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Aquaculture and fisheries

Review article

Technification-promoting policies and their effect on aquaculture productivity

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Abstract

Continental aquaculture in Peru is gaining exposure as a propitious sector to implement production strategies and achieve technification since its production is based on few species and some regions. This literature review paper aims to present successful technification policies adopted by various developed countries and their impact on aquaculture productivity, compared to Latin American and Peruvian policies. We reviewed scientific articles published in the Scopus, Scielo, Directory of Open Access Journals (DOAJ), ScienceDirect, Latindex, and Google Scholar databases, as well as reports from the National Program for Innovation in Fisheries and Aquaculture (PNIPA) of Peru and the Ministry of Production (PRODUCE), using Mendeley reference manager. A total of 50 articles were selected based on relevance, impact level, and date of publication in the last five years. The countries that have technified their aquaculture processes have managed to position themselves as world benchmarks with high efficiency, productivity, and competitiveness levels. In conclusion, strategies, policies, technological development, and innovation must be promoted to improve and add value to the production chain and thus ensure aquaculture success.

Keywords: aquaculture, automation, economic and social development, productivity, technological change

Políticas promovedoras de la tecnificación y su efecto en la productividad acuícola

Resumen

La acuicultura en el Perú a nivel continental se proyecta como el sector propicio para desarrollar estrategias productivas y lograr la tecnificación, dado que su producción está basada en pocas especies y en algunas regiones. En ese sentido, el propósito del artículo de revisión bibliográfica es dar a conocer políticas exitosas de la tecnificación aplicadas en diversos países desarrollados y su impacto en la productividad acuícola, relacionado con las políticas de Latinoamérica y del Perú. Se revisaron artículos científicos publicados en las bases de datos Scopus, Scielo, Directory of Open Access Journals (DOAJ), ScienceDirect, Latindex, Google académico, así como reportes del Programa Nacional de Innovación en Pesca y Acuicultura (PNIPA) Perú y Ministerio de la producción (PRODUCE), utilizando el gestor de búsqueda de referencias Mendeley. Se seleccionaron 50 artículos basados en los criterios de relación con el tema, nivel de impacto y fecha de publicación en los últimos cinco años. Se encontró que los países que han tecnificado sus procesos acuícolas han logrado posicionarse como referentes mundiales con altos niveles de eficiencia, productividad y competitividad. Se concluye que, para asegurar el éxito acuícola, se deben promover estrategias, políticas, el desarrollo tecnológico y la innovación para lograr mejorar y dar valor a la cadena productiva.

Palabras clave: acuicultura, automatización, cambio tecnológico, desarrollo económico y social, productividad

Introduction

Aquaculture has become an option to meet future nutritional demands. Currently, 54 % of fish and shellfish come from this activity, with a tendency to increase significantly (Delgado Ramírez & Soto Aguirre, 2018). Thus, fish production plays a fundamental role in communities' food autonomy and economic sustainability (Rojas-Molina et al., 2017). For example, Torres-Barrera and Grandas-Rincón (2017) stated that some regions of Colombia have been historically engaged in traditional fish production and their activities revolve around it. Crispín-Sánchez et al. (2019) highlighted the importance of incorporating technological resources to make the most of natural resources, be environmentally sustainable and productive, and achieve market competitiveness.

Aquaculture growth faces significant challenges. Wasted water resources and the demand-production imbalance require adopting effective policies in this sector (Bonilla-Castillo et al., 2018). Therefore, it is urgent to introduce technology policies as a key factor to achieve competitiveness and business development (Martínez-Yáñez et al., 2018).

National governments play a fundamental role in implementing aquaculture sector policy; however, organizations lack the capacity to participate, define, and propose initiatives that can be considered within public policies, in addition to the nonexistence of participation bodies for fish farmers (Pereira-Gutiérrez et al., 2017). This incoordination between state entities and the aquaculture community makes the absence of policies for the sector's sustainable development more noticeable (Marcelino-Aranda et al., 2017).
At present, Asian countries dominate the global aquaculture production with growth of 2.6 million tons per year. Of the nine countries considered leaders in aquaculture, China is the largest producer and exporter of tilapia with more than 1,000 t/year (Carpio & Tito, 2017); the diverse technology implemented in the processes included in its aquaculture policies have turned this country into a world power (Hernández-Barraza et al., 2016).

