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Environmental, social, and economic impacts of shrimp farming in Brazil: an evaluation through bibliometric analysis

Impactos sociais, econômicos e ambientais da carcinicultura no Brasil: Uma análise bibliométrica

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Abstract: To promote more sustainable shrimp farming, it is essential to understand the balance between the development of the activity, the environmental impacts, and the social coexistence of communities. Considering the growing importance of shrimp farming in the Brazilian context and the impacts this activity has generated, the objective of this research was to describe the state of the art of the social, economic, and environmental impacts of shrimp farming in Brazil. For this purpose, a bibliometric survey was conducted on the Scielo, Scopus, and Web of Science platforms, with works published between 1993 and 2023 related to the proposed theme. After filtering, a total of 56 articles were analyzed in full and evaluated according to the Sustainable Development Goals (SDGs). It was found that analyses of environmental relationships were predominant, with 37 articles, followed by economic analyses, with 16 articles, and social issues, with only 3 articles. The most frequent environmental impacts included changes in mangrove areas, water quality, and the presence of the White Spot Syndrome Virus (WSSV). Additionally, there are also social and economic impacts, such as the modification of traditional livelihoods of local communities and job creation, among others. Thus, the minimization of these impacts can be achieved through efficient management strategies aligned with the SDGs.
Keywords: Environmental impacts; Sustainable management; Sustainable aquaculture.

Resumo: Para promover uma carcinicultura mais sustentável, é essencial comprender o equilíbrio entre o desenvolvimento da atividade, os impactos ambientais e o convívio social das comunidades. Considerando a crescente importância da carcinicultura no contexto brasileiro e os impactos que essa atividade tem gerado, o objetivo desta pesquisa foi descrever o estado da arte dos impactos sociais, econômicos e ambientais da carcinicultura no Brasil. Para isso, realizou-se um levantamento bibliométrico nas plataformas da Scielo, Scopus e Web of Science, com trabalhos publicados entre os anos de 1993 a 2023, relacionados ao tema proposto. Após a filtragem, um total de 56 artigos foram analisados na íntegra e avaliados de acordo com os Objetivo de Desenvolvimento Sustentável (ODS). Verificou-se que as análises das relações ambientais foram predominantes, com 37 artigos, seguida pelas econômicas, com 16 artigos, e sociais, com apenas 3 artigos. Os impactos ambientais mais frequentes incluíram às alterações nas áreas de manguezais, na qualidade da água e à presença do vírus da Síndrome da Mancha Branca (WSSV), além desses, há também impactos sociais e econômicos, como a modificação de vidas tradicionais das comunidades locais e criação de empregos, entre outros. Assim, a minimização desses impactos pode ser alcançada por meio de estratégias de gestão eficiente alinhadas aos ODS.
Palavras-chave: Impactos ambientais; Manejo sustentável; Aquicultura sustentável.

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1. Introduction

Shrimp farming, which is the cultivation of shrimp in captivity, accounted for approximately 13% of Brazil's aquaculture production (78,000 tons) (ROCHA, 2022). The combination of a favorable climate and mastery of new production technologies has positioned Brazil as one of the largest shrimp producers (FREITAS et al., 2008). To achieve more sustainable shrimp farming, it is necessary to produce aquatic organisms in a way that maintains a harmonious relationship between the ecosystem, the local community, and economic indicators (RIBEIRO et al., 2016; TAHIM et al., 2019). It is important to note, however, that fully sustainable systems are far from being achieved, but there is a spectrum between unsustainable and sustainable systems. It is within this spectrum that sustainability can be recognized, measured, considered, and reconsidered (VALENTI et al., 2018).

Thus, as highlighted by the Food and Agriculture Organization of the United Nations (FAO, 2018a), sustainability objectives for promoting fish production are closely related. Therefore, it is crucial to ensure cohesion among the various stakeholders involved, both in the principles of conduct for sustainability and in the policies adopted at all levels, with the aim of implementing the Sustainable Development Goals (SDGs).

Shrimp farming is an economic activity that, despite having a relatively recent history compared to other aquaculture segments, has already become the main driver of technology and service development for the global aquaculture sector (SALDANHA et al., 2015). The worldwide expansion of this economic activity is directly related to several factors, such as profitability levels, the growing international market for the product, and especially the generation of revenue for producing regions or countries (TAHIM et al., 2014). Despite this, the spread of shrimp farming has occurred in the absence of effective systems for its planning and management, as well as regulatory mechanisms for the activities (PÁEZ-OSUNA, 2001).

The cultivated shrimp production chain in Brazil is already well-established and continues to expand as the number of input suppliers in the country increases, generating economic and social benefits, especially in the Northeast Region (ARAÚJO et al., 2018). Brazil has great potential for shrimp farming in its coastal zone, due to favorable climatic, hydrobiological, and topographic conditions, particularly in the North and Northeast regions, which offer the best environmental conditions for the full development of this productive activity (SALDANHA et al., 2015).

As such, the development of shrimp farming has grown significantly, bringing financial returns; however, its uncontrolled expansion has led to various environmental, economic, and social impacts. These changes include deforestation of mangroves for the installation of ponds, reduced soil fertility in shrimp farms, diseases affecting farmed shrimp, water contamination, displacement of local communities, degradation of ecosystems, among others (RIBEIRO et al., 2014).

