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EXPLORING SUSTAINABILITY THROUGH STAKEHOLDERS' EYES: THE CASE OF SMALL-SCALE AQUACULTURE IN THE GULF OF NICOYA

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ABSTRACT

Small-scale aquaculture emerges as a socially and environmentally sustainable alternative, capable of meeting food needs, combating poverty, promoting gender equality, and generating direct and indirect employment. This study examines the Gulf of Nicoya, Costa Rica, as a model of small-scale production to describe its current situation and productive trajectory, and to identify opportunities and challenges to achieve sustainability. It is carried out through a mixed, transdisciplinary approach, incorporating qualitative and quantitative methodologies to collect information from the farm, producers, surrounding communities, the public sector, academia, and NGOs. Descriptive, genealogical, stakeholder network, and content analyses were applied. The results reveal that the production of white shrimp, Japanese oyster, spotted rose snapper, and mussels is identified in the Gulf of Nicoya, with varying volumes, productive structures, and evolutionary histories. The aquaculture activity presents a robust business ecosystem, with multiple actors from different sectors involved; however, there is a notable lack of community involvement and interaction among productive species. Opportunities for improvement focus on the financial structure, marketing strategies, knowledge capital, cohesion among producers, infrastructure and equipment, management practices, and the use of the most appropriate technologies.

Introduction

The notion of sustainable development was coined at the United Nations Development Summit. It was formally defined as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (World Commission on Environment and Development 1987). In line with this definition, there is a need to develop national and international policies that enable the achievement of the Sustainable Development Goals and ensure sustainability (United Nations, 2016).

Linked to the concept of sustainable development is the Sustainable Livelihoods Framework (SLF) model proposed by Chambers and Conway (1991), which outlines mechanisms for communities and individuals to use resources, capacities, and strategies to live without compromising the long-term sustainability of those resources. These are resilient models that consider the available human, financial, social, natural, and physical assets to address poverty in its multiple dimensions through ecologically sustainable food security platforms (Chambers & Conway, 1991). The model has been adopted by international institutions that have proposed methodologies for monitoring these types of systems (SIDA, 2001; CARE, 2002; FAO & DFID, 2007).

These models have been applied in small-scale aquaculture systems. Such is the case in Nigeria, where experiences in fish farming have been documented (Mudashiru, 2025). In Indonesia, aquaculture systems that adopt this model have led to significant changes in structural balance, social projections, and community equity (Diartho *et al.*, 2024). In Madagascar, this model is evident in women's cooperatives engaged in freshwater aquaculture (Angermayr *et al.*, 2023). In Uganda, the feasibility of implementing SLF in small-scale lake-based aquaculture systems is being analysed (Byabasaija *et al.*, 2025).

In line with this global goal, the Blue Economy concept has been proposed as an economic model that aligns with SDG14: Marine Life, aiming to promote the development of sustainable practices in fisheries and aquaculture (Bennett *et al.*, 2019). The blue economy is defined as the sustainable use of marine and aquatic resources. This involves generating economic activities that protect ecosystems while also promoting economic growth, employment, food resources, and well-being in coastal areas (International Union for Conservation of Nature, 2024). This model is highly relevant from an economic and social point of view, contributing trillions of United States dollars to the economy and providing livelihoods for billions of people; environmental and climate change, through the protection of ecosystems, the promotion of blue carbon, renewable marine energy, and ecosystem-based management; innovation and employment, through the expansion of ocean industries; and policy coherence, through a sustainable blue approach that integrates oceans, coasts, and inland waters with the circular economy and energy transitions (Approach & Operations, n.d.). Its development gained momentum in 2012 when the United Nations promoted it at its Rio+20 conference (European Commission, 2012). Today, its practices are promoted by major international organisations and have been adopted across the globe, including by the European Union, the African Union, the Association of Southeast Asian Nations (ASEAN), and the Caribbean (European Commission, 2012; AU-IBAR, 2019; ASEAN, 2023).

Similarly, the Food and Agriculture Organisation (FAO, 2024) has asserted that sustainable aquaculture constitutes an economic alternative that meets global food security needs, generates employment opportunities and reduces fishing pressure. In addition, the aquaculture industry has experienced notable increases in production and technological advances in recent years, in contrast to the fishing industry (Boyd *et al.*, 2020). However, the aquaculture industry faces significant challenges in achieving sustainability, particularly in environmental and social dimensions (Isabelle & Westerlund, 2022). From a social perspective, key challenges include equity, equality, and human rights, which remain critical concerns. Consequently, there is an increasing call for a more human-centred approach to aquaculture-one that prioritises the needs of marginalised populations while fostering a more inclusive and socially responsible industry (Brugere *et al.*, 2023).

In contrast, small-scale aquaculture has been reported in South American countries (FAO, 2000), Africa (Syanya *et al.*, 2024), and South Asia (Haque *et al.*, 2025). In past decades, this form of production experienced a decline in attention across Latin America (Athanasiadis, 1999). However, it remained viable due to the government programmes that provide financial support to sustain the activity. In contrast, in recent years, this type of production has become increasingly important as a sustainable alternative that can serve communities with limited socioeconomic conditions (Syanya *et al.*, 2024). Likewise, the activity stands out as an economic alternative that enables the integration of women under equitable conditions, particularly in coastal areas (Siar *et al.*, 1995). Typically, these productions are characterised by being communal or family subsistence projects, with extensive or semi-intensive techniques, low production costs, and low levels of technology (Subasinghe *et al.*, 2009; Boyd *et al.*, 2020; Haque *et al.*, 2025). This supports the social contribution of this type of production as an effective alternative to alleviate poverty and meet food needs as a source of direct and indirect employment (Padhy *et al.*, 2022; Ababouch *et al.*, 2023). Likewise, its humanistic approach creates conditions that favour gender equality and inclusion (Dompreh *et al.*, 2024). In addition, recent studies highlight the low environmental impact of this type of production (Andrade-Silva *et al.*, 2025). Despite its potential contribution to sustainability, this type of production is poorly documented (Syanya *et al.*, 2024).

This study focuses on the Costa Rican marine aquaculture case, which is historically characterised by responding mainly to small-scale family models (FAO, 2022), with an estimated production of 19,976 tonnes per year for 2019, the latest published report available (INCOPESCA & SEPSA, 2019). The first species cultivated in the country were tilapia (*Oreochromis niloticus*) and white shrimp (*Peanaeus vannamei*), both of which continue to lead national aquaculture production.

