ENVIRONMENTAL IMPACT OF AQUACULTURE

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Summary

Animal rearing impacts the natural environment, as does every human activity. Major modifications induced by aquaculture are related to the basic biological processes in living animals. Major causes of impact are associated with feeding and nutritional wastes, the existence of diseases and the interbreeding of wild and selected strains. All over the world, these impacts have been described. In some cases, they have been serious.

The major reported impact is modification of the benthos and its consequences on water quality, spreading of disease and faunal modification. Site selection is the first discriminating level when the environment is concerned. Generally, when farms are properly situated and managed, environmental impacts are low and reversible. Tools are now available to reduce or avoid adverse impacts, either through prediction of holding capacities, nutritional improvement, water treatment, vaccination or integrated aquaculture. Genetic issues will have to be addressed during the forthcoming years.

1. Introduction

Aquaculture systems depend on the use of natural waters and natural food chains. As such, they are part of the environment and two-way interactions are numerous. Like food production in agriculture, aquaculture can affect the environment by modifying natural habitats, wildlife, the soil, the water, and the landscape. Furthermore, it is subject to environmental impacts from other activities. Neither is aquaculture the only activity to affect natural resources, in freshwater and marine environments, but it is the latest in a long list. The rapid development of the aquaculture industry since the late 1980s has made decision makers extremely aware that the huge demand for sites requires more environmental controls and pertinent allocation measures, in order to avoid detrimental impacts and conflicts.

Better knowledge of the actual consequences of installing new aquaculture plants, and respect for codes of good practice, are necessary to facilitate the integration of aquaculture in the coastal zone and to avoid conflicts of interest. This is of particular importance for the industry itself, because it is generally the first to suffer from any disturbance due to environmental degradation. In shrimp farming in particular, production collapses have resulted from mismanagement of natural resources. Experience from this example may help the aquaculture sector to develop tools and strategies to minimize loadings and impacts.

Awareness of environmental impact has focused mainly on animal rearing. Indeed, plants mainly have positive effects on water quality and contribute to lower water nutrient content. In consequence, we shall here consider rearing of animals, among them fish, shrimps and mollusks. To understand in which ways aquaculture may induce impacts, it is necessary to know about the biological functions involved, the production systems, and the nature of the wastes. This will be the objective of Chapters 2 and 3. The range of known impacts will be described in Chapter 4. Chapter 5 will give some indications about the ways available to reduce negative impacts.

2. Biological Basis of Fish Production

2.1. Nutritional Metabolism

Plants are primary producers (autotrophic organisms) that use light energy and inorganic compounds to grow. They incorporate soluble inorganic molecules (nitrate, phosphate) and dissolved organic matter into living organisms and they process CO_2 into O_2. In this way, they contribute to purify water.

Conversely, every animal (mollusk shrimp and fish) obtains its vital energy through feeding on complex molecules (heterotrophic organisms). These molecules are processed by the animal to gain biomass (anabolism), the remainder being transformed into heat and excretory products (catabolism). Thus, animals present qualitative nutritional requirements (proteins, lipids, carbohydrates, minerals, and vitamins) and quantitative ones, including nutrients and oxygen. All living animals produce metabolic wastes, which are a function of their requirements and the feeding level they are subject to.

Compared to terrestrial animals, aquatic animals (except marine mammals) present specific adaptations that make them different. Being cold blood, their energetic requirements can be up to ten times lower than mammals, which have to maintain their temperature at a constant level and are temperature dependant. Thus, in rainbow trout, for example, the maintenance requirement increases from 12 to 42 kJ $kg^{-0.82}d^{-1}$ at temperatures ranging from 7.5 to 20 °C, whereas the equivalent figure for a human at rest is 150.

Besides, they grow throughout their life, either continuously (fish, mollusks) or sequentially (shrimps). Their requirements vary also with age. One thousand 5 g rainbow trout need twice as much energy as a 5 kg trout to increase their biomass collectively by one kg. This is due to the different abilities of metabolizing protein and lipids. Generally speaking, fish and shrimp use protein with a better yield than other farmed animals. The protein retention efficiency is more than 30% in fish while it is only 18% in chickens and 13% in hogs. This explains why the protein content of the feed, usually provided through fishmeal, is so high in shrimp and fish culture.

