CHAPTER 3

Inland water aquaculture: The role of good management practices and the use of ecotechnologies for the sustainability of the activity

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ABSTRACT

It is known that the health of fish and other aquatic organisms depend on good quality water in adequate quantity, its maintenance is a constant concern in aquaculture, as they directly affect productive performance, such as survival, growth, reproduction and susceptibility to diseases, a fact that compromises economic success. The concept of "Sustainable Aquaculture" or "Responsible Aquaculture" is increasingly discussed, which designates the desirable way of producing fish in the aquatic environment, with environmental, economic, social and political rationality. In this sense, this chapter addresses the legal aspects of aquaculture, the main impacts caused by the activity, the adoption of good management practices and the use of ecotechnologies aiming at the sustainability of the activity.

Keywords: Sustainable aquaculture, Effluent, Phosphorus, Legislation, Environment, Water quality.

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INTRODUCTION

Aquaculture (production of aquatic organisms) is a booming global economic sector due to its ability to produce healthy and nutritionally rich food, being a primary source of protein in many countries (FAO, 2020). In Brazil, the aquaculture sector stands out compared to other animal production activities, only between the years 2014 and 2023 the growth rate of the activity was 5.33% (Peixe-Br, 2024), and should be considered as a reality and no longer an activity with future growth potential, generating for Brazil an annual direct revenue of more than one billion dollars (Valenti et al., 2021).

Although it is impossible to produce fish without causing environmental changes, the current challenge for aquaculture is to develop while reducing this impact as much as possible. The development of management techniques to increase productivity without evaluating the impacts produced is not conceived, and it should be understood that environmental preservation is part of the production process (Valenti et al., 2018).

Aquaculture activities can affect the environment more or less intensely, according to the modality with which the cultivation is practiced: Extensive, Semi-intensive, Intensive and super-intensive. The environmental problems potentially associated with the creation of aquatic organisms are: Alteration of the landscape with the conversion of preserved areas for the implementation of the projects; Deterioration of water quality mainly due to leftover feed; Impacts on aquatic diversity. In this way, the measures to mitigate the problems caused by aquaculture can be divided into actions before and after the start of production.

In this sense, the concept of "Sustainable Aquaculture" or "Responsible Aquaculture" is increasingly discussed, which designates the desirable way of producing fish in the aquatic environment, with environmental, economic, social and political rationality.

This chapter is aimed at undergraduate and graduate students from different areas of knowledge, such as: environmental sciences, biological sciences, agronomic engineering, fisheries engineering, veterinary medicine, zootechnics, among other related courses, as well as for professionals in the field of aquaculture. The next items will address general aspects of the impacts caused by aquaculture activity, the adoption of good management practices and the use of ecotechnologies aiming at the sustainability of the activity.

AQUACULTURE AND SUSTAINABILITY

Sustainable aquaculture can be defined as the profitable production of aquatic organisms, maintaining a lasting harmonious interaction with ecosystems and local communities, and must be evaluated in the environmental, economic and social dimensions, which are inseparable and essential for a perennial activity (Valenti, 2008).

Aquaculture has some characteristics that make it sustainable, since the investment cost is relatively low and the productivity is high, which represents the ability to expand food production significantly, thus contributing to greater food security in the world (Siqueira, 2017). As an activity with low implementation and operational costs, as well as accessible technology, aquaculture presents itself as an alternative for generating employment and income in a competitive way in less developed regions (Siqueira, 2017). It should also be noted that in the state of São Paulo, through article 1 of State Decree No. 60,582 of June 27, 2014, the recognition of aquaculture activity as of social and economic interest (São Paulo, 2014).

Knowing that the health of fish and other aquatic organisms depend on water of good quality and in adequate quantity, its maintenance is a constant concern in fish farming, as it directly affects productive performance, such as survival, growth, reproduction and susceptibility to diseases, a fact that compromises economic success (Boyd, 1990; Mercante et al., 2020a).

In addition to the constant concern with water quality for the success of production, there is also concern about the impacts that the activity can cause on the receiving water body due to waste discharged via effluent (Mercante et al., 2020a). These impacts depend on the species cultivated, the method of cultivation, the hydrography of the region, the type of food provided, and management practices (Cao et al., 2007). In this sense, in Brazil, states have increasingly intensified the monitoring and control of water quality, a fact that has led to the readjustment of legal requirements (Mercante et al., 2020b).