In Costa Rica, significant efforts in marine fish aquaculture have been made since the 1990's, particularly with the rose spot snapper (*Lutjanus guttatus*), a species whose life cycle has been completed in captivity, allowing reproduction and commercial production in marine cages. These efforts have been led by Universidad Nacional (UNA) and Parque Marino del Pacífico (Herrera Ulloa, 2019). Similarly, research and development initiatives have focused on mollusc species, such as the Japanese oyster (*Crassostrea gigas*), also spearheaded by UNA, as part of broader efforts to diversify marine aquaculture in the country (Rojas-Alfaro *et al.*, 2017).

As a result of these research and development efforts, certain regions of the country have emerged as key aquaculture hubs. Among them, the Gulf of Nicoya stands out for its production of shrimp and oysters (Ramírez *et al.*, 2023) and, more recently, snappers and mussels. This region is characterised by low economic indicators due to a lack of employment and poor socioeconomic conditions (UCR & PNUD, 2022). Traditionally, the local economy is characterised by a high dependence on extractive activities, such as fishing and mollusc harvesting (Pacheco, 1998; Picón and Flores, 2010), which pose significant environmental challenges (Juárez-Matute *et al.*, 2019). Therefore, aquaculture has been mentioned as a productive alternative with the potential to develop the local economy (Arias, 2019). However, no studies have evaluated the sustainability of the aquaculture system in Costa Rica (Robles-Herrera, 2025).

This study presents an exploratory study that employs a mixed-methods approach, focusing on stakeholder perceptions of aquaculture sustainability utilising a participatory data collection methodology. The objective of this study is to characterise aquaculture production in the Gulf of Nicoya by identifying opportunities for sustainability from the perspective of the stakeholders. The study addresses the following research questions: What are the production characteristics present the Gulf of Nicoya aquaculture system; what historical events led to the current state of aquaculture; how is the governance structure of the aquaculture system defined based on the business ecosystem; and, what are the challenges and opportunities of small-scale aquaculture in the case of the Gulf of Nicoya perceived from producers and stakeholder's perspective. This study provides a historical account of aquaculture production in the Gulf of Nicoya, followed by an analysis of the business ecosystem's structure. The study concludes with an examination of the challenges confronting the sector.

Materials and Methods

A phenomenological study with an exploratory scope and a mixed-methods approach was conducted to ascertain the current status of aquaculture in the Gulf of Nicoya. The research was conducted from March 2024 to December 2024. The study included collecting information from governmental institutions and trade associations, using a variety of instruments integrated through triangulation to define four constructs: Production characterisation, production history, business ecosystem, and challenges and opportunities. The information was collected and processed using a transdisciplinary approach, incorporating external representatives from the biological, social, and engineering sciences.

Information Collecting Processes

Various activities drove the information-collecting processes, the description of which is provided:

Database integration: Unpublished databases containing information on farms, localisation, area, producers, and permissions maintained by various governmental entities and trade groups were accessed, including those from environmental, animal health, fisheries, and aquaculture offices, as well as producer association sources. The databases include institutions such as the Animal Health National Service (SENASA, in Spanish), the Environment and Energy Ministry (MINAE, in Spanish), the Costa Rican Fishery and Aquaculture Ministry (INCOPESCA, in Spanish), and the Shrimp Producers Chamber (CAPROCAM). The information contained in these databases was consolidated into a single database, which was further enriched with information on organisation type, owners, production estimates, and employees derived from field data obtained during subsequent stages of the study. The information obtained was used to determine the number of farms in the region producing

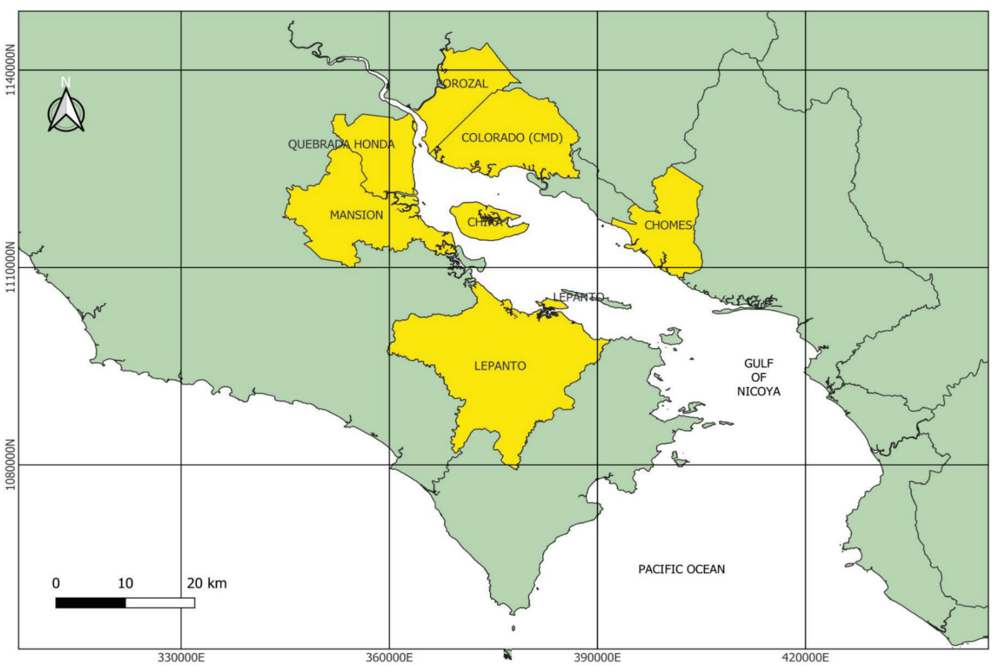

Figure 1: Gulf of Nicoya map with political administrative distribution
Source: Map produced by Gustavo Pérez Ugalde (topographer), based on field survey data

aquaculture by species. It was analysed using descriptive statistics.

Farm visits: Field visits were conducted to collect information on facility conditions and management practices, including production, productive history, governance, cultural practices, facility conditions, and business ecosystem relations. The survey was designed by the authors, taking into account field guides from the sanitary Costa Rican office (an internal document not published). The data were collected through semi-structured interviews, a methodology used in aquaculture sustainability assessment (Valenti *et al.*, 2018). A total of 40 aquaculture units were visited, representing 100% of oyster farms and 30% of shrimp farms. The farms were selected to allow sampling of all farms. Aquaculture units were excluded because they were inactive or because producers chose not to participate in the study. The sampled farms are representative of the population in terms of sectors, farm sizes, and producers' sociodemographic characteristics. The sites sampled included the districts of Chomes, Colorado, Porozal, Quebrada Honda, Mansión, Lepanto, Chira, and Venado Island, where all aquaculture farms in the Gulf of Nicoya are distributed (supplementary information). Information was obtained on production characterisation, business ecosystem, and challenges and opportunities.

