bush, S. R., Cao, L., Klinger, D. H., et al., 2021. A 20-year retrospective review of global aquaculture. Nature, 591(7851), 551-563.
39. Parrado, Y. A., 2016. [In Spanish]. Historia de la Acuicultura en Colombia. Revista científica de la Sociedad Española de Acuicultura AquaTIC, (37), p. 60-77.
40. Pillay, T. V. R. , 1997. Economic and social dimensions of aquaculture management, Aquaculture Economics & Management, 1:1-2, 3-11, DOI: https://doi.org/10.1080/13657309709380199.

41. Pullin, R., Froese, R., Pauly, D., 2007. Indicators for the sustainability of aquaculture. In: Bert, T.M. (Ed.), Ecological and Genetic Implications of Aquaculture Activities. Springer, Dordrecht, Germany, pp. 53–72.
42. Troell, M., Costa-Pierce, B., Stead, S., Cottrell, R. S., Brugere, C., Farmery, A. K., Little, D. C., Strand, Å., Pullin, R., Soto, D., Beveridge, M., Salie, K., Dresdner, J., Moraes-Valenti, P., Blanchard, J., James, P., Yossa, R., Allison, E., Devaney, C., and Barg, U., 2023. Perspectives on aquaculture's contribution to the Sustainable Development Goals for improved human and planetary health. Journal of the World Aquaculture Society, 54( 2), 251– 342. https://doi.org/10.1111/jwas.12946.
43. UN (United Nations), 1992. Agenda 21. In: United Nations Sustainable Development, United Nations Conference on Environment & Development. United Nations, New York.
44. UN (United Nations), 2007. Indicators of Sustainable Development: Guidelines and Methodologies, 3rd ed. United Nations, New York.
45. Valenti, W.C., 2008. [In Portuguese]. ¿A aquicultura Brasileira é sustentável? Aquicultura & Pesca. 34 (4), 36–44.
46. Valenti, W.C., Kimpara, J. M., Preto, B. L., Valenti, P. M., 2018. Indicators of sustainability to assess aquaculture systems, Ecological Indicators, Volume 88, 402-413, ISSN 1470-160X, https://doi.org/10.1016/j.ecolind.2017.12.068.
47. Williamson, T.R., Tilley, D.R., Campbell, E., 2015. Emergy analysis to evaluate the sustainability of two oyster aquaculture systems in the Chesapeake Bay. Ecol. Eng. 85, 103–120.

# APPENDIX

## Appendix A. Comprehensive compilation of scores from API assessments.

**Table A.1.** Aquaculture Performance Indicators – Outputs.

| Dimension | Component | Metric | Export-oriented | Domestically oriented |
|---|---|---|---|---|
| | | | Score (Quality) | |
| Environmental Health | Feed-related impacts | Sustainability of aquatic feed sources | 5 (B) | 5 (B) |
| | | Sustainability of non-marine feed ingredients | 5 (B) | 4 (B) |
| | Water use and effluents | Impact of discharge (nutrient emissions) | 4 (A) | 4 (B) |
| | | Non-nutrient emissions | 3 (B) | 3 (B) |
| | | Freshwater use | 4 (B) | 3 (B) |
| | Impacts on wildlife | Wildlife mortality | 2 (C) | 3 (B) |
| | | Benefits to wildlife | 2 (B) | 2 (B) |
| | | Ecological impacts of escaped fish | 2 (B) | 3 (B) |
| | | Genetic impacts of escaped fish | 3 (B) | 3 (B) |
| | | Parasite and disease transmission | 5 (A) | 5 (B) |
| | | Site use | 5 (A) | 5 (B) |
| | | Land Use | 2 (B) | 4 (B) |
| | | GHG emissions | 2 (A) | 4 (B) |
| | Environmental compliance | Compliance with environmental law | 4 (B) | 2 (B) |
| | Certification | Proportion of production with 3rd party certification | 5 (B) | 2 (B) |
| Production Sector | Production Performance | Production Technology | 4 (B) | 2 (B) |
| | | Adult feed | 4 (B) | 4 (B) |
| | | Juvenile survival rate | 5 (B) | 3 (A) |
| | | Juvenile production | 5 (B) | 5 (A) |
| | | Selective breeding and production time | 3 (B) | 1 (C) |
| | | Survival trend | 4 (A) | 3 (A) |
| | | Survival rate | 4 (A) | 2 (A) |
| | | Proportion of production affected by disease and parasites | 4 (B) | 3 (A) |
| | | Proportion of production affected by predation | 4 (B) | 3 (A) |
| | | Proportion of production that escapes | 4 (A) | 4 (A) |
| | | Proportion of production lost to handling and unspecified loss | 4 (B) | 4 (A) |
| | | Production costs compared to historic low | 2 (B) | 2 (B) |
| | Production Assets | Ratio of Asset Value to Gross Earnings | 2 (B) | 2 (B) |
| | | Total Revenue Compared to Historic High | 5 (A) | 5 (A) |

