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SUMMARY - With increasing environmental awareness, more effort is being devoted to minimising the impact of aquaculture. Feed is the biggest source of nutrient loading to the environment in fish production. The impact of aquaculture feeds in the aquatic environment can be minimised by feeding better, more environmentally friendly diets, and by a sound farm management. Feeds are being continuously improved to increase its digestibility, reduce the feed conversion ratio (FCR) of the cultured fish, and reduce the total nitrogen and phosphorus content of the feeds. Optimum feeding strategies allow to make the best possible use of these feeds, minimising feed waste and nitrogen and phosphorus excretion. All these measures not only contribute to a cleaner environment, but also to the overall health and productivity of the farm.

Key words: Aquaculture, fish farming, feeds, environment, eutrophication, nutrition.

***RESUME** - "Les aliments pour l'aquaculture et l'environnement". La défense de l'environnement devient de plus en plus importante et donc il faut consacrer plus d'efforts à ce problème. En général, la nourriture est la source la plus importante de pollution en aquaculture. Cette pollution peut être diminuée par une meilleure utilisation de l'aliment, et la mise au point de formules moins polluantes. La nourriture pour les poissons devient de plus en plus digestible, et elle a amélioré la croissance et l'indece de consommation. Elle présente également une moindre quantité de substances azotées et de phosphates. L'optimisation de la nourriture aide à ne pas gaspiller l'aliment et aussi à réduire les rejets de phosphates et azotés. Tous ces aspects contribuent non seulement à la défense de l'environnement mais encore ils améliorent la santé et optimisent la production des piscicultures*

***Mots-clés** : Aquaculture, nourriture, environnement, eutrophisation, nutrition.*

Introduction

As the world population increases, the demand for high protein foods will gradually rise. This demand is not likely to be covered by livestock production, and with a total world fisheries stabilised or declining, aquaculture is bound to be a major source of quality protein for human consumption. The intensification and expansion of aquatic production will mean an increased pressure on the environment, due to wastes from aquaculture farms, in the form of nutrients (mainly ammonia and phosphorus) and suspended solids that create an oxygen demand in the receiving waters. These nutrients can cause the eutrophication of coastal and inland waters, that is, the increase in the rate of supply of organic matter to an ecosystem (Nixon, 1995) with the associated risk of red tides, algal blooms and a general bad environment, besides other modifications in the wildlife surrounding the farms. This impact is in turn bad for the industry, both in terms of water quality, and public opinion about aquaculture.

In the Mediterranean, where large human populations concentrate around a largely closed sea, we should pay special attention to the environment. In this region (not including northern Europe, including north Africa) aquaculture production is close to 1 million metric tones (MT) per year (1996 estimate). That is about 5% of the world total. About one third of aquaculture production in the Mediterranean corresponds to finfish, most of which is cultured intensively or semi-intensively using complete diets. Assuming a mean FCR of 2.0 for the cultured species, and that about 80 % of the cultured fish are produced intensively or semi-intensively, total feed used in the Mediterranean should be nearly 500,000 MT per year. If the predictions are correct, cultured fish production in the region could double in the next five years, meaning that the consumption of aquaculture feeds could reach a level of 1 million MT. per year. This increased input of nutrients could have an adverse effect on the aquatic environment. The effects of fish feeds on the environment, and possible solutions, are discussed in the coming sections.

Environmental impact of aquaculture

Intensive fish farming either in cages or on land produces moderate amounts of wastes that are loaded to the environment. Feeds are the main nutrient input in an intensive aquaculture operation. Feed consumed by fish will in part be assimilated. The fish will excrete some of the nutrients (mainly ammonia) through the gills, and through the faeces and urine. The main products released to the natural waters are solids, and nutrients such as phosphorus and nitrogen. Most of the solids produced from uneaten feeds and faeces, settle to the sediment near the farm, and may have a strong impact in the area near the farm. However, the impact of these sediments is very localised, and it is limited to the surroundings of the farm. Some of the effects of these sediments are the flux of ammonia and phosphates to the overlying water layer, and changes in the structure of the benthic population. The amount of solids generated by a fish farm, as well as the nutrient load, can be estimated by data of feeding rates, feed conversion ratios, nitrogen and phosphorus content of the diets used, and digestibility of the diets.

Figure 1 shows the flux of nutrients through a gilthead sea bream farm. To produce 1 ton of fish, 1800 kg of feed are needed (for a FCR of 1.8). For a 47% protein diet with 1% phosphorus content, this means an input of 18 kg phosphorus and 135.4 kg nitrogen with the diets. Of this, 5 kg of phosphorus and 30 kg nitrogen will be retained by the fish for growth. The rest will be loaded to the environment, resulting in a total release of 180 kg of solids, 13 kg phosphorus and 105.4 kg nitrogen.

Figure 2 shows schematically the nitrogen cycle in nature. Nitrogen is excreted by higher animals in the form of ammonia and urea. Nitrifying bacteria transform ammonia and urea into nitrites and nitrates, which are not as toxic to fish, and are easily assimilated by plants and algae for autotrophic growth. Nitrogen fixing bacteria can also take atmospheric nitrogen and fix it as organic nitrogen.

