

The Future of Aquaculture

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In the last 35 years the production of marine aquaculture has grown from a million tons per year to about 55 million tons [1]. Growth continues at about 10% per year and for certain species, the quantity produced by aquaculture exceeds the quantity fished. However, we know that there are bottlenecks for further development of marine aquaculture and even for its survival, at least as it is practised today. For example, in the near future it will be necessary to assess the energy balance of aquaculture: production of carnivorous species is not energy efficient and energy losses at each step in the production chain could be avoided if the primary material of feedstocks (anchovies, sardines, mackerel, ...) was consumed directly by humans and aquaculture concentrated more on herbivorous and detritivorous species.

The farming of fish in land-based and offshore fish farms has two critical aspects: the availability of protein to produce industrial feedstock and the impact of fish-farm wastewater on marine coastal areas. The most critical aspect of mollusc farming is the impact of intensive plants and the methods used to harvest from natural populations.

There are also many other problems associated with aquaculture that may be no less critical than energy consumption and environmental damage. They include introduction of allochthonous species, which may be vectors of viral and bacterial infections, major or even exaggerated use of pesticides and antibiotics (especially in the recent past) and alteration of benthic and plankton communities.

To tackle these problems, the FAO recommends an ecosystem approach to aquaculture, integrating "the activity within the wider ecosystem in such a way that it promotes sustainable development, equity, and resilience of interlinked social and ecological systems" [2].

Availability of Proteins

The protein requirements of most commercially raised fish are high, ranging from 30-55% of their diet [3]. Industrial feed is used to produce about 29 million tons of fish and prawns, and uses large quantities of fish oil and fishmeal made from wild "bluefish" (anchovies, sardines, mackerel, ...), especially for products aimed at markets of rich countries. Major production of fishmeal occurs in South America, Asia-Oceania and Europe [4]. Research conducted in the North Atlantic, an area defined as being at risk of contamination by the European Food Safety Authority (EFSA), shows that aquaculture systems often favour production of fish that are more contaminated than wild species, as in the case of European farmed salmon, and also that the degree of contamination is often due to the use of highly contaminated feedstocks [5]. European fishmeal, mainly produced in Denmark, Norway and Iceland, is among the highest in contaminants. These accumulate more in fatty species, such as salmon and eels. It is also known that farmed fish are richer in fat than wild fish.

Further development of aquaculture must therefore involve a reduction in the quantity of fish oil and fishmeal in feedstocks, because different nutritional management of farmed fish could reduce the risk of persistent organic pollutants and because replacement of these feed components would reduce the impact of overfishing on wild fish stocks. Proteins and oils of plant origin are available in large volumes. Research shows that many of these primary materials are suitable for use in feedstocks and can partly replace feedstocks containing fish oil

and fishmeal [6]. More research is needed in order to increase plant proteins, and it is necessary to overcome the resistance of many bream and sea bass farmers. Current modified feedstocks do not seem to fully meet their needs: they sustain that fish growth is not the same and that the fish are more susceptible to disease. There is nevertheless the possibility of using fish meal and oil obtained from by-products of the processing of farmed and wild fish, provided it has not been cooked at temperatures above 90°C which denatures the proteins [7]. In this case, the problem of contaminants is not completely solved, but overfishing of wild stock is mitigated.

The biofuels industry is generating protein by-products that have not yet been fully evaluated. Beyond this, algae and bioproteins derived from microorganisms can become economically competitive, also providing long-chain omega-3 fatty acids. The AQUAMAX project (sustainable aquafeeds to maximise the health benefits of farmed fish for consumers), financed by the EU and coordinated by the National Institute of Nutrition and Seafood Research (NIFES) of Norway, brought together 33 research groups from many European and extra-European countries. The aim of the project was to replace fish meal and oil in feedstocks for salmon, trout, carp, sea bass and bream as much as possible with sustainable contaminant-free alternatives (contaminants such as dioxins, PCBs and flame retardants), while maintaining the health benefits of fish consumption. An objective was to reduce fishmeal to 12-16% and fish oil to 8-12% for salmon, 5% and 5% respectively for trout, 15% and 10% respectively for sea bass and bream and 0% and 0% respectively for carp. The alternative feeds seemed to maintain flesh quality, including omega-3 content. The final assessments were conducted with children and pregnant women, in whom a significant uptake of omega-3 fats was observed.

Eutrophication

According to Pearson and Black (2001), intensive aquaculture can have environmental impact inshore and offshore [8]. Release of phosphorus is 19.6-22.4 kg/ton of product, 34-41% of which is released in dissolved form [9], while dispersal of nitrogen is 52-95% of the nitrogen in the feed [10]. In a Mediterranean land-based fish farm producing bream and sea bass, more than 80% of dissolved inorganic nitrogen in wastewater was ammonium and 86.2% of the variability of total ammonia was feed-dependent, indicating the importance of correct feeding [11]. Intensive land-based fish farms produce particulate high in organic matter (feed residues, faeces, algal detritus, etc.) which is discharged by wastewater and disperses in the final receptor

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environment, causing water turbidity in surrounding marine areas and enrichment of sediment with organic matter. This flow of organic carbon can significantly upset sediment biogeochemical processes, alter benthic communities and create conditions of anoxia. Sea grass meadows near fish farms may suffer heavy impact. Aquaculture has been the cause of widespread loss of marine phanerogams (2% per year) throughout the world [12].

Reducing impacts to a minimum is still a scientific challenge and many authors have concentrated their attention in this field [13-24]. Bivalves in land-based modules (13) or near offshore plants, where they can grow more than in the open sea, could reduce impact [22,24].

Harvesting of Molluscs

Harvesting of wild molluscs, also considered an aquacultural practice, must also be mentioned. Molluscs are increasingly harvested by mechanised methods that have a heavy impact on the substrate. This is true, for example, for the harvesting of *Solen marginatus*, *Tellina* sp., *Callista chione* and other clams, which is conducted with turbojets that aspirate and sieve vast quantities of sand, and for harvesting of the allochthonous *Tapes philippinarum* in the lagoon of Venice, which is carried out with a great variety of devices. These operations affect a deep layer of sediment for hundreds of hectares, destroying the biocoenoses present, eradicating phanerogams and preventing their establishment [25]. Measures to protect the Mediterranean coasts are being discussed at European level with a view to passing laws, still disputed and delayed, to limit harvesting and reduce impact.

Conclusions

Industrial aquaculture was invented in the 1970s. It is different from traditional aquaculture that has been carried on for millennia. It began like the conquest of the Wild West, with great passion and the desire to get rich quickly through “fish gold”. Nobody at the time thought that it could have environmental consequences.

The location of plants, stock density and feeding efficiency are all factors that must increasingly be considered in order to reduce the impact of fish farming on coastal ecosystems. Fish feed must always be managed and distributed efficiently by systems that ensure access to feed on demand, reducing waste and lowering conversion factors, obviously also to the advantage of farmers. Consumers should be educated to prefer small pelagic fish, “bluefish” and herbivores to carnivores. In the latter case, fishmeal should be replaced with plant meal as far as possible, and above all fishmeal should be obtained from by-products of fish processing. Land-based plants should have systems for lowering nutrient load, such as sedimentation ponds and primary and secondary production based on the energy load of wastewater. Offshore plants should be sufficiently far from the coast so as not to affect coastal sea grass meadows, even by nutrients borne on sea currents. Only in this way can the possibility of future sustainable production of sea proteins be contemplated. Scientific journals like the Journal of Aquaculture Research and Development can play a determinant role in the debate and in the circulation of ideas and possible solutions through open access publishing.

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