Plants and bivalve mollusks belong to the two first steps of the trophic chain in the aquatic ecosystem. Bivalves are primarily herbivorous and feed on phytoplankton which contains large amounts of carbohydrates. Higher levels (shrimp, fish, aquatic mammals) are mainly carnivorous, and have a great ability to use proteins and lipids as metabolic fuels. Only a few fish species are herbivorous or omnivorous (tilapia, carp, milkfish, and mullet).

During the aquaculture process, irrespective of the species, water is the vehicle for both feed and waste. Oxygen content in water is very low (generally less than 10 g per ton) compared to air (200 kg per ton). In that sense, oxygen is very limiting in aquaculture production and the energy required to extract it from the water is higher in aquatic animals than in terrestrial ones. Its concentration can decrease very rapidly, associated with an increase in that of CO_2, a toxic molecule. The fact that all the wastes, soluble or not, are released into the water body makes them very difficult to separate. Thus, water quality degradation has a great impact on the animals, wild or not, that live in it.

There are four components of waste originating from food:

- **Uneaten feed**. This is the case during artificial feeding, generally due to bad husbandry, fish sickness or unsuitable environmental conditions.
- **Undigested feed**. This is the case, mainly, in bivalves, which do not have sufficient control of intake and repletion. Thus, they ingest more than they can process and release the intact micro algae in the form of feces called pseudo-feces.
- **Indigestible compounds**. Complex molecules in the feed are split into small molecules that either can or cannot cross the intestinal border during digestion. Those that cannot, due to their size or their spatial shape, are rejected under the form of particulate matter (feces). Table 1 gives values for some artificial feed components, of the relative proportions of nutrients potentially rejected into the environment.
- **Excreta**. Excretion is the physiological phenomenon by which molecules that came into the body and become dissolved in the plasma are released after being processed and degraded. These are soluble compounds that are discharged into the water through particular organs, such as gills. Living in the water, these animals are directly submitted to the effect of their own wastes. Figure 1 summarizes these processes.

Nutrient type	**Origin**	**Proportion (in % of intake) in Salmonid**	**Proportion (in % of intake) in Penaeid**
Protein	Blood mill drum dried	68	
	Soybean cake	15–25	5
	Beer yeast	15–18	
	Fish meals	10–20	15–20
	Fish Soluble Protein Concentrate	< 7	
Lipid	Palmitic (C16: 0) and Stéaric (C18: 0) acids	50	10–20
	Oleic acid (C18: 1)	20	10
	Linoleic (C18: 2) and Linolenic (C18: 3) acids	10	5
Carbohydrate	Potato	95	30
	Corn amylopectin	46	35
	Pre-gelatinized starch	4	5
Phosphorus	Phosphorus phytate	80	50
	Fish meals	40	40–50
	Beer yeast	10	

	Sodium monophosphate	2	32

Table 1. Fecal to ingested nutrient ratios for different nutrient origins.