|  |  |  |  |  |
|---|---|---|---|---|
|  |  | Asset (Permit, Quota, etc...) Value Compared to Historic High | 3 (B) | 5 (A) |
|  |  | Borrowing Rate Compared to Risk-free Rate | 4 (A) | 2 (A) |
|  |  | Source of Capital | 4 (B) | 2 (A) |
|  |  | Functionality of Production Capital | 5 (B) | 3 (A) |
|  | Risk | Annual Total Revenue Volatility | 3 (A) | 4 (A) |
|  |  | Annual Production Volatility | 3 (A) | 5 (A) |
|  |  | Intra-annual Production Volatility | 4 (A) | 5 (A) |
|  |  | Annual Price Volatility | 5 (A) | 4 (A) |
|  |  | Intra-annual Price Volatility | 5 (A) | 5 (A) |
|  |  | Spatial Price Volatility | 5 (A) | 5 (B) |
|  |  | Contestability & Legal Challenges | 3 (B) | 2 (B) |
|  | Farm Owners | Earnings Compared to Regional Average Earnings | 5 (B) | 2 (A) |
|  |  | Owner Wages Compared to Non-Aquaculture Wages | 5 (A) | 2 (B) |
|  |  | Education Access | 5 (B) | 3 (A) |
|  |  | Access to Health Care | 5 (B) | 3 (A) |
|  |  | Social Standing of Farm Owners | 4 (C) | 2 (A) |
|  |  | Proportion of Nonresident Owners | 3 (C) | 5 (B) |
|  | Farm Workers | Earnings Compared to Regional Average Earnings | 3 (B) | 1 (A) |
|  |  | Worker Wages Compared to Non-Aquaculture Wages | 3 (A) | 1 (A) |
|  |  | Education Access | 3 (A) | 2 (B) |
|  |  | Access to Health Care | 3 (A) | 3 (B) |
|  |  | Social Standing of Workers | 3 (A) | 1 (B) |
|  |  | Proportion of Nonresident Workers | 5 (B) | 5 (B) |
|  |  | Worker Experience | 3 (C) | 1 (B) |
|  |  | Age Structure of Workers | 4 (A) | 3 (B) |
|  |  | Proportion of income spent on food | 3 (A) | 3 (A) |
| Post-Harvest Sector | Markets | Farm-gate Price Compared to Historic High | 5 (A) | 5 (A) |
|  |  | Final Market Use | 3 (A) | 3 (B) |
|  |  | International Trade | 5 (B) | 1 (A) |
|  |  | Final Market Wealth | 5 (B) | 3 (A) |
|  |  | Wholesale Price Compared to Similar Products | 3 (A) | 2 (A) |
|  |  | Capacity of Firms to Export to the US & EU | 5 (A) | 2 (B) |
|  |  | Farm-gate to Wholesale Marketing Margins | 4 (A) | 2 (A) |
|  |  | Food safety | 5 (A) | 5 (B) |
|  | Supply Chain Performance | Processing Yield | 5 (A) | 2 (A) |
|  |  | Shrink | 2 (C) | 4 (B) |
|  |  | Capacity Utilization Rate | 5 (B) | 5 (A) |
|  |  | Product Improvement | 5 (B) | 3 (A) |
|  |  | Proportion of production sold fresh | 4 (B) | 3 (A) |
|  |  | Sanitation | 5 (B) | 2 (B) |
|  |  | Local Support Businesses | 2 (B) | 4 (B) |

