DEVELOPMENT OF AN EVALUATION INSTRUMENT FOR GOOD MANAGEMENT PRACTICES IN TILAPIA (*OREOCHROMIS NILOTICUS*) POND AQUACULTURE IN COSTA RICA

María del Pilar Arguedas Rodríguez
Costa Rican Institute of Fisheries and Aquaculture, Costa Rica
pilararguedas@hotmail.com

Supervisors:
David Benhaïm, Hólar University: benhaim@holar.is
Elvar Steinn Traustason, Arctic Fish: et@afish.is

ABSTRACT

Tilapia farming in Costa Rica is growing, and environmental problems will escalate without proper aquaculture regulation and compliance monitoring. To support sustainable aquaculture, farm performance must be measured to identify, analyze, and address barriers that prevent sustainable development in tilapia production. A diagnostic instrument was designed to verify the degree of management performance of tilapia aquaculture. A baseline of Management Subjects and Guidelines was established based on literature review and expert consultations. The instrument was tested on 50 pond-system tilapia farms across the seven provinces of Costa Rica. Descriptive statistics were used to analyze compliance in each evaluated management subject. Pearson's multiple correlations were then conducted to assess any potential interactions between the subjects. The results showed that 31 farms were in critical condition, 18 in regular condition, and 1 in good condition. Key challenges included permits, ecosystem care, and training, with biosecurity being positively correlated with all subjects. Most farmers keep businesses on a small scale, with direct sales to local buyers, and lack records of production and profits. Medium- and large-scale producers have more capacity to comply with guidelines, indicating that regulation cannot be the same for each scale company. Authorization processes need restructuring to include microproducers with simpler requirements. Aquaculture planning programs should include capacity support, progress monitoring, evaluation of results, and continuous capacity building for technicians to improve the results during the training of farmers. The instrument will help develop national policies, define appropriate training programs, and increase the performance of farms, and in the future, can be useful as a tracking mechanism.

Key words: evaluation instrument, management performance, tilapia aquaculture, Costa Rica

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1 INTRODUCTION

1.1 Background

In 2020, global aquaculture production reached 122.6 million tons, valued at 281.5 billion USD. Of this total, 49.9 million tons (valued at 109.8 billion USD) were produced through inland finfish aquaculture. Aquatic food now accounts for 17% of the animal protein consumed globally, with the apparent per capita consumption rising to 20.2 kg in 2020, according to resources provided by fisheries and aquaculture production (FAO, 2022).

The most extended inland farming method for finfish worldwide is earth ponds, followed by cages and pens. From which the highest inland aquaculture production species are Grass Carp (*Ctenopharyngodon idellus*), Silver Carp (*Hypophthalmichthys molitrix*) and Nile Tilapia (*Oreachromis niloticus*) with a production report in 2020 of 5,791 tons (11.8%), 4,896 tons (10%) and 4,407 tons (9%), respectively (FAO, 2022).

Socioeconomic development is the principal reason why aquaculture was promoted since 1960 in Costa Rica. It started with the introduction of freshwater species, positioning them to reach significant production volumes and impelling farming technologies. Ten years later marine aquaculture started with shrimp farming, which has expanded due to conversion of salt pans, and has transformed into an important productive activity for coastal areas. Research in aquaculture continues, trying to cultivate and expand production with other freshwater and marine species, but still has not reached important productive growth (INCOPESCA & SEPSA, 2019; Peña & Chacón, 2019). Currently, the two larger groups produced in Costa Rica correspond to Nile tilapia farming with 71% of national production (14,800 tons) and 14.4% of white leg shrimp (3,000 tons) (OCDE, 2019; FAO, 2021).

In 2018 aquaculture production in Costa Rica represented 0.018% of world production, with an annual increase of 4.33% from 2000 to 2018, from 9,708 tons to 20,820 tons (FAO, 2021). Agriculture, silviculture, and fisheries contributed 4.5% to GDP in 2021, creating employment for 12.8% of the workforce (FIDA, 2021). But because of the production value, a big amount is exported, and not consumed locally (FAO, 2021). In 2021, 24,200 tons of fish products were exported mostly to the United States, Panamá, El Salvador, Belgium, Hong Kong, and the United Kingdom, valued at 127 million USD. Imports however amounted to 68,500-ton, valued at 192 million USD, primarily from the United States, China, Ecuador, and Panamá (INCOPESCA, 2022; PROCOMER, 2021).

Costa Rica consumption of animal protein has been increasing, from 1993 to 2013 fish and seafood intake was doubled (2.4% to 4.9%), a significant increase in comparison with other kind of protein sources. The per capita fish consumption increased from 4.9 kg in 1997 to 18.5 kg in 2017, the highest in Central America and the fourth highest in Latin America and the Caribbean (FAO, 2021).

Thirty-five percent of this consumption is freshwater fish, but most of this comes from net import and fewer from domestic sources (FAO, 2021). Because of that, inland finfish production in Costa Rica has been decreasing, in response to the increase in imports of fish from Asia, especially tilapia and pangasius catfish (Peña y Chacón, 2019).

Fisheries have been declining in recent years, and there is a need to develop productive alternatives to reduce unemployment and poverty in rural areas. For this reason and to satisfy the seafood consumption demand, the expectations are to increase aquaculture production in

Costa Rica by strengthening technical capacity in farmers (FAO, 2021; OCDE, 2019; Peña y Chacón, 2019). Considering population increase, aquaculture in the country would need to grow 3 % per year until 2030 to generate enough extra supply (FAO, 2021).

For this reason, Costa Rica has a Strategic Plan for Aquaculture in the country (PEAC), a management instrument which aims to create the necessary conditions to promote an organized, sustainable, and environmentally balanced development of both continental and marine aquaculture.

Recently, Costa Rica signed a financing contract with the International Bank for Reconstruction and Development (BIRF) for the Program called "Sustainable Development of Fisheries and Aquaculture in Costa Rica (PDSPA-CR)", approved by Law No. 10037; the execution of which is overseen by the Institute of Fisheries and Aquaculture in Costa Rica. This program aims to improve the management of fisheries and aquaculture resources prioritized and increase the economic benefits of these resources for the local and national market in Costa Rica.

1.2 Problem statement:

The global production of aquatic food is expected to grow by 13% by 2030. Aquaculture could satisfy human necessity and demand for more healthy and nutritious food (FIPA 2018). But this expansion of aquaculture is causing degradation of ecosystems, because of the introduction of species to new environments, affect water quality because of farm waste, the use of chemical products, the abuse of antibiotic medication even triggering conflicts with artisanal fishing (Ovando, 2013; FIPA, 2018).

Aquaculture must develop by maintaining the aquatic ecosystem's well-being, reducing contamination, protecting biodiversity, and promoting social equality. It must develop efficiently, be resilient, and sustainable. For this, it is required to update aquaculture governance, improve planning, legal and institution frameworks and policies as intended for the new vision of Blue Transformation. This trend is looking for expansion and intensification of sustainable aquaculture, effective management of fisheries, and updated value chains (FAO, 2022). Also, growth of aquaculture must include alternatives that allow mitigate the effects of environmental deterioration (Ramírez, 2010).

Traditional aquaculture in Costa Rica is mainly done in ponds, the most important species is Nile tilapia, with industrial, medium, and small-scale producers (Peña y Chacón, 2019). The demand for tilapia has increased, and can be found more commonly in markets, supermarkets, fairs, restaurants, and recreational fishing ponds. It is marketed as whole fish, fillets, or belly portions (Peña y Chacón, 2019).

With population expansion and the growing demand for protein, the food production sector is more aware of climatic change and environmental risks. Acknowledging that generating more food per unit of land area will be needed to avoid more natural habitats to be affected, but it comes with the risk of pollution due to waste accumulation (Boyd et al., 2020).

Ponds systems in Costa Rica have several conflicts with the use of water, farmers don't have authorization to use it, and they have poor water waste management or none. To return the wastewater without previous treatment is a concern for communities because of the impact it could cause to the quality of water of rivers and lakes, and how they would affect natural populations (Chacón & Santamaría 2007).

A large quantity of fish escapes from farms are impacting native fish stocks in rivers and lakes, because of the absence of filters and controls on the water outlet system of the ponds. The environment authorities are doing stock assessments of freshwater native fish species found in protected areas and are concerned about the amount of tilapia they found, and the decrease in native fish populations of ecological and economic importance (SINAC, 2022).

Tilapia farming is growing, and there will be more environmental problems if there is no proper aquaculture regulation and compliance monitoring. It is important to include alternatives that mitigate environmental deterioration, and the best solution is to tackle this in a comprehensive management framework, which considers balance between economic wellness, social and environmental development (Ramírez, 2010).

An overview of the aquaculture agribusinesses' situation and necessities can be created establishing a general model indicator to quantify the performance of this productive activity, and the results of capacitation given by educational organizations (Monge, 2019). Institutions need an assessment based on scientific criteria to generate action plans. Identifying, analyzing, and prioritizing critical points in tilapia production, processing, and commercialization chain, preventing their sustainable development (Chacón & Santamaría, 2007).

This project proposes to support national institutions to ensure good management practices in tilapia aquaculture and help national production by developing an evaluation instrument for management practices in pond aquaculture of tilapia, considering the aquaculture scales defined by Costa Rica regulation. The instrument is going be useful for aquaculture farmers to identify the main management problems, so they can prioritize actions and goals to develop their production. This evaluation instrument aims to present a proposal to add into regulation requirements for aquaculture authorizations in Costa Rica.

1.3 General Objective

Develop a diagnosis evaluation instrument considering small, medium, and large production scale to verify the performance in good management practices in Nile tilapia (*Oreochromis niloticus*) ponds aquaculture systems in Costa Rica.

1.4 Specific Objectives

1. Elaborate a diagnosis instrument of good management practices considering small, medium, and large production scale for tilapia farms with ponds aquaculture system.

2. Validate the instrument in tilapia farms with pond systems distributed around Costa Rica.

3. Assess the main management problems in small scale tilapia pond farming using the evaluation instrument.

2 LITERATURE REVIEW

2.1 Sustainable Aquaculture

Nowadays there is more awareness of environmental issues, and an interest in reducing the footprint caused by aquaculture practices. Sustainability has been defined by the United Nations World Commission on Environment and Development as *"the use of the environment and resources that meets the needs of the present without compromising the ability of future"* (Boyd *et al.*, 2020, p. 3).

Environment sustainability looks for alternatives to manage, reduce and efficiently use resources such as energy, water, land, feed, and fertilizer. And seeks to achieve better control over the negative impacts on local ecosystems (Boyd et al., 2020).

Aquaculture can achieve sustainability if it manages to reduce and avoid pollution on localized environments, and use more efficiently natural resources such as fossil, fuel, water, and land. Activities should look for carbon dioxide remotion with carbon sequester species, to recover waste, decrease water use by using filtration, recirculation, and water treatments. Utilization of alternative energy sources, and use of feed with alternative ingredients that grow on waste and by-products of other activities (Boyd et al., 2020).