Excess of nutrients in the water induce the growth of both macro and micro-algae, some of which are toxic to fish and may develop massively (red tides). In 1994 a red tide of long duration killed wild and cultured fish in Uwajima Bay, Japan, worth 800 million yen (Koizumi *et al.*, 1995). The death of fish was mainly attributable to the anoxic waters with high sulphide and ammonia concentrations caused by the decomposition of the algae. Ammonia itself is toxic in its non-ionised form, and it can cause retarded growth and bad health if the concentrations in tanks and ponds are high. Larvae are specially sensitive to ammonia (Guillen *et al.* 1993) and special care should be taken in hatcheries. At high pH and high temperature, most of the ammonia is in its unionised form. These are the typical conditions of sea water in the Mediterranean.

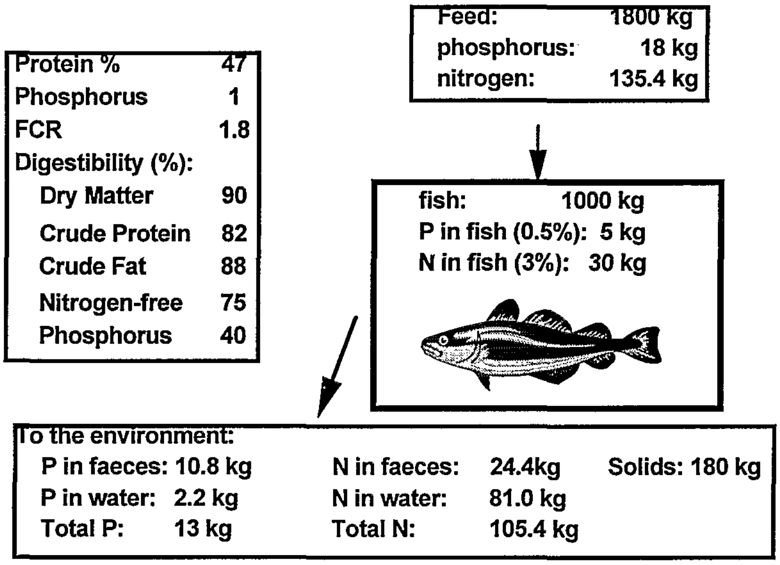

Fig. 1. Characteristics of Ewos extruded bream diets, and nutrient loading (Kg) per tonne of fish produced.

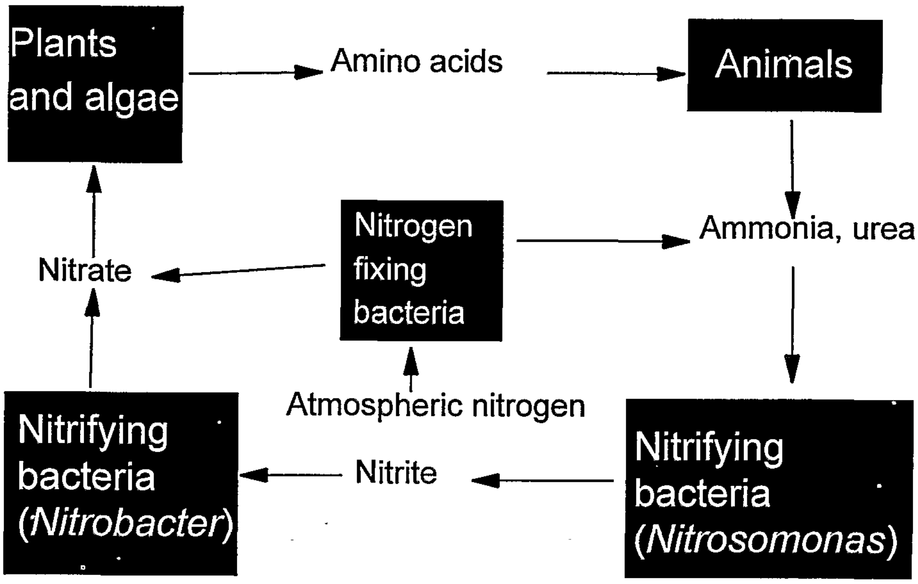

Fig. 2. The nitrogen cycle.

Solids generated from the faeces and uneaten feeds settle near the aquaculture operation (bottom of cages or ponds) and causes anoxic sediments. The impact of solid sediments is very localised (limited to the vicinity of the farm). These sediments, when disturbed, release sulphurous compounds that can cause a bad water quality to the fish. The benthic communities in the vicinity of a fish farm are greatly affected by the sediments. The number of species in the benthos diminishes, and the more opportunistic species of invertebrates dominate over the others. Similarly, there is an increase in the fish stocks associated with an increase in the primary production, but highly eutrophic water bodies tend to have dominant populations of rough fish such as carp (Lee *et al.*, 1991). Wild fish inturn are usually attracted to aquaculture cages in great numbers, enhancing the local population of coastal fishes.

Baden *et al.*, (1990) studied the effects of eutrophication on benthic communities in Sweden. There were changes in the macrophyte species from *Fucus* spp. to filamentous green algae. When oxygen saturation in the sediments declined below 40%, fish disappeared and lobsters emerged from their burrows. Below 15% oxygen saturation, lobsters were immobilised and benthic infaunal species emerged from the sediments. Lobsters died when oxygen saturation dropped to 10%, while many infauna species tolerated levels of 7-5% for several weeks. Subsequent to the re-oxygenation of the bottom sediments during the winter, flatfish and benthic infauna recovered, while cod and lobster populations did not.