| | | | | |
|---|---|---|---|---|
| | | Availability of Support Businesses | 3 (B) | 4 (B) |
| | | Proportion of feed ingredients sourced from socially responsible sectors | 4 (B) | 4 (A) |
| | Post-Harvest Assets | Borrowing Rate Compared to Risk-free Rate | 4 (A) | 2 (B) |
| | | Source of Capital | 4 (B) | 3 (B) |
| | | Age of Facilities | 4 (B) | 3 (B) |
| | Processing Managers | Earnings Compared to Regional Average Earnings | 4 (B) | 2 (B) |
| | | Manager Wages Compared to Non-fish farming Wages | 4 (B) | 2 (B) |
| | | Education Access | 5 (B) | 4 (B) |
| | | Access to Health Care | 4 (B) | 4 (B) |
| | | Social Standing of Processing Managers | 4 (C) | 2 (B) |
| | | Nonresident Ownership of Processing Capacity | 3 (B) | 4 (B) |
| | Processing Workers | Earnings Compared to Regional Average Earnings | 3 (B) | 2 (B) |
| | | Worker Wages Compared to Non-fish farming Wages | 3 (A) | 2 (B) |
| | | Education Access | 3 (A) | 2 (B) |
| | | Access to Health Care | 3 (A) | 3 (B) |
| | | Social Standing of Processing Workers | 3 (C) | 2 (B) |
| | | Proportion of Nonresident Employment | 5 (B) | 4 (B) |
| | | Worker Experience | 3 (C) | 4 (B) |

**Table A.2.** Aquaculture Performance Indicators – Inputs.

| Dimension | Component | Metric | Export-oriented | Domestically oriented |
|---|---|---|---|---|
| | | | Score (Quality) | |
| Macro Factors | National Environment | Environmental Performance Index (EPI) | 3 (A) | 3 (A) |
| | Exogenous Factors | Natural Disasters and Catastrophes | 4 (A) | 4 (B) |
| | | Drought | 2 (B) | 2 (B) |
| | | Pollution Shocks and Accidents | 3 (A) | 4 (B) |
| | | Level of Chronic Pollution - Production Effects | 4 (A) | 3 (B) |
| | | Level of Chronic Pollution - Consumption Effects | 5 (A) | 5 (B) |
| | Governance | Governance Quality | 3 (A) | 3 (A) |
| | | Governance Responsiveness | 2 (A) | 2 (A) |
| | Economic Conditions | Index of Economic Freedom | 5 (A) | 5 (A) |
| | | Gross Domestic Product (GDP) Per Capita | 3 (A) | 3 (A) |
| Property Rights | Land Rights | Proportion of Production with Property or Lease Right | 5 (B) | 4 (A) |
| | | Transferability Index | 3 (B) | 1 (A) |

