Ecosystem approach to semi-intensive cultivation of *Penaeus vannamei*

Enfoque ecosistémico del cultivo semiintensivo de *Penaeus vannamei*

Abordagem ecossistêmica para o cultivo semi-intensivo de *Penaeus vannamei*

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Abstract

The ecosystem approach to semi-intensive culture of *Penaeus vannamei* is crucial for understanding and managing water quality and planktonic communities in aquaculture systems. This study focuses on analyzing the interrelationship between structural and functional elements, using phytoplankton and zooplankton as bioindicators of water quality and trophic conditions. The objective is to provide detailed information on the dynamics of these communities in culture systems, which will improve survival, feed conversion and shrimp production. A systematic review was carried out using specific keywords in relevant scientific databases, which made it possible to collect updated and relevant information on the topic. The discussion focuses on the importance of phytoplankton as a primary producer, its influence on water quality and its role in the diet of shrimp. Recommendations for maintaining a beneficial balance of phytoplankton communities in cropping systems are detailed. Furthermore, the role of zooplankton as a crucial link in the food chain is analyzed, providing recommendations on the desirable amount of zooplankton in semi-intensive farming. Strategies to address challenges related to primary productivity and food chains in culture ponds are also discussed. In conclusion, this study highlights the importance of the ecosystem approach in shrimp farming, underlining the need to understand and manage planktonic communities to achieve successful and sustainable aquaculture.

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Resumen

El enfoque ecosistémico del cultivo semiintensivo de *Penaeus vannamei* es crucial para comprender y gestionar la calidad del agua y las comunidades planctónicas en los sistemas acuícolas. Este estudio se enfoca en analizar la interrelación entre los elementos estructurales y funcionales, utilizando el fitoplancton y el zooplancton como bioindicadores de la calidad del agua y las condiciones tróficas. El objetivo es proporcionar información detallada sobre la dinámica de estas comunidades en los sistemas de cultivo, lo que permitirá mejorar la supervivencia, la conversión alimenticia y la producción de camarones. Se realizó una revisión sistemática utilizando palabras claves específicas en bases de datos científicas relevantes, lo que permitió recopilar información actualizada y crucial sobre el tema. La discusión se centra en la importancia del fitoplancton como productor primario, su influencia en la calidad del agua y su papel en la dieta de los camarones. Se detallan las recomendaciones para mantener un equilibrio beneficioso de las comunidades de fitoplancton en los sistemas de cultivo. Además, se analiza el papel del zooplancton como eslabón crucial en la cadena alimentaria, proporcionando recomendaciones sobre la cantidad deseable de zooplancton en el cultivo semiintensivo. Se discuten también estrategias para abordar desafíos relacionados con la productividad primaria y las cadenas alimenticias en los estanques de cultivo. En conclusión, este estudio destaca la importancia del enfoque ecosistémico en el cultivo de camarón, subrayando la necesidad de comprender y gestionar las comunidades planctónicas para lograr una acuicultura exitosa y sostenible.

Palabras clave: factores bióticos, fitoplancton, zooplancton, revisión sistemática, cultivo de camarón.

Resumo

A abordagem ecossistêmica da cultura semi-intensiva de *Penaeus vannamei* é crucial para a compreensão e gestão da qualidade da água e das comunidades planctônicas em sistemas de aquicultura. Este estudo tem como foco analisar a inter-relação entre elementos estruturais e funcionais, utilizando o fitoplâncton e o zooplâncton como bioindicadores da qualidade da água e das condições tróficas. O objetivo é fornecer informações detalhadas sobre a dinâmica dessas comunidades em sistemas de cultivo, o que melhorará a sobrevivência, a conversão alimentar e a produção de camarões. Foi realizada uma revisão sistemática utilizando palavras-chave específicas em bases de dados científicas relevantes, o que possibilitou coletar informações atualizadas e relevantes sobre o tema. A discussão centra-se na importância do fitoplâncton como produtor primário, na sua influência na qualidade da água e no seu papel na dieta do camarão. São detalhadas recomendações para manter um equilíbrio benéfico das comunidades fitoplanctônicas nos sistemas de cultivo. Além disso, é analisado o papel do zooplâncton como elo crucial na cadeia alimentar, fornecendo recomendações sobre a quantidade desejável de zooplâncton na agricultura semi-intensiva. Também são discutidas estratégias para enfrentar os desafios relacionados com a produtividade primária e as cadeias alimentares em tanques de cultura. Em conclusão, este estudo destaca a importância da abordagem ecossistémica na carcinicultura, sublinhando a necessidade de compreender e gerir as comunidades planctónicas para alcançar uma aquicultura bem-sucedida e sustentável.

