Constructed Wetlands for Marine Aquaculture Wastewater Treatment: A New Challenge

Perez LM[1,2,3]*

[1]Grupo de Biotecnología de Materiales y Medioambiente (Bio&TecMA, UCA-CONICET), Instituto de Investigaciones en Ingeniería Ambiental, Química y Biotecnología Aplicada (INGEBIO-UCA), Facultad de Química e Ingeniería del Rosario, Pontificia Universidad Católica Argentina (UCA), Av. Pellegrini 3314, S2002QEO Rosario (Santa Fe), Argentina

[2]Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Ministerio de Ciencia, Tecnología e Innovación, Godoy Cruz 2290, C1425FQB CABA (Buenos Aires), Argentina

[3]UNESCOSOST-Argentina, UNESCO Chair on Sustainability-Universitat Politècnica de Catalunya (UPC-BarcelonaTech), C/ Colom, 1, TR1, ESEIAAT, 08222 Terrassa, Spain

*Corresponding author: Prof. Leonardo Martín Pérez, Ph.D. Instituto de Investigaciones en Ingeniería Ambiental, Química y Biotecnología Aplicada (INGEBIO-UCA), Facultad de Química e Ingeniería del Rosario, Pontificia Universidad Católica Argentina (UCA), Av. Pellegrini 3314, S2002QEO Rosario (Santa Fe), Argentina, Email: leonardoperez@uca.edu.ar

Abstract

Aquaculture is the fastest growing food production sector worldwide. Global demand for seafood continues to grow, and land-based aquaculture is expected to grow in order to meet the increasing market demand. In this context, marine aquaculture production systems are moving towards land-based farming. However, due to the large volumes of wastewater with high salinity and other fish-metabolism derived pollutants (e.g., nitrogen compounds), it remains a challenge for treatment of effluents from land-based marine aquaculture. In this scenario, development of environmental-friendly and efficient aquaculture effluent treatment system is crucial for sustainable intensification of aquaculture. Owing to low capital, operating costs, and low energy consumption, constructed wetlands (CWs) are becoming a promising technique to treat aquaculture effluents before discharge.

Keywords: Marine Aquaculture; Hypersaline Effluents; Ecotechnologies; Constructed Wetlands

Mini Review

Aquaculture provides nearly 50% of the world's fish production, and this is expected to fast increase in the next years due to the growing demand for marine fishery products. Land-based marine aquaculture systems will play an important role in meeting this demand and will also do so in a more environmentally sustainable way regarding marine aquaculture in the ocean [1]. In addition, development of environment-friendly and efficient aquaculture effluent treatment system is crucial for sustainable intensification of aquaculture, including recirculating aquaculture systems (RAS) (Figure 1). The main benefit of RAS is the ability to reduce the need for fresh, clean water while still maintaining a healthy environment for fish. To be operated economically commercial RAS must have high fish stocking densities, and many researchers are currently conducting studies to determine if RAS is a viable form of intensive aquaculture [2].
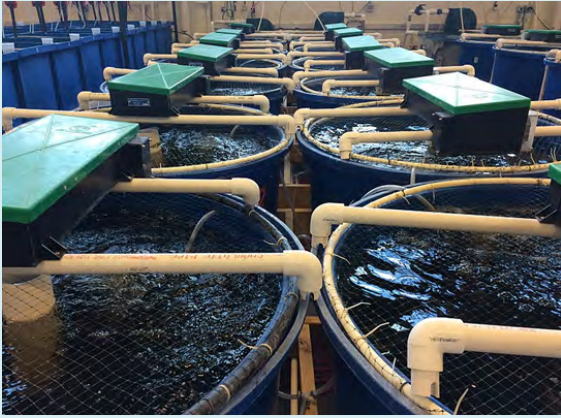
Figure1: An example of recirculating aquaculture systems (RAS) located at the Virginia Tech Department of Food Science and Technology (Blacksburg, VA, USA). (Image taken from Wikipedia; https://en.wikipedia.org/wiki/Recirculating_aquaculture_system).