Given the significant social and economic importance of shrimp farming in Brazil, as well as the potential impacts this practice can have on the environment, the need for an in-depth analysis arises. Moreover, considering the current state of scientific research on the subject and the scarcity of specific studies focused on the environmental, social, and economic impacts of shrimp farming, the objective of this research was to identify current knowledge about the social, economic, and environmental impacts of shrimp farming in Brazil. Additionally, the study aimed to conduct a thorough analysis of the main contributions found in existing research, especially those related to conflicts associated with this activity.

2. Methodology

For the development of the study, a bibliometric research was conducted using the PRISMA method (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) to structure the research planning. The databases used were Scielo, Scopus, and Web of Science to gather articles related to the proposed topic. To achieve this, searches were conducted considering titles, keywords, and abstracts from the years 1993 to 2023.

For the search process, the terms "carcinicultura" and "impactos" (shrimp farming and impacts) were used. These keywords were searched in Portuguese, English, and Spanish, and their combinations were applied using the Boolean operator "AND." The general search expression used was "Shrimp farming AND impacts." The articles were exported into a unified database using the Zotero software.

Subsequently, a selection screening was carried out to eliminate duplicate studies, those that were not conducted in Brazil, and those that fell outside the scope of the research. The search returned a total of 1,652 articles, with 643 articles from the Scopus database, 1,000 from Web of Science, and 9 articles identified in Scielo. Next, the following eligibility criteria were applied: describing environmental characteristics, as well as social and economic impacts, as central elements of the analysis. Based on these established criteria, a total of 56 articles were analyzed for the preparation of this review (Figure 1).

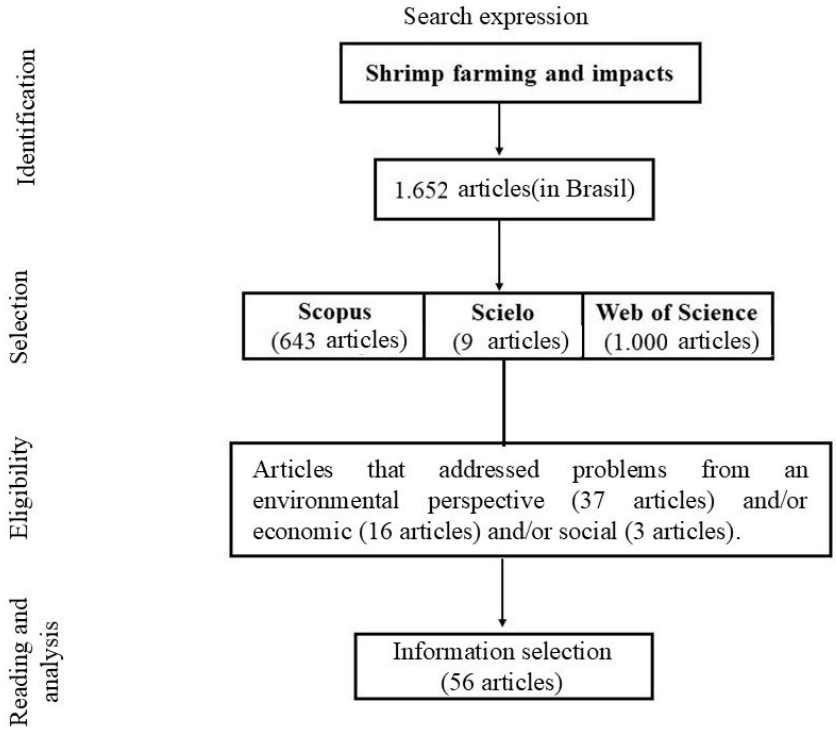

Figure 1 – Flowchart of the bibliometric research conducted in Scopus, Scielo, and Web of Science for the period 1993-2023. Source: Authors (2024).

The Tags content from the article package was used to analyze the occurrence of terms based on frequency and centrality, utilizing the VOSviewer software (Visualizing Scientific Landscapes). This was done through a co-occurrence network analysis of the most relevant expressions and the classification of studies according to the dimension addressed (social, economic, and environmental) and their association with the Sustainable Development Goals (SDGs). Additionally, an analysis of the tentative conceptual triad of sustainable aquaculture was conducted, following the approach proposed by Arana (1999).

3. Results and discussion

By contextualizing the topic within a specific scope, this study emerges as significant in the scientific landscape, exploring an issue debated in both international and national journals. It was observed that 63% of publications related to the topic were published in international journals, while 37% originated from national sources. When analyzing studies conducted in Brazil, as shown in Figure 2, the Northeast region stands out. The climatic characteristics of this area, such as high temperatures and a short rainy season, contribute to high shrimp productivity. This is one of the main factors that has led to the significant development of shrimp farming in the region (XIMENES & VIDAL, 2023).