LEGAL ASPECTS OF BRAZILIAN AQUACULTURE

In Brazilian legislation, the National Council for the Environment (CONAMA), a federal collegiate body of the Ministry of the Environment, provides for the classification of water bodies and environmental guidelines for their framing, as well as establishes the conditions and standards for the discharge of effluents through resolutions 357/2005 and 430/2011 and their amendments (Brasil, 2005; 2011). That is, it regulates the permissible limit of nutrient concentrations in the discharged effluent according to the framework of the water body.

Within the scope of the State of São Paulo, through State Decree 62.243 of November 1, 2016 (São Paulo, 2016), the rules and procedures for the environmental licensing of aquaculture in São Paulo are established. In particular, the aforementioned Decree was drafted with the aim of promoting actions to strengthen and encourage aquaculture in São Paulo, which has grown in recent years. Such measures allow the regularization of aquaculture activities, enabling small producers in São Paulo to leave informality and start working safely, in accordance with current legislation (Mercante et al., 2020b). Fish farmers, frog farmers, mariculturists, algae farmers and other producers of aquatic organisms in the State of São Paulo can regularize their activities through the Declaration of Conformity of Aquaculture Activity (DCAA) (São Paulo, 2016).

In this context, the technical manual prepared by Secanho et al. (2022), brings extensively and with accessible language the stages of environmental licensing of aquaculture in the state of São Paulo, with information ranging from the need, or not, of environmental licensing according to the size of production, through the different stages of the authorization process and/or regularity of the activity.

The search for sustainable production, which combines the necessary speed for an economically viable production, without compromising the due care with environmental quality, is the great challenge of the new public policies. In this sense, the directives presented above can be considered as an advance for the sustainability of the activity, however, the control of water quality, in quantity and quality, and the control of the discharge of effluents from the production systems, are still a great challenge for the producer.

In excavated systems (nurseries and tanks), the control of effluent discharge follows the standards of CONAMA resolutions 357/2005 and 430/2011 and their amendments, bringing guidelines on the water quality parameters to be met for the discharge of liquid waste from the activity. Currently, meeting these standards established by current legislation has been an obstacle to environmental regularization, especially for small and medium-sized producers, who increasingly need tools to develop a more productive activity, with the lowest possible environmental impact. In this sense, the development and popularization of the insertion of good management practices throughout the production process are crucial, as well as the development of *eco-friendly technologies* that are aimed at the environmental sustainability of the activity.

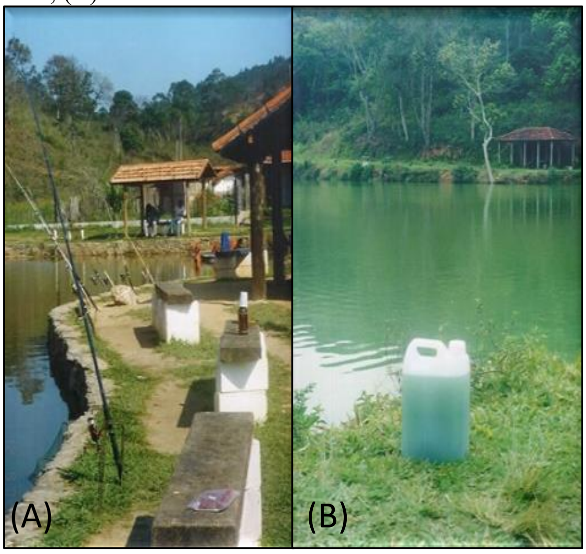
GOOD MANAGEMENT PRACTICES IN AQUACULTURE

Inadequate water management can trigger the process of artificial eutrophication, generating a chain reaction, breaking the stability of the system, since the factors act in an interconnected way, affecting the success of the enterprise (Vinatea, 1997; Sipaúba-Tavares et al., 1998). According to Boyd (1990), eutrophication in production systems occurs due to the excess of food offered to fish, which is not fully consumed, causing food leftovers and, therefore, accumulation of organic matter in the water

The economic success of this activity, according to Eler et al. (2001), depends on the good maintenance of water quality, and this quality can be influenced by several factors, but mainly by food management.