Producer workshops: Participatory methodologies are recommended to identify sustainability priorities, and workshops have been used in aquaculture governance scenarios (Ainsworth *et al.*, 2023). Four workshops with producers were conducted using participatory methods to collect their perceptions of the challenges and opportunities facing aquaculture in the Gulf of Nicoya, following the methodology suggested by Ballesteros (2014). The information collected included the relationships between the economic ecosystem and governance, as well as the challenges and opportunities from the producers' perspective. The workshops included oyster and shrimp producers from districts of Chomes, Colorado, Porozal, Quebrada Honda, Mansión, and Lepanto, as well as Chira and Venado Islands. Information was obtained on the business ecosystem, its challenges, and opportunities.

Community visits: A survey was conducted among residents of neighbouring communities by visiting individual households where surveys were administered, a method reported in sustainability assessment (Valenti *et al.*, 2018). Information collected included the relationship between aquaculture units and the community, opportunities for community involvement in production, and community members' perceptions of aquaculture, which contribute to understanding the business ecosystem construct. A total of 56 residents were included in the survey.

Stakeholder consultation: Key stakeholders in the aquaculture ecosystem, including producers, government officials, academic representatives, NGOs, consultants, and seed suppliers, were engaged through in-depth interviews, a methodology reported in sustainability assessments (Yuedi *et al.*, 2023). The sample was selected by aquaculture experts in the Gulf of Nicoya. A snowball sampling method was used, in which each expert recommended other individuals based on their field experience. The information collected focused on the history of production, the business ecosystem, production characterisation, and the challenges and opportunities faced by the sector. These discussions provided valuable insights into the current state of aquaculture in the country and the Gulf of Nicoya, as well as perspectives on the challenges and opportunities facing the sector.

Field journals: Researchers made observations during visits to farms and communities, which were systematised in field diaries. These included aspects of infrastructure, management, social, and environmental conditions. Comments from producers and community members not included in the measurement instruments were also included. Information was obtained from production characterisation, production history, and challenges and opportunities.

Table 1: Information collection processes measurement instruments by population citation, producers, the academic sector, consultants, Non-Governmental Organisation (NGOs), and neighbouring communities

Collecting Information Activity	Type of Instrument	Construct	Population Target	Number of Instruments	Information Analysis
Database integration	Data bases	Production characterisation	Governmental offices	6	Descriptive analysis
			Trade associations	1	
Farms visits	Semi-structured interview	Production characterisation; business ecosystem; challenges and opportunities	Producers	40	Genealogical analysis; network analysis; content analysis
Producers workshop	Workshop summaries	Business ecosystem; challenges and opportunities	Producers	4	
Community visits	Administrated surveys	Business ecosystem;	Community	56	
Stakeholders consultation	In-depth interview	Production history; business ecosystem; challenges and opportunities	Producers representatives	5	
			Governmental employees	4	
			Academic	4	
			NGO and consultants	2	
			Suppliers	2	
Field journal	Field observations	Production characterisation; production history; challenges and opportunities	Farms community	5	Content analysis

Source: Self-constructed (2025)

Information Systematisation and Analysis Processes

Descriptive analysis: The collected data were merged into a single database with information from different sources. Information from interviews and farms visited was used to feed the database. The averages for production and employees across the visited farms were used to estimate total production and direct and indirect employees. The data were analysed using descriptive statistics in Excel and RStudio® with the ggplot2 library to graph the information.

Genealogical approach historical analysis: The genealogical approach has been proposed for sustainable analysis in agriculture as a methodology that focuses not only on the present, but also on historical events that originate the current situation. Employs narratives of key events and actors involved in the evolution of production (Bless *et al.*, 2023). Following this methodological approach, the authors analysed interview data using a narrative analysis that highlights relevant events in the development and evolution of aquaculture production.

The information from interviews was analysed and systematised in a database of events classified by production species. Stages classified historical events: (1) Experimental (E), defined as stage led by academic actor with pilot project resulting from experiment in field; (2) Technology transfer (T), defined as process led by academic sector which knowledge and techniques are transferred to producers driven by training; (3) Development (D), defined as processes which producer develop their own production by themselves ; (4) Crisis (C), stage in production domain by production depletion caused by diversity of factors; (5) Recovery (R), a period after crisis stage where production present a tendency to increase a recover the original state; (6) Peak (P), a period where production reach the maximum historical production with several elements of success (supplementary information). The history of aquaculture in the Gulf of Nicoya was illustrated using Publisher® software.

Network analysis: a qualitative methodology used to understand governance frameworks (Hermans & Thissen, 2009). This study follows the methodology proposed by Newman (2010). The relationships reported by producers and stakeholders of the aquaculture system in the Gulf of Nicoya were systematised in an adjacency matrix with weight, closeness, and vice versa relations. A social network analysis was conducted using RStudio® with the tidyverse, paqueteadp, tidygraph, ggraph, and ggcorrplot libraries. The adjacency matrix was mapped, representing the governance structure relationships. Centrality measures such as weighted degree, betweenness degree, closeness, and weighted pagerank were also calculated (Newman, 2010). The information was analysed using descriptive statistics by organisation type to interpret the structure of the governance framework (supplementary information).

At the same time, a value chain was constructed using the information from the interviews and workshops. The seed suppliers and commerce intermediaries were identified. The information was presented graphically using Publisher® software.

Content analysis: The information from the interviews and the field journal were analysed using Atlas.ti® software according to categories sorted by dimensions, challenges, and opportunities. The analysis was driven by the qualitative methodology content analysis (Ballesteros, 2014). The categories were summarised by type of production, challenges, and opportunities, taking into account comments and quotes from all the stakeholders and producers interviewed.

Results

Production Characterisation of Gulf of Nicoya Aquaculture

A preponderance of small-scale farms characterises aquaculture production in the Gulf of Nicoya, although it accounts for only 4% of the country's annual national aquaculture production. However, these farms cover 82% of the productive area, providing income for 198 families, which accounts for 12% of the jobs generated by aquaculture nationwide.

The farms within this system are dedicated to the production of shrimp (728 annual tonnes and 104 active farms), oysters (114 annual tonnes and 6 active farms), and snapper and mussels (1 farm each, with 8 and 3 annual tonnes, respectively). Figure 2 shows the distribution of weights by species in terms of annual metric tonnes, production area, and number of aquaculture units.