2.2 Aquaculture authorization in Costa Rica

Aquaculture has a robust legal framework to support the development of the activity in Costa Rica. To operate, every farm requires an ´Authorization for the Farming of Aquatic Organisms in inland and marine waters´, issued by INCOPESCA (Fisheries and Aquaculture Institute of Costa Rica) regulated by the Law of Fisheries and Aquaculture (N° 8436) and the Regulation of Fisheries and Aquaculture Law N° 8436 (Exec. Order N°36782). To obtain it, they must present several documents that link the authorization with other institutions:

1. An environmental impact assessment approval given by SETENA (National Environmental Technical Secretariat) regulated by the General Regulation on Environmental Impact Assessment Procedures (EIA) (Exec. Order N°31849).
2. A water use concession approved by the Water Directorate of the Ministry of Environment and Energy (MINAE) regulated by the Law of Waters (Law N° 276).
3. A technical document must be provided with information about the farm infrastructure, production planning, and management practices (Law of Fisheries and Aquaculture, 2005; Regulation to the fishing and aquaculture Law N° 8436, 2011).

Some of this paperwork is for environmental management compromises, for example the technical document has a segment with biosecurity measures for the project. The environmental impact assessment document requests an environmental compliance plan, looking for proposals to lower carbon footprint.

The government institutions lack controls, and pressure farmers with high levels of administrative paperwork, which is why most of the aquaculture farmers operate illegally and disregard environmental impacts on the natural water sources and ecosystems (OCDE, 2019). In most cases, farmers lack knowledge about the culture of fishes, and about good practices for farming. Therefore, the aim is to give technical assistance, and training to aquacultures, and to encourage them to complete the required paperwork for the aquaculture authorization.

2.3 Aquaculture production scales

Aquaculture in Costa Rica has several production and purpose scales described in the Regulation of Fisheries and Aquaculture Law N° 8436 (Exec. Order N°36782):

- Domestic aquaculture: Farming for subsistence purposes, self-consumption, not for commercial purposes.
- Small scale aquaculture: Farming of aquatic organisms from which production is commercialized exclusively to production unit levels, producer-consumer direct, the production doesn't exceed 5 tons a year.
- Medium scale aquaculture: Farming of aquatic organisms from which production is commercialized exclusively to production unit levels, producer-consumer direct, the production doesn´t exceed 50 tons a year.
- Large scale aquaculture: Farming of aquatic organisms from which production is commercialized exclusively to production unit levels, producer-consumer direct or to internal and external markets, the production exceeds 50 tons a year.

For FAO small-scale is an aquaculture system with limited investments in livelihood assets, small investment in operational costs, such as family labor, infrastructure, and capital (FAO, 2009).

Tilapia farming in Costa Rica is carried out mostly as semi-intensive and extensive production, and intensive production is in the minority by industrial sector. A survey carried out in 2016 by FAO, shows that most tilapia farms with ponds systems are small-scale production (81%), few have a medium-scale production capacity (12%), and mainly two companies (3%) carried out large scale production (Figure 1).

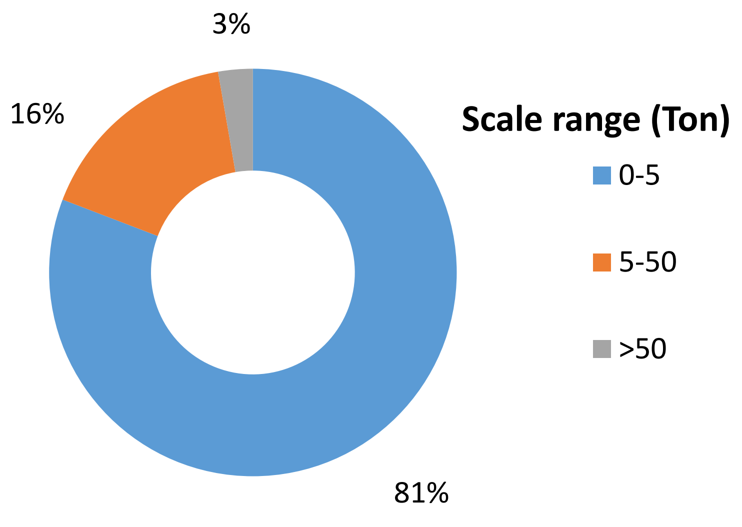

Figure 1. Quantity of tilapia pond farms by production scale. Data source from Diagnosis of the Aquaculture Sector in Costa Rica (Project TCP/COS/ 3501-. FAO, 2016).

2.4 Aquaculture and Environment Management Regulations in Costa Rica

Environment regulations in Costa Rica are wide and cover many pollution issues. The main law for the creation of all other regulations about environmental pollution issues is the Law for Comprehensive Waste Management (N° 8899). In 2014, according to an analysis of the State of the Nation on environmental regulations in Costa Rica, many legal dispositions to regulate fishing and aquaculture sectors where set, but very few of them implied significant changes in environmental management (INCOPESCA & SEPSA, 2019).

Regulations are more focused on reducing health risks during aquaculture activities, led by the National Animal Health Service Institute (SENASA), which has developed procedures and regulations to normalize aquaculture from a sanitary perspective. SENASA is responsible for the control of import of seeds, the monitoring of residues in the water discharged by aquaculture plants, and the quality of food, the regulation and use of medicines and antibiotics, and the oversight and control of diseases (INCOPESCA & SEPSA, 2019).

The principal control system for SENASA is the Operative Veterinary Certificate that every primary producer needs. Several manuals for aquaculture with a sanitary vision have been created, from which only two will be highlighted:

- Manual of Biosecurity Good Practices for Primary Aquaculture Production Establishment, which is a practical guide aimed only on prevention and elimination of diseases, pathogens, and vectors for different aquaculture species.
- Manual of Good Practices for Tilapia and Trout Primary Aquaculture Production Establishment, with some guidelines for good farm management.

Even though these two manuals exist, the main problems are that they are not obligatory, they are not linked with aquaculture authorization given by INCOPESCA. Farmers don’t have knowledge of their existence. In addition, they are not made for every production scale and capacity, not everything can be done by domestic and small-scale aquaculture. They lack a more environmental vision, as they only focus on prevention of diseases and sanitary issues.

Sustainable aquaculture can be developed under criteria and techniques appropriate to mitigate possible negative effects while remaining economically viable and socially acceptable. Environmental management of aquaculture should focus on mitigating the negative environmental aspects generated by this activity. Success can be achieved with adequate planning, environmental impact evaluations, contemplating water quality, soil, and biodiversity, for mitigation measures (Ramírez, 2010).

2.5 Management problems in aquaculture

2.5.1 Production management problems

Research by Chacón & Santamaría (2007) on critical points in aquaculture in Costa Rica's northern region identified several issues related to inadequate management along the production chain. These include insufficient technical assistance, lack of grading or systematic sampling, inadequate feeding control, and poor harvest planning. Farmers were found to poorly manage water sources, had limited knowledge of stocking density and biological loads, lacked water concessions, and did not treat wastewater. Additionally, there was an absence of proper record-keeping, poor seed quality and management, insufficient understanding of pathogens, and a need for greater training in fish processing, industrialization, accounting, and business administration. Furthermore, farmers demonstrated limited knowledge of disease-causing agents and disease control, and there was no evidence of collaboration or associations between them.

2.5.2 Escapes of fish and impacts.

Introduction of non-native species causes space competition, hybridization, trophic chain alterations, diseases, and parasites (Ramírez, 2010). Tilapia is one of the most noticeable invasive species in freshwater ecosystems, with a high fecundity and larval survival rate, tolerant in extreme conditions of low oxygen, with the presence of various pollutants (Vicente & Fonseca-Alves, 2013; Schmitter, 2006).

Tilapia is an omnivorous species, can feed on detritus, destroys vegetation from the lake bottom and sometimes is a predator on the eggs and young fishes of other species. In high amounts it can cause organic contamination because of the feces, and even be the reason for introduction of parasites to natural environments. It is proven that the introduction of this species in a good environment, reproduces in abundance, and is the major cause of biodiversity loss. As happened in Lake Nicaragua and Lake Chichancanab in Mexico, which caused the extinction of native species (Vicente & Fonseca-Alves, 2013; Schmitter, 2006). In Costa Rica this organism has caused changes in the dynamics of fish populations in Caño Negro National Reserve, in the Arenal lagoon and in Cañas canton rivers and surroundings (Hernández, 2002).

A population study presented in wildlife Mix Refuge Caño Negro, in Costa Rica, has proved that tilapia is the third most abundant fish species found in the refuge. Tilapia is a species that is not native to Costa Rica, but was introduced for aquaculture, and due to poor management on farms it is observed in rivers and is developing successfully. This species is causing a possible impact on a lagoon of national value, with a wetland category, a breeding area for many species of fish. The same thing is happening with the presence of Tropical Gar (*Atractosteus tropicus*), a species only distributed on the northern Caribbean slope, and whose populations are being diminished in the last years (SINAC, 2022).

2.5.3 Aquaculture water waste and impacts.

Aquaculture can cause environmental problems such as pollution of surrounding waters with nutrients, solid wastes, and chemicals (antibiotics and pesticides) used for disease control in the fishponds (Justino *et al.*, 2016). Antibiotics can cause qualitative and quantitative changes in microbial flora, toxic effects to wild organisms, alterations in biodiversity, incidence in the trophic chain, development of antibacterial defenses in fish and even transfer antibacterial resistance to human (Ramírez, 2010).

Ingredients in some feeds for the fishes can be responsible for food safety risks in aquaculture. Because of veterinary drug residues, organic pollutants, use of metals and mineral salts as mercury, lead, cadmium, hexavalent chromium, arsenic, and selenium. Some of this can be excreted or even bioaccumulate in fish as toxic contaminants (Justino *et al.*, 2016).

To enhance production of fish it is common to add fertilizers to the water, to achieve phytoplankton growth. Some of the most used inorganic fertilizers are nitrogen, phosphorus and potassium compounds, trace metals and silicate, but the excessive use of them can cause soil and water contamination (Boyd & Massaut, 1999; Ramírez, 2010).

The Code of Conduct for Responsible Fisheries developed by FAO, requires countries to regulate the use of chemical inputs in aquaculture and underlines the responsibilities of producers, since this can be hazardous to human health and the environment (Boyd & Massaut, 1999).

3 METHODOLOGY

3.1 Study Area

This study was done in Costa Rica, a country with a population of five million, 51,100 km^2 of continental territory, 572,877 km^2 of marine waters, with a volcanic mountain range from which rivers flow to both Pacific and Caribbean coastlines and is known for its biodiversity richness. Divided in seven provinces: San José, Alajuela, Heredia, Cartago, Puntarenas, Guanacaste, and Limón; and with six socioeconomic regions delimitation: North Huetar Region, Chorotega Region, Brunca Region, Atlantic Huetar Region, Central Region, Central Pacific Region.