Studies carried out in fishing grounds (Figure 1) located in the metropolitan region of São Paulo indicated a high degree of water deterioration, suggesting, among other factors, that the management employed promoted an intense eutrophication process in these places (Mercante et al., 2005; Mercante et al., 2007). Also with regard to sanitary aspects, cyanotoxins (toxins produced by cyanobacteria) were found in 60% of the fish-pays, a fact related, among others, to the high concentrations of phosphorus present in the water (Honda et al., 2006), due to inadequate management.

Figure 1 – Fishing grounds located in the metropolitan region of São Paulo. (A) highlighting the fishing grounds and fishing equipment used by the visitors; (B) Flask used for water collection



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Compared to other macronutrients needed by aquatic life, phosphorus is the one that occurs in the least abundance, therefore, it is considered the limiting element to biological productivity (Wetzel, 1993). In addition, this element is one of the main causes of artificial eutrophication.

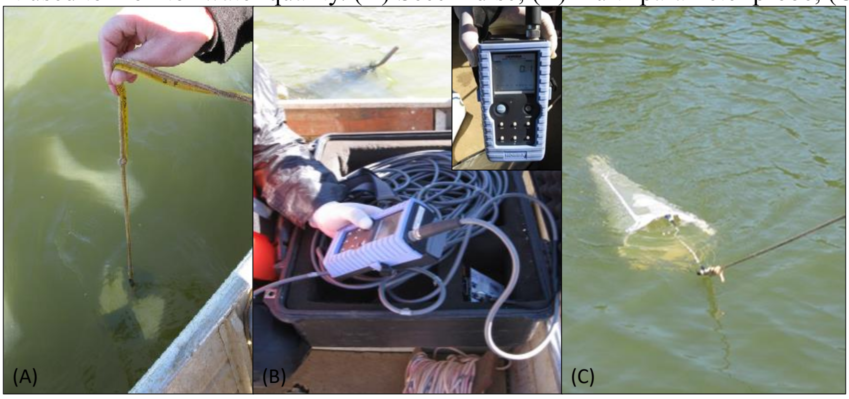
Another element of great importance for the metabolism of aquatic systems is nitrogen. This element participates in the formation of proteins, and like phosphorus, it also acts as a limiting factor in primary production (Wetzel, 1993).

The increase of nitrogen in the medium can also occur due to animal excreta, the application of ammoniac nitrogen fertilizers, such as ammonium sulfate, ammonium nitrate, and monoammonium and diamonic phosphates. When there is a high concentration of organic nitrogen in the aquatic substrate, it is released into the water in the form of ammonia, which is very toxic to aquatic organisms (Sipaúba-Tavares et al., 1998).

The assimilation of ammonia, nitrate and phosphorus by phytoplankton can lead to uncontrolled growth of this community, causing algal blooms in the environment (Paerl; Tucker, 1995).

In order to control water quality in fish farming, it is essential to monitor physical variables (e.g., temperature, turbidity, transparency of the water "secchi disk"), chemical (e.g., pH, alkalinity, hardness, dissolved oxygen, ammonia ion) and biological variables (e.g., phytoplankton and zooplankton) (Figure 2). And the understanding of the relationship between these variables, together with the application of good management practices, becomes a useful tool for environmental sustainability.

Figure 2 – Equipment used to monitor water quality. (A) Secchi disc; (B) multi-parameter probe; (C) Plankton network



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According to the general principles of the FAO Code of Conduct for Responsible Fisheries (1997), States should produce and regulate aquaculture development strategies as requirements to ensure its ecologically sustainable development, allowing the rational use of sources in their different uses. In Brazil, adhering to this global demand, the Ministry of Agriculture, Livestock and Supply – MAPA published in 2022 the "Manual of good practices in farmed fish farming" (Barcelos et al., 2022), with information that transcends from fish welfare, health, physiology, water quality, facilities to aspects of nutrition and food management. For these authors, the maintenance of water quality at levels appropriate to production is strongly and directly linked to the well-being of fish and related to "Environmental Freedom", which advocates that animals should remain in conditions free of discomfort.