The total fish catches in the Baltic Sea (dominated by herring, sprat and cod) has doubled in the last 25 years. This increase in mainly due to an increase in fishing effort, but also possibly due to eutrophication and its associated increase in primary productivity (Hansson and Rudstam, 1990). Eutrophication in lakes has negative effects on natural populations of salmonids, while percids and cyprinids benefit. The negative impact on salmonids is explained by the decrease in oxygen concentration in the deeper, cooler waters preferred by these species.

Medicated feeds have been used in aquaculture during episodes of infection in hatcheries and farms. Some of the drugs used to fight microbes and parasites are not very stable in water, and are readily decomposed to simple compounds. However, some antibiotics (e.g. malachite green, oxytetracycline) and parasitecides (e.g. dichlorvos, used to fight the salmon lice) are very stable in water, remaining in the sediments near aquaculture sites for long periods. This is a cause of great concern, since strains of bacteria could become resistant to these substances. Besides, crossed resistance with related drugs could develop, making a strain of bacteria very resistant to a wide range of drugs. Only drugs approved for aquaculture should be used, and these only in acute episodes, and not as a routine treatment. In a recent study, Vaughan *et al.* (1996) demonstrated that resistance to oxytetracycline in the effluents of salmon farms was obvious even in farms that had not used any oxytetracycline for three years. In laboratory tests, the same authors demonstrated that in the presence of anaerobically decomposing fish feeds, oxytetracycline resistant strains developed rapidly from 1 to 25%. In similar laboratory conditions without decomposing fish feeds, the frequency of resistance remained below 1%. These results suggest that high resistance to oxytetracycline may be encountered in areas near the farm where uneaten feeds accumulate.

Table 1 shows the nitrogen and phosphorus loading to the environment in the Baltic

Sea in 1989. When total nitrogen and phosphorus loading in the environment are considered, the impact of aquaculture is very low, compared to other human and natural activities. In 1989, less than 1% of the nitrogen and 3.6% of the phosphorus loaded into the Baltic Sea was estimated to have have been due to aquaculture. Agriculture was the main nitrogen contributor, while urban wastes were the first contributors of phosphorus to the environment. In the Mediterranean, where aquaculture is not as developed as in the Baltic, and where a larger human population lives, the impact of aquaculture in the environment is even lower compared to other human and natural activities.

Table 1. Nitrogen and phosphorus loading in the Baltic Sea in 1989 (modified from Enell and Ackefors, 1992)

Source of nutrient	Nitrogen (Tonnes)	Nitrogen (% of total)	Phosphorus (Tonnes)	Phosphorus (% of total)
Agriculture	607800.00	39.50	12800.00	19.50
Forestry	87600.00	5.70	3600.00	5.50
Urban wastes	214600.00	13.90	33700.00	51.20
Industries	32900.00	2.10	6600.00	10.00
Aquaculture	14200.00	0.90	2400.00	3.60
Atmospheric deposition in the sea	448000.00	29.10	6700.00	10.20
Nitrogen fixation	134000.00	8.70	----------	--------------
Total	1539100.00	100.00	65800.00	100.00

Ways to reduce the environmental impact of aquaculture

There are a number of measures that we can take to minimise the environmental impact of aquaculture:

Management and design

Site selection

The selection of an appropriate site for a fish farm is of vital importance. Wu *et al.* (1994) compared the impact of marine fish farming in relation to the hydrographic and culture conditions. The main impact was identified in the sediments near the farm, where anoxic conditions developed, with the production of hydrogen sulphide and a decrease or elimination of benthic life. In the water column, the impact was very related to the site conditions. A decrease in dissolved oxygen was observed in all sites, while increases in ammonia, phosphorous, nitrate and nitrite were observed only at sites with poor water circulation and high stocking densities.

In the site selection process we must first of all know what is the background level of nutrients in the body of water were we intend to culture fish or shellfish. Then we can calculate how much additional nutrients that body of water can take without a negative effect on the aquatic environment. A good knowledge of the physical conditions of the site is needed in order to calculate how the additional load of nutrients will be dispersed and/or assimilated by other organisms. From these data, we can calculate the optimum farm size for a given site and species to be cultured. As a guideline, total phosphorus in water should be lower than 0.02 mg/l, and nitrogen as unionised ammonia should be lower than 0.1 mg/l for intensive culture conditions of most fish.

Farm and factory design

Regarding the environmental effect of the process of fish feed production itself, the main impact is the production of odour and emission of sulphur dioxide. Several measures have been taken to minimise this impact. Ewos' fish feed plants introduced multi-stage chemical scrubbers for odour removal in 1988-90. Even though odour is not a recognised pollutant, and its environmental impact is minimum, the inconvenience caused to people in the area near the plants justify its removal. Odour removal using the new biofilters and bioscrubbers is based on the digestive action of microbes in the filter bed and circulating washing liquor. Strong chemicals such as caustic soda and sulphuric acid are not required, thus reducing the impact of the process on the environment. Dust released during raw material unloading is also filtered. All Ewos' plants have their own boilers for production of the necessary heat and steam. In order to reduce sulphur dioxide emissions, the Canadian and Danish plants burn natural gas, and the Norwegian plant uses low-sulphur fuel oil.

The packaging of the feeds is other of the main sources of pollution in a feed plant. Our plants are now using polyethylene (PE) as packaging material. This material can be reused, recycled, or burned for energy production. The environmental impact of used packages is also being reduced by more bulk feed deliveries.