Palavras-chave: fatores bióticos, fitoplâncton, zooplâncton, revisão sistemática, carcinicultura.

Introduction

In aquaculture, water quality is the first and most important consideration for a successful outcome; being one of the most relevant problems in aquaculture systems, since it deteriorates due to production practices. For this reason, water must be managed with extreme care during the production cycles, in order to guarantee good growth and avoid stress and death of the cultured species (Lucas *et al*., 2019).

Given that shrimp farming takes place in aquatic environments and these are home to a high diversity, any alteration that occurs will be translated into changes in the structure and functionality of the communities that inhabit them. The response capacity developed by certain organisms such as plankton, to which the term "bioindicators" is attributed, can be used to provide information on physical and chemical changes, which in the long term reveal modifications in the composition of the community (González *et al*., 2014).

In this sense, phytoplankton comprise the largest fraction of primary producers in aquatic ecosystems, having a greater influence on water quality than other plants and is the staple food for consumers such as zooplankton. The changes triggered by plankton condition the water quality of shrimp farms, which is why they must be adequately monitored in order to increase survival, food conversion and production (Boyd, 2015).

The use of planktonic organisms as bioindicators currently represents an important tool in aquaculture cultures, and this is because plankton react quickly to ecological changes and are seen as excellent indicators of water quality and trophic conditions, due to their short life cycles and rapid reproduction rate (Wang *et al*., 2022). The occurrence of planktonic organisms is related to the range of resistance in relation to abiotic ecological components (temperature, oxygen fixation, and pH), as well as biotic connections between organisms. Changes occurring within plankton communities provide the platform for determining the trophic state, and hence the quality of water bodies (Saraswathy *et al*., 2013; Parmar *et al*., 2016).

Therefore, the following review is proposed in order to address the planktonic communities that live inside the pools as an aspect of vital importance to consider, since they allow obtaining a comprehensive view of the environment, constituting a key to good management.

Methods

The systematic review (meta-data analysis) was carried out taking into account studies carried out on the planktonic community in *P. vanammei* culture systems. A search was performed using the keywords "Phytoplankton", "Zooplankton", "*P. vannamei*", "semi-intensive culture", "bioindicator" in both Spanish and English. To optimize the search, the Boolean operator AND was used to refine the search results within the different databases, thus selecting the scientific articles with exact matches. The search engines used were Google Scholar as it is currently the best free tool for locating open access academic information and Science Direct, as the digital platform and database that makes it possible to consult Elsevier publications (Gil, 2015; Codina, 2018).

Discussion

Generalities on systemic approach and its application to production processes

The study of systems, defined as a set of components interacting to achieve a common purpose, requires a clear understanding of their boundaries and the interrelationships between their components. General Systems Theory (GST), developed by Ludwig von Bertalanffy, provides a framework for this analysis, although its reductionist approach has proven insufficient to explain complexity in natural systems (Davidson, 1983). Subsequently, Odum's Systems Ecology incorporated aspects of GST and cybernetics to model ecosystems in greater detail (Ramage and Shipp, 2009). The intention of presenting the applicability of the systems approach to productive processes is based on the importance of knowing the internal and external flows of matter and energy, recognizing the connections between the different subsystems that contribute to the search for integral solutions.

Components of the *P. vannamei* planktonic production system

Aquaculture as a productive process requires various elements of the environment, which allow the development of the activity, as well as specific inputs; all in order to obtain the desired results from the productive point of view. In this sense, semi-intensive shrimp farming falls within the organismic theory of von Bertalanffy's Biological Systems (Betancourt *et al*., 2016), where physicochemical and biological factors converge, which together will give the shrimp postlarvae the optimal conditions to obtain the final product that will be marketed.

Biological subsystem

A diagram was designed to identify the various energy inputs, the modifications that all the elements undergo once they enter the system, as well as the outputs; in order to better understand the dynamics of these culture systems (figure 1). Water quality is the main element that must be monitored when working in aquaculture production, since it is the medium in which the organism will develop and therefore all the factors that influence it must be controlled. In this sense, feeding is an important factor, not only because of the benefit that the natural biota of the pond represents for shrimp growth, but also because it is the main source of deterioration of water quality, which has repercussions on the poor productive response of the organisms in culture and on the economic profitability of the culture.

It is well known that in semi-intensive culture of *P. vannamei* the main source of feed is concentrate, however, phytoplankton is a natural food source that plays a key role in maintaining ecological functions, including ways to balance the aquatic ecosystem by promoting feed conversion ratio and increased shrimp production (Qiao *et al*., 2020). Anderson *et al*. (1987) showed that 53-77 % of *P. vannamei* growth in semi-intensive systems came from natural feed, while formulated feeds accounted for the remaining 30-40 %.

