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Sustainable Treatment of Aquaculture Effluents in Future-A Review

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***Abstract*— *There is a growing contamination of soil and irrigation water by intensive agricultural use and environmentally-unfriendly activity, which is due to the need to generate ever greater quantities of food to meet the demands of the growing population throughout the world. Many aquaculture systems produce high amounts of wastewater containing compounds such as suspended solids, total nitrogen (N) and total phosphorus (P). However, the load of waste is directly proportional to the fish production. Therefore, it is necessary to develop more intensive fish culture with efficient management for wastewater treatment. A number of physical, chemical and biological methods used in conventional wastewater treatment have been applied in aquaculture systems. This review gives an overview about possibilities to avoid the pollution of water resources; it focuses initially on the use of systems combining aquaculture and plants with a historical review of aquaculture and the treatment of its effluents. It discusses the present state, taking into account the load of pollutants in wastewater such as nitrates and phosphates, and finishes with recommendations to prevent or at least reduce the pollution of water resources in the future. All aspects of water treatment play a vital role in intensive fish production, because the control and monitoring of water quality is of significant importance to the success or failure of the aquaculture venture and its production. It is therefore necessary to develop new research applications focused on minimizing or at least reducing the negative impacts of aquaculture effluents on the environment. This review aims at giving an overview about aquaculture systems developed in historical times which could still be valuable for the future generation, about the present problems, and about innovative ideas, especially with respect to the integration of halophytic plants as bio-filter in saline aquaculture systems.*

***Keywords*— *Soil and irrigation water, environmentally-unfriendly, sustainable aquaculture, solid waste, total nitrogen and total phosphorus.*

I. INTRODUCTION

Aquaculture plays a vital role in nutrition, employment, foreign exchange earnings and the socio-economic development because worldwide demands on food production are increasing due to declining fisheries stocks and an increasing world population that is approaching 8 billion people. Total aquaculture production was valued at $60 billion in 2002 and aquaculture contributed almost a third of global fisheries (FAO, 2004). In the last three decades aquaculture has expanded and has the potential to increase local food security, alleviate poverty level, and improve the standard of rural livelihoods (FAO, 2004). The direct discharge of nutrient-rich effluent into the environment is one drawback of many aquaculture methods. This discharge includes feed-derived wastes composed of dissolved components, such as nitrogen, phosphorus, and other suspended solids (Losordo and Westers, 1994). Aquaculture has increasingly been viewed as environmentally detrimental (Naylor et al., 2000). Mariculture in sea cages has been associated by the public with deterioration of water quality and eutrophication of coastal waters (e.g., Staniford, 2001). Uncontrolled nutrient release by mariculture operations harms the industry in at least three ways—it reduces coastal water quality (which can generate negative public perception and legal-regulatory consequences), it wastes valuable nutrients, and, of course, it compromises the health of the organisms that are cultured in these waters. It is in the best interest of mariculturists, therefore, to minimize nutrient release from their culture facilities into the environment. Bio-filtration is the most effective way to treat aquaculture water, due to its low concentration of pollutants compared with domestic effluents (vanRijn, 1996). Bio-filtration of fishpond water can be done by bacteria (van Rijn, 1996), microalgae (Neori and Krom, 1991), macroalgae (Neori et al., 1996), and suspension feeders (Shpigel and Blaylock, 1991; Shpigel et al., 1997). Hardly any of these approaches is practical or even effective in the treatment of effluent water from fish-cage farms (Ahn et al., 1998). Protein is the most expensive component in fish feed and the main source of nitrogenous pollution in fish culture. It is therefore economically desirable to maximize the conversion of feed protein into a valuable biomass, and environmentally desirable to minimize nitrogenous waste. Both ends can be achieved in algal-dependent integrated mariculture. Unlike fish-cage effluents, fishpond effluents can be treated. Use of marketable organisms as bio-filters increases both diversification and income of the mariculture operation. Algal bio-filtration has a stabilizing influence on water quality since, unlike bacteria, algae counteract the consumption of O_2 and the production of CO_2 by the fish. However, algal bio-filters probably cost more to build and use a larger land area when compared with the alternative bacterial nitrification- denitrification aquaculture bio-filter systems. Additional organisms that consumed the solid wastes were cultured in a food chain. Dissolved nutrients in the final effluent were bio-filtered by seaweed. This aimed at sustainable treatment of aquaculture effluents to evaluate the effectiveness of a halophytes bio-filter to reduce effluent nutrient concentrations of aquaculture effluent and support aquaculture effluent treatment. It will also evaluate the effect higher salinity halophytes on the efficiency of the bio-filter from aquaculture effluent.

