Asian Fisheries Science **10** (1997):91-100
Asian Fisheries Society, Manila, Philippines
https://doi.org/10.33997/j.afs.1997.10.2.001

Options to Reduce the Discharge of Wastes from Intensive Fish Culture[1]

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Abstract

In contrast to fisheries, aquaculture has grown substantially in several regions of the world, and will continue to be a significant employer in food production. With the growth of the industry, pressures on the water resource system will increase, and protective mea-sures must be taken to permit its sustainable use. In modern aquaculture with carnivorous species, improved diet formulation leading to reduced nutrient output is one method of choice effectively employed in European and other industrialized countries, where efficient methods for effluent treatment in land-based fish culture systems have also been devel-oped. The use of recirculation systems will become more important for a number of appli-cations, especially for rearing juvenile fish for stocking. However, know-how on required system components and their interactions needs to be improved to tailor their application to species-specific requirements. Environmental regulations, their control and enforcement, is one issue of increasing worldwide importance. While in some countries aquaculture is over-regulated, the lack of enforcement in many tropical countries of even existing regu-lations is counterproductive to the needs of the industry itself. There is also room to im-prove cost-effective treatment methods for effluents for intensive fish culture systems. This paper deals mainly with experience gained under European conditions.

Introduction

Whereas the world catch of fish has decreased or levelled since the end of the 1980s, world aquaculture production increased markedly during the last years (Fig. 1). This trend will continue. Aquaculture will become more significant as a producer of valuable foodstuffs in many regions. It also will be a significant employer in many countries.

Besides extensive pond culture as an environmentally friendly technique, intensive aquaculture can cause unavoidable environmental problems if not managed properly.

The excretion of feces (organic matter, nitrogen, phosphorus), the direct excretion of nitrogenous compounds (ammonia), mainly via gills and urine, as well as loss of feeds, are the main sources of pollutional loads (Steffens 1989, 1995; Lall 1991; Ackefors and Enell 1994).

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[1]Paper presented at the Fourth Asian Fisheries Forum, 16-20 October 1995, Beijing, China.

Phosphorus and nitrogen are the limiting nutrients for primary production in many waters, and their excessive release can contribute to hypernutrification and, in extreme cases, to eutrophication. Most of the discharged phosphorus appears in particulate form, while nitrogen is excreted mainly in dissolved form (Table 1).

Better Feed Utilization by Improving Diet Formulation

Decisive criteria for feed quality with respect to environmental impact are digestible energy, and protein and phosphorus contents of the diet.

High levels of digestible energy in the feed improve the feed conversion ratio and, at the same time, considerably reduce undigested organic content (Table 2). In order to reduce the fecal load by undigested feed and thus reduce oxygen depletion of the water, the digestible energy content of the diet can be

