4. Effluent water treatment: Algal Ponds

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1. Introduction

As availability of freshwater decreases, the future of fish culture will probably be mainly based on seawater culture. Whatever the aquaculture production system, cultured animals produce wastes, mainly composed of solids – carbon (C), nitrogen (N) and phosphorous (P); soluble wastes – carbon dioxide (CO_2), ammonia (TAN), ortho-phosphate (PO_4) and trace elements. These all return to the natural environment.

In the present work, several treatment systems were developed to try to prevent adverse environmental impacts from these aquaculture wastes.

The main types of treatment described are:

1. bacterial dissimilation into gases
2. plant assimilation into biomass.

Bacterial biofilters oxidize ammonia and other organic N forms as urea into nitrate (NO_3), which is less toxic but still a pollutant. Plants assimilate nitrate as a nutrient for their growth.

Fish and many bacteria produce CO_2 and consume oxygen (O_2), while algae generally do the reverse. Consequently, the interest in integrating fish culture with plant culture is that plants utilize solar energy and the excess of nutrients generated from the fish wastes (particularly C, N and P) for their growth.
Algae culture (plant culture in general) is a type of extractive aquaculture. Integrated aquaculture systems utilize the complementarities between productive heterotrophic aquaculture and autotrophic extractive aquaculture for creating value from the nutrients supplied to the system (naturally, and through feed).

2. Basics of algal treatment

Algae use solar energy to turn nutrients (in effluents) into usable resources, by the process of photosynthesis (Figure 1, see next page).

This treatment must be well adjusted to balance the quantity of O_2, CO_2 and nutrient exchanges between the heterotrophic and autotrophic compartments[1,2]. Where this is so, the fish wastes are considered to be a resource for the algae, which restore the water quality for the fish culture. Accordingly, algal growth is related to fish-effluent parameters (particularly nitrogen, phosphorus, dissolved oxygen) but it is also affected by temperature and light in outdoor systems.

The effect of temperature on algal growth follows the Van’t Hoff law (see Glossary) for the majority of relevant species. However, the maximum, minimum and optimal growth temperatures are different from one alga to another

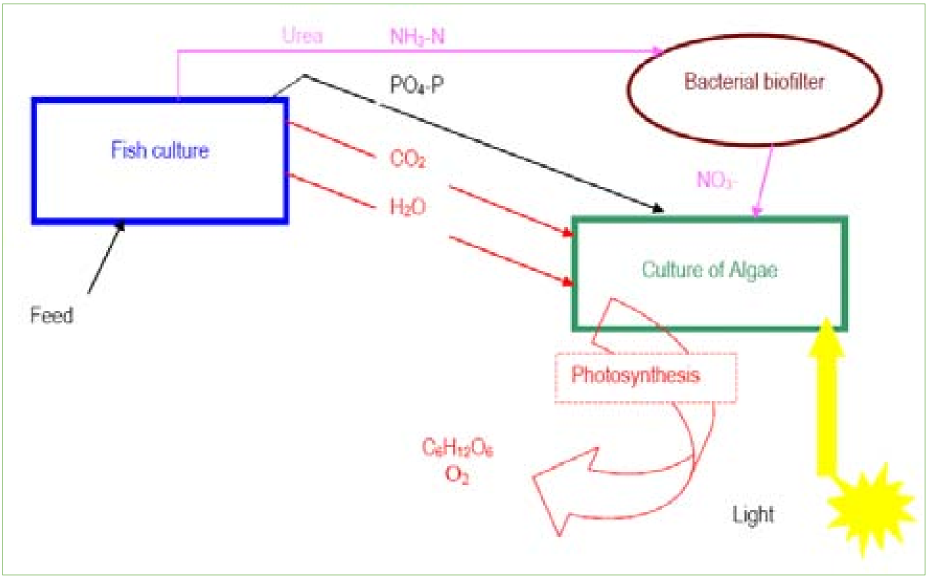

Figure 1: The role of algal photosynthesis in transforming fish farm wastes into usable resources

Moreover, algal growth depends on light intensity, which is essential for photosynthesis.