In Latin America, Mexico is a pioneer in aquaculture innovation, as the implementation of environmental policies, planning tools, ongoing support and monitoring have increased its production efficiency (Jiménez-Sánchez et al., 2019). Thus, aquaculture production has risen steadily and progressively, representing more than 60 % of the country's total production (Hernández-Barraza et al., 2016). Similarly, the national governments of Brazil, Chile, and Colombia have invested in aquaculture projects since they consider it a relevant activity for the national economy (García-Ramos et al., 2016).

Peru, in the twelfth place in world aquaculture production with 155,000 t/year, has grown rapidly in the last decade (Carpio & Tito, 2017), focusing on two farming systems: traditional environments and artificial ponds (Arqueros et al., 2017). Nationwide, it is estimated that there are around 12,000 lentic resources in high Andean areas, of which 600 have been deemed suitable by the Regional Production Directorate to carry out aquaculture activities (Carpio & Tito, 2017). While the government regulates and runs plans to promote its sustainable development and communities' income generation (Aramayo, 2016), the marketing of species is limited in most of the country's regions; consequently, they are unable to achieve production levels due to low demand (Chichizola et al., 2016).

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This paper aims to identify technification-promoting policies adopted by various developed countries and their impact on aquaculture productivity. For this, we reviewed a series of original articles published in countries whose aquaculture sector competitiveness has made them world benchmarks, with high efficiency and productivity levels. We also intend to provide the entire production community involved in aquaculture with useful information that contributes to optimizing its processes and market competitiveness.

Materials and methods

For the literature review, we combined Boolean operators and stored articles from high impact journals in Scopus, Scielo, Directory of Open Access Journals (DOAJ), ScienceDirect, Latindex, and Google Scholar, as well as reports from the National Program for Innovation in Fisheries and Aquaculture (PNIPA) of Peru and the Ministry of Production (PRODUCE). We used the Mendeley reference manager, selecting 50 articles based on relevance, impact level, and date of publication in the last five years.

Results and discussion

The search results were arranged in order of success of the technification policies followed by various developed countries, with no link to their weighting.

Technology policies and tools in world aquaculture

Innovation and technological advances are essential factors for business development and competitiveness (Zamora-Torres & González-García, 2018); therefore, companies look for tools that allow them to survive in an increasingly competitive world (Del Carpio- Gallegos & Miralles, 2019).

Asian countries are global benchmarks for their productivity and incorporation of technology in their processes (Torres-Barrera & Grandas-Rincón, 2017). Research carried out in China indicates that agriculture is the main cause of pollution, releasing 57 % of nitrogen and 69 % of phosphorus into the water (Rojas & Salazar, 2018). Ribeiro et al. (2019) reported that the government implemented the strategy called *circular economy*, referring to comprehensive input usage and waste reduction. Integrated aquaculture and polyculture are incorporated in this context, making fish farmers migrate to new strategies such as recirculating aquaculture systems (RAS), aquaponics, and bioflocs (Castillo & Espitia, 2020). As a result of technology adoption and public policy support, the country has positioned itself as the world's leading producer of aquaculture species for decades (Porras-Rivera & Rodriguez-Pulido, 2019).

The United States is no stranger to the technification of aquaculture processes (Morán-Silva et al., 2017). The National Oceanic and Atmospheric Administration (NOAA) promotes science and technology tool management and transfer for aquaculturists to meet the growing demand for seafood and restore fishery resources (Dowbor et al., 2018). Beltrán (2017) asserted that Global Blue Technologies, an innovative super-intensive shrimp hatchery based in Texas, has a three-fold objective: to take care of the planet, people, and the company. It has also run a project called *Zero Discharge* to the environment, which is about reusing industrial wastewater. This application of technology has produced impressively large shrimp in an environmentally responsible manner since 2015.