Otárola (2008) mentions that in Costa Rica, farming of aquatic organisms inland was estimated to be around 1,775 producers in 2007, and 77% of them are tilapia farms, from which Alajuela and Limón provinces seem to be the main producers (Figure 2).

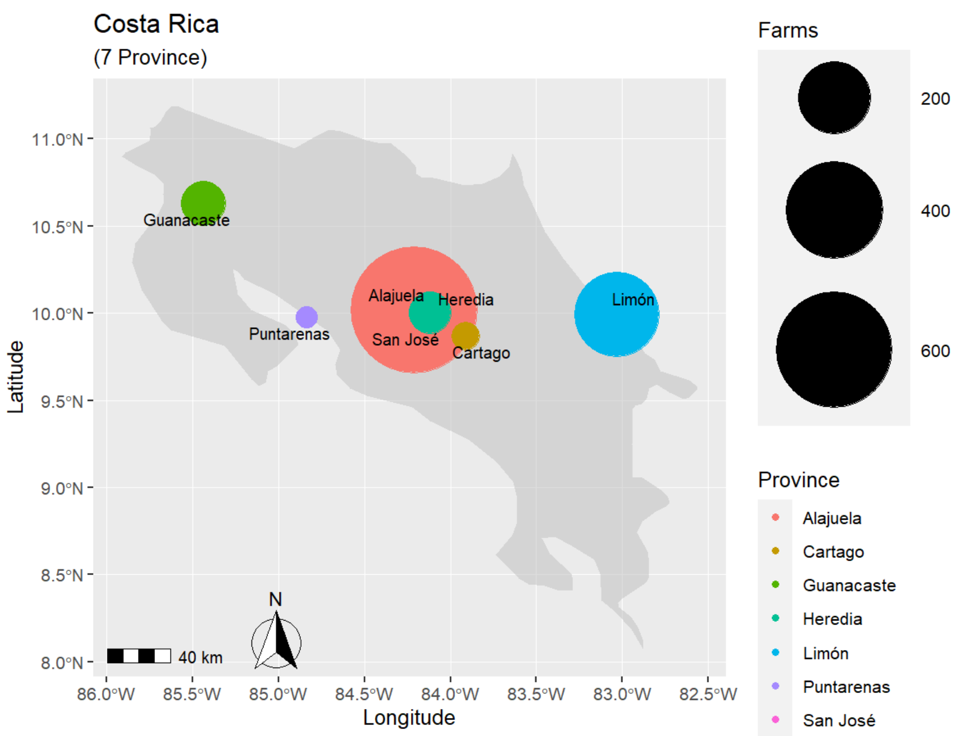

Figure 2. Bubble map of Costa Rica showing the quantity of farms in each province in 2007: Alajuela, Cartago, Guanacaste, Heredia, Limón, Puntarenas, and San José. Made by: Pilar Arguedas Rodríguez, data base: Otárola (2008).

3.2 Objective 1. Elaborate a diagnosis instrument of good management practices.

A diagnostic instrument was designed for the use of farmers and institutions as a way of verifying the degree of management performance considering three production levels for tilapia farms with pond aquaculture systems. This tool serves not only as a diagnostic instrument but has also been used in previous years as a tracking mechanism to monitor progress over time.

The evaluation methodology uses as reference the Evaluation Instrument for Environmental Institutional Management, made by the Directorate of Environmental Quality Management of the Ministry of Environment and Energy (Astorga, 2007).

The instrument was adapted for aquaculture management and consists of management subjects considered standard for aquaculture, and each of these subjects has guidelines for good practices in aquaculture.

A baseline of management subjects and guidelines were determined by performing a literature review, considering regulations, manuals of good practices and biosecurity in aquaculture, indicators studies, and experiences in management of sustainable aquaculture in other countries.

A meeting consultation was held on February 15th, 2023, with a biologist in the Aquaculture Promotion Department from the Institute of Fisheries and Aquaculture of Costa Rica. Two dynamics were created using as help the app Miro, which is a free web tool used to develop team workflows remotely through a virtual whiteboard.

The first dynamic consisted of assembling guidelines with the subjects previously defined, removing, and adding new guidelines and subjects based on their criteria and experience. The second dynamic consisted in indicating the production scale each guideline should be asked (Figure 3).

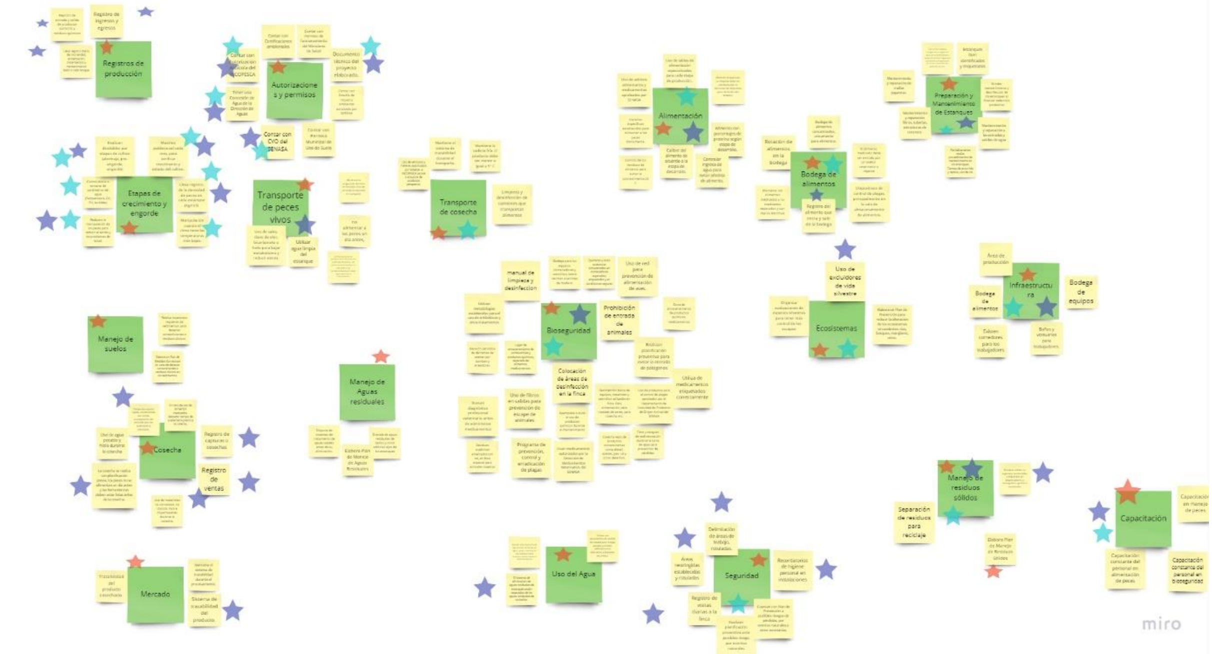

Figure 3. Dynamics of consultation to define management subjects and guidelines for each production scale using the app Miro.com. Green notes: management subjects; Yellow notes: guidelines.

The Evaluation instrument has the following criteria:

A. Each management subject of the evaluation instrument has a qualification shown as percentage of compliance. This percentage is calculated considering the compliance of the guidelines defined for each subject (Figure 4).

Management Subject	Qualification
Authorizations and permits	40%
Production Records	60%
Feeding	96%
Management during growth and harvest	78%
Production incomes and outcomes	0%
Infrastructure	100%

Figure 4. Example of management subjects final qualification.

B. Each guideline is qualified with a condition of compliance or non-compliance, with the following assigned score: "1" if it is met and "0" if the guideline is not met. If the items do not apply (Don´t apply), the percentage of the respective Subject will not consider this item in the calculation (Figure 5).

	Guidelines for Authorizations and Permits	Compliance
1	Have a Municipality License	Yes
2	Have an operating Permit from Ministry of Health	Yes
3	Have a Environmental Impact Assesment approved by SETENA	Yes
4	Have a Water Consession from Ministry of Environment	No Don apply
5	Have an Aquaculture Authotization from INCOPESCA	No
6	Have an Operative Veterinary Certificate from SENASA	N/A
	Total	**2**
	Guidelines considered	**5**
	Percentage of Compliance	**40%**

Figure 5. Example of guidelines for a management subject named authorizations and permits.

C. At the end of the evaluation, the management subjects of lower rating may be considered as those with weak performance and will need attention from the farmer.

D. As an extra addition, the guidelines are separated by aquaculture scale, so farmers can evaluate their compliance based on their production capacity. This can be useful to farmers so to consider if they are prepared to growth one step further in production scale.

3.3 Objective 2. Validate the instrument in Tilapia farms.

The instrument was validated from March 2th to March 27th, 2023, in tilapia farms with pond systems distributed around Costa Rica. The evaluation instrument was applied to owners of farms selected randomly from a database from 2021 to 2023 collected by the staff of the Guapiles Aquaculture Experimental Station of INCOPESCA. It was applied by a collaborator in Costa Rica, who visited and called the owners of the farms.

A total of 50 farms were evaluated, considered a 4% sample according to the estimation of 1,297 pond tilapia farmers that exist in Costa Rica (Otárola, 2008). Efforts were made to have information from farms from the seven provinces in Costa Rica, 14% are from Alajuela, 14% from Cartago, 4% from Guanacaste, 12% from Heredia, 34% from Limón, 2% from Puntarenas and 20% from San José (Figure 6).

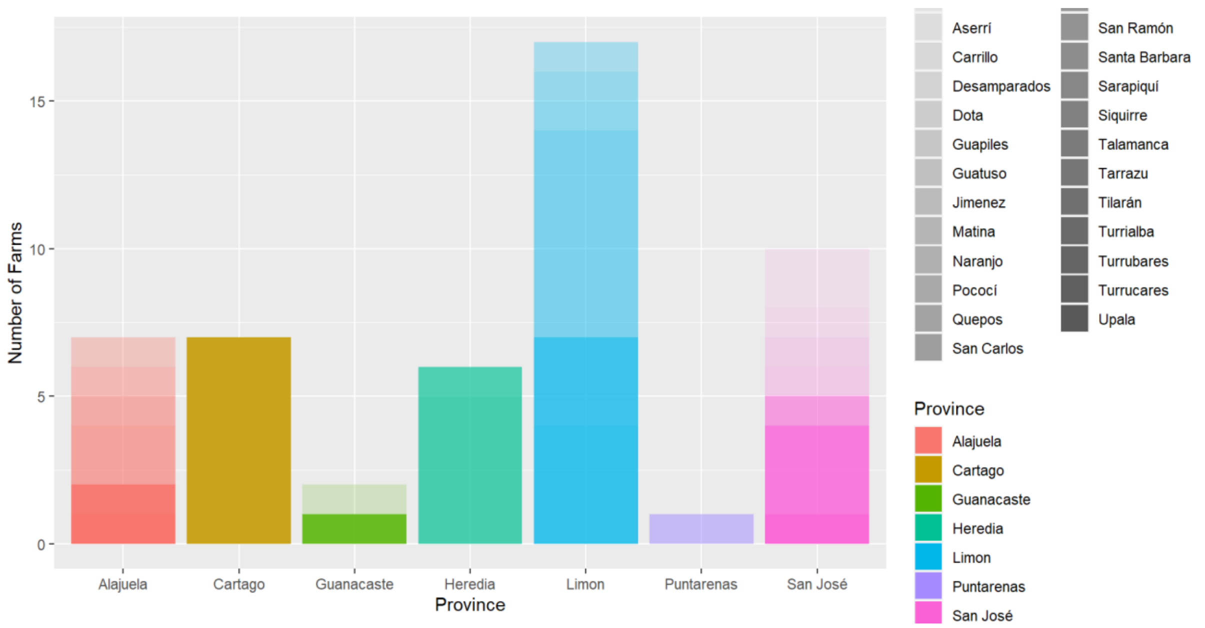

Figure 6. Number of farms per province and canton evaluated with the diagnosis instrument.