Shrimp production is exclusively the domain of private entities, operating within semi-intensive systems characterised by low-

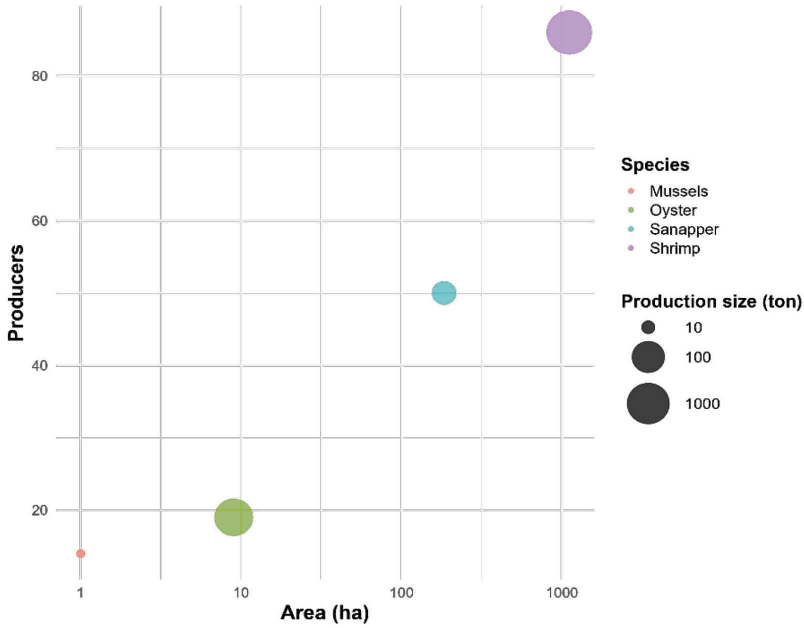

Figure 2: Aquaculture production in the Gulf of Nicoya by species, illustrating the relationship between total cultivated area (x-axis), number of producers (y-axis), and annual production volume (dot size)
Source: Self-constructed from database information (2025)

density cultivation, with an average of eight to 12 shrimp per square meter. These systems are established within ponds in the mangrove area, on state-owned land that has been granted concessions dating back to the 1950s and 1980s. The Gulf of Nicoya shrimp production represents nearly 50% of the national production (46%). The majority of the aquaculture units are small-scale farms, ranging in area from one hectare to 30 hectares, with a few exceptions of larger-scale farms. These farms are estimated to generate approximately 213 direct and indirect employment opportunities. The production is distributed across the coastal zones of the Gulf of Nicoya, with a major concentration in the Chomes de Puntarenas, Colorado de Abangares, Quebrada Honda de Nicoya, and Lepanto de Puntarenas communities.

Conversely, oyster, snapper, and mussel production are the purview of mariculture overseen by communal and fishermen associations. The farms are established in the communities of Costa Pájaros (in Chomes de Puntarenas), Chira, and Venado (in Puntarenas and Lepanto de Puntarenas, respectively), with each farm encompassing approximately one hectare. The production model is semi-intensive, characterised by the cultivation of oysters and mussels in lines, and of snapper in cages.

The shrimp in question is white *(Penaeus vannamei*), and production is supplied with national seed from three reproduction laboratories, all located in the Gulf of Nicoya, with national genetics obtained from broodstock. In the case of oysters, the seed is supplied by the Universidad Nacional oyster seed laboratory.

Aquaculture System Genealogical Analysis

The history of aquaculture in the Gulf of Nicoya begins in 1973, when the very first shrimp farm was established in Chomes, Puntarenas. Subsequently, several determining events occurred, leading to the current situation of the aquaculture system, with relevant differences between species. Figure 3 presents the main events that occurred. The description of these event sequences is detailed by species

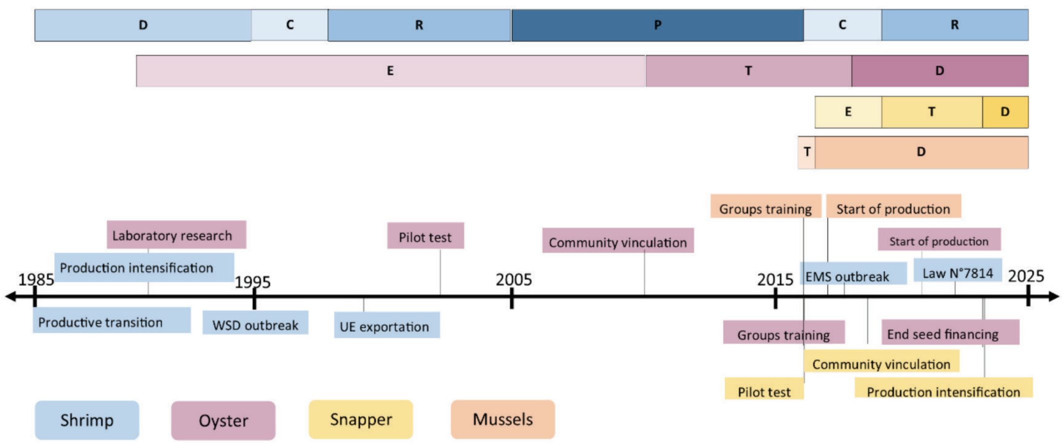

Figure 3: History of aquaculture by production species in Gulf of Nicoya, Costa Rica. Stages: E: Experimental, T: Transference, D: Development, C: Crisis, R: Recovery, P: Peak
Source: Self-constructed from field information (2025)

as follows. These have been classified in six stages: Experimental (E), Technology transfer (T), Development (D), Crisis (C), Recovery (R), and Peak (P). Not all stages are present in all four production species; some are unique to one species.

Shrimp Production

The production history of shrimp farming in Costa Rica, initiated in the Development stage, as illustrated in Figure 3. Due to the private origin of this production, the Experimental and Technology transfer stage was absent. On this initial development, the Free Trade Agreement with Mexico in 1986 led to a substantial increase in shrimp farming operations across the Gulf of Nicoya. This expansion was primarily driven by the conversion of salt flats into aquaculture ponds, a process promoted by a producer's cooperative (Coonaprosal R.L) with financing from the National Production Council (CNP, in Spanish). At its peak, approximately 130 farms were operating along the Gulf of Nicoya.