Water depuration and recirculating systems

Once our farm is in operation, we can reduce the impact of pollution by using bio-filters, in order to reduce the organic load to the environment. In land-based farms and hatcheries, primary and secondary water treatment previous to its disposal, and recirculation systems, can greatly help to reduce water pollution. In a recent paper, Rijn (1996) reviewed the biological treatment systems available in recirculating fish culture. Most treatment systems used currently are based on solid removal and nitrification. Solid removal can be achieved by sedimentation or mechanical filtration. Mechanical filters of several designs are commercially available, with mesh sizes from 40 µm to more than 100 µm depending on the amount of solids that we need to remove and the volume of water that we have to treat daily. It is very difficult to remove all the solids and some solids could accumulate in a recirculating system. Nitrification can be done using a variety of biofilters. The ideal material for these biofilters should have a high surface/ volume, be cheap, durable, not clog and promote a uniform spread of the water. Nitrifying bacteria transform ammonia into nitrites and nitrates, that can in turn be assimilated by plants (hydroponic culture), macroalgae or molluscs. This "green" approach has obvious ecological advantages besides producing an additional crop of high value products. In the future, further integration of aquaculture and agriculture at commercial scale is desirable both in economic and ecological terms.

Integrated aquaculture and polyculture

The practice of integrated systems of aquaculture and livestock production have existed in China for more than 1000 years. In these systems, the "wastes" from livestock production are the input to the aquaculture system. The food web of a pond system is stimulated by nutrients, and various levels of consumers and decomposers recycle the nutrients, with virtually zero emissions to the environment. Integrated open-sea aquaculture systems have been proposed, in which mussels and salmonids are cultured nearby. Besides reducing the load of nutrients to the environment, the production of both salmon and salmon food in the same place means that the nutrients are being recirculated rather than added to the environment (Folke and Kautsky, 1992).

Law

In some countries there are already regulations about the total amount of feed that can be used in a site, the total phosphorus allowed in a feed, or the nutrient levels in waste water. Denmark has one of the most strict environmental regulations in the world. Table 2 shows the requirements to be fulfilled by fish feeds by 1992 and later. Table 3 shows the emission standards of aquaculture waste water in Denmark. In Spain, BOD_5 of waste water from aquaculture must be <10 mg/l. Suspended solids can only be increased by 20% of the level existing in the area. The temperature of waste water can only increase by 3 °C from its natural value. As environmental awareness increases, these regulations will probably become more widespread throughout the Mediterranean.

Table 2. Environmental regulations to be fulfilled by fish feeds in Denmark (modified from Jensen, 1991)

Parameter	1989	1990-91	1992-
Feed Conversion Ratio	1.20	1.10	1.00
Gross energy content (Mj/Kg)	> 23	> 24	> 25
Metabolizable energy	> 70%	> 74%	> 78%
Nitrogen content	< 9%	< 9%	< 8%
Phosphorus content	< 1.1%	< 1.1%	< 1.0%
Dust content	< 1%	< 1%	< 1%

Biological alternatives to drugs

As discussed before, pathogenic episodes can appear in any fish farm. There are alternatives to the use of drugs in fish feeds. Recent research shows that probiotics (non-pathogenic opportunistic bacteria) could be used in aquaculture operations to replace pathogenic species. Parasites can be controlled by the use of "live parasitecides": for example, some species of wrasse are currently cultured together with Atlantic salmon; these small fish preying on the ectoparasites such as the sea lice infecting the skin of the salmon.

Table 3. Emission standards of Aquaculture waste water in Denmark (modified from Jensen, 1991)

Parameter	Maximum increase in concentration (mg/L)
BOD_5	1.00
Suspended solids	3.00
Total phosphorus	0.05
Ammonia nitrogen	0.40
Total nitrogen	0.60

Farm management

Improved knowledge on feeding strategy has also helped to improve diet utilisation and reduce the FCR and wasted feed, reducing the environmental impact of fish production. Figure 3 shows the results of a trial with rainbow trout fed at different feeding levels. When you feed a very low ration, the fish do not grow much since all the energy is being utilised for maintenance. Both FCR and nitrogen excretion are high at these low feeding levels. If you feed a ration that is too high, more feed is wasted, and feed utilisation is reduced. There is an optimum area (quite wide) in which SGR is maximum and at the same time the FCR and nitrogen loading are low. This area (feeding rate 70 to 130% of the recommended level) is optimal both from the economic point of view (minimising feed cost and getting the fish to the market as soon as possible), and from the environmental point of view (low nitrogen loading). We at Ewos recommend feeding at a level of 110-130% of our model in order to increase growth while keeping low the FCR and nitrogen excretion. A slight over feeding will be highly compensated by a reduction in the crop cycle.