With the validation process the evaluation tool was fixed and perfected, according to what the farmers indicated during the meetings.

3.4 Objective 3. Assess the main management problems.

To identify the main management problems, the diagnosis information collected from the farms was digitalized and analyzed. Descriptive statistics were run to analyze the compliance in each management subject evaluated: minimum, maximum, mean, median value and standard deviation were calculated using R Studio. The compliance results were categorized, counted, and tabulated.

R studio was used for graph and map design, and to understand the relation level between the management subjects evaluated and the capacity of stocked fish per cycle. A Pearson multiple correlation was conducted.

4 RESULTS

4.1 Objective 1. Elaborate a diagnosis instrument of good management practices.

The evaluation instrument was created in an Excel file; it is separated in tabs, which is composed of an Instructions tab, Basic Information Questions Tab, Results tab, and Guidelines Compliance tab for each of the three production scales (Figure 7).

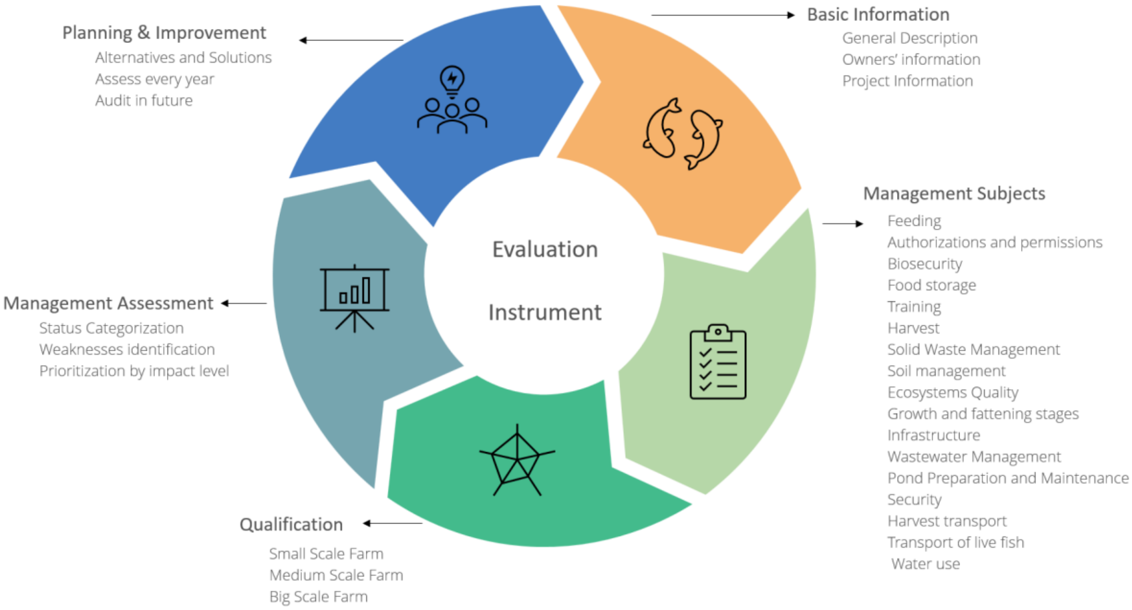

Figure 7. Contents of the Evaluation Instrument for Aquaculture Management Diagnosis

4.1.1 Instruction tab

The instruction tab is divided into information boxes, such as the Objective of the instrument, the Uses, Instructions, Definitions and References. Initially, it describes the main goal of the evaluation which is to verify the performance in good management practices in Tilapia (*Oreochromis niloticus*) ponds aquaculture systems in Costa Rica considering the three production levels. Then, it enlists the different uses that can be given to the evaluation instrument:

1. A diagnosis tool to verify the management performance of aquaculture farmers.
2. Generate a database of aquaculture farms and their condition.
3. Assess the current situation of aquaculture in Costa Rica, to plan capacitation and technical support based on the results.
4. Can be used by farmers as guidelines to improve management and development.
5. Can be used as a tracking mechanism in the following years.

Next, the tab has step-by-step instructions explaining how to travel through the evaluation instrument to complete it. Instructions as follows:

1. The information provided by you in this evaluation instrument will be used by INCOPESCA to generate a database of aquaculture management of tilapia in ponds in Costa Rica. This instrument is just to get an overview of aquaculture in the country, and the results would not affect your operations or authorization status.

2. Please start completing the information requested in the tab named "Basic Information". The explanations can be found in the "Definitions" box.
3. Continue filling out the tabs named "Guidelines", there is one Guideline page for each production scale, so you only have to complete the one that fits your production scale status. The delimitation for each production scale is explained in the "Definitions" box.
   The instrument consists in the evaluation of several Management Subjects considered standard for aquaculture, and each of these subjects have Guidelines for good practices in aquaculture.
   You must read each, and in the column named "Compliance" select "Yes" if the guideline is met, "No" if the guideline is not met, and "Don´t apply" if the guideline is not applicable to your aquaculture project.
   You can add any detail or information about each guideline in the column named "Comments".
4. The page "Results" will give you a summary of the results for each subject evaluated.
5. To complete the evaluation, it would take you around 45 minutes.

Finally, there are some definitions described in the tab, in case of uncertainty during the reading of the instrument (Appendix 1). Accompanied by a list of references used for instrument construction.

4.1.2 Basic Information tab
This tab requests general information about the farm, address, owners’ name, ID and contacts. About general production information that should be managed in every project: Total water area (m2), Number of ponds (n°), Density of fish (Kg/m3), Initial Individual weight (g), Harvest Individual weight (g), Feed consumed per year (Kg), Survival (%), Number of harvests per year (n°), Annual Production (Kg/year), Origin of the seed (name farm or company), Origin of the feed (name of brand), Final market (independent buyer, restaurant, hotel, supermarket, etc.).

4.1.3 Guidelines tabs
The evaluation tool has three guideline tabs, one for each production scale. There are 17 subjects covered, each with guidelines that the person should answer to see if they comply or not, and with a comments column if they need to add more information (Appendix 2).
The subjects are about Feeding, Authorizations and Permissions, Biosecurity, Food Storage, Training, Harvest, Solid Waste Management, Soil Management, Ecosystems, Growth and Fattening Stages, Infrastructure, Wastewater Management, Pond Preparation and Maintenance, Security, Harvest Transport, Transport of Live Fish, Water Use, and Reproduction.

4.1.4 Results tab
The results page is a summary of the qualifications given in each subject during the guideline compliance questions.

4.2 Objectives 2 and 3. Validate the instrument and assess the main management problems.

Of the 50 farms evaluated, one was large-scale, one was medium-scale, and the remaining 48 were small-scale. Since there are few tilapia farms in Costa Rica with production exceeding 5 tons, a comparison between production scales was not feasible in this study.

Most farmers were not able to answer questions about their yearly production (Kg), density of fish (Kg/m^3), or the amount of feed (Kg) given during the cycle.

Because of the lack of data regarding biomass yearly production, and to create relevant categories, the farms were divided into three categories based on the quantity of fish stocked during a production cycle. Of the 50 farms, 36 have a stock capacity below 2,000 fish per cycle, 9 farms had a stock capacity of 2,000 to 6,000 fish per cycle, and only 5 farms were above 6,000 fish stock per cycle (Figure 8).

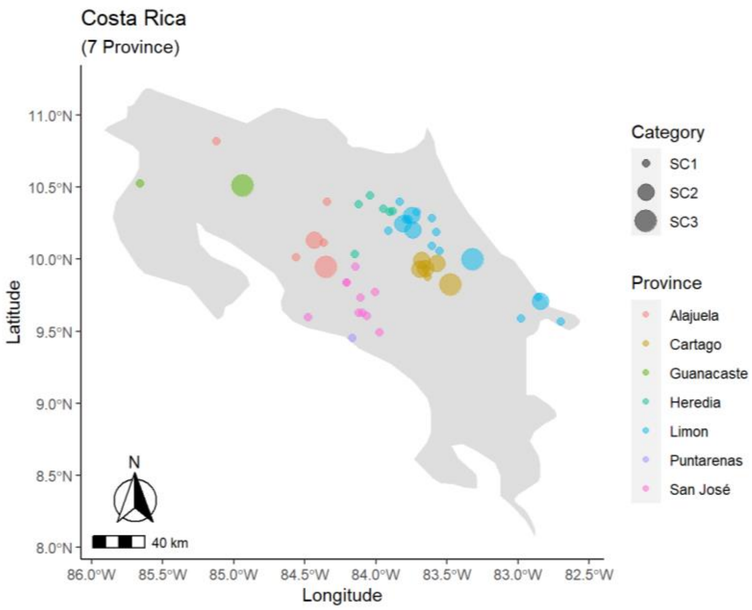

Figure 8. Bubble map of Costa Rica showing the farms evaluated in each province divided into three categories: SC1: from 0 to 1,999 fish stock per cycle, SC2: from 2,000 to 5,999 fish stock per cycle, and SC3: above 6,000 fish stock per cycle.

Most farmers interviewed sell their production to local buyers (42%), and others use it for self-consumption (34%), very few have markets with restaurants (10%), or raise them for fishing sports (8%), and other activities (6%).

The seed origin is mostly from INCOPESCA (90%), and from farms in Perez Zeledón (8%), and Biopez (2%).

The feeding source is mostly from Belina which is known too as Acuaoro (50%), other farmers buy feed in Colono (24%), and many others buy unbranded feed (28%), unaware of its origin and quality.

The results of compliance were classified into three categories of management status: Critical when the compliance score was from 0 to 49%, Regular when it was from 50% to 84%, and Good when it was from 85% to 100%. Considering the median of the 17 management subjects evaluated, seven of them were qualified at critical management status, eight at regular status and two at good status (Appendix 3).

Small scale guidelines don't include the management subjects of wastewater management, soil management, harvest transport and water use, which is the reason why these subjects' descriptive data are calculated only with two samples. In addition, the descriptive data of the subject transport of live fish only has 5 samples out of 40 farms, because small scale farmers don't usually transport fish alive in their regular activities. Finally, some subjects' descriptive values were calculated only with 49 samples, due to farmers answering that it was not applicable to them.