The most studied species was *Penaeus vannamei* (BOONE, 1931), followed by *Farfantepenaeus paulensis* (PÉREZ FARFANTE, 1967) and *Macrobrachium amazonicum* (HELLER, 1862). The species *P. vannamei* is widely cultivated in various regions of Brazil, especially in coastal areas and estuaries that provide favorable conditions for its development. However, despite the economic benefits that shrimp farming brings to the country, it faces significant challenges, with White Spot Syndrome Virus (WSSV) being one of the main concerns for producers (CAVALLI et al., 2008).

White Spot Syndrome Virus (WSSV) is a viral disease that affects shrimp, causing white spots on the exoskeleton, leading to reduced production and, in severe cases, high mortality rates. To combat the disease and ensure the sustainability of Brazilian shrimp farming, proper sanitary management and the adoption of preventive measures are essential. Continuous research is fundamental to developing more resilient and disease-resistant techniques. Additionally, raising awareness about best farming practices and biosecurity measures helps prevent the spread of the disease, ensuring a sustainable and high-quality production (DE ARAÚJO NEVES et al., 2021).

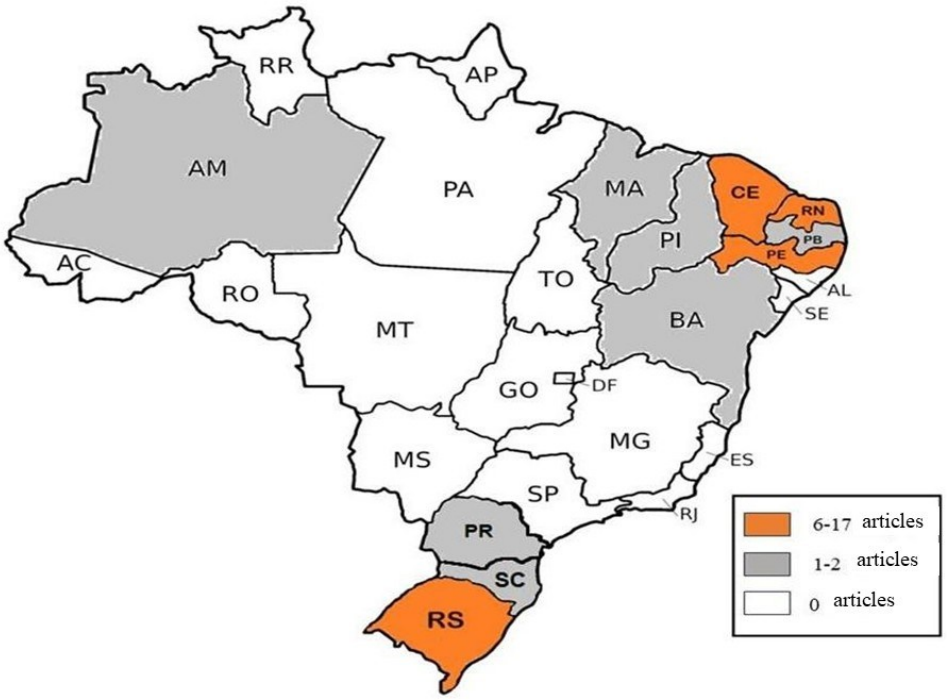

Figure 2 – Number of articles found by the Brazilian state on the social, economic, and environmental impacts of shrimp farming.
Source: Authors (2024).

During the analysis of article production over the years, a significant contribution was observed in the year 2021 (Figure 3). This greater contribution to article production may reflect the growing recognition of the importance of the topic, possibly due to environmental pressures and public policies focused on the area. According to the Food and Agriculture Organization of the United Nations (FAO), the coming decades will present major challenges for food production, such as: eradication of hunger and food insecurity; providing sufficient food and other agricultural products to meet global growth and changing demands; increasing production sustainably; adapting to climate change and contributing to its mitigation (FAO, 2018b).

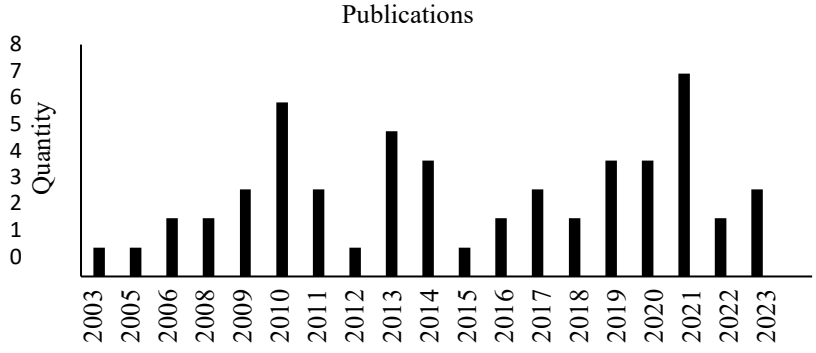

Figure 3 – Distribution of studies by year of publication.
Source: Authors (2024).

When considering the dimensions addressed (Figure 4), it was found that environmental relationship analyses were the most studied, with a total of 37 articles, followed by economic relationship analyses, with 16 articles, and social issues, with only 3 articles, highlighting a predominant concern with the possible interferences in the environment in the regions where shrimp farming is established. The main reasons for the impacts of shrimp farming are the lack of proper environmental monitoring, the

lack of scientific knowledge, management practices and inadequate planning (ISLAM & BHUIYAN, 2016), illegal shrimp farming (HATJE et al., 2016), and lack of regulatory oversight in the sector (RIBEIRO et al., 2014). Even in legal enterprises, the social impacts are often neglected in assessments, where entrepreneurs, in most cases, have no connection with local communities and receive no incentives from relevant authorities to cultivate shrimp sustainably (RIBEIRO et al., 2014). This applies to both small-scale producers and large-scale enterprises.

