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SUMMARY – The negative impact of aquaculture derives mainly from particulate and dissolved nutrients. Different methods have been tried to minimize the effects of nutrient loading. Integrated aquaculture is a feasible method to reduce the environmental impacts of by-products from fish culture. In this paper a revision is made of different models whose main target is the realisation of integrated mariculture, introducing cultivations of algae, molluscs in a fish farm. The use of seaweeds as biofilters to remove dissolved nitrogen from fish pond effluents has been widely studied. Different approaches to integrate the seaweed biofilters into fish culture for a sustainable mariculture have been described by several authors. Therefore, cultivation of molluscs on fish farms may control nutrient production and ensure better water flows around the fish net.

Key words: Integrated mariculture, eutrophication, biofiltering.

RESUME – *"Systèmes intégrés : Une aquaculture propre pour l'environnement". L'impact négatif de l'aquaculture provient surtout des éléments nutritifs en particules et dissous. On a essayé différentes méthodes pour minimiser les effets de la charge en éléments nutritifs. L'aquaculture intégrée est une méthode possible pour réduire les impacts sur l'environnement des sous-produits de l'aquaculture. Cet article présente une révision de différents modèles visant à instaurer une mariculture intégrée, en introduisant dans l'exploitation piscicole des cultures d'algues et mollusques. On a étudié l'utilisation d'algues marines comme biofiltres dans le but d'éliminer l'azote dissous provenant des effluents des étangs de poissons. Plusieurs auteurs ont décrit différentes approches pour intégrer les algues biofiltres dans la pisciculture afin de mettre en place une mariculture durable. Par conséquent, la culture de mollusques dans les centres de pisciculture peut contrôler la production d'éléments nutritifs et assurer une meilleure circulation d'eau autour des filets à poissons.*

Mots-clés : *Mariculture intégrée, eutrophisation, biofiltrage.*

Introduction

The Mediterranean coast supports many human activities, such as tourism, maritime traffic, industry, fisheries, aquaculture or conservation, all of them competing for coastal zone resources. In this context, the aquaculture industry has grown rapidly during recent years. However, the increasing production through intensified aquaculture systems is affecting the carrying capacity of the environment on which the farming activity takes place, and therefore threatens further developments.

Fish farming release nutrients to the environment causing hypernutrification (Gowen and Bradbury, 1987). Concentrating many animals in a small place creates high oxygen demand and increases the concentration of waste products (Qian *et al.,* 1999), so it can favour the growth of the phytoplankton until the degree of eutrophication situations. In general the soluble inorganic nitrogen is a limiting factor in marine waters.

The impact of this excessive level of nutrients depends on the hydrogeographic conditions of the area. Some authors found hypernutrification but not eutrophication near fish farming in the Scotland coast (Ervick *et al.,* 1985; Gowen *et al.,* 1985).

The eutrophication associated to intensive marine culture is common in closed areas with insufficient water replacement. In the North Atlantic (Norway or Faroe Island) the eutrophication is mainly associated to closed areas (Aure and Stigebrant, 1989, 1990; Braaten, 1991). But the Mediterranean is an oligotrophic sea, with low nutrient levels; it is an especially sensitive area due to its low energy and has limiting nutrient levels, that is the reason why a minimum increment of nutrients gives rise to important increases in the primary production. Gowen and Bradbury (1987) indicate that aquaculture farms have a visible effect on the primary production. On the other hand, macrophyte growth can be favoured because of new substrata for their establishment, and an increase of nutrient concentrations (Rosenthal *et al.*, 1988). In places where this variation does not seem detectable, the growth of the macroalgae on the surface can be 20 times more than that of the control stations (Leskinen *et al.*, 1986).

The negative impact of aquaculture derives mainly from particulate and dissolved nutrients from animal excretion and uneaten food (Krom and Neori, 1989). To minimize the impact consequences on the environment should be a priority in any project (Ackefors and Enell, 1992). Current techniques for the reduction of particulate matter in wastewater involve mechanical removal by sedimentation and microsaving (Gowen *et al.*, 1989; Cripps, 1991), but removal of particular matter by sedimentations alone is inefficient (Hennessy, 1991) and microsieves are relatively expensive and require regular maintenance (Heerfordt, 1991).