In Spain, as Varela-Mejías (2018) indicated, the government emphasizes R&D (research and development) investments to develop and transfer technology. Since 1986, with the creation of the Science Act (Scientific and Technical Research Promotion and Coordination Act) and the government's participation in the first National Plan for Scientific Research and Technological Development, this country has strengthened ties and signed agreements with the private sector to implement technology by acquiring specialized laboratories and establishing various sites for the aquaculture sector. As stated by Beltrán (2017), Spain's objective is not to depend on the import of aquaculture species (seeds) and contribute to mitigating fish diseases.

Technology policies and tools in Latin American aquaculture

Gavito et al. (2017) pointed out that the Mexican government, through the National Aquaculture and Fisheries Commission (CONAPESCA), encourages micro-enterprises with developed and organized value chains to establish partnerships to improve market competitiveness. For this, it creates policies as an instrument related to innovation and technology transfer in the aquaculture sector (Díaz et al., 2017). Cisneros-Montemayor and Cisneros-Mata (2018) reported that the program called *Revolución Verde* [Green Revolution] increased the yield of aquaculture crops and exports in a short period through the massive application of technology packages (table 1).

Table 1. Goals and technology tools derived from the *Revolución Verde* program

Sustainable development goals	Technology tools
Efficient management of rainwater and irrigation	Support software, design of efficient water harvesting and irrigation systems, image analysis, and training courses
Circular economy and nutrient stoichiometry	Software and applications to optimize fertilization
Selection of viable production systems for edaphic, climatic, and socioeconomic conditions	Weather software, databases, and monitoring

Source: Adapted from Gavito et al. (2017)

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As a result, Mexico has recently attained a growth rate of 15 % per year, reaching historical figures of 337,000 tons of aquaculture production in 2016 (Cuéllar Lugo et al., 2018).

Because of its geographical and topographic location, Colombia has great potential for aquaculture, given its 25,000 million m³ of available water resources (Camero-Escoba & Calderón-Calderón, 2018). Hernandez et al. (2019) reported that the Colombian government prioritizes innovative technologies that follow aquaculture production development schemes: economic viability, environment sustainability, and social acceptability. Faced with this challenge, bioflocs arise as an alternative to mitigate the adverse environmental impacts caused by water discharges from aquaculture.

Reality of aquaculture in Peru

The fishing sector in Peru, globally recognized for the export of fishmeal (Crispín-Sánchez et al., 2019), has not been alien to aquaculture ventures. Since the beginning of the 21st century, it has achieved slight growth, still focused on few species and regions (Gonzales et al., 2019), as shown in figures 1 and 2.