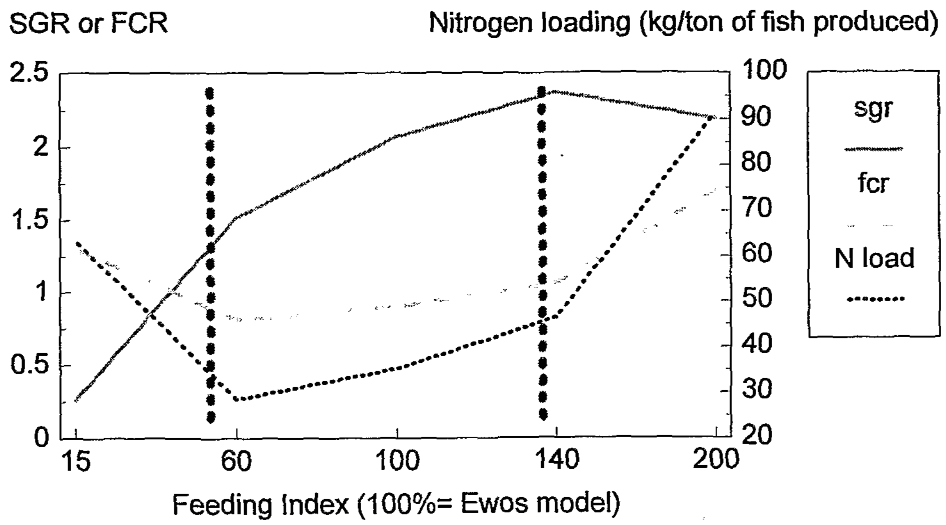

Fig. 3. SGR, FCR and nitrogen load to the environment by rainbow trout fed at several levels.

Care must be taken not to waste feed. Some feed waste is unavoidable, but we can minimise this waste, thus reducing FCR and pollution. One way to reduce waste is to use one of the currently available equipment for feeding control. These are sophisticated computer-controlled systems that detect the sinking feed particles as they pass through a sensor near the bottom of the cage. Feeding is automatically stopped at this time, and feeding rate is recalculated by the system control. In this way, almost no feed goes out of the cage. This method is good in sheltered places where currents are very slow and feed particles sink almost vertically. In sites with stronger currents, many particles will inevitably drift and go out of the cage. It is advisable to feed throwing the feeds near the centre of the cages, in order to minimise the amount of feed that escapes out of the cages.

A good way to assess how much feed is wasted is to regularly sample wild fish around the cages, and examine the stomach contents. If they are full of feeds we are probably wasting too much feed.

Another way to minimise pollution, and at the same time reduce the FCR and minimise the risk of pathogenic infections is to collect uneaten feeds and dead fish from the bottom of the cages through a lift-up system. In this system, the net in the bottom of the cages has a very small mesh, retaining all uneaten feeds and dead fish. These are taken to the surface through an air-lift pipe connected to the bottom of the cage. In this way, pollution is reduced, and feeding rates can be adjusted to the appropriate level.

In earth ponds, much feed is wasted just because some fish are in another part of the pond at the time of feeding (some ponds are several hectares in area). A possible solution is the use of sounds and condition the fish to eat when they hear this sound. This concept is currently applied in ocean-ranching, and could be a useful tool for farm management in earth ponds.

Feeding frequency (number of meals per day) and feeding time is also important. More feed will be consumed and better utilised if the fish are fed at the times of the day when they are more active.

FarmControl, a farm management computer programme recently developed by Ewos, is currently used as a tool in many commercial farms. The knowledge gained from these data will in short help to further increase the efficiency of fish feeds.

Diets

Regarding feeds and feeding, the pollution caused by aqua-farms in the early years of aquaculture was very high, due to the use of trash fish and moist pellets, with very low water stability, high FCR, and high nitrogen and phosphorus contents.

Over the years, leading fish feed manufacturers like EWOS have been continuously improving its feeds and feeding strategies to reduce the environmental impact of aquaculture. This has been achieved through a number of measures:

Lowering nitrogen and phosphorus content of feeds

Total and available dietary phosphorous and nitrogen levels have decreased, to reduce the load of these nutrients into the environment. In two decades, phosphorus released to the aquatic environment per ton of trout produced has been reduced by 75% (Fig. 4), and nitrogen released has been reduced by 50% (Fig. 5). This has been achieved by reducing phosphorus and nitrogen in the feeds, and mainly by using more digestible raw materials and reducing the FCR.

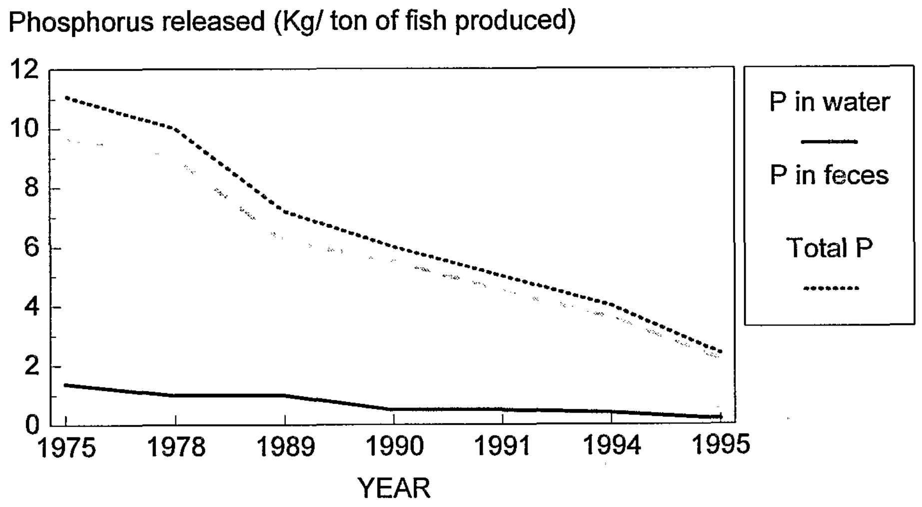

Fig. 4. Phosphorus load released into the environment (Kg per ton of trout produced) using Ewos diets.