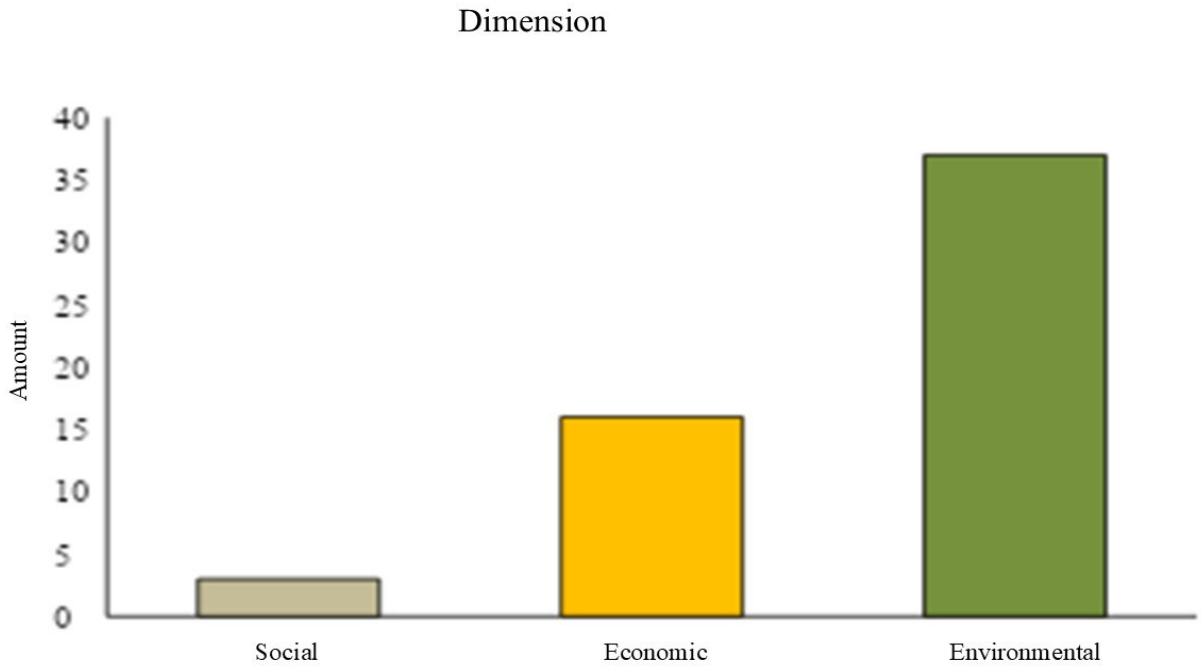

Figure 4 – Social, economic, and environmental dimensions identified during the study.
Source: Authors (2024).

3.1 Social impacts

The success of aquaculture is influenced not only by economic and environmental considerations but also by political and governance factors, which require the active participation of all stakeholders, as indicated by Krause et al. (2015). There is a consensus among researchers on the need for more effective legislation and the implementation of action plans by regulatory authorities in countries involved in aquaculture to ensure its conservation in the face of climate change challenges. Additionally, there is a need to promote sustainability, food security, and ecosystem preservation, as well as to protect traditional communities (YANIK & ASLAN, 2018).

According to the study by Silva and Pierri (2022), the expansion of shrimp farming was not only driven by private initiatives but also received public investment support, especially in Northeastern Brazil, and had its licensing process simplified by environmental agencies (CMADS, 2005; RAMALHO, 2015). This expansion led to negative socio-environmental impacts and Job creation in shrimp farming is not only linked to labor demand but also to income generation, which, in this sector, tends to be consistent for the workforce involved. Since shrimp farming is concentrated in specific municipalities, it has a significant impact on local employment and income levels. The increase in income is expected to enhance municipal revenue collection, both directly and indirectly, creating better conditions for social investment subsequent conflicts. During its growth phase, shrimp farming enterprises caused negative environmental and social impacts, leading to various conflicts, mainly stemming from the expropriation of territories belonging to traditional populations, particularly fishing communities. This resulted in the loss of their means of production, spaces, and ways of life (CMADS, 2005; QUEIROZ et al., 2013; RAMALHO, 2015). After the approval of the new Forest Code, shrimp farming enterprises in apicum areas were authorized and regularized, allowing previously irregular farms to obtain licenses by signing commitment agreements with state environmental agencies. Additionally, amnesty for fines was granted to entrepreneurs operating illegally in conservation areas, thereby increasing environmental pressure (BRASIL, 2012). Increasing the pressure on these environments.