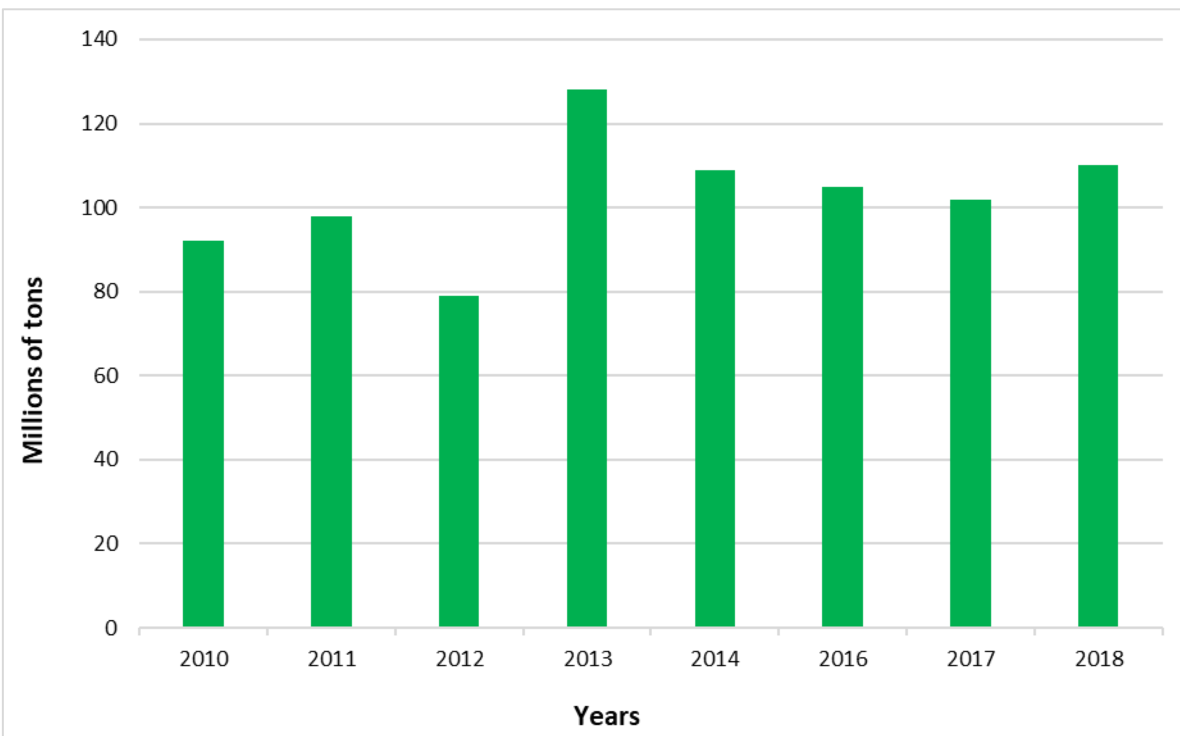

Figure 1. Growth of aquaculture in Peru from 2010 to 2018.
Source: Adapted from Olaya (2020)

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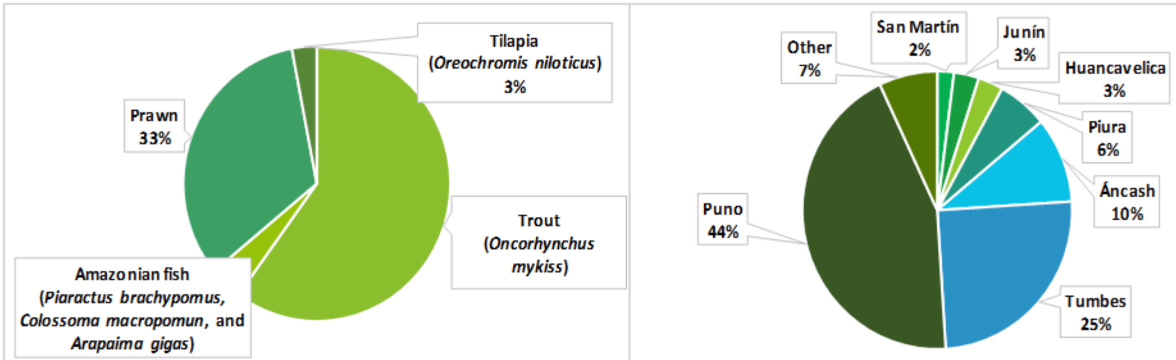

Figure 2. Production by species and region in Peru (2018).
Source: Adapted from Berger (2020)

Peru is one of the most biodiverse countries in the world, with potential for fishing, continental water resources, and a highly productive coastline (Aramayo, 2016). However, it has problems that adversely affect aquaculture development, expansion, and competitiveness (Adams & Flores, 2016); for example, aquaculture companies' limited capacity for production, marketing, management, and organization with a focus on production chains (Zafra-Trelles et al., 2017) and the little information on the demand for aquaculture products nationally and internationally (Rodríguez-Félix et al., 2016).

Bonilla-Castillo et al. (2018) mentioned that in Peru the awarding of technology packages aimed at strengthening production chains and growing the aquaculture of species with market prospects is low; therefore, most fish farms use artisan means since they lack technological tools to automate their processes (Rodríguez-Cruz & Pinto, 2018).