II. Systems Combining Aquaculture and Plants

Several systems for combining aquaculture and bio-filtering plants exist at different levels of more or less sophisticated techniques. The simple co-culture of different fish species from the same trophic level has been practiced for a long time and is known as aquatic polyculture. These organisms share the same biological and chemical processes. The culture systems show only a few synergistic benefits. Some traditional polyculture systems incorporate a greater diversity of species, occupying several niches as extensive cultures within the same pond (Binh, C.T; 1997 and Fernando et al., 2008)

III. Microalgae as Bio-filters

Dense microalgae populations can develop in fishponds and their effluents and can provide efficient bio-filtration in situ if they are given proper environmental conditions, including ample sunlight and low-to-medium water exchange rates (up to about 2 exchanges=day [d], depending on season and location) (Kromet al., 1989a, b; Neori et al., 1989). The microalgae recharge the water with dissolved oxygen (DO) and recover $CO_{2,}$ ammonia and phosphate in their high-protein biomass (Krom and Neori, 1989; Neori and Krom, 1991). In the NCM's medium-flow intensive fishponds, algal blooms usually consisted of one dominant species, mainly planktonic microalgae such as *Olithodiscus* spp., *Chlorella* spp., *Tetraselmis* spp., *Chaetocerous* spp., or *Pyramimonas* spp. These populations usually maintained good water quality in the ponds, although they were periodically grazed out by heterotrophic micro flagellate sand ciliates (Neori et al., 1989).

IV. Seaweeds as Bio-Filters

Methods for treating effluents from enclosed mariculture systems with macroalgae were initiated in the mid 1970s. This approach has recently gained new interest verifying that wastewater from intensive and semi-intensive mariculture is suitable as a nutrient source for seaweed production, and that integration with seaweeds significantly reduces the loading of dissolved nutrients to the environment. However, in open culture systems, like fish cage farming, the continuous exchange of water makes waste disposal difficult to control, and so far, few studies have investigated the possibilities of integrating seaweeds with such cultures. There is also a serious dearth of literature focusing on the feasibility or application of integrated cultures of seaweeds and aquaculture. The nutrient content of algae was also higher close to the cages. Yield of agar per biomass ranged between 17–23% of dry weight, being somewhat lower closer to the farm but, due to higher growth rates, the accumulated agar production still peaked close to the fish cages. The degree of epiphytes and bryozoan coverage was low overall. An extrapolation of the results shows that 1 ha of *Gracilaria*, cultivated close to the fish cages, has the potential to remove at least 6.5% of dissolved nitrogen and 27% of dissolved phosphorus released from the fish farm. For nitrogen this may seem a minor reduction but, because the fish farm released nearly 16 tons of nitrogen annually, the volume assimilated by the algae is substantial. Although the size of Gracilaria culture used for the above calculation is small, it would give an annual harvest of 34 t (d. wt) *of Gracilaria*, valued at US$ 34,000. This Figure is twice that of a *Gracilaria* monoculture, not integrated with fish cage farming.

The conclusions from this study are that both economic and environmental advantages could be achieved by integrating algal cultivation with fish farming in open sea systems. A larger cultivation unit would increase nutrient removal efficiency and profits, but further studies focusing on full scale cultivation during different seasons are needed. The high water exchange rates that often characterize coastal fish farming will be of importance when integrating seaweeds with fish. Unlike particulate nutrients, the dissolved fraction will be transported over much greater distances. The proportion of integrated seaweeds benefiting from the surplus of dissolved nutrients will increase with the time that nutrient levels remain high in the water package passing the cages (Løland, 1993). There are two main factors that will determine the potential for seaweeds to remove nutrients: one is the capacity of the seaweeds to respond to an increased nutrient concentration, and the other is how precise the current pattern can be predicted, or how exposure to the nutrient rich water can be maximized (Troell & Norberg, 1998).

V. Mangrove as Bio-Filter

Mangrove ecology is important to ecosystem biology and nutrient cycling. Mangal susceptibility to a variety of anthropogenic and natural stressors is examined, followed by a description of the uses of mangroves and their potential as effluent bio-filters. Recent studies of mangroves as wastewater treatment areas are reviewed and the limitations in current research are identified. In recent years, high inputs of eutrophic waste have been labelled as one of the main culprits of mangrove degradation. The global expansion of shrimp aquaculture operations has resulted in large effluxes of nutrient-rich waste into mangrove areas. Although some researchers predict that high loads of aquaculture effluent are detrimental to mangroves (e.g. Feller 1995, Madeira et al., 1999), at present there is no conclusive evidence that shrimp farms negatively affect mangrove dynamics. Some studies actually suggest that shrimp farms may contribute to increased growth and survival rates (Rajendran and Kathiresan 1996).