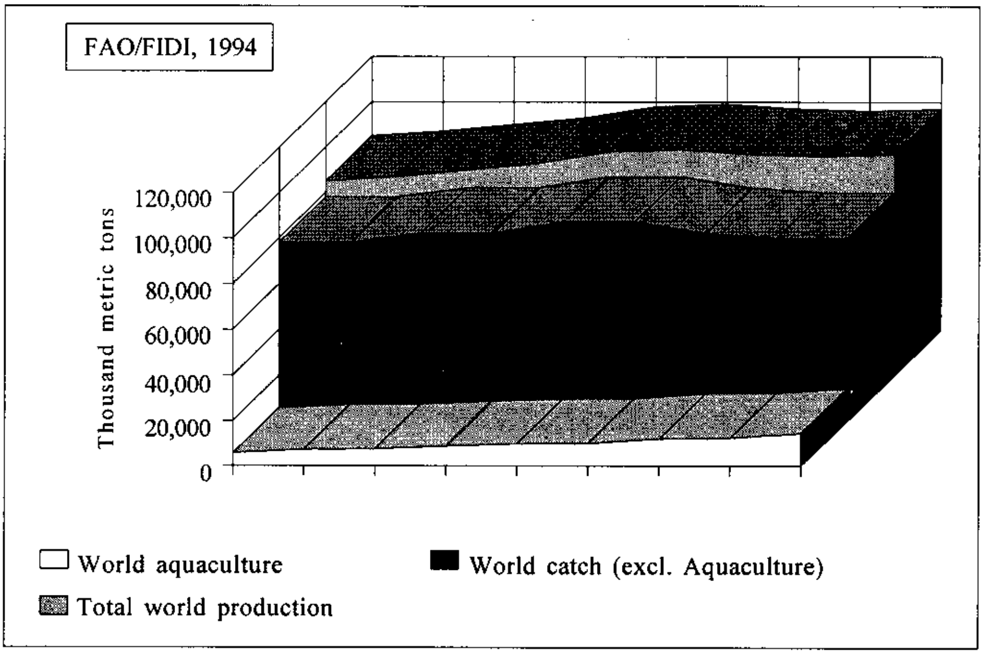

Fig. 1. World aquaculture and total production of fish and shellfish.

Table 1. Conversion and excretion of phosphorus and nitrogen contained in modern feeds for salmonid culture. Data given in percentage of the nutrients in the feed (combined after Enell 1985 and Christensen and Horsted 1991).

Nutrient in the feed	Retained in the fish (%)	Discharged in dissolved form (%)	Discharged in particulate form (%)
Phosphorus	27 - 35	16 - 30	38 - 54
Nitrogen	28 - 39	36 - 56	13 - 17

Table 2. Relationship between dietary content of digestible energy (DE), feed conversion ratio (FCR) and fecal organic matter (OM) in salmonid feeds (Pfeffer 1993).

Dietary DE ($MJ \cdot kg^{-1}$)	Energy digestibility (%)	FCR (kg feed• kg $gain^{-1}$)	Fecal OM ($g \cdot kg^{-1}$ gain)
14	72	1.43	450
15	75	1.33	380
16	78	1.25	320
17	81	1.18	280
18	84	1.11	220
19	87	1.05	180
20	90	1.00	150

increased mainly by increasing fat content, and by using better digestible (hydrothermically-treated) starch as carbohydrate source.

Lipid supplementation in fish feed, especially for salmonids, has been successfully employed (Steffens and Albrecht 1973, 1975; Steffens 1987; Alsted 1991; Johnsen and Wandsvik 1991). Generally, fish oils are used and dietary lipid levels often reach 15-25% or even higher. Digestibility of fish oils is very high (up to 90% and more). A partial substitution of oils by hard fats (e.g., lard) is possible (Steffens and Albrecht 1979).

Although lipid is the most important dietary energy source, hydrothermically-treated starch may also be utilized for this purpose by several fish species (Steffens 1993). In rainbow trout, gross energy demand$\cdot kg^{-1}$ gain was at a minimum, and energy and protein retention at a maximum when the non-protein energy proportion of the diet was composed of both fat and carbohydrate (Bieber-Wlaschny and Pfeffer 1987). But the carbohydrate content of feed must be restricted since higher dietary levels of starch reduce its digestibility, and intermediary carbohydrate utilization is limited in some fish species, especially salmonids (Brauge et al. 1994).

Lipid-supplemented high-energy diets can be produced by extrusion. Such feeds have a protein-sparing effect because the ratio of digestible energy to digestible protein is increased. With decreasing dietary intake of nitrogen, nitrogen utilization for growth is improved and nitrogen excretion is reduced (Steffens et al. 1995a).

To attain high growth rates, the qualitative and quantitative amino acid requirements must be met, and a favorable ratio of digestible protein to digestible energy is necessary (Steffens 1981; Cho and Kaushik 1985). However, for optimum retention of dietary protein and reduction of nitrogen excretion, the protein content of feed should be as low as possible. It seems to be sufficient, in the case of readily digestible dietary components, if 40% of the gross energy in feed is made up of protein (Petrasch and Pfeffer 1982). The positive effects of a high-energy diet on feed conversion ratio as well as on energy and protein utilization in rainbow trout is shown in Table 3.