| | | | | |
|---|---|---|---|---|
| | | Security Index | 3 (A) | 2 (A) |
| | | Durability Index | 3 (A) | 2 (A) |
| | | Flexibility Index | 2 (A) | 1 (A) |
| | | Exclusivity Index | 3 (B) | 1 (B) |
| Co-management | Collective Action | Proportion of Farmers in Industry Organizations | 5 (B) | 1 (B) |
| | | Farmer Organization Influence on Management | 4 (B) | 3 (B) |
| | | Farmer Organization Influence on Business & Marketing | 4 (B) | 2 (B) |
| | Participation | Days in Stakeholder Meetings | 4 (B) | 2 (B) |
| | | Industry Financial Support for Management | 4 (B) | 2 (B) |
| | Community | Leadership | 4 (B) | 2 (B) |
| | | Social Cohesion | 4 (B) | 3 (B) |
| | Gender | Business Management Influence | 3 (B) | 3 (B) |
| | | Resource Management Influence | 1 (B) | 3 (B) |
| | | Labor Participation in Production Sector | 1 (B) | 2 (B) |
| | | Labor Participation in Processing Sector | 3 (A) | 2 (B) |
| Management | Management Inputs | Management Expenditure Compared to Farm-Gate Value | 4 (A) | 4 (B) |
| | | Enforcement Capability | 3 (B) | 2 (B) |
| | | Management Jurisdiction | 3 (C) | 3 (C) |
| | | Generations separated by selective breeding | 1 (A) | 1 (A) |
| | | Coordination of regulatory authorities | 2 (B) | 2 (B) |
| | | Level of Subsidies | 2 (B) | 3 (A) |
| | | Percentage of marine ingredients | 5 (A) | 4 (A) |
| | | Traceability of feed inputs | 4 (B) | 4 (B) |
| | | R&D | 4 (A) | 3 (A) |
| | | Private R&D | 4 (A) | 2 (B) |
| | Data | Biological data collection | 3 (B) | 3 (B) |
| | | Market and economic data | 2 (A) | 2 (A) |
| | Management Methods | Regional disease control | 2 (B) | 2 (B) |
| | | Genetic management | 1 (B) | 1 (B) |
| | | Discharge/effluent control | 2 (B) | 2 (B) |
| | | Antibiotic use | 4 (B) | 3 (B) |
| | | Antibiotic use practices | 4 (B) | 2 (B) |
| | | Food safety services | 2 (B) | 2 (B) |
| | | Animal welfare/handling practices | 2 (B) | 2 (B) |
| | | Damage compensation/management | 2 (B) | 2 (B) |
| | | Access to Water | 4 (B) | 2 (B) |
| | | Land or water zoning/management | 2 (B) | 2 (B) |
| Supply Chain | | Transparency of Farm-gate price | 4 (A) | 4 (B) |

| | | | | |
|---|---|---|---|---|
| | Markets & Market Institutions | Availability of Farm-gate Price & Quantity Information | 3 (B) | 3 (B) |
| | | Number of Buyers | 1 (B) | 4 (A) |
| | | Degree of Vertical Integration | 5 (B) | 1 (B) |
| | | Level of Tariffs | 5 (A) | 4 (B) |
| | | Level of Non-tariff Barriers | 4 (B) | 5 (B) |
| | | Contribution to Economy | 3 (B) | 1 (B) |
| | Infrastructure | International Shipping Service | 5 (A) | 4 (B) |
| | | Road Quality Index | 3 (A) | 3 (A) |
| | | Technology Adoption in Production | 3 (B) | 2 (B) |
| | | Technology Adoption in Processing | 4 (B) | 3 (A) |
| | | Extension Service | 4 (B) | 2 (B) |
| | | Reliability of Utilities/Electricity | 3 (B) | 2 (A) |
| | | Access to Ice & Refrigeration | 4 (B) | 3 (A) |
| Production | Producer characteristics | Scale of farm | 5 (B) | 2 (B) |
| | | Integrated culture | 1 (B) | 2 (A) |
| | | Production under contract farming | 4 (B) | 2 (A) |