When the wastewater management, soil management, harvest transport and water use subjects were taken out, out of the 13 subjects remaining, subjects authorizations and permits, ecosystems care, and training, had the lowest scores (0% median); meanwhile the infrastructure subject had the highest score (100% median), followed by the food storage subject (83.3% median) (Figure 9).

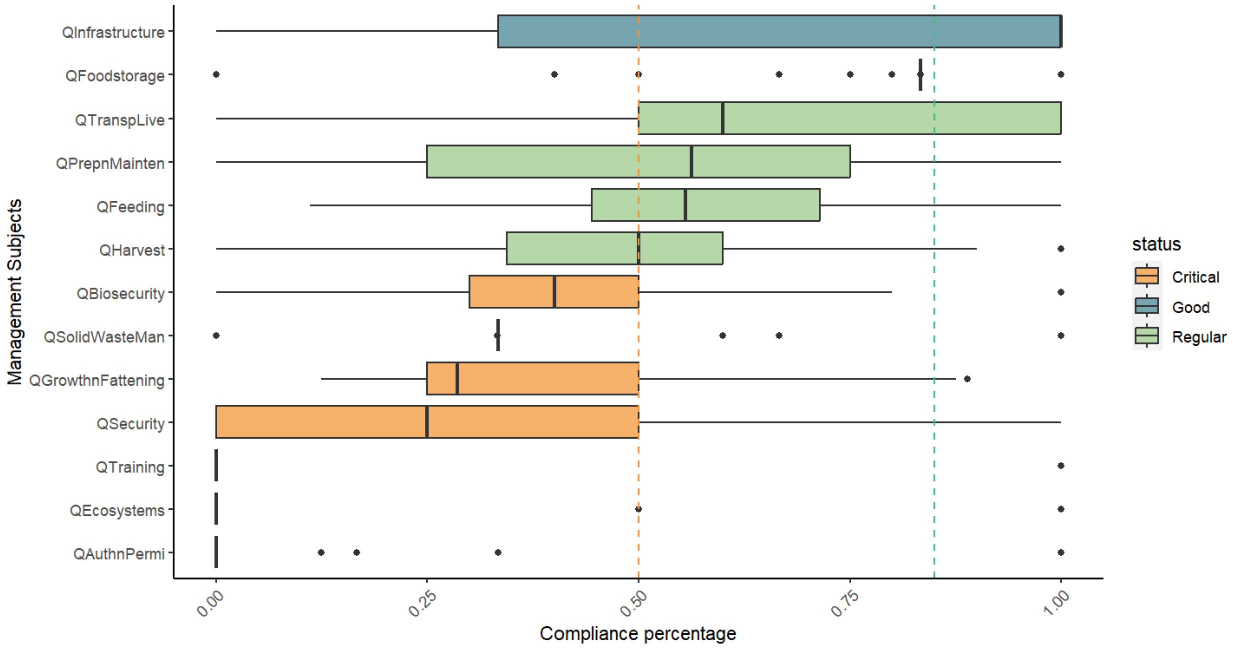

Figure 9. Boxplot of compliance percentage obtained in each Management Subject, separated into three status categories: Critical from 0 to 49%, Regular from 50% to 84%, and Good from 85 to 100%. In were QAuthnPermi: Authorizations and permissions, QEcosystems: Ecosystems, QTraining: Training, QSecurity: Security, QGrowthnFattening: Growth and fattening stages, QSolidWasteMan: Solid Waste Management, QBiosecurity: Biosecurity, QHarvest: Harvest, QFeeding: Feeding, QPrepnMainten: Pond Preparation and Maintenance, QTranspLive: Transport of live fish, QFoodstorage: Food storage, QInfrastructure: Infrastructure.

Regarding the farms' general management, 31 farms stand at critical status, 18 at regular and only 1 at good. In relation to each of the management subjects, the majority of farms have regular management in the way they feed their fish (64%), farms which don't have authorization or permits for their aquaculture projects (98%), farms which don't have good biosecurity measures (72%), farms which have regular food storage rooms (78%), farms which don't have official or specialized training in aquaculture (98 %), farms which have regular management during the harvest stage (46%), farms which don't manage correctly their solid waste (76%), farms which don't keep the adjacent ecosystems safe with their practices (78%), farms which have bad management during growth and fattening stages (63%), farms which keep adequate infrastructure for aquaculture (70%), farms which don´t have a very good preparation and maintenance of the ponds (52%), and farms in which the security measures of the infrastructure are regular (52%) (Figure 10).

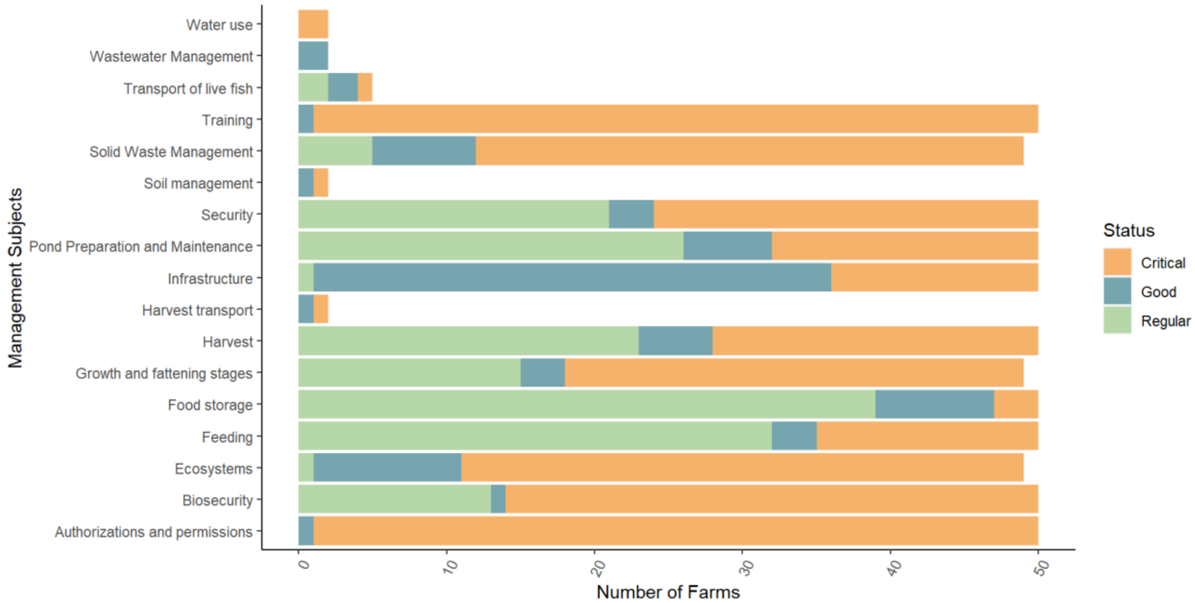

Figure 10. Farms compliance status composition for each management subject.

The Pearson correlations revealed two main sets of correlations (Figure 11): A positive correlation between Preparation, Maintenance and Feeding (r= 0.517, p<0.001), and with Solid Waste Management (r= 0.553, p<0.001). In addition, another positive correlation between Security and Harvest (r= 0.584, p<0.001), and with Biosecurity (r= 0.598, p<0.001). Finally, between Harvest and Fish stocked per cycle (r= 0.546, p<0.001) (Appendix 4 & 5).

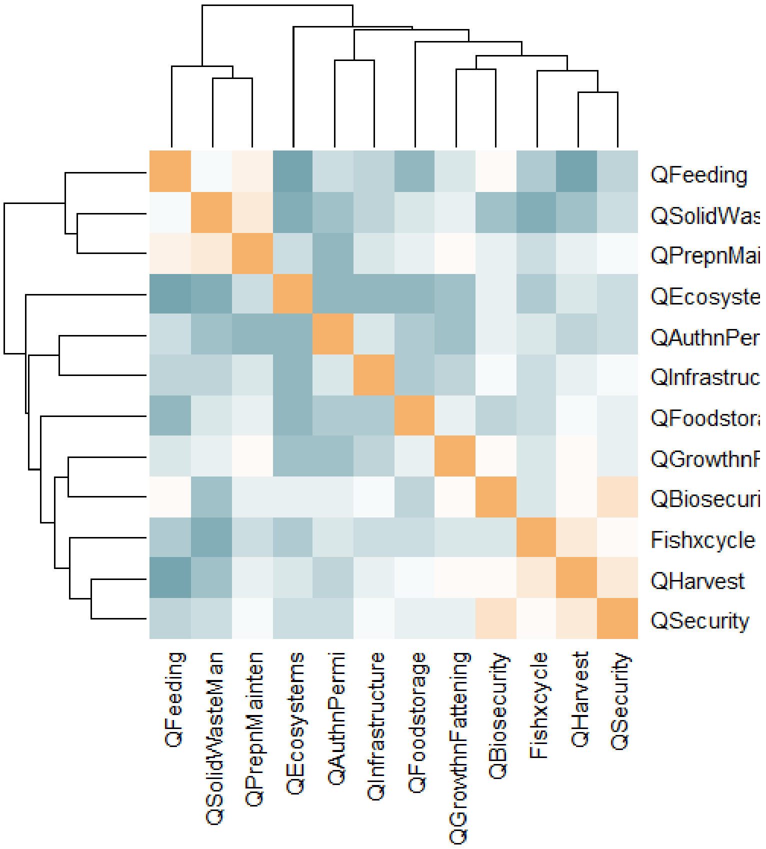

Figure 11. Pearson Correlation Heatmap showing the relation between the management subjects evaluated for small scale farms.

5 DISCUSSION

The aim of this project was to elaborate a diagnosis instrument of good management practices for tilapia pond aquaculture in Costa Rica. To achieve that goal some issues needed to be solved, such as defining the subjects and guidelines required to elaborate a standardized instrument for stakeholders to have measurable information about farm performance. A total of 17 subjects were essential for the management of tilapia farms, and their guidelines are different according to the production capacity. Another line of inquiry was to identify the most critical issues related to small-scale tilapia farming management in Costa Rica. In general, aquaculture needs important improvements in almost all subjects, but the biggest limitations were related to authorizations and permits, training, and ecosystem care. A third line of inquiry was to investigate potential links between the subjects evaluated and the farm's production capacity, which turned out to be that the greater capacity of cycle production a farm has, the better the management.

5.1 Standardizing the instrument

The target of the instrument was to quantify and categorize the issues that limit tilapia aquaculture development in Costa Rica. Indicators used to assess sustainable aquaculture require certain information that is difficult to obtain. Unfortunately, developing countries with limited data sources cannot use these recommended indicators, having to use more traditional data sources (FAO, 2009). The instrument elaborated in this project uses a simple methodology that estimates the performance based in a dichotomous condition of compliance and non-compliance, as used in the Evaluation Protocol to elaborate Programs of Environmental Management in Institutions (Astorga 2007).