Recently, different authors (Silva and Jambrina, 1999) and Associations (Greenpeace, 1995) outline "Diversification" like one of the basic principles of sustainability and it should be kept in mind by the countries in planning and future development of aquaculture sector. The projects with a wide range of species culture contemplated in the same installation (polyculture or multicomponent system) should be a priority.

The biological treatment of sewage by algae and bivalves was studied by Ryther *et al.* (1972, 1975) and Goldman *et al.* (1974). In this system, secondarily treated sewage, mixed with seawater, was used to culture bivalves and seaweeds. The integration of biofilters with aquaculture has indeed been proposed and tried (Cohen and Neori, 1991; De-Pauw and Salomi, 1991).

Integrated aquaculture is a biologically and technically feasible method to reduce the environmental impacts of by-products from fish culture. The concept of developing an "environmentally clean" aquaculture based on an integrated fish – molluscs and macroalgae system was first proposed by Gordin *et al.* (1981). The system was tested in the following years (Gordin, 1982; Gordin *et al.,* 1990; Shpigel *et al.*, 1991). Other authors developed systems integrating fish and macroalgae (McDonald, 1987), fish or shrimp and oyster in land-based facilities (Wang, 1990; Wang *et al.,* 1990; Qian *et al.*, 1999).

Biofilter

From the point of view of minimum environmental impact, a recycling or recirculating system of aquaculture would be ideal, as there would be only reduced discharges into open water bodies. The development of such systems requires the removal of solid compounds and dissolved metabolites contained in outflowing water. Filtration or other mechanical processes can easily remove solids but removal of dissolved metabolites requires more complex and expensive processes (Jiménez del Río, *et al.*, 1994)

The use of seaweeds as biofilters to remove dissolved nitrogen from fish pond effluents has been widely studied (De Boer and Ryther, 1977; Fralick, 1979). Harlym *et al.* (1979) used *Gracilaria sp.* to remove the ammonium produced by the fish *Fundulus heteroclitus*, removing lightly more ammonium than was produced by an equal biomass of fish. Similar results were reported by Haglund and Pedersen (1993) in a system of *Gracilaria tenuistipitata*. Jiménez del Río *et al.* (1994, 1996) described that *Ulva spp.* not only show a higher N-removal capacity than *Gracilaria spp.* but also a higher resistance to epiphytes.

Model for environmentally clean land-based mariculture (Shpigel *et al.*, 1993)

These authors proposed a two-water-pathway system (Fig. 1). In the main pathway, fresh seawater enter the fish pond and drains through an earthen sedimentation pond, a bivalve filtration unit and finally, a seaweed filtration/production unit from which it is discharged back into the sea. The second pathway is a loop, recirculating water from the sedimentation pond through a bivalve production unit.

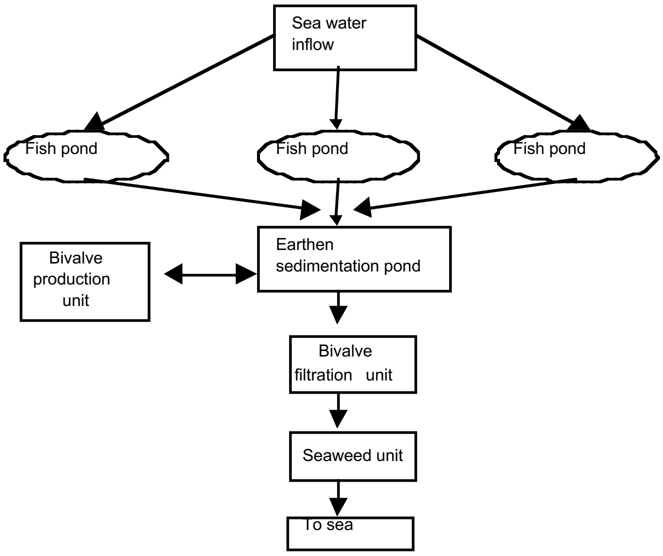

Fig. 1. Schematic diagram of the integrated system proposed by Shpigel *et al.* (1993).