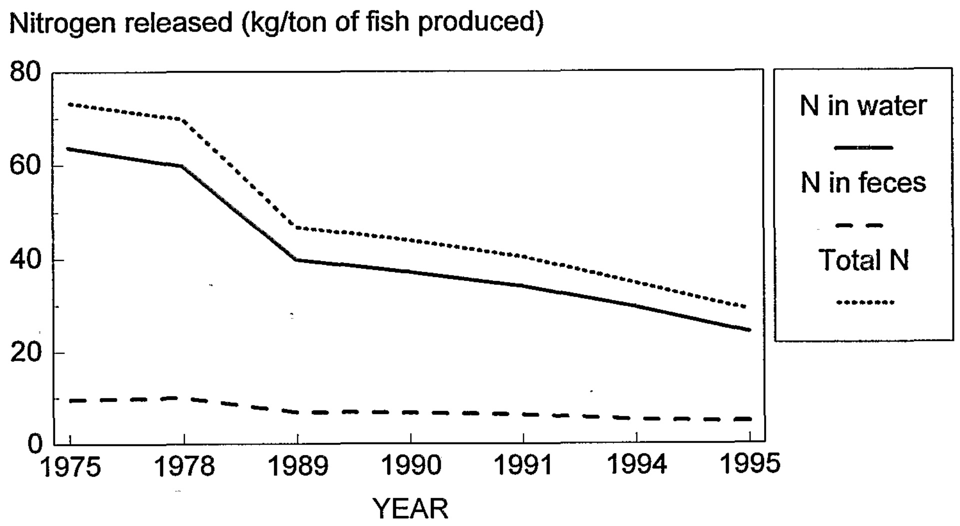

Fig. 5. Nitrogen load released into the environment (Kg per ton of trout produced) using Ewos diets.

Reducing FCR

High quality diets, with a low FCR help to minimise water pollution by knowledge of nutritional requirements, palatability (reduced wastes), and improved digestibility of raw materials. Raw materials are being selected for adequate nutrient profile, digestibility and biological value. This will produce a better growth and lower nitrogen and phosphorus loading to the environment. Palatability and absence of antinutrients in raw materials also help to reduce feed waste and hence water pollution. The FCR of salmon feeds has been reduced in the last two decades by more than 50% (Fig. 6). As a consequence of this and an improved diet utilisation due to the use of more digestible feeds, the discharge of solids has been dramatically reduced (Fig. 7) by about 80%.

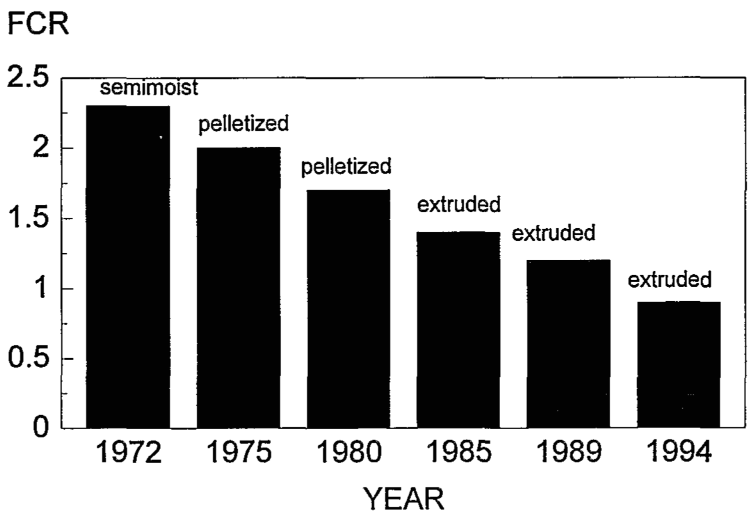

Fig. 6. Feed Conversion Ratios of salmon feeds in Norway.

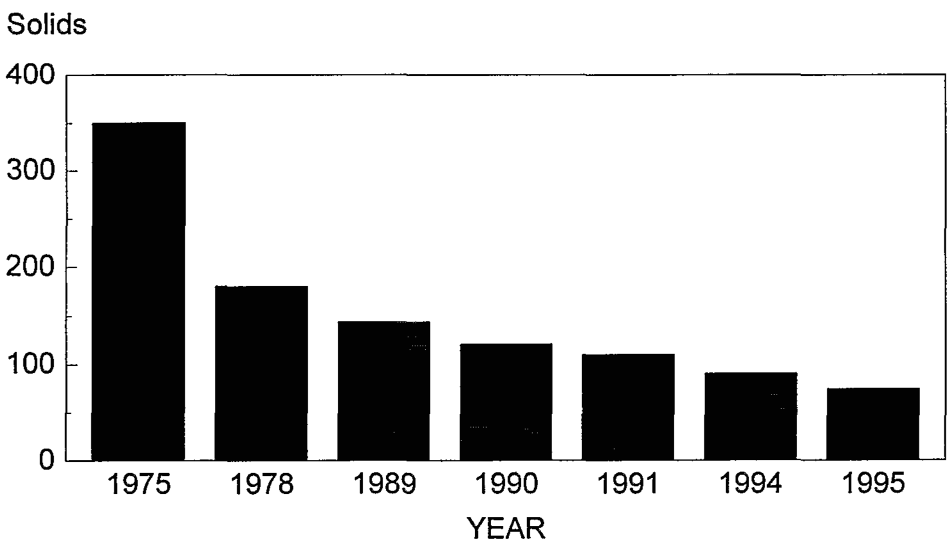

Fig. 7. Sludge (solids) released into the environment (Kg/ ton of trout produced) using Ewos diets.