Our aim is to standardize the instrument to be easily used by all stakeholders and to generate a more formal diagnosis with comparable standard measurements (Pamela, 2012). One big challenge in aquaculture is the lack of statistical data and its inconsistency. Without standardization it is difficult to make the information comparable within and between countries, and to follow up on improvement (Álvarez, 2009).

The subjects chosen are mainly related to the preproduction, primary production, and harvest stages. Processing and commercialization were not contemplated in this instrument because they are supervised by different regulations and procedures, some of these activities require that they are carried out outside the farms. The guidelines chosen in this instrument were only the ones considered as mandatory compliance for Good Practices in Aquaculture Production: procedures, conditions, and controls required for establishment, so aquaculture products fulfill specifications of safety, and control of hazard agents (OIRSA, 2017).

The subjects and guidelines of this project concentrate on the production processes inside the farms, with components such as: the management of external sources like water use, and the management during each preproduction and production stage (pond maintenance, growth harvest, transportation). It also contemplates the management of waste products from the activity (solid and wastewater), and ecosystem care. In addition, the mandatory requirements of facilities, and hygiene and safety management throughout the process. Finally, administrative issues such as obtaining authorizations, as well as staff training are considered.

5.2 Main management problems in small scale tilapia farms

Observing that out of the 13 subjects evaluated for small-scale only one is at good status, shows that aquaculture management in Costa Rica needs improvement. Most are not managing their farms properly, the diagnosis instrument revealed that the main management problems in small-scale farms are related to informality due to lack of authorizations and permits, the need to improve training in aquaculture and to lower the impacts on adjacent ecosystems.

According to the risk analysis matrix prepared in 2007 (Chacón & Santamaría), the most urgent points of attention in aquaculture in the north region of Costa Rica were the lack of quality of the seed sold, the deficiencies in the farms regarding water management, the lack of water concessions in farms, mortality problems and lack of knowledge of the causal agents and how to treat them. Some of them are connected and are still a limitation, as for example the water use concessions, which implies that they do not have aquaculture authorization either. The lack of knowledge of causal agents of disease is still a flaw in biosecurity practices and there is a need to improve capacity building.

5.2.1 Authorization and permits.

Most farmers work without permits and authorizations, this is one of the biggest challenges in Costa Rica’s aquaculture. The authorization for farming aquatic organisms is the final paperwork after several procedures that are required to formalize a business in Costa Rica. And this simple subject generates a succession of bad practices throughout the activity, making it extremely difficult to monitor aquaculture in the country.

It is necessary to promote the integration of informal aquaculture farms, facilitating a gradual incorporation into the formal sector. Farmers need to be aware that not being formalized for the exercise of the activity is not just about the risk of getting sanctions and fines for non-compliance with laws. But this also affects the possibilities to improve working conditions, and limits business opportunities, the growth and credibility of the company, and even access to benefits offered by state institutions (MEIC, 2019), as for example financial resources from Development Banking and other entities in Costa Rica (Abarca, 2019).

Redefining and strengthening requirements for the authorization category for domestic or self-consumption production, with no commercial purposes, could be a solution for people who are starting in the aquaculture field. In Peru, they have an authorization category named AREL or Limited Resources Aquaculture, which is for productions lower than 3.5 tons, the authorization requirements are simpler: they are exempted from payment, don’t need to present a Good Aquaculture Practices Program, or a Hygiene and Sanitation Program, Layout Plan for Sanitary Facilities and Contingency Plans for Disease Outbreak, and other category requirements. But they still must inform authorities about their annual production and abide by sanitary measures (Supreme Decree N° 002-2020-PRODUCE). Around 45% of farmers in Peru comply with the AREL category, giving farmers the opportunity to keep their projects in order, and the authorities to track producers and the country's production (Mendoza, 2013).

Furthermore, authorization categories need some restructuring. In terms of guidelines, during the development of this instrument, it was noticed that medium-scale and large-scale producers share most of the guidelines. Conversely, not all the guidelines evaluated apply to small-scale producers because it requires a higher level of production and investment. For example, some management subjects were evaluated only for medium and large scale, such as Wastewater Management, Soil management, Harvest Transport and Water Use, in which guidelines ask for plans and protocols compliance, and infrastructure requirements.

Some small-scale guidelines are still complex for people with domestic or self-consumption production. Aquaculture can be restructured to be more inclusive, taking into consideration not only the year production biomass, but the production purpose (commercial or domestic), and the number of workers on the farm.

In Costa Rica some institutions classify enterprises based on the number of workers, for example microenterprises are 1 to 5 workers, small enterprises are 6 to 30 workers, medium are 31 to 100 workers, and big enterprises are more than 100 workers (Pamela, 2012). The same methodology should be adapted to define aquaculture authorization categories for greater efficiency during control and tracking of aquaculture activity in the country.

Álvarez (2009) says that the major statistical barrier when there is no formality in Micro, Small and Medium Enterprises (MIPYMES), is that they do not appear in a registry, and it is very common for entrepreneurs to be afraid to respond to diagnostic surveys. They are afraid of the possibility that the results will be used to punish them legally and/or fiscally, as happened during the validation of this instrument. Abarca (2019) suggests viewing informality as an inclusive process that fosters innovation and modernization, serving as a transitional stage toward consolidation. The study also emphasizes the importance of addressing institutional barriers that prevent farmers from fully participating in formal economic and social systems.

5.2.2 Training

The lack of knowledge is the second biggest challenge in aquaculture. The authorities' aim of improvement should be focused not only on capacitation and technical assistance, but also offer a planning program, giving support and progress monitoring. In Peru, aquaculture expansion has a focused and planned educational model, evaluating results at the end of the activity undertaken. The program looks to upgrade farming capacities, including topics such as business management, market strategies, administration, accounting, and most importantly, formalization (Mendoza, 2013).

Many people are learning and trying to start tilapia production farms, which is why 34% of farmers answered that their production target was for self-consumption. However, lack of guidance and knowledge is the reason why many are in a critical state of management. They require more support in training and during the development of their projects.

Another deficiency observed in this project, related to lack of training in management practices, is that small-scale farmers don't perform periodic samples or gradings, and don´t keep records of the following: feed given to fish, the growing process, or their yearly biomass production. Not being able to give authorities this information is a problem for statistical national records. This is because of a lack of knowledge, not only about production, but administration and financial topics. There is a tendency in micro and small enterprises that operate in the informal sector, to lack financial information, documented credit histories, and many other registries. Recommendations are for small farms to organize together for better management, strengthening the socio-organizational component is essential for the sustainability of the business (Monge, 2019).

Also, this lack of record keeping can be linked to the limited knowledge of technicians of topics such as enterprises management, economics, markets, and value chain. In Peru, it is considered important to work on the capacity building of technicians, to standardize the technical criteria they share with farmers, to expand their knowledge in topics that may help on production scaling, and teach technicians how to keep records of indicators such as production increase, market articulation, percentage use of transferred knowledge, increases in economic income, formalization, improvement in life quality (Mendoza, 2013).

5.2.3 Ecosystem care

Another major problem in management perceived in this study is the impact on adjacent ecosystems during tilapia production due to bad practices. Generally, ponds are close to water bodies, and the control of escapees is non-existent. Sometimes individuals are released indiscriminately into to water bodies during pond maintenance, or even during the rainy season due to flash floods (CAR, 2017). Tilapia can monopolize niches, eat the eggs of other species, sustain themselves on vegetation and other foods found at the site, and take over environments normally used by other fish (Hernández, 2002).

Due to the carelessness of fish farmers, farmed tilapia can be found in rivers (Hernández, 2002). In other countries such as Norway, Australia, Chile, Scotia, and Canada, norms have been established to regulate escapees from marine fish cages. A requirement for cage farming is to have prevention protocols, in which authorities must be informed in case of escapees, and to activate contingency plans immediately, and recapture with previous permit from authorities, and present a detailed report of actions (Izquierdo-Gómez et al. 2014). For inland aquaculture of tilapia, the logistic is different, but recommendations are to carry out environmental guidelines and implement sustainable environmental measures such as conserving biodiversity and promoting habitat restoration (OSPESCA, 2022).

5.3 Relation between subjects and cycle production capacity

This study showed 27 significant correlations between all the subjects and the production cycle capacity, but only 5 significant correlations were emphasized. And even those correlations highlighted between preparation maintenance, feeding and solid waste, security, harvest and biosecurity, and harvest and fish stock per cycle, were not very strong. It is important to take into consideration that only 50 farms were evaluated, representing approximately 4% of farmers in the country, so that these results must be carefully interpreted.

A general observation of these correlations is that the greater the capacity of the production cycle a farm has, the better the management qualification throughout the different stages. As stated previously, medium, and large-scale producers have more capacity to comply with the guidelines, but regulation should not be the same for each scale of company, or it will become an inefficient allocation of resources and efforts (Álvarez, 2009).

Furthermore, some guidelines have clear relation to several management subjects at a time. During the construction of the instrument, it was a very enriching discussion to decide which subject in each guideline should be evaluated. For example, the biosecurity subject was related to all the production stages. Because it is a process to control the risk of pathogen contamination outside and inside the farm, which can cause diseases and important economic losses if not well managed at every step in the production (OSPESCA, 2022). Therefore, good management qualification in biosecurity should come together with good practices in harvest and security subjects.

5.4 Incentives for small scale farms

An incentive for farmers is to give them tools to have a better competitive opportunity. Nowadays consumers are looking for good prices, flavor, and nutritional products, so efforts must be intensified to generate a greater quality-oriented culture of aquaculture products. This quality can be achieved if farmers abide with the good practice guidelines recommended, for example, the use of balanced concentrate diets for each growth stage of tilapia, provide adequate maintenance to the ponds, be vigilant about biosecurity and hygiene, and maintain good harvest handling (Cedeño, 2007).

The highest response regarding targeted market during this project was that the farmers sell their product to local buyers. Many farmers keep small productions and sell directly to buyers in their community, and don't have or rent transportation to sell their products further afield.

Moreover, in 2006 aquaculture farms were being supported by the government in projects with an agro-ecotourism modality, integrating their activities with sport fishing, and opening farm doors for product sale. During those years, a growth in consumption was achieved, but the efforts were directed towards increasing local consumption, and not towards transporting and selling in central valley communities and other markets (Chacón & Santamaría). It is likely that this modality has remained over the years, adding to low demand in recent years, and reduction of transport throughout the value chain because of the COVID-19 pandemic in 2020 (OSPESCA, 2022).

Supermarkets in Costa Rica say that they are willing to support national producers and offer Costa Rican product to consumers. However, during a survey they revealed that if a farmer wants to sell his product in a supermarket, he must match prices to those of imported products. In Costa Rica most imported products come from Asiatic countries, where they produce fish in large quantities at low cost, making it difficult for small farmers to compete. In addition, small scale farmers don't have the capacity to offer a constant weekly quota of products (Cedeño, 2007; Fonseca, Galera & Vargas, 2020).