Jablonski and Filet (2008) observed an intensification of conflicts along Brazil's coastal region, involving small-scale fishers, industries, shrimp farming, crab harvesting in mangroves, resort developments, and native communities, as well as disputes over environmental licenses between federal and state government agencies, among other issues. The authors suggested that participatory management and stakeholder engagement are key elements in resolving these conflicts. Despite these challenges and disputes, a study conducted by Sampaio et al. (2008) highlighted the socioeconomic importance of shrimp farming in 10 municipalities across the main shrimp-producing states in Northeast Brazil. The activity plays a crucial role in generating formal employment, especially in smaller municipalities, where it serves as the primary source of jobs. Job creation in shrimp farming is not only linked to labor demand but also to income generation, which, in this sector, tends to be consistent for the workforce involved. Since shrimp farming is concentrated in specific municipalities, it has a significant impact on local employment and income levels. The increase in income is expected to enhance municipal revenue collection, both directly and indirectly, creating better conditions for social investment (SAMPAIO et al., 2008).

3.2 Economical impacts

The challenges faced by shrimp farming, with significant economic implications, were analyzed by Andrade et al. (2022), who highlighted the impact of Infectious Myonecrosis Virus (IMNV) on the sustainable growth of shrimp aquaculture in Brazil and other producing regions worldwide. In recent years (2016 to 2021), unusual mortality events have been observed, progressing rapidly and resulting in cumulative mortality rates of up to 80% in several Brazilian states (Pará, Maranhão, Piauí, Ceará, Rio Grande do Norte, Alagoas, Sergipe, and Bahia). These cases were characterized by atypical IMNV infection patterns. Tests conducted on moribund shrimp confirmed the presence of the virus, with histological examinations revealing typical lesions associated with IMNV. During the study, next-generation sequencing was used to determine the complete genome of a new IMNV strain (Br-1), which was isolated in Ceará during the 2018 production cycle, a period marked by high mortality rates. The findings suggest potential movement of infected shrimp between different production regions and emphasize the need for stricter testing measures to mitigate the spread of lethal pathogens, which could jeopardize the sustainability of global shrimp aquaculture. Thus, shrimp farming, like any form of animal cultivation, faces disease-related challenges, both bacterial and viral. However, viral infections tend to cause greater economic damage (FLEGEL, 2001).

In addition to challenges related to viruses, the presence of exotic species in aquaculture ponds is also a concern, as highlighted by Thé et al. (2021). Invasive species, such as jellyfish of the genus *Cassiopea*, pose one of the greatest threats to coastal areas. According to the authors, the presence of these organisms in aquaculture systems, such as shrimp farms, can result in significant economic damage. The study revealed the occurrence of jellyfish in *Penaeus vannamei* farms, with morphological and genetic characteristics similar to those found in natural environments, originating from the Red Sea (*Cassiopea andromeda*). Thus, the high abundance and dispersal capacity of these species may have considerable economic impacts, especially in regions where shrimp farms are located in tropical mangroves.

Another relevant aspect is the study conducted by Cozer et al. (2020), which analyzed the operational processes of a shrimp aquaculture pond system in Brazil, focusing on characterizing energy flows. The study found that shrimp production in tanks is highly energy-intensive, emphasizing the importance of energy efficiency to ensure the long-term sustainability of Brazilian shrimp farming. Several studies confirm the economic relevance of shrimp farming for the municipalities where farms are located and for Brazil as a whole, as evidenced by Ximenes and Vidal (2023), Silva and Sampaio (2009), and Tahim and Araújo (2014). Therefore, it is essential to continue improving management practices to balance environmental sustainability with the socioeconomic benefits of the activity.

3.3 Environmental impacts

The study conducted by Cargnin and João (2024) highlights that shrimp farming, due to its high water demand, can cause significant environmental impacts when effluents are released without proper treatment into water bodies. Therefore, the implementation of wastewater treatment is crucial not only to ensure the economic viability but also the environmental sustainability of this activity. On the other hand, Santos et al. (2021) investigated the impact of aquaculture wastewater on aquatic communities, observing that nutrient availability influenced plankton density in shrimp ponds. However, they found that, in a neotropical estuary, shrimp farming wastewater did not affect the zooplankton community in the short term. Although several studies have been conducted on water quality in shrimp aquaculture, as highlighted by Kimpara et al. (2013), Figueiredo et al. (2005), and Angelo et al. (2010), the research by Poersch et al. (2020) analyzed total organic carbon, total nitrogen, copper, and zinc concentrations in sediments. Their findings did not indicate adverse environmental effects in semi-intensive shrimp farming ponds evaluated in southern Brazil.

Roversi et al. (2020) addressed the effects of aquaculture farms in tanks on hydrosedimentary processes in coastal systems. The study concluded that water exchange operations and sediment intake can alter the morphological balance of coastal lagoon

systems, affecting the depth and configuration of tidal channels. The authors demonstrated that these findings and the modeling approach have significant implications for the sustainable development of tank-based aquaculture and can be extended to other systems influenced by shrimp farming activities.

Lima et al. (2012) presented an analysis of scientific methods used to assess the sustainability of aquaculture production systems. By comparing organic and conventional marine shrimp farms in Lagoa de Guaraíras-RN, they observed that both systems showed considerable flows of non-renewable concentrated energy. The authors concluded that further improvements in the organic system are necessary to optimize efficiency and ensure the economic sustainability of these operations.