Use of enzymes in the feeds

Current research shows that the use of enzymes in feeds allows a better utilisation of vegetable proteins such as soya (Carter *et al.*, 1994). In the future this will allow us to use a higher percentage of vegetable proteins in fish feeds, that at the same time have a lower phosphorus content, reducing both phosphorus and nitrogen loading.

Extrusion technology

Extrusion technology has made possible many improvements in feed performance, by increasing the energy levels in the diet through higher fish oil inclusion and improved starch digestibility, by destroying anti-nutrients and potential pathogens and by improving physical properties of the diet. Water stability has been improved while the production of dust from the feeds in now minimal. The utilisation of vegetable proteins is also enhanced by extrusion, reducing the impact of the feeds on the environment.

Reduce N excretion by optimising amino acid profile in diet

The excretion of ammonia increases in diets deficient in some amino acid. If the dietary requirement of one single amino acid (e.g. methionine) is not covered by the feed, the utilisation of the other amino acids (that are in excess compared to the deficient amino acid) will be reduced. The fish will use these amino acids as a source of energy, and excrete ammonia as an end product (Fig. 8). The excretion of ammonia is lower if the amino acid deficiency is not very severe, and it is minimum if there is no amino acid deficiency in the diet.

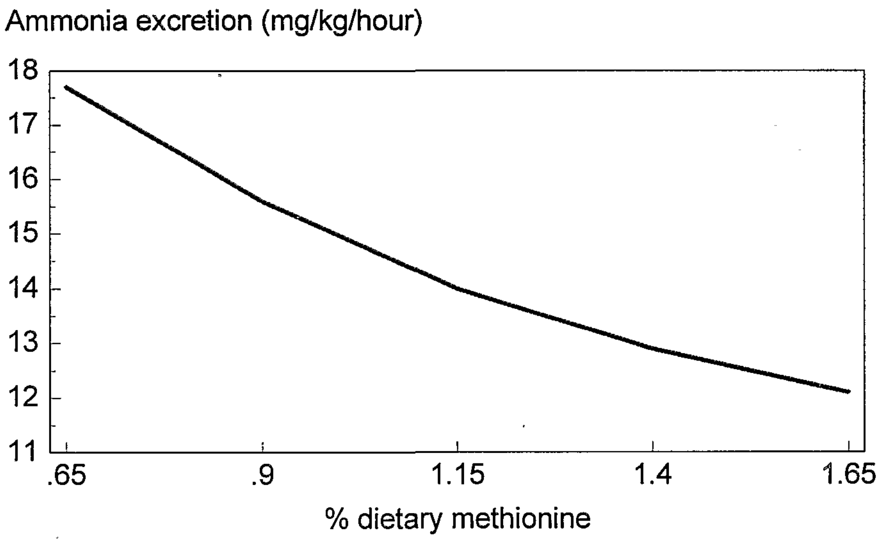

Fig. 8. Ammonia excretion by sea bream, *Sparus aurata* fed a diet with several levels of methionine (modified from Sierra *et al.*, 1995).

Optimise P/E for optimum growth and minimum nitrogen excretion

Fish use part of the dietary protein as an energy source, excreting ammonia as an end product. When high fat diets are used, a larger portion of the energy comes from the fat, and more protein is used for growth, reducing ammonia excretion and maximising growth and feed efficiency. In the last two decades, fish feeds have changed a lot in terms of protein and energy levels (Fig. 9). Feeds now contain a high energy/protein ratio to spare protein and reduce N-NH_3 excretion.

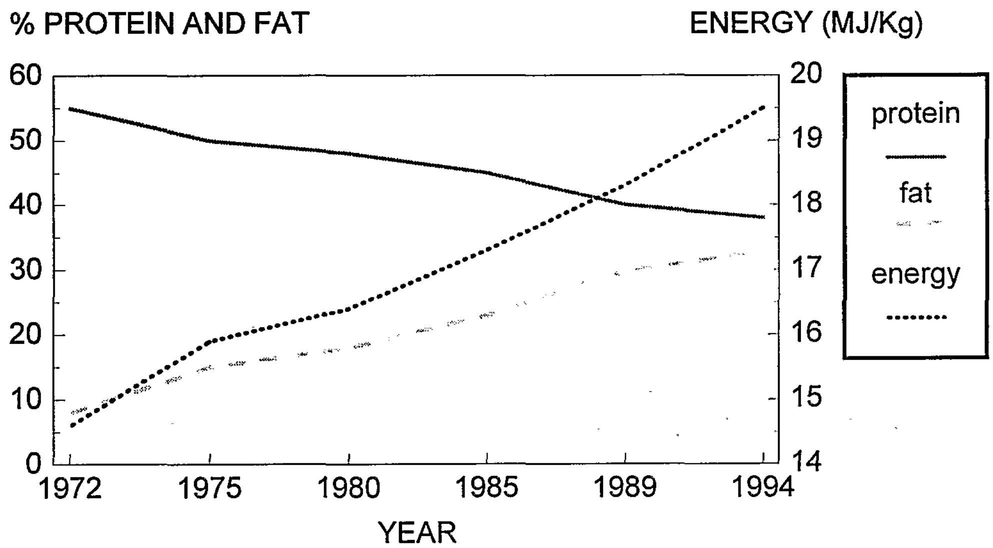

Fig. 9. Protein, fat, and total energy contents of Salmon feeds in Norway.