Good management practices should consider several aspects that involve both fish production and the maintenance of fish in ponds for sports practices such as catch and release or fishing grounds for recreation and consumption. The implementation of good management practices aims to ensure good water quality, preserving the health and well-being of the animals, as well as controlling the impact generated in the receiving water body from the effluent discharge.

Good practices involve the elaboration of implementation projects that consider water management with monitoring and control of the flow and residence time of the water. And feeding management, which involves the effective control of nitrogen and phosphorus input from food and fertilization. In this sense, feed conversion is an important factor for pollution control, considering that only about 30% of the food offered is consumed by fish and 70% remains in the water, being either assimilated by phytoplankton or deposited at the bottom of ponds (Frasca-Scorvo et al., 2013; Moraes et al., 2016; David et al., 2017; Osti et al., 2018a). Therefore, the density of fish per production area associated with the growth phase should be considered for the practice of feeding. As a result, it is possible to drastically reduce the concentrations of phosphorus and nitrogen in the water, avoiding intense eutrophication processes, which cause both environmental and health damage to the animals.

Procedures to reduce nitrogen and phosphorus levels in the water of production systems are necessary to control eutrophication, minimizing the impact on the environment (Pereira et al., 2012; Alexander et al., 2016). Thus, the monitoring and maintenance of water quality at adequate levels for rearing is essential for productive success and can be one of the biggest obstacles to the regularization of aquaculture enterprises, so the control arising from knowledge about water quality, with the interaction between physical, chemical and biological factors, should be considered as an ally of the producer.

ECOTECHNOLOGIES AIMED AT IMPROVING WATER QUALITY

The recommended treatment techniques for aquaculture effluents are dependent on the composition and volume generated in the different production systems. The quality of the effluent generated can vary between that produced in the extensive and intensive system, depending on the characteristics of the crop. The intensive cultivation system is characterized by high stocking density and total dependence on exogenous feed, and the natural food production of the nursery is even disregarded. The amount of food should be increased according to the increasing consumption, that is, regulated according to the size of the fish, the stocking density and the temperature of the water. In this way, a large rate of water turnover is used for the removal of metabolites and food residues present in the water.

The high density of fish stocking requires a large amount of artificial food to be introduced daily to the production systems, generating a proportional amount of organic matter formed by feces and food scraps. Most of the organic matter produced in the cultivation system is in particulate form and has a short sedimentation time, being accumulated at the bottom of the system or released to the receiving water body.

In Brazil, there are few studies developed with the purpose of generating adequate and efficient technologies to reduce or improve effluent quality. Such technologies include integrated aquaculture-agriculture systems, integrated multitrophic aquaculture systems (IMTA), recirculating systems (RAS), bioflocs (BFT), natural filtration (constructed *wetlands*), sedimentation tanks, among others (Tucker; Hargreaves, 2003; Henares et al., 2020). Currently, the development and adoption of these systems aim to meet the requirements of new legislation and the pressures of environmental agencies and society itself.

Natural filtration ecotechnology (constructed *wetland* - WC) is an option in the treatment choice of liquid effluents generated by breeding ponds. Toilets are systems designed and built for the treatment of effluents in order to use natural processes in the removal of pollutants (Kivaisi, 2001). In these systems, aquatic macrophytes play an important role in the removal of nutrients by assimilation, in addition to providing substrate for the development of microorganisms that act in the mineralization of organic matter and in the absorption of nutrients (Brix, 1997; Sipauba-Tavares et al. 2015). It is also noteworthy that other processes occur in these treatment systems and contribute to the removal of nutrients from the effluent, such as sedimentation, chemical precipitation and biochemical transformations (e.g. ammoniation and denitrification) (USEPA, 2000; Braskerud, 2002).

A synthesis of the main forms of toilets developed for effluent treatment was elaborated by Salati et al. (2009). In aquaculture, toilets have been shown to be an economically interesting alternative, as they have a low cost for preparation and simple operation and maintenance, and are highly efficient in removing organic matter from aquaculture ponds (Lin et al., 2005; Henry-Silva; Camargo, 2008; Carballeira et al., 2016; Osti et al., 2018b).