In its nascent stages, producers adopted rudimentary production techniques under the guidance of approximately five biologists who provided weekly consultations. During this period, there was a pursuit of production intensification, with stocking densities reaching up to 25 shrimp per square meter. Production practices adhered to standardised protocols, including fertilisation and liming, without integration of aeration systems. However, a crisis stage emerged in 1995 with the outbreak of White Spot Disease (WSD), resulting in up to 90% mortality and significant financial losses across the sector.

A recovery stage followed the initial crisis; shrimp farms transitioned to lower stocking densities, ranging from 10 shrimp per square meter to 15 shrimp per square meter, and introduced emergency aerators alongside the implementation of Best Aquaculture Practices (BAP). By 2005, shrimp production had reached a Peak stage, accessing both traditional and organic export markets to Europe. This phase of prosperity lasted for approximately 15 years. However, a confluence of factors, including delays in permit renewals, accumulated debts, increased shrimp imports, and declining export prices, began to compromise the economic sustainability of the activity.

In 2018, an outbreak of Early Mortality Syndrome (EMS) resulted in substantial economic losses and led to a formal declaration of a second Crisis stage in the sector. Consequently, numerous producers chose to cease operations, while others entered leasing arrangements for the farms. The crisis was further compounded by the emergence of Coronavirus Disease 2019 (COVID-19), which imposed limitations on domestic marketing channels.

Since 2022, the sector has been gradually recovering, marked by structural and operational changes. These include a shift toward serving the domestic market, lower stocking densities, a trend toward natural production methods, and the adoption of primary productivity enhancers. Other adjustments involve reduced pumping, limited technical advisory services, and minimal investment. There is also a trend toward self-financing of production. While these changes aim to enhance economic resilience, they also highlight the challenges of operating in a more constrained and resource-limited environment.

Even though shrimp production is managed exclusively by private capital, its historical development has been closely associated with trade organisations. Presently, three recognised entities operate within the sector: Two cooperatives with some associates and the Shrimp Producers Chamber (CAPROCAM), which endeavours to unify all producers. In recent years, the latter has assumed a leadership role, striving to enhance conditions within the sector. Consequently, efforts are underway to legalise shrimp farm permits through collaborative efforts with government entities. Furthermore, training and technical improvement options are also being sought for the sector in collaboration with the academic sector, as well as strategies to strengthen commercialisation.

Oyster Production

The history of oyster production in Costa Rica began with an Experimental stage in 1990, with the initiation of laboratory research on the reproduction of Japanese oysters *(Crassostrea gigas*) by the Universidad Nacional de Costa Rica (UNA). This initiative was undertaken as a low-cost, productive alternative for coastal communities. By 2000, efforts to engage community groups had commenced, and in 2002, an experimental pilot project for growth-out operations was initiated in Punta Cuchillo. Since 2010, the Technology transfer stage has started, with UNA collaborating with other institutions. Work has been conducted with 10 community associations comprising both women and men, focusing on training in production techniques and financial management. Currently, legal permission has been obtained. The development stage of the productive phase commenced in 2020, with the financial backing of the Rural Development Institute (INDER, in Spanish). This funding was allocated for the establishment of infrastructure, the procurement of operational equipment, and the coverage of oyster seed expenses for a period of two years (Figure 3).

Presently, six oyster farms are in operation in the marine-coastal zones adjacent to the communities of Costa Pájaros, Isla Chira, Isla Vendado, Colorado, and Paquera. Five of these enterprises are situated within designated marine protected areas that are part of the Responsible Fishing Areas Program (AMPR, in Spanish), a programme overseen by the Instituto Costarricense de Pesca y Acuacultura (INCOPESCA)—the government entity responsible for fisheries and aquaculture. A total of 19 producers are involved in this initiative, generating 32 direct and indirect employment opportunities and achieving an annual production of 114 tonnes. The seed supply is provided by the UNA, which has the capacity to support twice the current production levels.

The production is targeted at high-end restaurant and hotel markets. The depuration process is conducted at UNA facilities, ensuring product safety. Furthermore, UNA and SENASA collaborate to monitor oysters and meat to prevent red tide contamination.

The predominant challenge confronting oyster producers at present pertains to the imperative to transition from a fisherman-oriented perspective, marked by daily subsistence and short-term decision-making, to a producer-oriented approach that emphasises strategic planning, resource management, and long-term sustainability. This transition is imperative to enable oyster producers to achieve self-management and financial autonomy on their farms following the termination of seed subsidies.

Snapper Production

Snapper production started in the Development stage, without an Experimental stage. The Technology transfer occurred simultaneously with the production development. This production was developed by Isla Venado Fishermen's Cooperative in 2016 to diversify their economic activities and improve their living conditions. This cooperative comprises 50 members who produce snapper and derive their livelihoods from it. This integrated initiative encompasses aquaculture production through open systems in floating cages, complemented by tourism and commercialisation via a floating restaurant. The species cultivated include snapper (*Lutjanus guttatus*), croaker, and shrimp (*Litopennaeus vannamei*), with low-density cultivation practices employed. The annual production of these species is approximately eight tonnes, and all production is self-commercialised. The aquaculture practices employed in this integrated project entail the use of artificial seed stock, supplied by the Parque Marino del Pacífico and regional shrimp hatcheries. The feed is locally produced by a group of women from Isla Venado using artisanal techniques.

During the project's inaugural stage, the National Learning Institute (INA, in Spanish) and the Parque Marino del Pacífico provided support through training and infrastructure construction. They also assisted in acquiring the requisite permits. The initial capital of the project was provided by producers themselves. Subsequently, other institutions have joined in supporting the initiative. The initiative has been successful, as evidenced by the establishment of the floating cages of Isla Venado as a rural community tourism project. This project has generated employment opportunities and has bolstered the local economy. The initiative also engages in environmental conservation activities, mangrove reforestation, environmental education for tourists, and sport fishing in aquaculture floating cages, among others.

Beyond the sustainability success of the floating cages project, the Parque Marino del Pacífico, Universidad Técnica Nacional (UTN), and INA, in collaboration with various state institutions and NGOs, have joined forces to scale up the productive use of floating cages as an alternative activity for fishing groups. Presently, the initiative is in a training phase targeting community associations from diverse regions across the country. The overarching objective of this initiative is threefold: (1) to expand aquaculture projects, (2) to strengthen training based on sustainable management and best aquaculture practices, (3) to promote technical certification of producers, and (4) to continue leading tourism activities integrated with aquaculture production through an economy-of-scale approach.