VI. Wastewater Filtration

Freshwater wetlands have been analysed for their wastewater treatment capacity for many years, but very little research has focused on halophytic wetlands, specifically mangroves. There are several reasons for the lack of information regarding mangrove bio-filtration. Until recently, mangroves were regarded as barren wastelands suitable only for clearing. With the realisation of the ecological importance of mangroves, efforts have been made to protect these coastal forests. The establishment of shrimp farms in mangrove areas

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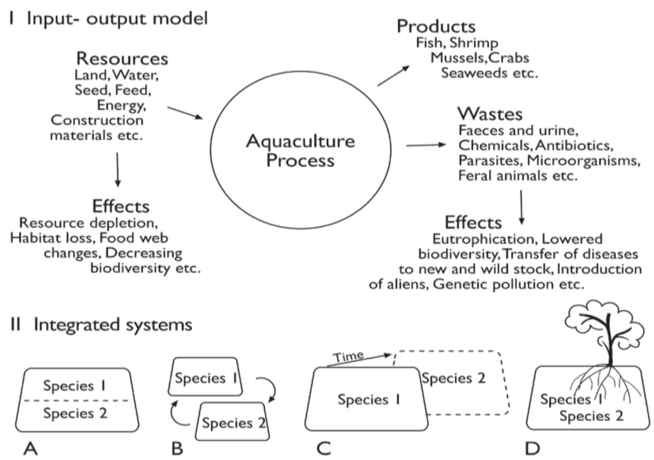
as well as the dumping of sewage and eutrophic or industrial pollutants into mangal habitats has been discouraged if not prohibited in many countries such as Australia, the United States, Thailand and parts of Indonesia (Kathiresan and Bingham 2001, Kongkeo 1994). The complexity of mangrove systems and their interrelationships with other ecosystems, along with newly-enforced regulations regarding mangrove management, has probably deterred many researchers from conducting experiments in mangal regions. Despite the difficulties inherent in mangrove analyses, some have realised the potential benefits these intertidal forests may provide and have pursued studies in this field. The research specific to mangroves as wastewater treatment wetlands has produced both indeterminate and promising results. The effectiveness of mangroves in the treatment of nitrogen and phosphorus wastes is also supported by Ye et al. (2001). Research revealed that when livestock waste was applied to a mangrove, the system was capable of removing over 80% of the nitrogen and 70% of the phosphorus from the effluent.



I. Diagram illustrating the use of resources by aquaculture, generation of wastes, and direct and indirect environmental effects; II. Main models of integrated aquaculture in marine or brackish waters

VII. CONCLUSION

The ever-increasing popularity of aquaculture farming has raised concern within international communities due to the unknown detrimental effects of high effluent loading on coastal ecosystems. Despite the global attention aquaculture farming has received in recent years, few studies have provided feasible solutions to effluent management issues. The purpose of this review was to investigate the potential of modified marine halophytes in treating effluent originating from an intensive aquaculture effluent farm in future. The potential of these intertidal forests to extend their nutrient cycling capacities to the treatment of effluent originating from anthropogenic sources has only recently become of interest. The few studies that have been conducted show great potential for microalgae and mangroves as wastewater bio-filters from aquaculture. Until in-depth research reveals the intricacies underlying natural mangrove dynamics and marine phytoplankton, it may be more suitable to examine the bio-filtration capacity of modified or constructed mangroves and microalgae. Research showed that the efficiency of a modified microalgae and mangrove as an effluent filtration system and attempts to provide insight into the potential of this form of natural wastewater treatment and its significance for many coastal regions throughout the world.

VIII. FUTURE RESEARCH DIRECTIONS

The rapid expansion of intensive shrimp farming and the affiliated discharge of nutrient-rich effluent into surrounding coastal waters throughout the developing world have raised global concern about the environmental impacts of high intensity practices. Research has identified the key effects associated with unregulated effluent flushing, but despite the undeniable fact that shrimp farming has the potential to harm coastal ecosystems if management techniques are not made more environmentally friendly, little to no feasible options for decreasing the impact of effluent have been discovered.

This review has revealed following areas that should be the focus of future research in this field:

- The impact of long-term effluent loading on natural and modified mangroves and microalgae species
- Farm-scale studies analysing nutrient removal and assimilation capacities of small mangrove wetlands and selective marine microalgae effluent treatment accounting for both above-ground and sediment nutrient cycling processes for aquaculture effluent in future.

Conflict of Interest Statement: We declare that we have no conflict of interest.

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