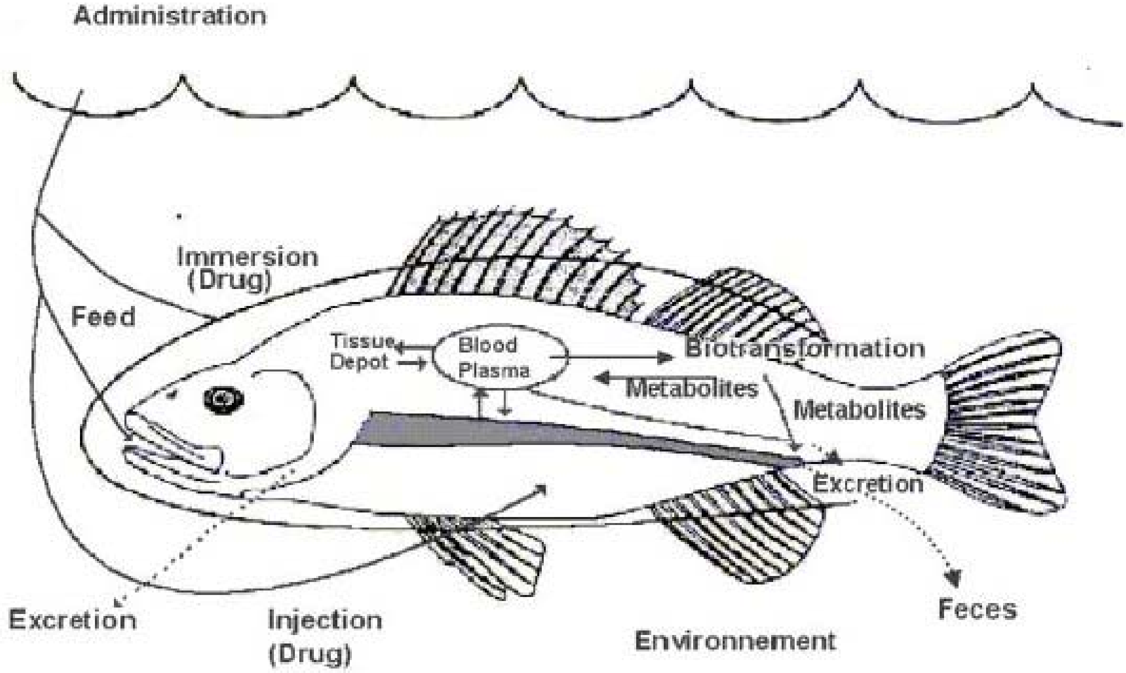

Figure 1. Metabolic processes.

2.2. Therapeutic Agents

The main diseases encountered in fish, as in terrestrial animals, are due to a range of organisms, from viruses through bacteria and fungi to metazoan parasites. Their origin is from the wild, but rearing single species at high density acts in favor of the development of disease. More, the detrimental effect of these organisms on fish depends on the environmental and, generally speaking, husbandry conditions. These infectious organisms are all (parasites) living on the fish (ectoparasites) or in the fish (endoparasites). The most common fish disease is vibriosis, due to a bacterium (*Vibrio anguillarum*). More than forty different diseases have been described solely for fish. Fish, unlike shrimp and mollusks, have a specific immune system compared to other vertebrates. So the use of vaccines is not possible for them in the same way.

To maintain their osmotic pressure, aquatic animals have to balance their water and ion contents. They present a number of pathways (skin, gills, and intestinal tract) for entrance of dissolved molecules and water. Epithelial tissues of these organs are permanently acting. The equilibrium between the fish and its environment is not stable, and needs constant adjustment through drinking and/or excretion.

To treat ectoparasites and external fungi, the only available way is the bath. According to their size and shape, some molecules can penetrate the fish, in which case some drugs (malachite green for example) can penetrate the fish body. These may have toxic effects on the fish and the consumer.

To treat internal viruses, bacteria and parasites, three ways are available: the bath, oral delivery and injection. In case of oral administration (antimicrobials for example), the fate of the drug is comparable to nutrients. Then, the pharmacokinetics follow the same principle as represented in Figure 1.

2.3. Breeding and Selection

Animals and plants are the consequences of genes and environment. Living organisms are constituted of protein—either structural (e.g. muscle, skin) or in the fluids (enzymes, hormones). These proteins are the result of gene-controlled production mechanisms and play a decisive role in all physiological events. In nature, genetic variation is important both within and between species. This basis for evolution in the wild is used for selective breeding and improvement in the farms. Useful characteristics (traits) borne by some individuals (growth, resistance to stress, sex, food utilization, age of maturity) depend on one or more genes. These individuals can be selected to pass on their ability to their descendants. This genetic progress is highly dependent on the traits and the species.

Marine fish used for aquaculture are low in the hierarchy of vertebrate animals. Their plasticity is high. Very often the chromosome number is not constant within the same species, and sex determinism is not always under strict genetic control. This allows the possibility of chromosome manipulations, as triploids and tetraploids are generally viable. Their interest lies in the fact that they are generally sterile.

Recently, direct transfer of useful genes (gene coding for growth hormone for example) has proved to be successful in fish, opening up a new era of genetic engineering in building GMOs.