Mussels Production

The initiative to cultivate mussels in the Gulf of Nicoya began in 2016 through a pilot extension project for coastal communities, led by the Universidad Estatal a Distancia (UNED), during the Experimental stage. Figure 3 presents a chronology of significant events in the history of mussel production in the Gulf of Nicoya. In 2019, the project initiates the Technology transfer stage, involving a community group from the Fisherman's Association of Palito, Isla Chira, consisting of 14 members. The initiative was carried out within a designated marine protected area under the purview of the AMPR administered by INCOPESCA.

This is an open system within an in situ reproduction project that aims to promote mussel bed settlement through mariculture techniques. Presently, the farm is the sole mussel farm in the nation, with an annual production capacity of three tonnes. The farm has 14 direct employees and approximately three indirect jobs. Figure 2 illustrates the contribution of mussel production in the Gulf of Nicoya. In its nascent phase, UNED, with the support of other organisations, established the cultivation infrastructure and provided guidance, training and capacity building for the community group. Presently, the group has attained a Development stage of operational independence. The group has successfully secured external funding independently (Figure 3) and currently manages the production and commercialisation of the resource.

At present, UNED continues to monitor physicochemical and oceanographic parameters. The present phase of the project is one of consolidation, accompanied by projections of increased field production and technological improvements in the monitoring process. The establishment of inter-university partnerships at national and international level is being pursued, with the aim of securing funding and the procuring technological capabilities of production monitoring.

Governance Framework in Gulf of Nicoya, Costa Rica

In the Gulf of Nicoya, aquaculture production networks exhibit varying degrees of complexity and interconnections with pivotal actors. Shrimp production exhibits the most intricate network, encompassing suppliers and marketers, though these interactions are confined to the commercial domain. In contrast, oyster, mussel, and snapper aquaculture production networks exhibit a comparatively less intricate structure. However, they demonstrate notable interactions with multi-sector institutions that enhance their overall activity. Figure 4 presents a diagram of the network interactions in aquaculture systems.

CAPROCAM is the most influential group association in the activity. CAPROCAM's role is to promote relations between the public sector, academia, NGOs, banks, and commerce. However, its scope is restricted to shrimp production. The academic sector, spearheaded by the UNA, plays a pivotal role as a proponent and a provider of technical support to all production endeavours. Furthermore, the academic sector has been instrumental in establishing connections with other institutions that have contributed to the empowerment of aquaculture. The government, through institutions such as INDER, INCOPESCA, and SENASA, plays regulatory and financing roles, while NGOs participate selectively in different production processes. The centrality measures of the key actors are presented in Table 2.

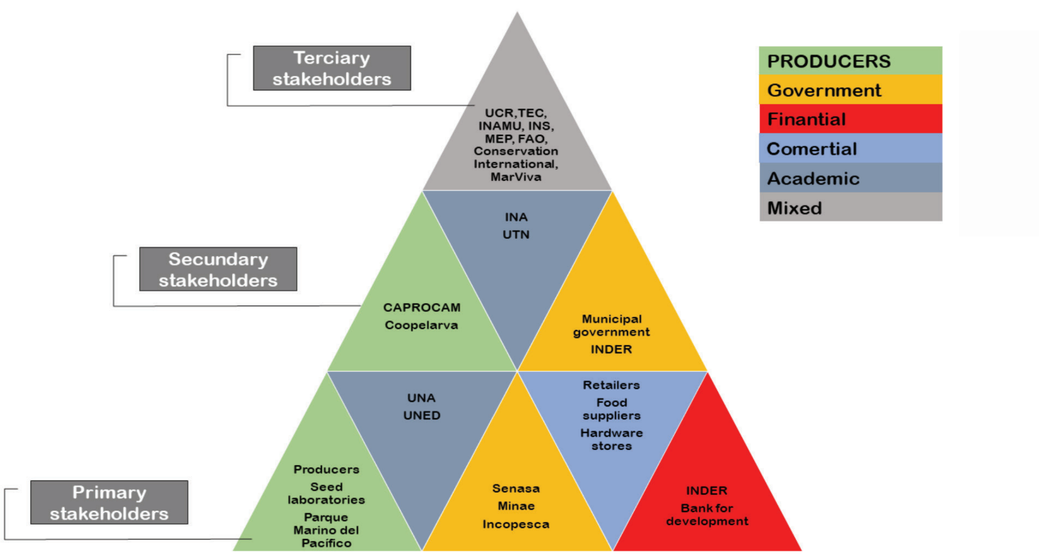

Figure 4: Stakeholders network, according to the type of function with aquaculture system in Gulf of Nicoya Costa Rica

Source: Self-constructed from field information (2025)

Table 2: Gulf of Nicoya aquaculture network centrality measures from key actors

Type of Institution	Institution	Degree	Pagerank
Guild association	CAPROCAM	9	0.028
Academic	UNA	14	0.030
	INA	7	0.018
	UNED	6	0.012
	TEC	7	0.012
	UCR	7	0.011
	UTN	4	0.010
Government	INDER	9	0.043
	INCOPESCA	7	0.016
	SENASA	8	0.013
ONG	Marine Pacific Park	5	0.010
	Conservation International	4	0.010

Source: Self-constructed from field information (2025)

There is also a lack of interaction between the producers of the different species cultivated in the Gulf of Nicoya. This absence of interaction is also reflected in the relationship with local communities. Conversely, red snapper production shows a dynamic interaction with the community, with local members actively involved in the productive and commercial processes and thus playing a prominent role. On the other hand, shrimp production is recognised by the community and is seen as an independent endeavour without significant interaction. Oyster and mussel production remains largely unrecognised and undervalued by the local community.

The commercial value chain, as illustrated in Figure 5, encompasses several distinct stages. The presence of one middleman in the oyster production process and five in shrimp production has been identified. These

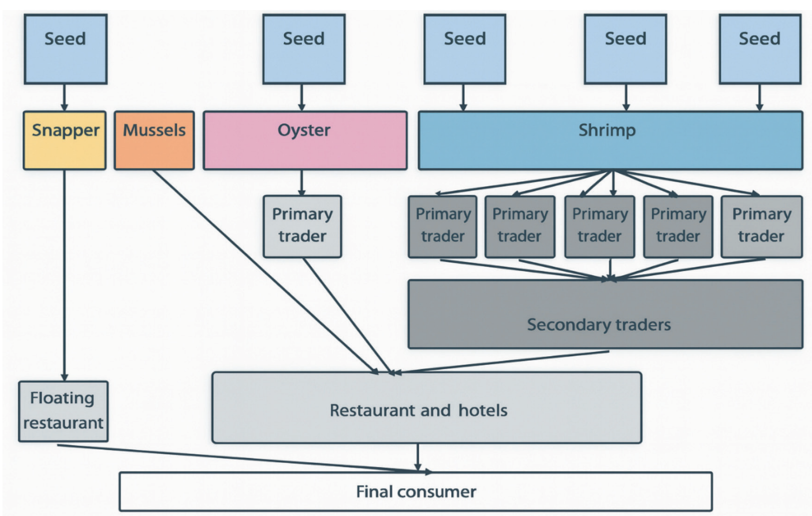

Figure 5: Aquaculture value chain in Gulf of Nicoya
Source: Self-constructed from field information (2025)

individuals act as a link to the next levels of the commercial chain, exerting control over market prices. This situation places the producer in a condition of commercial vulnerability. In contrast, the production of mussels and snapper has completed the commercialisation chain, enabling them to reach the final consumer and exercise greater control over market prices.