Soares et al. (2021) identified five major ongoing changes in semi-arid tropical areas in Brazil, including increased eutrophication and hypoxia, loss of vegetation cover and biodiversity due to urbanization, agriculture, shrimp farming, and land use changes, such as the construction of dams for water supply. Based on these concerns, the authors proposed key questions to guide research during the Decade of Ocean Science for Sustainable Development (2021-2030), aiming to support science-based management strategies in similar semi-arid regions worldwide.

In a literature review conducted by De Oliveira Júnior et al. (2021), the environmental impacts of shrimp farming in coastal environments were analyzed. The results indicated that the most common impacts of this activity include the destruction of mangrove areas, pollution of water bodies, extinction of fish and coastal fauna species, and increased coastal erosion. The authors suggested that the implementation of environmental and business management strategies is essential to mitigate these impacts.

On the other hand, Ottoni et al. (2021) highlighted that changes to the National Action Plan and other legal instruments, which historically protected coastal environments, especially mangroves, have weakened conservation measures. This places Brazil at odds with the global demand for mangrove preservation and with the United Nations' Sustainable Development Goals (SDGs). Medeiros et al. (2023) identified the effectiveness of Federal Protected Areas along the coast of Paraíba in preserving mangrove forests, emphasizing the negative impacts of urban expansion, sugarcane monoculture, and shrimp farming in these areas. These studies underscore the importance of conservation measures to protect vulnerable coastal ecosystems.

Even in light of these studies, Law 12.651/2012 (BRASIL, 2012) allows the occupation of apicuns and salt flats for shrimp farming and salt production, provided the following requirements are met:

> Art. 11- A [...] I - Even in light of these studies, Law 12.651/2012 (BRASIL, 2012) allows the occupation of apicuns and salt flats for shrimp farming and salt production, provided the following requirements are met:; II - Absolute integrity of arboreal mangroves and the essential ecological processes associated with them must be safeguarded, as well as their biological productivity and role as nurseries for fishery resources; III - The activity and its facilities must be licensed by the state environmental agency, with IBAMA being notified, and in the case of the use of marine lands or other Union-owned properties, prior regularization of land titles must be carried out before the Union; IV - Effluents and waste must be properly collected, treated, and disposed of; V - The quality of water and soil must be maintained, respecting Permanent Preservation Areas; and VI - Traditional survival activities of local communities must be respected (BRASIL, 2012).

Ward et al. (2023) highlighted that, despite state legal protections in Ceará and federal regulations in Brazil, mangroves have suffered significant losses due to urban expansion and the installation of shrimp farms, a trend that continues to this day. According to the authors, recent changes in legislation have increased pressure on these ecosystems' ability to adapt and remain resilient, heightening the threats to coastal systems and the ecosystem services they provide. In Brazil, where the Coastal Zone is considered national heritage, as established by the Federal Constitution (BRASIL, 1988), coastal vegetation has limited legal protection under the Brazilian Forest Code (BRASIL, 2012). The country holds the largest extent of legally protected mangrove forests in the world, located within sustainable-use protected areas, such as extractive reserves (Resex) and environmental protection areas (APA) (BORGES et al., 2017). However, mangroves are among the most impacted ecosystems along the Brazilian coast, despite their ecological, socioeconomic, and cultural importance (FERREIRA & LACERDA, 2016; LACERDA et al., 2019).

On the other hand, De Lacerda et al. (2021) explain that the primary impacts on mangroves are often indirect, stemming from pollutants in shrimp farm effluents, leading to the loss of essential ecosystem services. These losses include reduced primary productivity, carbon storage capacity, resilience to environmental stressors, estuarine filtering efficiency, biodiversity, and the abundance of subsistence marine species. Soil damage and degradation of remaining infrastructure after shrimp farm operations hinder mangrove recovery, prolonging impacts and enabling further degradation by activities that may permanently disrupt ecosystem functions. Land occupation pressure leads to deforestation, landfill operations, and sewage discharge, all of which threaten mangrove health. Additionally, erosion and sedimentation processes can result in forest die-off—erosion destabilizes and uproots mangrove trees, while sedimentation drowns and suffocates mangrove roots, endangering their survival (OLIVEIRA, 2005).

Meanwhile, Benevides et al. (2021) discuss how phenological behavior studies can provide valuable insights for natural

resource conservation projects. Their research examined the reproductive phenology of three mangrove species in areas affected by different environmental impacts (solid waste, deforestation, and shrimp farm effluents) as well as in low-impact areas over the course of a year. The study found that Avicennia spp. and Rhizophora mangle L. flower year-round under natural conditions, but in impacted areas, their flowering patterns were irregular. Rainfall and salinity were key factors influencing species exposed to human-induced impacts. The comparative analysis of different phenological assessment methods revealed that each method provides distinct yet complementary data on reproductive behavior and the negative effects of environmental disturbances on mangrove flora.