## Appendix B. Supplementary tables.

**Table B.1.** Aquaculture Performance Indicators: Outputs (Triple Bottom Line).

| DIMENSION | COMPONENT | EXPORT-ORIENTED | DOMESTICALLY ORIENTED | DIFFERENCE (%) |
|---|---|---|---|---|
| Environmental | Feed | 5.00 | 4.50 | 0.50 (10%) |
| | Water use and effluent | 3.67 | 3.33 | 0.33 (9.1%) |
| | Impacts on wildlife | 3.25 | 3.75 | -0.50 (-15.4%) |
| | Env. Compliance | 4.00 | 2.00 | 2.00 (50%) |
| | Certification | 5.00 | 2.00 | 3.00 (60%) |
| | **Dimension average** | **4.18** | **3.12** | **1.07 (25.5%)** |
| Economic | Production Performance | 4.00 | 3.15 | 0.85 (21.2%) |
| | Production Assets | 3.83 | 3.17 | 0.67 (17.4%) |
| | Risk | 4.17 | 4.67 | -0.50 (-12.0%) |
| | Product Form | 4.13 | 3.38 | 0.75 (18.2%) |
| | Trade | 4.50 | 2.00 | 2.50 (55.6%) |
| | Supply Chain Perform. | 3.00 | 4.00 | -1.00 (-33.3%) |
| | Post-Harvest Assets | 4.00 | 2.67 | 1.33 (33.3%) |
| | **Dimension average** | **3.95** | **3.29** | **0.66 (16.6%)** |
| Community | Managerial Returns | 4.33 | 2.00 | 2.33 (53.8%) |
| | Labor Returns | 3.00 | 1.50 | 1.50 (50.0%) |
| | Health & Sanitation | 3.83 | 3.00 | 0.83 (21.7%) |
| | Community Services | 3.80 | 2.60 | 1.20 (31.6%) |
| | Local Ownership | 3.00 | 4.50 | -1.50 (-50.0%) |
| | Local Labor | 5.00 | 4.50 | 0.50 (10.0%) |
| | Career | 3.33 | 2.67 | 0.67 (20.0%) |
| | **Dimension average** | **3.76** | **2.97** | **0.79 (21.0%)** |

**Table B.2.** Aquaculture Performance Indicators: Outputs (Sector).

| DIMENSION | COMPONENT | EXPORT-ORIENTED | DOMESTICALLY ORIENTED | DIFFERENCE (%) |
|---|---|---|---|---|
| Environmental | Feed | 5.00 | 4.50 | 0.50 (10%) |
| | Water use and effluent | 3.67 | 3.33 | 0.33 (9.1%) |
| | Impacts on wildlife | 3.25 | 3.75 | -0.50 (-15.4%) |
| | Env. Compliance | 4.00 | 2.00 | 2.00 (50%) |
| | Certification | 5.00 | 2.00 | 3.00 (60%) |
| | **Dimension average** | **4.18** | **3.12** | **1.07 (25.5%)** |
| Production sector | Production Performance | 3.92 | 3.00 | 0.92 (23.4%) |
| | Production Assets | 3.83 | 3.17 | 0.67 (17.4%) |
| | Risk | 4.00 | 4.29 | -0.29 (-7.1%) |
| | Owners | 4.50 | 2.83 | 1.67 (37.0%) |
| | Crew | 3.33 | 2.22 | 1.11 (33.3%) |
| | **Dimension average** | **3.92** | **3.10** | **0.82 (20.8%)** |
| Post-production sector | Markets | 4.29 | 2.57 | 1.71 (40.0%) |
| | Supply Chain Performance | 4.00 | 3.60 | 0.40 (10.0%) |
| | Post Harvest Assets | 4.00 | 2.67 | 1.33 (33.3%) |
| | Processing Managers | 4.00 | 3.00 | 1.00 (25.0%) |
| | Processing Workers | 3.29 | 2.71 | 0.57 (17.4%) |
| | **Dimension average** | **3.91** | **2.91** | **1.00 (25.6%)** |

**Table B.3.** Inputs by dimension. Export-oriented versus domestically oriented tilapia production sectors in Huila. Year 2023.