Challenges and Opportunities Toward Sustainable Production

According to producers and stakeholders, the pursuit of sustainable aquaculture in the Gulf of Nicoya is hindered by several challenges and accompanied by several opportunities. The most salient of these challenges are discussed below and summarised by dimension. In the following section, the description of those challenges and opportunities is provided in detail.

Technical dimension: Stakeholders describe this as one of the main areas of opportunity in Gulf of Nicoya aquaculture. Production in all cultured species relies on rudimentary techniques and low levels of technology. The technology acquisition path differs among experts, but the challenges and opportunities identified are improvements in facilities and equipment, and in management practices. In addition, research gaps in key areas such as environmental impacts, sustainability assessment, production risks, management practices, and ecological agriculture.

Addressing these needs through strategic financial planning that integrates maintenance costs into operational expenses can enhance occupational health, optimise productivity, and strengthen the long-term sustainability of aquaculture operations. In addition, formulating a focused research agenda to improve aquaculture management practices and foster knowledge transfer can support the development of sustainable, competitive production systems in the country.

Economic dimension: The economic dimension highlights relevant differences among production species. While mussel and snapper production show economic stability, shrimp and oyster producers highlight major difficulties they face. The main challenges are an expanding market, constraints imposed by intermediaries, and limited financial management skills.

Consequently, there is an evident need to formulate an integrated market strategy that facilitates competitive differentiation with imported products while ensuring equitable prices for producers, provides training in financial management, and develops mechanisms for accessing credit specifically tailored to this type of activity.

Environmental dimension: In environmental terms, according to the interviews madden, producers from all species cultured assert a strong commitment to sustainable production practices. In terms of environmental impact, shrimp and snapper production with weak or non-existent soil management results in the accumulation of organic matter on the bottom. Pest management relies on chemical treatments, which can impact surrounding ecosystems. Conversely, the pumping emits carbon, although some sectors have adopted lower-emission electric motors. However, electricity is not readily available in most shrimp farming regions, prompting the use of diesel engines that emit substantially higher levels of pollutants. However, there is a paucity of empirical studies to substantiate these environmental impacts. In addition, several waste management issues were identified in farms visited and reported by stakeholders. The farms lack waste management services, and the absence of recycling systems in the vicinity poses a significant challenge for environmental management.

Regarding the environmental impact on production, interviews indicate that both producers and stakeholders agree that the primary environmental concern is climatic conditions. They assert that the aquaculture industry is influenced by environmental conditions, including water quality, as well as climatological and oceanographic events. This situation is further exacerbated by climate change and pollution processes affecting the Gulf of Nicoya.

This underscores the necessity of implementing research and management practices grounded in an ecosystem-based approach, aimed at enhancing resilience to environmental fluctuations and supported by a waste management programme.

Social dimension: The main social challenges for aquaculture in the Gulf of Nicoya include the limited knowledge capital of producers, who often lack training in management, finance, and technology, along with the low participation in existing academic programmes. Sectoral fragmentation further complicates progress, as producers of oysters, mussels, and cage systems operate in isolation, without strong guild associations or collaborative mechanisms to promote cohesion. These gaps weaken the sector's ability to advance collectively and sustainably.

At the same time, important opportunities emerge. Strengthening training programmes through multisectoral strategies can enhance producer capacities and competitiveness. Building alliances and fostering sectoral cohesion would create synergies for collective growth. Moreover, promoting community integration into aquaculture management offers a valuable path to sustainability, positioning local communities as active partners in strengthening social equity and resilience.

Governance dimension: The governance dimension of aquaculture in Costa Rica faces important challenges. The legal framework is complex, with multiple institutions involved and procedures that are often unclear, lengthy, and costly, leaving many producers without proper authorisation. This lack of accessible and efficient permitting weakens sector sustainability and limits formal development.

At the same time, opportunities arise from ongoing collaborations among producers, government, academia, and NGOs to regularise farms and strengthen governance. Expanding these initiatives and integrating community and commercial actors into a comprehensive regional strategy would enhance coordination, legitimacy, and long-term sustainability of aquaculture in the Gulf of Nicoya.

Discussion

The study's findings indicate the presence of four distinct forms of small-scale aquaculture production in the Gulf of Nicoya, each with its unique developmental trajectory. However, despite the disparities in their trajectory and productive structure, all sectors share common characteristics such as small farms, limited technological development, considerable financial challenges and relatively low environmental impact. These characteristics have been reported in small-scale production across various latitudes, including Kenya, China, and Bangladesh (Syanya *et al.*, 2024; Dompreh *et al.*, 2024; Haque *et al.*, 2025). Therefore, successful experiences from other latitudes could be considered and adapted to the context of aquaculture in the Gulf of Nicoya, with a view to improving its sustainability.

From the perspective of the sector's sustainability, the study reveals that the Gulf of Nicoya offers opportunities to improve toward this objective. From this perspective, Boyd *et al.* (2020) indicate that aquaculture systems should focus on developing sustainable production in social, economic and environmental terms. In this sense, small-scale aquaculture has demonstrated a significant social impact on poverty reduction, serving as an alternative economic activity and a source of food and employment (Syanya *et al.*, 2024). It has also been noted that this activity has a low environmental impact (Andrade-Silva *et al.*, 2025). However, the search for sustainability must be accompanied by monitoring indicators, which is why Robles-Herrera (2025) emphasises the need to develop specific indexes and indicators for the context of aquaculture in Costa Rica.