4. Co-occurrence Analysis, Shrimp Farming, and the Sustainable Development Goals (SDGs)

To understand the social, economic, and environmental components of shrimp farming in an integrated manner, a co-occurrence network analysis of terms was conducted based on the review of scientific articles. The findings revealed that the most frequently discussed topics included eutrophication processes, bioflocs, nitrate concentration, and mangrove alterations, among others (Figure 5). However, the analysis also indicated that other segments of the shrimp farming production chain could be further explored, such as impacts at the larviculture stage and waste generation from product processing, etc. The environmental challenges of shrimp farming are highly complex since each stage of its production chain (larviculture, grow-out phase, processing, and shrimp waste processing) may cause different environmental impacts (FIGUEIREDO et al., 2003). Nevertheless, sustainable practices in shrimp farming projects such as best management practices, monitoring and management strategies, as well as public policies for environmental promotion and regulation play a crucial role in minimizing potential negative impacts during the implementation and operation of shrimp farming enterprises (MESQUITA et al., 2012).

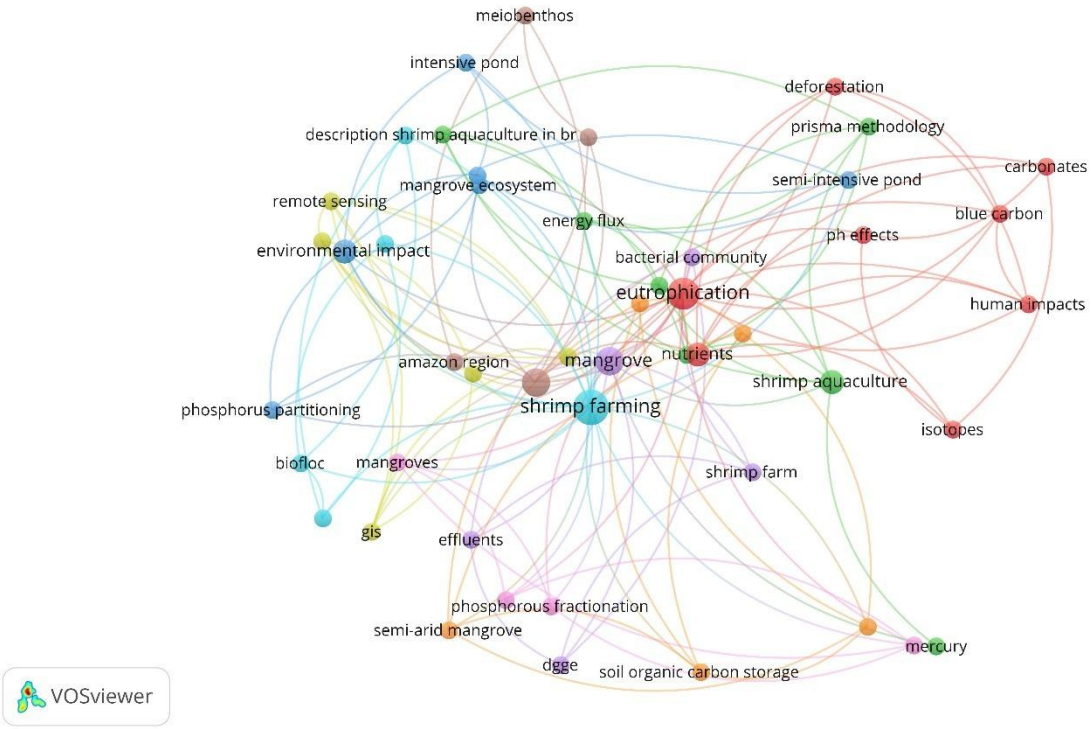

Figure 5 – Co-occurrence Network.
Source: Authors (2024).

Based on the analysis of the articles, a direct interaction between shrimp farming (carciniculture) and the environment was observed, particularly affecting the mangrove areas surrounding these sites. One major challenge identified was the significant influence of viruses, which impact both environmental and economic aspects. In this context, the correlation between the sustainability of shrimp farming and the Sustainable Development Goals (SDGs) was analyzed. The UN SDGs, established in 2015, represent a global call for sustainable practices. With 17 goals, they aim to eradicate poverty, protect the environment and climate, and ensure prosperity and peace for humanity. These objectives address development challenges in Brazil and worldwide

(UN, 2015). The SDGs take a comprehensive approach, examining a broader spectrum of challenges. They aim to eliminate inequalities in all forms by 2030, considering the economic, social, and environmental dimensions of sustainability (UNDP, 2015).

Thus, this bibliometric review revealed that shrimp farming (carciniculture) can contribute to achieving the Sustainable Development Goals (SDGs) when implemented sustainably. The analyzed studies provide a foundation for several SDGs, including poverty eradication (SDG 1), food security (SDG 2), access to clean water and sanitation (SDG 6), sustainable economic growth (SDG 8), responsible consumption and production (SDG 12), and marine life conservation (SDG 14) (UNITED NATIONS BRAZIL, 2023). These findings highlight the importance of conducting research that promotes the responsible use of natural resources to better understand the complex social, economic, and environmental interactions associated with shrimp farming.

Given the need to establish a development paradigm based on sustainability, it is essential for aquaculture to harmonize interactions between society, the environment, and economic development. In an effort to develop a model aligned with sustainable aquaculture principles, Arana (1999) proposed a framework, as shown in Figure 6. The three domains social, environmental, and economic must be integrated into aquaculture strategies based on sustainable development principles. This analysis provides a broader perspective, enabling the adoption of more conscious and sustainable practices.