Table 3. Feed conversion ratio, energy and protein utilization of rainbow trout (*Oncorhynchus mykiss*) fed diets of different energy content (Steffens et al. 1995b).

	Diet I	Diet II
Gross energy content ($MJ \cdot kg^{-1}$)	19.1	23.5
Protein content (%)	46.8	48.4
Lipid content (%)	12.9	23.8
Feed conversion ratio (kg feed$\cdot$kg gain^{-1})	1.06	0.72
Gross energy consumption (MJ$\cdot$kg gain^{-1})	20.2	16.9
Gross energy retention (%)	38.5	50.5
Protein efficiency ratio (PER)	2.02	2.87
Productive protein value (PPV)	36.1	55.6

Feed is the main source of phosphorus for fish. However, the availability of dietary phosphorus differs depending on its origin, and from species to species (Ogino et al. 1979; Steffens 1989; Lall 1991). To reduce phosphorus discharge, it is important that the dietary phosphorus level meets the physiological requirements of the fish but is not too high, that dietary phosphorus is well available, and that there is a favorable feed conversion ratio (Jacobsen and Børresen 1994; Rodehutscord and Pfeffer 1994a, 1994b; Rodehutscord et al. 1994). Thus, using high-energy diets with low but adequate contents of available phosphorus can reduce the phosphorus output from aquaculture (Table 4).

Rennert (1995) pointed to the substantial progress made in northern European countries in diet development for salmonids, particularly through partial fishmeal replacement and fat addition to gain high-energy density and low phosphorus levels (Fig. 2).

Although fish (mainly salmon) production increased in northern European countries, the nitrogen and phosphorus loads decreased in the last years by improving the diet formulation (Fig. 3).

Treatment of Fish Farm Effluents

Wastewaters from land-based flow-through aquaculture facilities are generally characterized by high flow rates and low concentrations of nutrients and organics, which makes treatment difficult if a high removal efficacy of the total load is required (Table 5). On the other hand, a large fraction of the suspended solid load can easily be settled or removed through mechanical filtration.

Several mechanical treatment methods are used for aquaculture purposes, the two principal ways of which are settling and sieving.

Sedimentation or settling ponds (tanks) need a large area, and flow rates are restricted. To achieve efficient sedimentation, water has to stay at least 30 minutes in the basins (Fladung 1993). Sludge must be removed daily to avoid phosphorus release. According to the investigations of Fladung (1993), 97% of suspended matter and 34% of total phosphorus of the effluent load of a trout

Table 4. Calculation of phosphorus excretion by rainbow trout (g•kg gain^{-1}) as a function of feed conversion ratio (FCR) and phosphorus content of the feed (assumed P content of the trout: 4.1 g•kg^{-1}) (Pfeffer 1993).

FCR (kg feed•kg gain^{-1})	P content of the feed (g•kg^{-1})		
	6	9	12
0.8	0.7	3.1	5.5
1.0	1.9	4.9	7.9
1.2	3.1	6.7	10.3
1.4	4.3	8.5	12.7

Table 5. Comparison of domestic and aquaculture wastewater loadings (Cripps 1994).

	Suspended matter (mg•l^{-1})	Total phosphorus (mg•l^{-1})	Total nitrogen (mg•l^{-1})	BOD (mg•l^{-1})
Domestic wastewater				
Weak	350	4	20	110
Medium	720	8	40	220
Strong	1,200	15	85	400
Aquaculture wastewater	14	0.13	1.4	8