The fish would assimilate 26% of N. A further 10% of the N would settle in the fishponds and would be drained into the sedimentation pond as heavy particles, which presumably will be removed by settling in the sedimentation process. The remaining 64% N would flow, dissolved and suspended in the water, from fishpond. From the 64% carried in the water, 54% would be in form of phytoplankton and the remaining 10% would be dissolved N.

The bivalve production unit, which would operate at 80% filtration efficiency, would filter particulate matter from the sedimentation pond water. The bivalve can assimilate 10.5% of the original N. An additional 33% of the original N, in particulate form, would be metabolised by the mollusc and converted approximately half of it to faeces and the remainder to dissolved N.

These effluents pass through a second bivalve biofiltration unit operating at 90% filtration efficiency, which would assimilate 4% of the original N. It would also metabolise 12.8% of the original N, half of it to faeces, which would settle out.

A fraction of 26.7% from the original N would flow from the bivalve biofiltration unit to the seaweed polishing/production unit. The seaweeds are capable of removing the dissolved N at 90% efficiency, thus taking up 22.4% of the original N. The final effluents would contain only 4.3% of the original N.

Self sustaining, self-cleaning modular integrated, land based abalone and seaweed experimental system (Neori *et al.*, 1998)

These authors have developed several approaches to integrate the seaweed biofilters into fish culture for a sustainable mariculture. These approaches are based on the use of algae and invertebrates to remove the dissolved and particular nutrients from fishpond effluents (Fig. 2).

The Shpigel and Neori (1996) and Neori *et al*. (1998) research describes the need to quantify the rates of production and consumption of excess nitrogen nutrients by the fish, abalone and seaweed cultures. For optimal sustainability of an integrated culture system the processes, those that produce pollutants and those that consume them, have to be quantitatively balanced.

They designed a pilot system that was the first and simplest trial in a series of progressive complexity regarding the concept of integrated culture of seaweed, abalone, fish and clams in modular and intensive land-based facilities. Effluents from abalone (*Haliotis tuberculata*) culture tanks drained into macroalgae (*Ulva lactuca* or *Gracilaria conferta*) culture and biofilter tanks, where nitrogenous waste products contributed to the nutrition of the algae. Net algal production from each algal tank was harvested and used to provide a mixed diet for the abalone (Fig. 3).

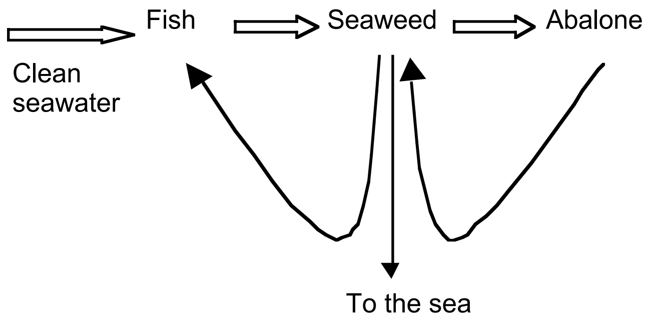

Fig. 2. Diagram of the land based abalone and seaweed experimental system proposed by Neori *et al.* (1998).

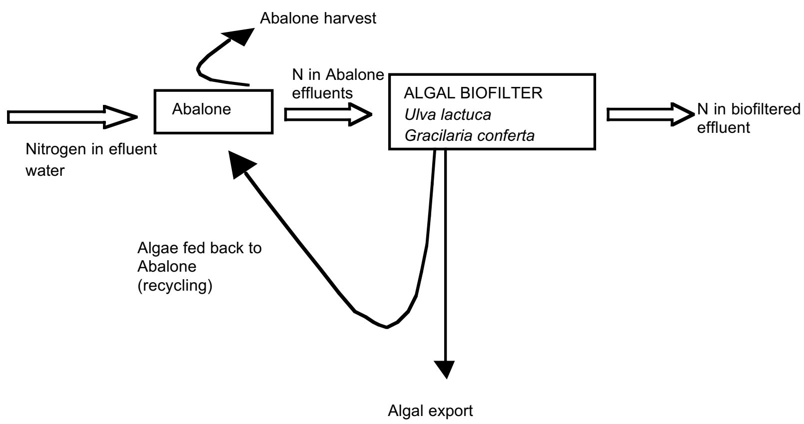

Fig. 3. Schematic partitioning of nitrogen within an integrate abalone/algal biofilter culture system (Neori *et al.,* 1998).