Phytoplankton or microalgae are phototrophic microorganisms with simple nutritional requirements that constitute the primary producers and the basis of nutrient cycling in aquatic ecosystems (Verma *et al*., 2012; Singh and Ahluwalia, 2013). Phytoplankton communities experience a continuous succession of dominant species due to dynamic changes in growth factors such as light, temperature and nutrient concentrations (Casé *et al*., 2008). It has been found that diatoms and green algae often dominate the initial phase of aquaculture, and as the culture progresses over time, cyanobacteria and dinoflagellates begin to proliferate and gradually become dominant groups (Chen *et al*., 2018).

Diatoms and green algae, are desired for their high nutritional value and contribution to water quality (Brito *et al*., 2016), while cyanobacteria and dinoflagellates, are undesirable for their low nutritional value and ability to produce toxins (Pérez-Morales *et al*., 2017). As a result, the establishment of a healthy aquaculture environment requires a balance of algae that is beneficial to aquaculture organisms. The literature suggests some recommendations for phytoplankton concentration in semi-intensive culture systems for these to be beneficial (table 1).

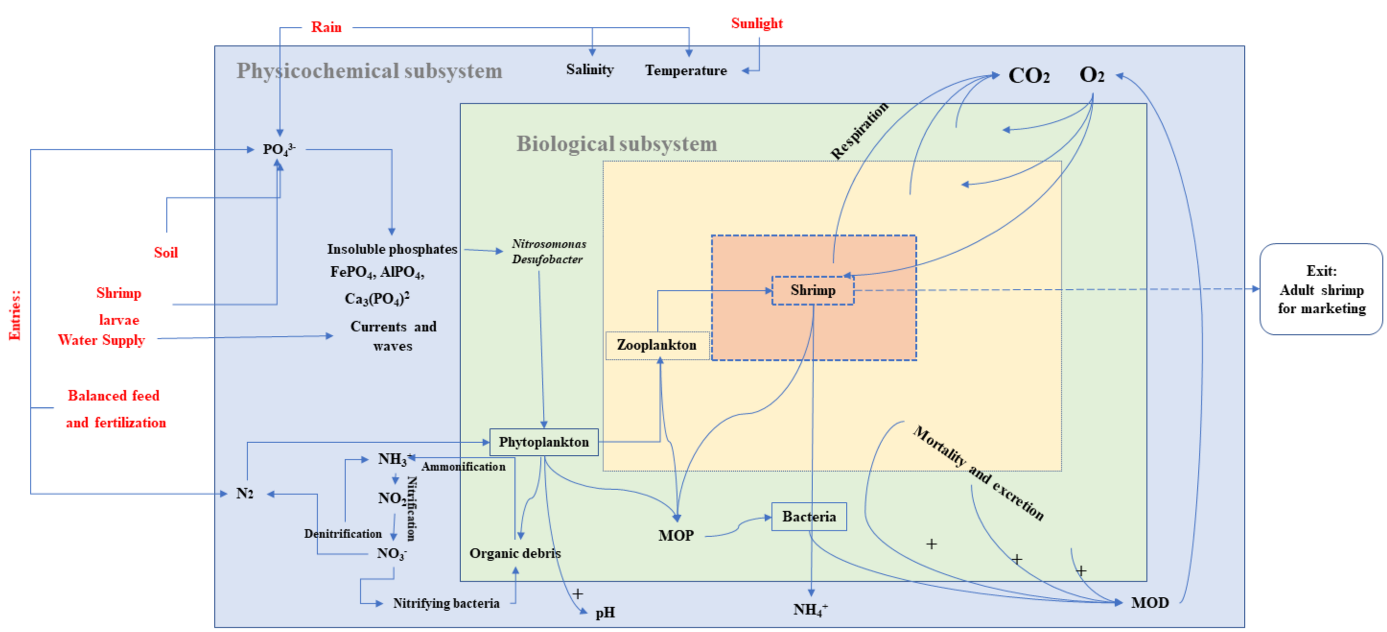

Figure 1. Interaction between the components of the planktonic production system in semi-intensive culture of *Penaeus vannamei*. Source: Author's elaboration.

Table 1. Desirable phytoplankton densities (cel.mL^{-1}) in semi-intensive shrimp culture ponds, adapted from Clifford (1994).