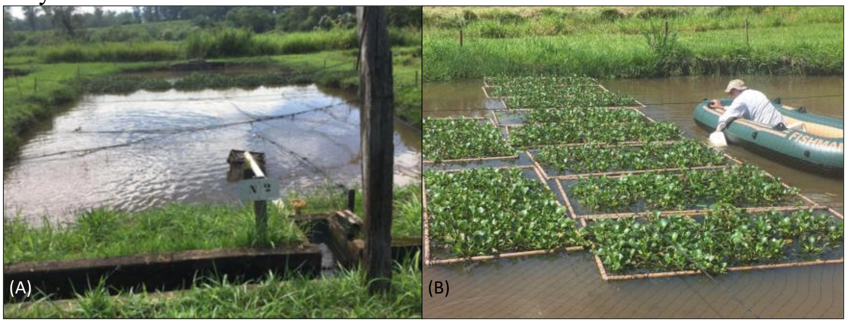
One of the great challenges of this technology is in the design of the WC, a fact that is fundamental for the planning and determination of the feasibility of using this technology (Camargo; Henares, 2014). For example, the work of Biudes (2007) concludes that the area required to treat the effluent from the breeding pond of *Macrobrachium rosenbergii* with floating aquatic macrophytes (*Eichornia crassipes*) at a nursery water renewal rate of 10% per day, corresponds to approximately 10% of the surface area of the pond. This same author shows in his work that the phase in which the macrophyte presents the best rate of nutrient absorption corresponds approximately when it is at a density between 5 and 25 kg of fresh mass/m².

The need to use at least 10% of the production area for the implementation of WCs in order to neutralize the effects of the activity on water resources can be a barrier to the economic viability of the activity, as it may be necessary to convert preserved areas or allocate the production area for the implementation of WCs.

Alternative technologies: WCs have been adopted in different regions for the purpose of pollution control, called artificial floating islands (APIs) which are designed to float on the surface of the water with floats and structured to stabilize plant roots and underground stems. Macrophytes are planted on the structures, which function similarly to natural floating mats. The use of artificial floating island systems (APIs) has been tested in the control of residues from activities such as: pig farming (Hubbard et al., 2004); in stormwater drainage systems (Headley; Tanner 2008; Lynch et al., 2015); in acid mine drainage basin sites (Gupta et al., 2020). Recently, an adaptation of this technology was devised with the aim of testing the efficiency of artificial floating islands for the treatment of tilapia effluents (Osti et al., 2020), as can be seen in Figure 3. The authors built PVC pipe structures of 2 m2 each and colonized them with free-floating macrophytes (*Eichhornia crassipes*), which occupied 10% of the tilapia production area. The results showed that the structure was efficient in the removal of nitrogen and phosphorus, reducing the load released by the effluent from the fish farming.

In common, the studies show that WC and API ecotechnologies are an economically and environmentally viable option for the removal of nutrients and metals from water and/or the retention of suspended particulate matter. However, the sizing and economic feasibility of these treatment systems are still challenges to be overcome in order to achieve the environmental sustainability of aquaculture.

Figure 3 – Tilapia fattening ponds. (A) detail of the nursery with the artificial floating island system; (B) Detail of artificial floating island systems



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CONCLUSIONS

The adoption of good management practices, ranging from soil correction, continuous monitoring of water quantity and quality, the use of good quality feed and offered in adequate quantities, among other actions that can and should be followed by the producer, aim at the sustainable development of the activity. In the last decades, aquaculture production systems with better technologies have been sought in order to reduce the impact generated on the environment, however, considering the state of the art of research developed in the State of São Paulo, we observe the scarcity of research on alternative technologies of low cost and viable to the small and medium producer aiming at the reduction or treatment of effluents and escapes from fish farming. Within the São Paulo State Aquaculture Plan, these issues were listed as a priority to comply with the current environmental legislation, recommending the use of new technologies for the treatment of effluents generated by aquaculture. It should be noted that these strategies must consider the specific conditions of each production system, where space constraints and high water flows must be contemplated. In summary, although we have developed research on this topic, it is concluded that there is a need to develop a technological package based on sustainability for the treatment of aquaculture effluent. This package should consider both good management practices and the size, cost and efficiency of the treatment.

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