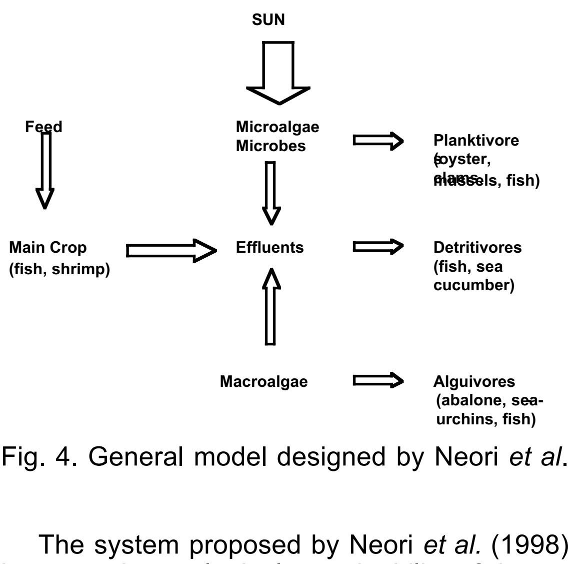

Fig. 4. General model designed by Neori *et al.* (1998).

The system proposed by Neori *et al.* (1998) (Fig. 4) incorporates a number of features that can increase the ecological sustainability of the proposed integrated culture system, as follows:

(i) The use of the same water for both abalone and seaweed cultures reduces seawater requirements.

(ii) Biofiltering and recycling of the abalone nutrients of abalone excretion by the seaweed reduce both the nutrient input requirements and the overall environmental impact.

(iii) The use of biofiltering grown seaweed eliminates the need for a destructive harvest of natural seaweed beds.

(iv) The chemical composition of the culture seaweed is controllable.

Algae, and in particular seaweed, allow the creation of flexible integrated sustainable mariculture operations.

Integrated lake farming

The first experience in this sense was the integrated lake farming for fish and aquatic plants. The objective was to increase harvestable primary production which fish could utilize in low primary production lakes. Lake farming increases primary production through the selection of suitable aquatic plants that can use solar energy efficiently and be directly used by man. These aquatic plants are raised for both food and fish feed. The concept of integrated lake farming is similar to integrated land farming. A successful model of integrated lake farming was the shallow lake, Tai (China) (Chang, 1987).

Examples of fish culture is the grass carp or *Megalobrama amblycephala*, and aquatic plants used in hydroculture are *Trapa natons, Euryale ferox* or water spinach (*Impomaea aquatic*). The vegetation consumed by the grass carp is partially digested, and the faeces of the fish can be either directly consumed as food materials by detritivores or used as fertilizers to enrich the production of natural food such as phytoplankton, zooplankton and benthos organisms. Other herbivorous, planktivorous and detritivorous fishes are also used in this culture system (Chang, 1991).

Benefits from a farming system are: (i) efficient way to manage lakes; (ii) increase profits; (iii) reduce the effects of eutrophication in large shallow lakes (the extensive planting of aquatic macrophytes for lake farming stabilizes the sediment and reduces nutrient resuspended, the result is a reduction in the frequency of blue-green algal blooms and reduced eutrophication); and (iv) the planting of these macrophytes creates areas of vegetation, which serve as refuges for young fish and spawning.

Cultivation of mussels and scallops at fish farms may help in controlling the development of biofouling communities on fish rafts, but particularly on fish nets. Consequently, it would reduce the labour cost for cleaning fish nets and ensure a better water flows around the fish net (Qian *et al.*, 1999). The fishes in this system can benefit from improved water quality while scallops or mussels in this system not only benefit from better quality of seawater but also from enriched food sources, bacteria, phytoplankton, zooplankton and detritus (Asare, 1980; Yin, 1987; Gosselin and Qian, in press).

It is a generally accepted hypothesis that integrated mariculture makes use of the ecological processes and functions, and utilises the by-products from mariculture (e.g. the organic and inorganic nutrients inputs from fish culture) to produce extra aquacultural products, thus lowering the environmental pollution from the by-products (Harlin *et al.*, 1979).

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