Growth and fattening stages are crucial to achieve a good quality product, and this is not being well managed by farms assessed in this study. Staggered production models are recommended, so that products are available throughout the year, which increases the level of competitiveness by placing a benchmark product in the market which offers a continuous product to customers. In addition, it is recommend carrying out pre-harvests in month 5, and a harvest at the end of the cycle, improving the FCR and obtaining greater profitability. With the latter, the price can be maintained and profits increased, or the product can be offered at a more competitive price (Dorantes *et al*. 2017).

Feeding practices revealed a regular management in this survey, historically this subject has been upgraded by improving the access to concentrated feed with balanced diets for tilapia, considered one of the technological advances that allowed tilapia aquaculture to develop in Costa Rica. This allows farmers to manage greater numbers of individuals per cubic meter, raising growth rates and improving meat quality (Chacón & Santamaría, 2007).

A large percentage of farms evaluated in this study reported a lack of knowledge of the feed brand which is given to the fish. It is very important for farmers to use recommended feed according to each stage of development, and to use feeding tables for an efficient relation feeding-growth. Especially because some formulas registered in Costa Rica recommend its use for all tilapia life stages, and these foods cause protein deficiency in some stages (Vargas, 2003). Worldwide, concentrated feeds are continuously innovating techniques to improve the nutritional value of conventional ingredients to meet the requirements for this species (Boyd *et al.*, 2020).

6 CONCLUSION

The diagnostic instrument developed is a practical tool for stakeholders, enabling a formal evaluation of aquaculture management practices. It provides measurable data that can be used to improve operations, track progress, and make comparisons over time.

Priority should be given to addressing authorization and training in government annual plans. Integrating informal aquaculture into the formal sector must be promoted by gradually redefining and strengthening the authorization process, starting with self-consumption categories. This will simplify tracking through government registries.

To be more inclusive, authorization categories should be restructured, taking into account factors such as annual production biomass, the production purpose (commercial or domestic), and the number of workers involved.

Extension programs should adopt a holistic approach, covering production techniques, best practices, business management, market strategies, formalization, and environmental sustainability. These programs must also include technical support, continuous progress monitoring, and result evaluation.

Capacity building for technicians is essential to ensure standardized criteria, expanded knowledge, and the tracking of sustainable indicators. The larger the farm's production capacity, the more effectively it can manage different stages of the production cycle. Therefore, regulations and guidelines should be adapted to suit various production scales.

In addition to strong biosecurity management, good practices across other stages—such as harvesting and safety protocols—are critical.

This evaluation instrument has the potential to inform national policy, shape the content of training programs, and ultimately enhance the performance of aquaculture farms.

7 RECOMMENDATIONS

The instrument should be a requirement to have authorization for farming of aquatic organism for the first time and should be applied once a year to maintain this authorization.

By the time a farm has more than 2 years of experience in aquaculture, they should be recording the information needed and being able to calculate their own production data.

To prioritize subjects during the planning process, the degree of impact for each subject can be assessed to determine which issues require urgent prioritization. This impact can be measured using three criteria: whether non-compliance with guidelines affects the farm itself, the surrounding ecosystems, or public health.

The results of compliance are based on the farmer's criteria, but their compliance is not verified. This instrument is made to assess the aquaculture situation, to plan intervention and improvement processes. But in the future, it could be an audit tool, in which case, farmers will have to prove good management with documents, and demonstrate actual compliance with the guidelines. The evaluation can have a green, yellow, and red flag, in which farms must be in green to maintain a specific certificate. If it is in yellow, they will have a limited number of days to correct themselves, or they will be marked with a red flag.

Restructuring of aquaculture categories, and authorization requirements can be contemplated during the process of law and regulation reform planned in the Program “Sustainable Development of Fisheries and Aquaculture in Costa Rica (PDSPA-CR), with the World Bank. Also, the instrument can be improved with a digital program that consolidates databases planned in the “INCOPESCA Digital” project.

Government must see informality as a stage in the consolidation process and create incentives for farmers to participate during the collection of information, and work towards eliminating institutional barriers that causes farmers to not be able to formally join.

Some incentives for farms can be given priority during capacity building programs: financial opportunities, facilitate paperwork with other institutions, or include them in PYMA list for tax exemption during purchase of inputs for aquaculture.

Finally, negotiations should be pursued with institutions involved in aquaculture authorization and permits (such as SENASA, the Water Directorate, SETENA, and MAG) to coordinate joint training initiatives and streamline administrative processes. Additionally, partnerships should be established with academic institutions to create accredited educational programs.

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10 APPENDICES

Appendix 1. Definitions described in the management evaluation instrument for tilapia pond farms.

Term	**Definition**
1. Total Water Area (m2)	the extension in square meters for aquaculture production, that is, the area where the farming of fish takes place.
2. Total water volume (m3)	Volume of the total number of ponds in the farm, calculated by multiplying the length x width x depth of the pond.
3. Density of fish (Kg/m3)	Biomass of fish farmed per unit area.
4. Initial Individual weight (g)	Initial weight of the fingerlings placed in the pond at the beginning of the production cycle
5. Harvest Individual weight (g)	Final weight of the fish at the end of the production cycle.
6. Factor Conversion Rate (FCR)	A measure of production efficiency: the weight of feed intake divided by the weight gained by the animal. Lower FCR values indicate higher efficiency.
7. Mortality (%)	Percentage of fish that di during the production cycle.
8. Production cycle	The period in months from the sowing of the post larva to the harvest for sale.
9. Number of harvests per year (n°)	Number of production cycles carry out in a year.
10. Annual production (Kg/year)	Biomass harvested in a year.
11. Cycle costs	Fixed and variable costs, incurred during the production.: Cost of services, cost of food and seed, payment of rent, among others.
12. Cycle revenue	Gross income, money earned from the commercialization of the aquaculture production.
13. Cycle Profit	Income earned by the producer: difference between sales revenue and total production costs, also known as net profit.
14. Small scale aquaculture	Farming of aquatic organisms from which production is commercialized exclusively to production units' level, productor-consumer directly, the production doesn't go higher than 5 tons a year.

15. Medium scale aquaculture	Farming of aquatic organisms from which production is commercialized exclusively to production units’ level, producer-consumer directly, the production is no higher than 50 tons a year.
16. Big scale aquaculture	Farming of aquatic organisms from which production is commercialized exclusively to production units’ level, producer-consumer directly or to internal and external markets, the production is higher than 50 tons a year.

Appendix 2. Management Subjects and Guidelines considered in the management evaluation instrument for tilapia pond farms.

Management Subjects	Guidelines	Small Scale	Medium Scale	Big Scale
Feeding	Use specialized feeding tables for each species and stage of development.	x	x	x
	Use food with percentages of protein according to the stage of development.	x	x	x
	Use the recommended feed sizes according to each stage of development.	x	x	x
	The food used is properly labeled. The label must be approved by the Animal Food Department of SENASA, and must contain: Food registration number, batch number, list of ingredients, expiration date, storage conditions.	x	x	x
	Medicated food is issued by a veterinary adviser or regent, they keep a copy of the recipes.	x	x	x
	Food additives and medicines used are approved by SENASA	x	x	x
	Have set times to feed the fish daily.	x	x	x
	An adequate observation of food consumption is carried out to avoid overfeeding. There should be no feed residue if fed properly and the fish are healthy.	x	x	x
	Regulate the flow of water entering the pond to avoid loss of food. Too high a flow can cause feed to come out through the drains before the fish can consume them.	x	x	x
Authorizations and permissions	Have some Environmental Certification			x
	Have Aquaculture Authorization from INCOPESCA (Fisheries and Aquaculture Law N° 8436 and Executive Order N° 36782)	x	x	x
	Have a Water Concession from the Water Directorate of the Ministry of the Environment (Water Law No. 276)	x	x	x
	Have an Environmental Impact Study approved by SETENA (Executive Order N°. 31849)	x	x	x
	Have an operating permit from the Ministry of Health (Executive Order N° 31849, N° 43432-S and N° 43784)		x	x
	Have a Municipal Land Use Permit, only cantons with a Territorial Regulatory Plan (Urban Planning Law N° 4240)		x	x

	Have a Technical Document of the project. It consists of a description of the project with information on: cultivated species, infrastructure, preparation prior to planting, management of production units, biosecurity measures, project costs, production characteristics. (See more details in the Freshwater and Marine Aquatic Organisms Culture Authorization application form).	x	x	x
	Have an Operational Veterinary Certificate from SENASA (Executive Order N° 34859)	x	x	x
Biosecurity	Have disinfection areas on the farm, foot baths, hand washing areas, or others.	x	x	x
	Perform daily disinfection of equipment, materials and utensils used on the farm. For feeding, for transferring fish, for harvesting, etc.	x	x	x
	Have a cleaning and disinfection manual		x	x
	Request a professional veterinary diagnosis before administering medications	x	x	x
	Only use medicines authorized by the Veterinary Medicines Directorate of SENASA	x	x	x
	Use methods and doses recommended by authorities and professionals for the use of treatments for disease control.	x	x	x
	Use pest control products approved by the Department of Safety of Animal Products of SENASA	x	x	x
	Have a Prevention, Control and Eradication Plan for pests, pathogens, and diseases.		x	x
	Keep chemicals and medicines stored in appropriate containers, correctly labeled, separated from other products, and in safety conditions recommended for each one.	x	x	x
	Perform periodic inspection of oil spills from pumps and aerators.	x	x	x
	Keep polluting products such as diesel, oil, gas, lime, and other waste away from the ponds.	x	x	x
	Keep a record of the entry and exit of medicines and chemical products.	x	x	x
	Regulate the inlet and outlet flow of water of the farm	x	x	x
	Have sedimentation and filtering systems in the farm's water intake to prevent losses, due to excess sediment or contamination risks.	x	x	x
	Have set up nets, fences, and other devices to prevent predation by birds, otters, and other organisms.	x	x	x
	Have filters or devices in the water outlets of the ponds to prevent the escape of animals into the natural environment.	x	x	x

	Prohibit the entry of animals to the farm to avoid predation, contamination, and entry of pathogens.	x	x	x
Food storage	The Concentrated Food Warehouse is kept clean, dry, organized, and well ventilated.	x	x	x
	The feed bags are placed on pallets.	x	x	x
	They rotate food in the warehouse, first thing that comes in is the first thing that comes out.	x	x	x
	Keep medicated and non-medicated foods separate and distinctively branded	x	x	x
	Contain pest control devices, mainly in the food storage cellar.	x	x	x
	Keep a record of the food that enters and leaves the warehouse	x	x	x
Training	Constantly train staff in fish feeding	x	x	x
	Constantly train staff in biosafety	x	x	x
	Constantly train the person in management and aquaculture production	x	x	x
	They make and hold records of staff training	x	x	x
Harvest	The harvest is carried out with prior planning, the tools are prepared prior to the harvest	x	x	x
	Don´t feed the fish one day before harvest	x	x	x
	Care is taken to handle the fish as little as possible as not to mistreat and stress it	x	x	x
	Time when fish is stressed/crowded is kept to a minimum	x	x	x
	Use non-corrosive, non-toxic, smooth, and waterproof materials during harvest.	x	x	x
	Use drinking water and ice during the harvest	x	x	x
	When use medicated feed, respect the quarantine time before harvesting.	x	x	x
	Keep records of the catches or harvests they make.	x	x	x
	Keep records of income, the detail of daily sales.	x	x	x
	Keep records of expenses, fixed and variable costs.	x	x	x
Solid Waste Management	Separate waste for recycling and deliver to authorized managers.	x	x	x
	Collect ordinary solid waste in appropriate dispensers for this purpose and deliver it to authorized managers.	x	x	x
	Organic waste, such as dead fish, is buried with lime in a special pit for the same purpose.	x	x	x