Phytoplankton component	cel.mL^{-1}	
	Minimum	Maximum
Bacilariophytes and Chrysophytes (Diatoms)	20,000	
Chlorophytes (Green algae)	50,000	
Cyanophytes (Cyanobacteria)	10,000	40,000
Dinophytes (Dinoflagellates)	--------------	500
Total number of cells in phytoplankton	80,000	300,000

Source: Martínez-Córdoba (2008).

Within the phytoplankton community, diatoms are the first bioavailable food for shrimp from the larval to the adult stage, providing an important contribution of proteins, carbohydrates, lipids, vitamins, minerals, fatty acids and amino acids (Nesara and Bedi, 2019). On the contrary, cyanobacteria are a deficient food for the trophic chain, affect the organoleptic properties of shrimp commonly known as "off flavor", can generate toxic compounds and therefore worsen water quality (Alonso-Rodríguez, 2004).

An interesting characteristic of benthic diatoms is their ability to colonize the entire surface of the reservoirs in which they live, forming biofilms or small clusters that adhere to the substrates, forming colonies of cells suspended in the water, which makes them affordable food of various sizes to feed shrimp larvae. The main nutritional value of diatoms is due to their high lipid content, with an average of 32-38 % crude protein, making them an important component of the natural food of penaeid shrimp; this nutritional value is relevant for shrimp growth and development, highlighting their importance in the food chain of aquaculture ponds (Mohanty *et al*., 2018). Diatoms also play a key role in the biogeochemical silicon cycle and in the global capture of carbon dioxide through photosynthesis. These unicellular beings use silicic acid dissolved in water and transform it into opaline silica to build their frustules (Pérez and Mancilla, 2012).

Phytoplankton absorb nutrients from the water for their use and growth and remove ammonia nitrogen from the water, which is particularly important for decreasing concentrations of this potentially toxic metabolite. These communities also favor the decrease of CO_2 levels, which in high concentrations can be toxic and even influence the pH values of the medium (Boyd, 2017c).

The N:P ratio has a close relationship with phytoplankton abundance, even influencing the composition of the phytoplankton class present in *P. vannamei* culture ponds. According to Masithah *et al*. (2019) when nitrate concentration increases, it favors the dominance of the Bacillariophyceae class and decreases the composition of the Cyanophyceae; and when that of ammonia in the water is high, it increases the composition of the Cyanophyceae and decreases that of the Bacillariophyceae. On the other hand, phosphate concentration favors the proliferation of phytoplankton of the Bacillariophyceae and Cyanophyceae classes.

In aquaculture, phosphorus is mainly found as phosphate ion and most of it is found in plankton biomass or adsorbed on suspended soil particles. In sediments, phosphorus forms poorly soluble compounds with iron and aluminum under acidic conditions and with calcium under basic conditions (Lucas *et al*., 2019). Soil phosphorus is not very soluble and is poorly available to pond organisms, which is why a constant supply of phosphorus to the medium is important to maintain phytoplankton blooms. It is estimated that shrimp release approximately 60-80 % of the phosphorus they consume, and once released into the water, if it is not absorbed by the soil it is lost with water turnover or during harvesting (Boyd, 2001).

Zooplankton, composed of minute aquatic organisms, plays a crucial role in semi-intensive shrimp farming. This heterotrophic planktonic fraction constitutes the next link in the food chain of the water body and serves as live food for the shrimp. This diverse community includes larval, juvenile and adult stages of various aquatic zoological groups, playing a pivotal role in linking primary producers to higher trophic levels (Singh *et al*., 2013).

In shrimp culture, the first three zooplankton fractions are the most important components of the diet. For postlarvae, microzooplankton is crucial, while for larvae, mesozooplankton is more useful. For adult shrimp, the main components of the zooplankton they consume are copepods, polychaete larvae, insect larvae (mosquitoes) and rotifers. To ensure significant food value in cultured shrimp, recommendations are established on the amount of zooplankton desirable in semi-intensive culture (table 2).

Table 2. Average recommended zooplankton organisms in shrimp culture ponds.

Zooplankton component	Abundance recommended (org.mL^{-1})
Copepods	2 to 50
Rotifers	2 to 50
Protozoa	10 to 150
Polychaete larvae	2 to 20

Source: Martínez-Córdoba (2008).

When comparing the variations present in a shrimp farm with a fish farm, the evidence suggests that the introduction of planktivorous species generates changes in the zooplankton structure, going from a predominance of copepods, rotifers and small cladocerans, such as Bosmina, to a predominance of large cladocerans, in turn altering the biomass and productivity of phytoplankton (Carpenter and Kitchell, 1993). This study illustrates the reality of shrimp farming, since fish are present in the drainage channels that supply the pools, as well as in the lagoons themselves, which affects the dynamics of the higher trophic levels that in turn condition the microalgae and even the concentration of nutrients in the system.