Table 4 shows the main feed characteristics in selected European countries. As shown before, the general trend is an increase in the use of high energy feeds and a gradual replacement of pelletized feeds by extruded feeds.

Table 4. Main feed characteristics in selected European countries

Country	Norway		Denmark	Greece	
Fish species	Salmon		Trout	Seabass and Seabream	
Market size	4-5 Kg		250-300 g	400-800 g	
Feed type	Extruded High energy	Extruded Standard	Extruded High energy	Pelletized	Extruded
Crude protein (%)	38	40	45.00	44-48	45-50
Crude Fat (%)	33	30	30.00	11-17	12-20
Phosphorous (%)	0.9	0.9	0.90	1.2	1.2
Average FCR*	1.2	1.3	0.90	2.5	1.8-2.0

* Average FCR= representative FCR for the industry. On specific farms and for certain crops, FCR may be lower.

Conclusions

In a global scale, and compared to other human, agricultural and industrial activities, aquaculture does not have a very important impact in total release of nutrients into the environment. The impact of aquaculture is very localised to the vicinity of the farms. This small impact could be further reduced by optimising feeds and feeding strategies. In the future, it is expected that the aquaculture industry in the Mediterranean will turn into the more efficient and more-environmentally friendly extruded feeds with high energy/protein ratios, highly digestible raw materials and low phosphorus levels. The production cost of fish and shellfish and the nutrient and sediment loads into the environment per ton of fish produced will in fact decrease due to the high performance of this new generation of feeds. This and a sound management of the aqua-farms will lead to a sustainable development of Mediterranean aquaculture through the 21st century.

References

Baden, S.P., Loo, L.-O., Pihl, L. and Rosenberg, R. (1990). Effects of eutrophication on benthic communities including fish: Swedish West Coast. *AMBIO*, 19: 113-122.

Carter, C.G., Houlihan, D.F., Buchanan, B. and Mitchell, A.I. (1994). Growth and feed utilization of seawater Atlantic salmon, *Salmo salar* L., fed a diet containing supplementary enzymes. Aquaculture and Fisheries Management, 25: 37-46.

Enell, M. and Ackefors, H. (1992). Development of Nordic production in aquaculture and nutrient discharges into adjacent sea areas. *Aquaculture Europe Magazine*, 16: 6-11.

Folke, C. and Kautsky, N. (1992). Aquaculture with its environment: prospects for sustainability. *Ocean & Coastal Management*, 17: 5-24.

Guillen, J.L., Endo, M., Turnbull, J.F, Kawatsu, H., Richards, R.H. and Aoki, T. (1993). Depressed growth rate and damage to the cartilage of red sea bream larvae associated with exposure to ammonia. *Nippon Suisan Gakkaishi*, 59: 1231-1234.

Gowen, R.J., Weston, D.P. and Ervik, A. (1991). Aquaculture and the benthic environment: a review. In *Nutritional Strategies and Aquaculture Waste*, Guelph, 1991, Cowey, C.B. and Cho, C.Y. (eds). Fish Nutrition Research Laboratory, Guelph, pp. 187-205.

Hansson, S. and Rudstam, L.G. (1990). Eutrophication in Baltic fish communities. *AMBIO*, 19, 123-130.

Jensen, J.B. (1991). Environmental regulation of fresh water fish farms in Denmark. In *Nutritional Strategies and Aquaculture Waste*, Guelph, 1991, Cowey, C.B. and Cho, C.Y. (eds). Fish Nutrition Research Laboratory, Guelph, pp. 251-262.

Koizumi, Y., Koheo, J., Matsuyama, N. Uchida, T. and Honjo, T. (1995). Environmental features and the mass mortality of fish and shellfish during the *Gonyaulax polygramma* red tide occurred in and around Uwalima Bay, Japan, in 1994. *Nippon Suisan Gakkaishi*, 62: 217-224.

Lee, G.F., Jones, P.E. and Jones, A.J. (1991). Effects of eutrophication on fisheries. *Reviews in Aquatic Sciences*, 5: 287-305.

Nixon, S.W. (1995). Coastal marine eutrophication: a definition, social causes, and future concerns. *Ophelia*, 41: 199-219.

Sierra, M.A., Hidalgo, F. and De La Higuera, M. (1995). Excrecion de amonio en dorada (*Sparus aurata*). In *Actas del V° Congreso Nacional de Acuicultura*, Barcelona, 1995, Castello i Orvay, F. and Calderer i Reig, A. (eds). Universitat de Barcelona, pp. 647-649.

van Rijn, J. (1996). The potential for integrated biological treatment systems in recirculating fish culture-A review. *Aquaculture*, 139: 181-201.

Vaughan, S., Coyne, R. and Smith, P. (1996). The critical importance of sample site in the determination of the frequency of oxytetracycline resistance in the effluent microflora of a fresh water fish farm. *Aquaculture*, 139: 47-54.

Wu, R.S.S., Lam, K.S., Mackay, D.W., Lau, T.C. and Yam, V. (1994). Impact of marine fish farming on water quality and bottom sediment: a case study in the sub-tropical environment. *Marine Environmental Research*, 38: 115-145.