In terms of economic sustainability, shrimp production shows fragile stability, as evidenced by inactive farms and modifications to cultural practices aimed at reducing costs. This phenomenon has been observed in other regions and has been linked to the effects of climate change (Toiba *et al.*, 2024). The findings reveal that one of the main concerns of the actors involved is the vulnerability of the production of all species to this phenomenon. This challenge was also observed in aquaculture systems in Egypt, where a 50% or greater reduction in production capacity was reported (Abdel-Hady *et al.*, 2025). This concern is supported by the research of Brugere *et al.* (2023), who argue that small-scale aquaculture is particularly vulnerable to climate change. Therefore, farm management should seek practices that are resilient to climate change, stabilise production, optimise economic returns and promote productive sustainability. In contrast, current cost-cutting practices could represent a productive risk that limits their ability to leverage unforeseen climatic or pathological events.

On the other hand, the aquaculture industry proposes adaptive measures that incorporate multiple technological elements, dependent on the availability of electricity and knowledge capital (Toiba *et al.*, 2024). However, these conditions are not present in most case study farms, which limits their implementation. When considering technological upgrades for farms, it is advisable to explore solar or wind energy alternatives that can be installed in aquaculture units.

In contrast, the implementation of Best Aquaculture Practices has proven successful in improving production efficiency in small-scale systems (Haque *et al.*, 2025). From this perspective, cultural challenges focus on knowledge capital through training processes targeted at producers (indem). Research and development models position academia as a key actor capable of generating knowledge, coordinating resources and external support, and facilitating technological transfers that promote community development (Chen *et al.*, 2023). This alternative is fully applicable to the current context of the Gulf of Nicoya and could therefore be incorporated into an aquaculture management plan for the region. Beyond cultural practices, sustainable models advocate for a comprehensive approach that considers the entire value chain and its socioeconomic interactions with the surrounding environment (Boyd *et al.*, 2020).

Socio-ecological models have been proposed as a synergistic alternative, integrating aquaculture and small-scale fishing systems, enhancing market potential, reducing environmental degradation, and mitigating climate change (Mansfield *et al.*, 2024). Responsible Marine Fishing Areas (AMPR) are documented examples of co-management in Costa Rica that follow this model. Three AMPRs have been established in the Gulf of Nicoya, which can serve as a platform for integrating socio-ecological models with aquaculture (García Lozano & Heinen, 2016). The case of floating cages in Isla Venado embodies the characteristics described by these models. It represents a successful example of small-scale sustainability, albeit limited to the immediate local community. Models of this type could be replicated in other areas of the Gulf of Nicoya, integrating the community and expanding income options, thereby achieving a social and environmental impact.

The circular economy is defined as a sustainable model that integrates multiple local actors into the value chain. This model not only reduces the carbon footprint but also strengthens the local economy through productive linkages (Nenciu *et al.*, 2022). The robust structure of the business ecosystem associated with aquaculture in the Gulf of Nicoya provides a strong platform for the development of circular economy-oriented productive linkages. Implementing a comprehensive strategy that integrates governmental, academic, NGO, productive, and community sectors into a circular economy model would significantly enhance aquaculture in the Gulf of Nicoya, transforming it into a driving force for local economic development.

The case of the Gulf of Nicoya illustrates an aquaculture business ecosystem strongly interconnected with academic sectors. Additionally, the government's role is notable, not only as a regulatory body but also as promoter and financial supporter of the sector's development. This aligns with the principles outlined in the Strategic Aquaculture Plan of Costa Rica (Instituto Costarricense de Pesca y Acuicultura and Secretaría Ejecutiva de Planificación Sectorial Agropecuaria (SEPSA), 2019). Moreover, other Latin American small-scale aquaculture experiences highlight the importance of government support for this type of system (Athanasiadis, 1999; Carrera-Quintana *et al.*, 2022).

Based on the analysis conducted and in alignment with the guidelines established in Costa Rica's Strategic Plan (INCOPESCA & SEPSA, 2019), the Costa Rica government should prioritise initiatives to address the identified opportunities. First, strengthening interinstitutional collaboration is essential to establish mechanisms that promote and facilitate the permitting processes for aquaculture units. Second, the development of the Sustainable Management Programme should be emphasised, focusing on training producers for the application of best management practices, financial management, infrastructure and equipment maintenance, and the implementation of adaptive measures for climate change. Third, fostering productive linkages in aquaculture should be encouraged to enhance community integration by creating collection centres that implement proper waste management practices and support both local and national commercialisation. Fourth, strategies for financing aquaculture units should be promoted, incorporating not only state entities but also national banks and production insurance systems. Lastly, research should be advanced on the environmental impacts of aquaculture units and on the development of production based on an ecosystem approach, socio-ecological production models, and climate change adaptation.

This study provides an initial overview of the path towards sustainability in aquaculture in the Gulf of Nicoya from the perspective of the stakeholders. However, this study must be analysed from a comprehensive perspective that includes sustainability indicators that assess actual conditions. Along these lines, a parallel study by the same authors examines the sustainability of aquaculture in the Gulf of Nicoya using indicators (Robles-Herrera *et al.*, 2025). Both studies should be considered when developing sustainability strategies for Costa Rican aquaculture in the Gulf of Nicoya.

Limitations of the Study

This study is exploratory in scope, viewed from the perspective of those involved in aquaculture production in the Gulf of Nicoya. Its conclusions cannot be extrapolated to other regions.

Conclusions

This study examines small-scale aquaculture in the Gulf of Nicoya, highlighting its distinctive characteristics and the challenges and opportunities along its path to sustainability. The findings point to priority areas, including strengthening the legal framework, advancing technological development, and promoting financial stability through integrated models. Costa Rica provides a favourable business environment where diverse actors contribute to knowledge transfer, financing, sector representation, and research, offering a strong platform for collaboration. Small-scale aquaculture emerges as a valuable economic alternative in rural areas, recognised for generating employment, promoting gender equality, and maintaining low environmental impact, underscoring the need for integrated management systems. Within this context, universities play a crucial role in technology transfer and knowledge generation, opening avenues for future research on environmental impacts, sustainability monitoring, socio-ecological and ecosystem-based models, and climate change resilience.

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Author Contributions Statement

Robles-Herrera conceptualised, conducted the research, and wrote and revised the article. Brugarola participated in information analysis and revised the article. Guzmán conceptualised the central research idea and provided the theoretical framework. Herrera-Ulloa anchored the review, revisions and approved the article submission.

Conflict of Interest Statement

The authors agree that this research was conducted in the absence of any self-benefit, commercial, or financial conflicts, and declare the absence of any conflicts of interest with the funders.

Ethics Statement

All information communicated in this article does not need ethical approval for research or informed consent because human or animal subjects were not involved.

Data Availability Statement

Anonymised databases on aquaculture production in the Gulf of Nicoya are provided in the supplementary information.

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