Therefore, the daily consumption of nutrients by algae fluctuates with the seasons (light, temperature changes). For example, it has been shown[3,4] that a culture of green seaweed (marine algae) in a high-rate algal pond could take up as much as 90% of the nitrogen produced by a recirculating system for Sea Bass (*Dicentrarchus labrax*) production in summer, but only 30% of the nitrogen production in winter. For phosphorous, the uptake varied between 70% and 0%, respectively, for the same seasons. In temperate climates, temperature, irradiance and day length are optimal for algal development during summer.

In integrated aquaculture, algal biofilters reduce the environmental impact of fish culture. This concept can be integrated into Coastal Zone Management policy[5,6,7]. The potential benefits of integrated aquaculture using algae are economic and ecological. The algae species selected as the biofilter can be chosen to provide additional benefits, including sale for human consumption; or for phycocolloid-, feed supplement-, agrichemical-, nutraceutical- and pharmaceutical-compounds' production[8].

Moreover, culture of algae is one of the best solutions for biofiltration, because production costs are low due to the high productivity of the algae[9].

Figure 2: Pilot-scale High Rate Algal Pond (Ifremer Palavas station)

3. What type of algal pond system - what types of algae?

Types of algal pond systems

There are two main types of algal pond systems: static algal ponds and high rate algal ponds (HRAP). Both can be used to treat the effluents of flow-through or recirculating fish culture systems. The effluents of flow-through systems are characterized by high flow rates and low concentrations of nitrogen and phosphorus. In contrast, the effluents of recirculation systems are 10 - 100 times more concentrated, and have reduced flow rates (1/10 - 1/100 those of flow-through culture systems). Hence the conditions in recirculation systems are particularly favourable to treatment of the water, and limit the impact of aquaculture on the environment.

In practice, static algal ponds are seldom used in aquaculture simply because they require a long water-residence time (months). This requires a large area, which is often difficult to find close to the farm, and is expensive.

High rate algal ponds may constitute a second loop of water treatment of flow-through or recirculating aquaculture systems. They are characterized by a continuous water circulation and mixing in a culture tank, either by a paddlewheel or by strong aeration, and by a short residence time (days) (Figure 2).

Selection of algae species:

Many species of algae have been tested as biofilters. The choice of seaweed species depends on their respective growth rates and nitrogen contents, on the susceptibility to control of their life cycles, on their resistance to epiphytes and disease-causing organisms, and on a match between their ecophysiological characteristics and the growth environment[10].

The SEAPURA Project[11] selected five red algae as good candidates for biofilters:
Gracilaria cornea, *G. verrucosa*, *Halopytis incurvus, Hypnea muciformis*, and *H. spinella.* These species can reduce about 50% of the ammonia concentration after one passage through an algal tank, and reach 85 - 90% of ammonia removal with a cascade tank[12].

Several investigations selected *Ulva* spp. or *Falkenbergia rufolanosa* as the favourite algae for algal pond systems. Both have a high nitrogen uptake rate, a high biomass yield and commercial value. Their life cycle and nutrient uptake capacities are well known.

Another important aspect of the algal pond approach is the possible valorization of the algal biomass produced:

- *Asparagopsis* is used as a source for halogenated and antibiotic compounds;
- *Gracilaria cornea* is used for the rheological and chemical properties of agar[13];
- *G. verrucosa* is a potential protein source for human or animal nutrition[14];
- *Hypnea* algae are cultured for their prostaglandin production;
- *Halopytis* for the extraction of dibromophenol and dimethyl sulphophoniopropionate, used as antibacterial agent;
- *Ulva* is used as a sea vegetable, as an aquarium feed or animal feed supplement, as an ingredient in neutraceutical mixtures and as an ingredient in topical preparations such as skin lotions used in spas;
- *Falkenbergia rufolanosa* has antibacterial and antifungal properties.

Treatment efficiency:

The uptake efficiency of *Ulva* spp. to treat the effluents of a recirculation system can reach 0.5 g $N/\underline{m^2}$/day and 0.03 g P/m^2/day for nitrate and phosphate respectively during optimal climatic conditions for algal growth[15].