The poor characterization of technological resources in aquaculture activities is another factor attributed to the inapplicability of technology to their processes (Zafra et al., 2018), specifically the traditional production of native species, where proper management is essential. The latter requires periodic monitoring, focusing on the control of physicochemical parameters of water, food, and disease control (Adams & Flores, 2016).

Various government agencies, including the PNIPA, foster the formalization, technification, and participatory work of small producers and communities; however, a large part of this sector opposes the adoption of these models and continues with extensive aquaculture (Marcelino-Aranda et al., 2017).

Alternatives to incorporate successful policies and improve Peruvian aquaculture

Peru is no stranger to aquaculture innovations; in recent decades, the government has sought to consolidate production and create new opportunities for sustainability, diversity, and market competitiveness (Aramayo, 2016). Continental aquaculture is emerging as a propitious sector to implement production strategies and achieve technification since its production is based on few species and some regions (Zender et al., 2016).

We prepared table 2 to carry out a systematic assessment. It compiles technification-promoting policies introduced by countries where aquaculture sector competitiveness has made them world benchmarks, with high efficiency and productivity levels. It was found that countries such as China and the United States, through their *Circular Economy* and *Zero Discharge* programs, incorporate aquaculture development-related technology aimed at recycling water from industries (Vázquez-López, 2018).

Table 2. Countries promoting technification and technological intervention in the aquaculture sector

Country	Program or agency	Technological intervention
China	*Circular Economy*	RAS, aquaponics, and bioflocs
United States	*Zero Discharge*	Incorporating technology packages in the reuse of wastewater
	NOAA	Promoting science and technology tool management and transfer
Spain	R&D investments	Agreements between the government and the private sector to acquire technology
	Science Act (Scientific and Technical Research Promotion and Coordination Act)	
Mexico	CONAPESCA	Boosting micro-enterprises through strategic partnerships and policies related to innovation and technology transfer
	Revolución Verde	Support *software*, design of water harvesting and irrigation systems, image analysis, and training courses
Colombia	National government	Prioritizing innovative technologies under the scheme of being economically viable, environmentally sustainable, and socially acceptable (bioflocs)

Source: Elaborated by the authors

In the specific case of the Peruvian aquaculture sector, which lacks technology in its processes, especially on the coast, few companies use aquaponic farms, RAS, and bioflocs, according to Del Carpio-Gallegos and Miralles (2019). Saldaña-Carranza et al. (2015) reported that it merits the incorporation of technological resources, primarily on the coast of Peru, where the largest number of industrial companies

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are concentrated. It should be emphasized that the incorporation of these packages has allowed China and the United States to be efficient in their production and take responsibility for water resources.

Based on table 2, Spain, Mexico, and Colombia favor strategic partnerships with the private sector and R&D investments to adopt technological resources; these policies are adapted and constantly monitored in such a way that they have an expected result according to plan.

In Peru's favorable conditions, such as the abundance of water resources and extensive coastline (Riquelme et al., 2017), it would be ideal to work with policies and strategies such as those implemented in Colombia since their realities and types of crops are similar (Liñan-Cabello et al., 2016). As reported by Reyes-Serna (2018), the set of proposals supported by a government must be efficient and tailored to the needs of fish farmers to accomplish their consolidation and improvement. Following the Colombian model and emphasizing policies such as those of Spain and Mexico, strategies in the aquaculture sector must be pursued in an orderly and continuous manner (Montoya-López et al., 2019).

Conclusions

From this review, we found that countries such as China, the United States, and Spain included technology in their aquaculture policies aimed at reusing industrial waters, which have positioned them as global benchmarks with high efficiency, productivity, and competitiveness levels. Regarding Latin American, Mexico and Colombia stand out due to their policies related to strategic partnerships with the private sector and R&D investments.

Undoubtedly, the policies implemented worldwide and in Latin America have been successful since they considered technology within their government strategies, which should be implemented in Peru to improve the aquaculture sector. The Peruvian government must replicate efficient policies that increase productivity and market competitiveness to ensure success.

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Disclaimers

The authors agree with the publication of this article and declare no conflicts of interest that affect the results of this study.

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