The productivity of aquatic ecosystems can vary depending on the energy input, in a reservoir, producers can reach a density of 108 - 1010 org.m^2 and have a biomass of 5 g.m^2, while secondary producers such as zooplankton have a slightly lower density of 105 - 107 org.m^2, with a much lower biomass than phytoplankton, reaching 0.5 g.m^2. These data highlight the importance of the subsystem constituted by the microbiota found in the lagoon sediments (Odum and Barret, 2006).

Low trophic link farming, as in the case of shrimp farming, poses challenges for ponds due to lower primary productivity and longer food chains. This situation has generated sustainability and pond management problems, especially with excessive feed intake. One strategy to address this situation has been water exchange, which reduces nutrient loading by flushing nutrients out of the system, and increasing the density of saprophytic organisms, which helps to recycle excess energy deposited in the sediments without drastically altering the physicochemical subsystem (Odum and Barret, 2006).

Planktonic filter feeders include protozoans, rotifers and crustaceans. Some rotifers feed primarily on detritus, while others eat small algae and bacteria. However, the main planktonic herbivores are cladocerans (e.g., Daphnia) and copepods, which are generally filter feeders, although some are rapacious. Individual filtration rates among planktonic filter feeders vary more than 1000-fold, from 0.02 mL of water on day 1 for small rotifers to more than 30 ml of water on day 1 for daphnia. Mussels, on the other hand, are the most important benthic filter feeders that move water through the body cavity, removing food particles using their gills as a filtering apparatus. These can become very abundant in culture ponds and generate water transparency problems due to their filtration volumes (Brönmark and Hansson, 2017).

Table 3. Filtration rates and preferred food particle size of some important herbivores (Based on Reynolds 1984).

	Filtration rate (mL^{-1})	Particle size preference (µm)
Rotifers	0.02 – 0.11	0.5 - 18
Calanoid copepods	2.4 – 21.6	5 - 15
Daphnia (small)	1.0 – 7.6	1 - 24
Daphnia (large)	31	1 - 47

Source: Brönmark & Hansson, (2017).

In aquaculture the presence of bacteria is indispensable due to natural decomposition processes, especially when abiotic factors allow the right conditions to be generated. The main factors to be considered are humidity, temperature (approximately 30 to 35 °C), ionic potential (pH 7.5 - 8.5 usually optimal), oxygen concentrations and sufficient, easily decomposable substrate.

Bacteria act in a directly proportional relationship to the content of organic matter available in the medium; therefore, the greater the supply of nutrients or concentrated feed, the greater will be the microbial activity. In aquaculture, organic matter accumulates mainly in the sediment, which is usually degraded almost entirely by bacteria during the culture period; and there is also another fraction that is usually retained (Boyd, 2017b).

In addition to the bacteria that fulfill their role of degrading, in recent years shrimp farming has begun to apply in a controlled manner what is known as probiotics, which are nothing more than microbial symbiont cells of the gastrointestinal tract of shrimp that have the role of generating beneficial effects in shrimp, such as improving their immune response to pathogens and also contributing to increased growth (Trujillo *et al*., 2017). However, contrary to what is believed Boyd (2017a) states that the addition of these products does not guarantee an improvement in water quality in productive systems.

Currently, a type of technology called Biofloc Tecnology has been incorporated, based on the stimulation of heterotrophic bacterial communities that can remove excess nutrients, this being its fundamental principle in which densely grown heterotrophic bacterial cells conglomerate together and become flocculated aggregates (bioflocs), controlling nitrogen concentrations, decreasing the risk of pathogens, and the bioflocs developed serve as natural protein food for shrimp (Rajeev *et al*., 2023). Furthermore, bacterial assemblages of various aquaculture components have been claimed to be biological indicators of shrimp health status (Zhang *et al*., 2014).

Conclusion

The ecosystem approach is fundamental to understanding the complex interactions in semi-intensive *P. vannamei* culture systems. This study highlights the importance of analyzing the interrelationship between biotic and abiotic factors, using phytoplankton and zooplankton as key bioindicators of water quality and trophic conditions. The crucial role of these planktonic communities in shrimp diet and nutrient regulation is discussed in detail. In addition, strategies to maintain a beneficial balance in phytoplankton communities and to address challenges related to primary productivity are discussed. The ecosystem approach provides insight into the complex interactions in culture systems and ensures their long-term viability, underscoring the need to properly monitor and manage planktonic communities for successful and sustainable aquaculture.

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