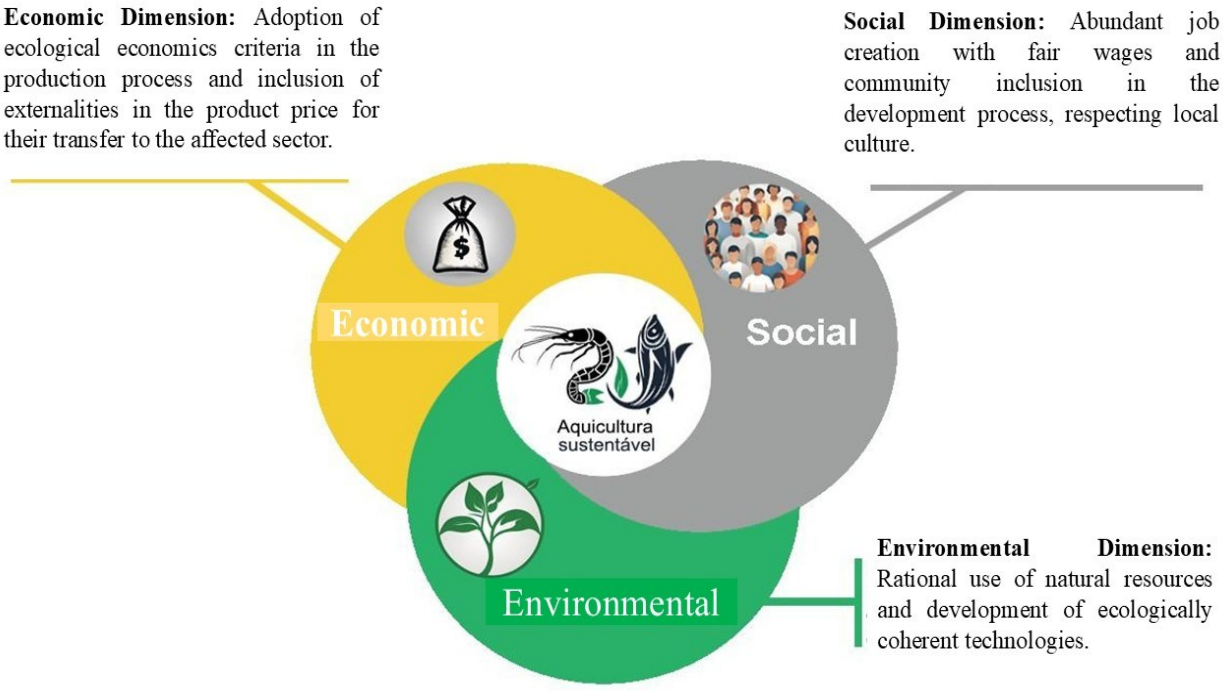

Figure 6 – Tentative Conceptual Trinomial of Sustainable Aquaculture.
Source: Arana (1999).

5. Final considerations

It was found that shrimp farming (carciniculture) can result in various impacts, having a direct relationship with social, economic, and environmental issues. According to the bibliometric review, the main impacts identified were on mangrove vegetation, the eutrophication process, and the presence of the infectious myonecrosis virus (IMNV), White Spot Syndrome Virus (WSSV), changes in water quality (nutrients and physical-chemical characteristics), wastewater (effluents), environmental changes and invasive species, impacts of shrimp farming on the long-term morphodynamics of coastal lagoons, the dismantling of environmental regulations, and new socio-environmental impacts.

Thus, these impacts may arise if shrimp farming is not strategically planned and subjected to proper management, highlighting the challenges for sustainability. Furthermore, it was found that shrimp farming can also generate positive impacts, particularly in the socio-economic context, by providing employment opportunities for coastal communities where this practice

represents the primary source of livelihood.

Therefore, implementing strategies to mitigate environmental impacts suggests that adopting innovative technologies to align this activity with the Sustainable Development Goals (SDGs) can help understand and minimize its effects, ultimately benefiting the industry. The bibliometric review revealed that shrimp farming can contribute to achieving the SDG targets when implemented sustainably. The analyzed studies addressed issues related to various SDGs, including poverty eradication (SDG 1), food security promotion (SDG 2), improved health and well-being (SDG 3), access to clean water and sanitation (SDG 6), stimulation of sustainable economic growth (SDG 8), promotion of responsible consumption and production (SDG 12), and marine life conservation (SDG 14). Additionally, according to the model aligned with the concept of sustainable aquaculture, Arana (1999) proposed a framework encompassing three key aspects—environmental, economic, and social—which should be considered when developing aquaculture practices based on sustainable development principles. Given this, it is essential to ensure the continuation of research investments to maintain and expand scientific knowledge in this field.

Therefore, future research should focus on other segments of the shrimp production chain, such as the impacts of the larviculture stage and the generation of processing waste, as each link in this chain uses resources differently and contributes to distinct environmental impacts. Moreover, studies evaluating the effectiveness of legislation and regulatory enforcement in promoting sustainability in shrimp farming should be further explored.

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