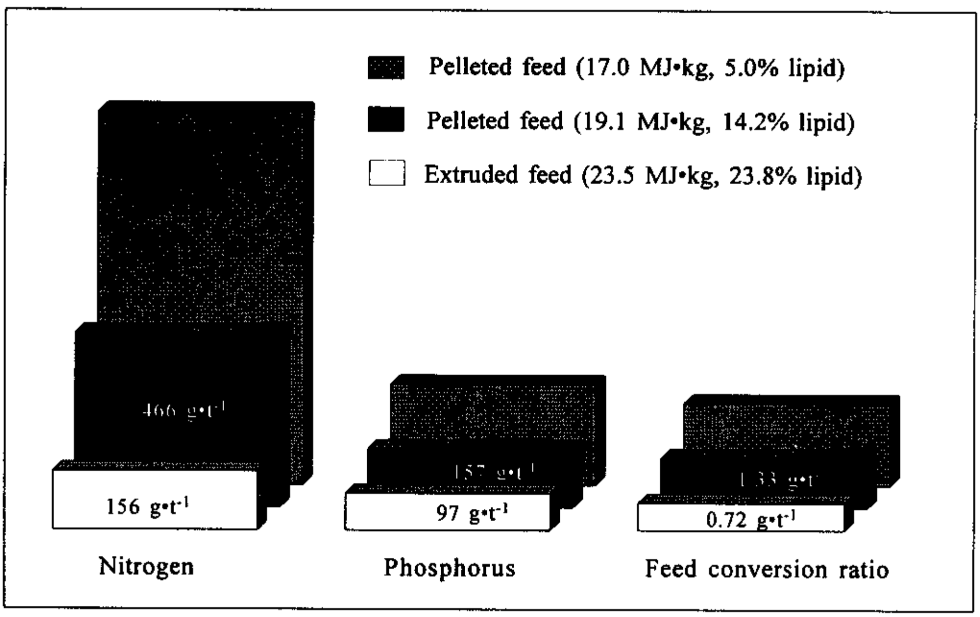

Fig. 2. Reduction of daily nitrogen and phosphorus loading rates from trout culture due to improvements in diet formulation in Eastern Germany (Rennert 1995).

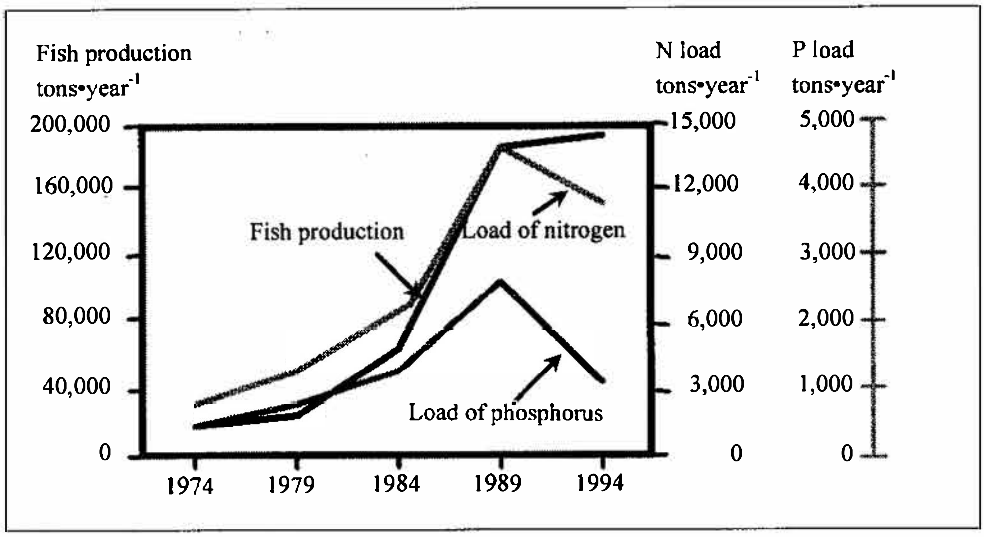

Fig. 3. The development of aquaculture production in Northern European countries from 1974-1994, in comparison with the loads of nitrogen and phosphorus caused by the farming activities (Enell and Ackefors 1992).

farm were removed by using a sedimentation pond. However, in the study of Hennessy (1991), settling ponds were inefficient. This underlines the importance of frequent sludge removal.

Compared to settling ponds, the use of lamella separators saves space, and these facilities can operate efficiently (Meylahn 1983).

Swirl concentrators which induce a fast spiral flow proved worthwhile in Scandinavian salmonid farms. Reduction of phosphorus loading was 10-60% and 40% on average (Mäkinen 1985).