| | **Export-oriented** | **Domestically oriented** | **Mann-Whitney U test** | | | |
|---|---|---|---|---|---|---|
| **Macro factors** | | | W | p-value | significance | effect size |
| Median | 3 | 3 | | | no | |
| IQR | 1 | 1 | | | | |
| Mean | 3.4 | 3.4 | | | | |
| SD | 1.08 | 1.08 | | | | |
| # Metrics | 10 | 10 | | | | |
| **Property rights** | | | W | p-value | significance | effect size |
| Median | 3 | 1.5 | 6 | p = 0.057 | no | r = 0.57 (large) |
| IQR | 1 | 1 | | | | |
| Mean | 3.17 | 1.83 | | | | |
| SD | 0.98 | 1.17 | | | | |
| # Metrics | 6 | 6 | | | | |
| **Co-management** | | | W | p-value | significance | effect size |
| Median | 4 | 2 | 15 | p = 0.017 | * | r = 0.51 (moderate) |
| IQR | 1 | 1 | | | | |
| Mean | 3.36 | 2.27 | | | | |
| SD | 1.29 | 0.65 | | | | |
| # Metrics | 11 | 11 | | | | |
| **Management** | | | W | p-value | significance | effect size |
| Median | 2.5 | 2 | 195 | p = 0.243 | no | r = 0.18 (small) |
| IQR | 1 | 1 | | | | |
| Mean | 2.82 | 2.41 | | | | |
| SD | 1.14 | 0.85 | | | | |
| # Metrics | 22 | 22 | | | | |
| **Supply chain** | | | W | p-value | significance | effect size |
| Median | 4 | 3 | 64.5 | p = 0.116 | no | r = 0.30 (moderate) |
| IQR | 1 | 2 | | | | |
| Mean | 3.64 | 2.93 | | | | |
| SD | 1.08 | 1.21 | | | | |
| # Metrics | 14 | 14 | | | | |
| **Production** | | | W | p-value | significance | effect size |
| Median | 4 | 2 | 3 | p = 0.643 | no | r = 0.28 (small) |
| IQR | 2 | 0 | | | | |
| Mean | 3.33 | 2 | | | | |
| SD | 2.08 | 0 | | | | |
| # Metrics | 3 | 3 | | | | |

Note: *, **, and *** indicate significance in mean differences at 10%, 5%, and 1% levels, respectively. Wilcoxon test statistic (W), Interquartile range (IQR), and Standard Deviation (SD).

**Table B.4.** Aquaculture Performance Indicators: Inputs.

| INDICATOR | EXPORT-ORIENTED | DOMESTICALLY ORIENTED | DIFFERENCE (%) |
|---|---|---|---|
| National Environment | 3.00 | 3.00 | 0.00 (0%) |
| Exogenous Factors | 3.60 | 3.60 | 0.00 (0%) |
| Governance | 2.50 | 2.50 | 0.00 (0%) |
| Economic Factors | 4.00 | 4.00 | 0.00 (0%) |
| Land Rights | 3.17 | 1.83 | 1.33 (42.1%) |
| Collective Action | 4.33 | 2.00 | 2.33 (53.8%) |
| Participation & Support | 4.00 | 2.00 | 2.00 (50%) |
| Leadership & Cohesion | 4.00 | 2.50 | 1.50 (37.5%) |
| Gender | 2.00 | 2.50 | -0.50 (-25.0%) |
| Management Inputs | 3.20 | 2.80 | 0.40 (12.5%) |
| Data | 2.50 | 2.50 | 0.00 (0%) |
| Management Methods | 2.50 | 2.00 | 0.50 (20.0%) |
| Markets & Market Institutions | 3.57 | 3.14 | 0.43 (12.0%) |
| Infrastructure | 3.71 | 2.71 | 1.00 (26.9%) |
| Scale | 5.00 | 2.00 | 3.00 (60%) |
| Integrated Culture | 1.00 | 2.00 | -1.00 (-100%) |
| Contract Farming | 4.00 | 2.00 | 2.00 (50%) |