With the same *algae* the nitrogen removal rate may reach 2.9 g/m^2/day in a flow-through system effluent containing mainly ammonia-nitrogen, with a protein content of the algal biomass up to 44% dry weight[16].
With the same type of effluent, total ammonia-nitrogen removal may be more than double that of *Ulva*[17]. Whatever the type of algae and nitrogen source (ammonia or nitrate), the best single-pass removal efficiency is obtained for a low nitrogen flux. However, a high biomass production per unit area is only possible with high nitrogen fluxes[18]. Designing such a system requires a

choice to be made of the main objective: that is, between algal production and high overall nutrient uptake (high flux) or low nutrient concentration (and low flux).

As an order-of-magnitude guide, in the climatic conditions of southern Portugal (38ºN) around 30 m^2 of *Falkenbergia rufolanosa* biofilter are necessary to treat the effluent of a system producing 1 tonne of Gilthead Sea Bream (*Sparus aurata)* reared at 21 °C. That biofilter would produce almost half a tonne of algae (fresh weight) per year[19]. In the south of France (43º30'N) a biofilter of 150 m^2 of *Ulva* spp. would be necessary to treat the effluent to keep a standing stock of 2 tonnes of Sea Bass reared at 20 °C over 1 year and it would produce half a tonne of algae (fresh weight) per year[20,21].

Reusing the treated water within and from a recirculation system is possible and does not induce fish mortality or biofilter disturbance, and does not reduce fish growth[22]. A first investigation showed a higher concentration of chromium, manganese, cobalt, nickel, copper, arsenic and thallium in fish muscle reared in a recirculating system compared to a flow-through system. However, as shown in Table 1, these concentrations were far below the FAO recommended values for fish destined for human consumption and the use of an algal pond allowed their reduction[23].

Table 1: Comparison of heavy metal content of fish muscle reared using recirculated farm water after its passage through algal pond treatment systems

	Maximum Recommended values (FAO)	All culture systems (Mean±SD)	Standard values in cultured fish
	(mg/kg dw)	(mg/kg dw)	(mg/kg dw)
Arsenic (As)	50[1]	6.85±1.31	2 – 11
Cadmium (Cd)	0.25 – 10	0.003±0.01	0.3
Copper (Cu)	50 – 150	0.75±1.97	20
Lead[2] (Pb)	2.5 – 30	0.05±0.10	2
Nickel (Ni)	2.5	0.16±0.42	–
Zinc (Zn)	200 – 250	13.50±9.35	45

4. Projects and current results

In the past 20 years, several projects have been developed to test and promote algal pond systems as a component of animal aquaculture production systems. Some of these projects are:

The SEAPURA project which, with fish farms in Spain and Portugal, selected, developed and tested cultivation of high-value seaweed species which had not been used before in polyculture. Accompanying research was conducted in Germany, France and Northern Ireland. The goal of the SEAPURA project was the development of sustainable polyculture systems based on economically valuable seaweed species. The cultivated seaweed biomass could be used for the human food market, mainly in France, and for fish feed additives with possible antibiotic effects of the cultivated seaweed, or for extraction of pharmaceutical substances.

The GENESIS project studied several types of integrated systems in warm water (Israel; 29º30'N)), temperate water (Southern France; 43º30'N) and cold water (Scotland; 58ºN), with a variety of valuable marine products including fish, crustacea, molluscs and aquatic plants. The different systems were evaluated for their performances in respect of water, nutrients and waste management. The GENESIS program also developed suitable products and services for the commercialization of the technology and established the financial viability and consumer acceptance of its products.

The LAGUNEST and PEARL projects focused on the use of algal pond systems to treat the waste water from recirculation systems in order to reuse it. At the time of writing (April 2007) these experiments are still in progress, and will investigate the flesh quality and welfare condition of Sea Bass reared in a completely closed system reusing the waste water, after purification in a high rate algal pond.

5. References

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