On the other hand, the treatment of effluents from land-based marine aquaculture remains being a challenge due to the large volumes of wastewater with high salinity to attend [3]. In addition, the development of RAS is not only limited by the ability to efficiently treat saline wastewater, but also because it accumulates a large amount of nitrogen compounds derived from the metabolism of culture organisms. The removal of nitrogen compounds from RAS, mainly ammonium (NH_4^+) and ammonia (NH_3), is a priority because these compounds quickly degrade the quality of the water which negatively impacts fish farming [4,5].

In fact, nitrogen pollution has become a worldwide emerging concern because the environmental impact of nitrogen-caused water eutrophication and subsequent toxicity to aquatic organisms. Inorganic nitrogen compounds (i.e., ammonia, nitrite and nitrate) in water and wastewater are also significant in public health, agriculture, industry, and geochemistry. Moreover, nitrate (NO_3^-) is a risk to human health, especially as a possible cause of infant methemoglobinemia [6,7]. Therefore, cost-effective and environmental-friendly nitrogen pollution abatement techniques are still desired and recommended.

A number of physical (e.g., mechanical filtration), chemical (e.g., catalytic reduction) and biological (e.g., biofilters) methods, used in conventional wastewater treatment have been applied for treating mariculture wastewater, while they are costly in terms of capital investment, energy demand, and system maintenance. Other types of filtration and environmental control are often also necessary to maintain clean water and provide a suitable habitat for fish [8].

Constructed wetlands (CWs) are treatment systems that use natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality. Alternatively, constructed wetlands (CWs) act as a natural biofilter and can remove considerable amounts of nutrients (e.g., nitrogen and phosphorus compounds), organic matter, and suspended solids from wastewater. Owing to low capital, operating costs, and low energy consumption, CWs are becoming a promising technique to treat aquaculture effluents before discharge [9-11].

In order to deal with the pollutant load that accumulates in marine RAS, the use of CWs with facultative or obligate halophytes has been proposed [12]. Halophytes are plants which naturally survive in salt-contaminated environments and can tolerate high saline concentrations. About 1% of the total flora of the world (both dicots and monocots) are halophytic plants. Moreover, halophyte plants have the ability to absorb different forms of nitrogen, depending on different environmental factors, such as CO_2 availability [13].

In addition, when plants are grown in wetland systems, the interactions between the soil, the filter media, the microorganisms, and the plants not only improve the potential of CWs to remove nitrogen compounds from wastewater but also affect biomass production which can be further used for animal feed or human food, or in the production of biofuels or by-products of interest to the pharmaceutical industry, among other applications [9-11].

On the other hand, microorganisms within the biofilm on the surface of filter media and plant roots in CWs are widely considered to play a key role in the removal of nitrogen pollutants [9,10,14]. Nitrogen removal is a microbial-governed process, where a great diversity of microorganisms related to the nitrogen cycle are involved. Simultaneous nitrification-denitrification plays a major role for nitrogen removal, being ammonium-oxidant bacteria (AOB) and denitrifiers the dominant microbial communities associated to such bioprocesses [10,14-16].

In recent years, a growing body of literature has examined the response of microbial community in CWs to wastewater quality characteristics, substrate type, filter material, plant diversity, pH variation, operational time, and so on [9-18]. In a generic context, a better understanding of the microbial communities in CWs and their influential parameters could aid in optimization and management of CWs toward further efficiency enhancement [19]. Until now, only a few published studies have focused on CWs for hypersaline wastewater treatment from offshore and coastal marine aquaculture [2,20], while the characteristics of the microbial communities in CWs for mariculture wastewater treatment has not yet been explored in depth.

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Accordingly, a number of methods are available for the analysis of environmental microbiota, such as plate count method, machine learning-based measurements, and molecular technologies [21-23]. In particular, high-throughput data, the information generated in a massive, fast manner by "omics'" technologies (*i.e.*, transcriptomics, metabolomics and proteomics) have opened a new era in microbiomes research. High-throughput sequencing technology is a highly efficient molecular biology method to profile complicated microbial populations in CWs, and provides an opportunity to investigate the links between the microbial communities and operational environment of CWs in particular [24-26]. To date, there are few published studies on the characteristics of microbial communities in CWs treating mariculture effluents, based on the high-throughput sequencing technology [2]. Therefore, more studies are needed in order to characterize the diversity and structure of microbial communities involved in mariculture wastewater treatment in order to investigate the relationships between nutrients' removal efficiency and the corresponding functional genera.

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