	Silageing or similar process made out of the organic waste from fish to enhance the circular economy of the product.		x	x
	Have a Solid Waste Management Plan		x	x
Soil management	Perform regular sediment sampling to detect contaminants or toxic residues.		x	x
	Have a Corrective Measures Plan in case of detecting contaminants or toxic residues in the sediments.		x	x
Ecosystems	Use mesh or wildlife excluder devices	x	x	x
	They have escape prevention protocols			x
	Have a Prevention Plan to reduce the alteration of the surrounding ecosystems: rivers, forests, mangroves, others.		x	x
Growth and fattening stages	Perform gradings by cultivation stages (fry, pre-fattening, fattening)	x	x	x
	Carry out population sampling every month, to verify growth and state of the culture.	x	x	x
	Carry daily or weekly control of the water parameters (Temperature, O2, PH, turbidity)		x	x
	Reduce handling of the fish to reduce stress and health problems.	x	x	x
	Keep records of the density of fish in each pond (Kg/m3)	x	x	x
	Don´t feed the fish one day before sampling or grading.	x	x	x
	Try to handle the fish during the hours and days when the temperatures are lower.	x	x	x
	Keep a daily record of mortality, feeding, treatments and maintenance given to each tank.	x	x	x
	Maintain a traceability system for the product from its entry into the farm, until the product leaves the aquaculture establishment. Pond number, start day and harvest day, number of fingerlings raised, medicines and chemicals used, food used, origin of the fingerlings and destination after harvesting.	x	x	x
Infrastructure	Have a feed warehouse, used only for food storage	x	x	x
	Have a warehouse for equipment, containers, and utensils. Which are placed on platforms	x	x	x
	Have bathrooms and changing rooms for workers.		x	x
	Have dining room for workers.		x	x
	Have an adequate area for the storage of chemical products and medicines	x	x	x

	Have a storage place for fuels and oils, separated from food, medicines and other chemical products.	x	x	x
Wastewater Management	Have a wastewater treatment system before its disposal.			x
	Wastewater drainage from toilets and other buildings is located away from ponds		x	x
	Have a Wastewater Management Plan			x
Pond Preparation and Maintenance	Ponds are well identified and labeled	x	x	x
	The use of inorganic or organic fertilizers is only carried out by the professional in charge of the farm.	x	x	x
	Organic fertilizers have a guarantee letter from the supplier stating that they have undergone heat treatment or disinfection before use.	x	x	x
	Provide maintenance and disinfection of ponds at the end of each production cycle	x	x	x
	Periodically they carry out maintenance procedures in the ponds: drainage, drying, rest and use of lime.	x	x	x
	Carry out maintenance and repair to the entrances and exits of water from the ponds	x	x	x
	Carry out maintenance and repair of bird netting and other protection devices	x	x	x
	Perform maintenance and repair filters, pipes, concrete structures.	x	x	x
Security	There is a clear delimitation of each work area, with adequate labeling	x	x	x
	Restricted areas are well established and labeled	x	x	x
	Have personal hygiene reminders on the building	x	x	x
	Have a record of daily visits to the farm	x	x	x
	Carry out preventive planning for possible risks due to natural events		x	x
	Have a Prevention Plan for possible risks of losses, due to natural events or other scenarios.		x	x
Harvest transport	The vehicles and coolers used to transport the product have the corresponding authorization from SENASA (Executive Order N° 39010-MAG) and INCOPESCA (Executive Order N° 36782).		x	x
	Maintain the cold chain of product during transport, less than or equal to 5° C (Executive Decree No. 18696 MAG-S), and ice-product ratio of 1:1 is recommended.		x	x
	Maintain the traceability system during transport.		x	x
	Clean and disinfect trucks after transporting the product		x	x
Transport of live fish	Use salts, cloves, bicarbonate, or ice to lower metabolism and reduce stress in the fish during transport.	x	x	x
	Use clean pond water to transport live fish.	x	x	x

	In cases of tank transportation, they keep water oxygenated during transfer with aerators or pure oxygen during transport.	x	x	x
	In cases of bags transportation, they use a double bag, inject oxygen into the bag before sealing and they do not exceed 8 hours of travel.	x	x	x
	Don´t feed the fish one day before carrying out the transport	x	x	x
	The handling of the fish is carried out with prior planning, the tools ready before carrying out the transport.	x	x	x
Water use	The pond wastewater disposal system is separated from the toilet wastewater.		x	x
	Have quality analysis documents for drinking water and ice used in the farm.		x	x
	Carry out regular chemical studies of water quality, in the water intake of the farm and in the outlet of some ponds to detect contaminants or toxic residues.		x	x

Appendix 3. Descriptive statistic for the compliance score obtained in each management subject evaluated.

Management Subject	n	mean	median	min	max	sd	Farms Critical	Farms Regular	Farms Good	General Status
Feeding	50	54%	56%	11%	100%	22%	15	32	3	Regular
Authorizations and permissions	50	6%	0%	0%	100%	16%	49	0	1	Critical
Biosecurity	50	40%	40%	0%	100%	18%	36	13	1	Critical
Food storage	50	79%	83%	0%	100%	21%	3	39	8	Regular
Training	50	2%	0%	0%	100%	14%	49	0	1	Critical
Harvest	50	49%	50%	0%	100%	23%	22	23	5	Regular
Solid Waste Management	49	41%	33%	0%	100%	29%	37	5	7	Critical
Soil management	2	50%	50%	0%	100%	71%	1	0	1	Regular
Ecosystems	49	21%	0%	0%	100%	41%	38	1	10	Critical
Growth and fattening stages	49	38%	29%	13%	89%	21%	31	15	3	Critical
Infrastructure	50	73%	100%	0%	100%	43%	14	1	35	Good
Wastewater Management	2	100%	100%	100%	100%	0%	0	0	2	Good
Pond Preparation and Maintenance	50	50%	56%	0%	100%	31%	18	26	6	Regular
Security	50	31%	25%	0%	100%	30%	26	21	3	Critical
Harvest transport	2	50%	50%	0%	100%	71%	1	0	1	Regular
Transport of live fish	5	62%	60%	0%	100%	41%	1	2	2	Regular
Water use	2	33%	33%	33%	33%	0%	2	0	0	Critical

Appendix 4. Pearson correlation P-value comparing all the Management Subjects compliance result.

	QFeeding	QAuthnPermi	QBiosecurity	QFoodstorage	QHarvest	QSolidWasteMan	QEcosystems	QGrowthnFattening	QInfrastructure	QPrepnMainten	QSecurity	Fishxcycle
QFeeding	NA	0.181	0.003	0.971	0.454	0.005	0.279	0.101	0.275	0.000	0.252	0.478
QAuthnPermi	0.181	NA	0.039	0.449	0.231	0.877	0.977	0.864	0.073	0.832	0.118	0.052
QBiosecurity	0.003	0.039	NA	0.243	0.002	0.875	0.041	0.002	0.006	0.033	0.000	0.085
QFoodstorage	0.971	0.449	0.243	NA	0.004	0.096	0.885	0.041	0.407	0.028	0.017	0.190
QHarvest	0.454	0.231	0.002	0.004	NA	0.696	0.050	0.002	0.038	0.014	0.000	0.000
QSolidWasteMan	0.005	0.877	0.875	0.096	0.696	NA	0.539	0.029	0.265	0.000	0.141	0.621
QEcosystems	0.279	0.977	0.041	0.885	0.050	0.539	NA	0.707	0.789	0.215	0.111	0.542
QGrowthnFattening	0.101	0.864	0.002	0.041	0.002	0.029	0.707	NA	0.294	0.002	0.018	0.067
QInfrastructure	0.275	0.073	0.006	0.407	0.038	0.265	0.789	0.294	NA	0.064	0.005	0.202
QPrepnMainten	0.000	0.832	0.033	0.028	0.014	0.000	0.215	0.002	0.064	NA	0.010	0.194
QSecurity	0.252	0.118	0.000	0.017	0.000	0.141	0.111	0.018	0.005	0.010	NA	0.003
Fishxcycle	0.478	0.052	0.085	0.190	0.000	0.621	0.542	0.067	0.202	0.194	0.003	NA

+

Green: p-value<0.05, Blue: p-value<0.001

Appendix 5. Pearson correlation coefficient (r) comparing all the Management Subjects compliance result**.**

	QFeeding	QAuthnPermi	QBiosecurity	QFoodstorage	QHarvest	QSolidWasteMan	QEcosystems	QGrowthnFattening	QInfrastructure	QPrepnMainten	QSecurity	Fishxcycle
QFeeding	NA	0.201	0.433	-0.005	-0.113	0.404	-0.163	0.245	0.164	0.517	0.172	0.107
QAuthnPermi	0.201	NA	0.305	0.114	0.180	0.024	0.004	0.026	0.267	-0.032	0.233	0.289
QBiosecurity	0.433	0.305	NA	0.176	0.452	0.024	0.302	0.451	0.400	0.315	0.598	0.257
QFoodstorage	-0.005	0.114	0.176	NA	0.418	0.248	-0.022	0.303	0.125	0.324	0.352	0.197
QHarvest	-0.113	0.180	0.452	0.418	NA	0.059	0.291	0.444	0.307	0.360	0.584	0.546
QSolidWasteMan	0.404	0.024	0.024	0.248	0.059	NA	-0.093	0.322	0.168	0.553	0.220	-0.075
QEcosystems	-0.163	0.004	0.302	-0.022	0.291	-0.093	NA	0.057	-0.041	0.186	0.238	0.092
QGrowthnFattening	0.245	0.026	0.451	0.303	0.444	0.322	0.057	NA	0.158	0.449	0.346	0.272
QInfrastructure	0.164	0.267	0.400	0.125	0.307	0.168	-0.041	0.158	NA	0.275	0.410	0.192
QPrepnMainten	0.517	-0.032	0.315	0.324	0.360	0.553	0.186	0.449	0.275	NA	0.377	0.195
QSecurity	0.172	0.233	0.598	0.352	0.584	0.220	0.238	0.346	0.410	0.377	NA	0.432
Fishxcycle	0.107	0.289	0.257	0.197	0.546	-0.075	0.092	0.272	0.192	0.195	0.432	NA