The use of microsieves seems to be a useful method to treat fish farm effluents. The removal efficiency of microsieves depends on effluent concentration, particle-size distribution of the effluents, and mesh size of the screen (Bergheim et al. 1993). The main types of microsieves are the chain-type rotary screen (band filter), the triangle filter, the rotating drum microsieve, and the rotary filter. Mesh size can vary between 60 and 350 mm. Some results on removal efficiency of microsieves are shown in Table 6. Michelsen (1991) reported the following according to Norwegian and Swedish experience: 70-80% reduction of suspended solids, 60-70% reduction of phosphorus, 60-80% reduction of BOD (5) and 25% reduction of nitrogen. The resulting sludge can be dewatered and used as fertilizer.

The Use of Recirculation Systems

The most reliable way to minimize fish farm discharge and, therefore, to protect the environment is driving a recirculation system. This technique enables the fish farmer to reduce waste output to 3-4% of total waste produced (Heinsbroek and Kamstra 1990). In addition, recirculation systems contribute

Table 6. Removal efficiency for suspended solids and total phosphorus in mechanical effluent treatment using several types of microsieves.

Reduction of suspended matter (%)	Reduction of total P (%)	Type of microsieve	Author
Not determined	40-80	Triangle filter	Mäkinen et al. 1988
17-64	32-40	Triangle filter	Hennessy 1991
68	63	Rotary filter	Bergheim et al. 1993
70	17	Band filter	Fladung 1993

to saving water and energy. This is especially important for warmwater recirculation systems.

However, compared to conventional flow-through farms, recirculation systems need further improvement and require higher investment and operating costs and well trained management. They are profitable for rearing high-quality fish or other aquatic animals that can be sold at high prices.

In a recirculation system, water is, after use in the rearing tanks, not only treated mechanically by settling or sieving to remove suspended solids, but also treated biologically to eliminate ammonia, and aerated so that it can be reused for fish culture.

The biological treatment of aquaculture wastewater is based on the oxidation of ammonia to nitrate by nitrifying bacteria (*Nitrosomonas, Nitrobacter*). Because pH is lowered during this process, nitrification has to be completed by denitrification at anaerobic conditions. Different fixed film reactors for the removal of ammonia by nitrifying bacteria may be used: trickling filters, biodrums or submerged filters.

Since nitrate is a significant plant nutrient, fish culture in recirculation systems can be combined successfully with production of vegetables in greenhouses (Rennert 1992). On average, discharge from fish production can meet the following requirements of plants: 16% of the nitrogen requirement, 14% of the phosphorus requirement and 12% of the potassium requirement. Vegetables produced were tomatoes and cucumbers. In addition, this combination is water- and energy-sparing and denitrification is not necessary.

Environmental Regulations

Amidst a clamor to protect the environment and to promote sustainable aquaculture, there is growing interest in effluent control and monitoring as well as in regulations of the environmental impact of fish farming in numerous countries (Rosenthal et al. 1993). For example, in Denmark, emission standards limit values for the increase in concentrations of BOD5, suspended matter, total phosphorus, ammonium nitrogen and total nitrogen. Since 1992, high energy feed must be used in Danish trout farms having a gross energy level of

> 25 MJ•kg^{-1} and a phosphorus content < 1.0%. Feed conversion ratio may not exceed 1.0 (Jensen 1991).

Conclusions

Further development of aquaculture requires the reduction of waste discharged into the environment. An effective method to minimize water pollution is the improvement of diet formulation which enables better feed utilization. This must be accompanied by careful feeding (daily feed ration, feeding time, feeding frequency) taking account of environmental conditions (water temperature, oxygen content). In addition, effluents from land-based fish farms can be treated efficiently by settling or sieving for removal of suspended solids. The resulting sludge may be used as fertilizer after dewatering. The lowest environmental load from aquaculture is achieved by rearing fish in closed recirculation systems. However, at present, this technique is cost-intensive and needs to be improved.

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Manuscript received 10 January 1996; accepted 19 February 1997.