3. Characterization of Discharge and Release

3.1. Metabolic Wastes

3.1.1 Digestion Products

Feces and pseudo-feces are solid particles from 5 μm to 5 mm that naturally sink at a speed of up to 4 mm s^{-1}. Their deposition on the seabed leads to organic enrichment of the sediment. In the aquatic environment, the effect of the quality of the organic matter on the benthic ecosystem is not well documented. Usually, the major driving element is the carbon load. In artificial feed, the average carbon content is 40 to 50% of dry weight, from which around 30% remain in the feces. In salmonid farming, one kg of feed (dry weight) is necessary to produce one kg of fish. Then, 100 to 200 g of feces are produced. Thus the carbon content of the feces is higher (60 to 70%) than the feed. The organic matter of these feces also contains nitrogen and phosphorus, amounting respectively to 10% and 40% of the ingested feed. In filter feeders, these proportions may reach as much as 80 and 90%. In intensive shrimp farming, 63% of the total organic matter losses, 24% of the nitrogen and 84% of the phosphorus remain in the sediment, which is a direct consequence of feces deposition. Some other feed components, such as lipids, pigments and minerals, are also loaded through this pathway. With increasing lipid content currently in salmon diets, lipid losses to the environment have been recently studied. These molecules have high carbon content and need more oxygen to be oxidized. The potential effect of starch and carbohydrate on bacterial flora (especially *Vibrio*) enhancement has been demonstrated in the laboratory, but it has not been proved that this occurs in the natural environment.

3.1.2 Excretory Products

The final degradation products of carbohydrates and lipids are excreted by the gills in the form of CO_2 (50% of the carbon losses) and H_2O, that generally have only a limited impact on the natural environment. Conversely, the end products originating from protein metabolism are more complex, inducing the release of soluble nitrogen to the water. In bivalves, ammonia represents 70% of the excreted nitrogen. It amounts to 85 to 90% in shrimp and fish. Ammonia is a toxic molecule that is excreted through the gills in fish and mollusks, and through the antennal gland in shrimp. Aquatic animals can tolerate a high concentration in blood: fish plasma concentrations can reach 4 mg l^{-1}, while a concentration of 0.4 mg l^{-1} is toxic in mammals. Ammonia excretion is under the control of nutritional status. It ranges from 300 to 1500 mg $N\text{-}NH_4$ per hour per kg of body weight in well-fed shrimp, from 20 to 200 in well-fed fish, but only 1 mg $N\text{-}NH_4$ kg^{-1} h^{-1} in filter feeders. Excretion of urea and other nitrogenous catabolites is low, except in some atypical species.

Phosphorus excretion (in the form of orthophosphate) is generally low: 10 to 20% of intake (10 to 20 $P\text{-}PO_4$ kg^{-1} d^{-1}) in fish and shrimp, and 5% in bivalves. The total discharge of phosphorus and nitrogen by a salmonid farm is estimated to be respectively 10 and 70 kg per ton of fish produced. In classical shrimp farming, these figures are respectively 25 and 100. Overall, it can be considered that respectively 40 to 45% and 2 to 5% of the nitrogen intake are retained in fish and in filter feeders.

3.2. Drug Discharge

Drug utilization is usually feasible in cases where the production process is controlled. Hatcheries present a sufficient degree of control, in both shellfish and fish culture, to enable the treatment by bath. During the growing-on phase, no treatment is feasible when extensive rearing procedures are being used. When the whole process is under control, treatments proceed by bath or oral delivery. Where baths are used, the drug is generally released to the environment. This is also possible for vaccines. Injection is rarely carried out, due to the large number of individuals reared in aquatic farms. It is generally used only on breeders.

A wide range of drugs is used in aquaculture, although fewer than in human medicine. The drugs generally have not been developed specifically for aquatic species, and their efficiency in cold-blooded animals and their impact on the environment have not been optimized. Table 2 summarizes the major drugs used in aquaculture.

Drug type	Name	Indication	Administration	Medication
Antibacterial	Sulphonamides	Bacterial infection	Oral	30–50 mg kg^{-1} j^{-1}
	Tetracyclines	Bacterial infection	Oral/bath/injection	50–100 mg kg^{-1} j^{-1}

	Quinolons	Bacterial infection	Oral	10 mg kg^{-1} j^{-1}
	Nitrofurans	Bacterial infection	Oral	
	Macro lids	Bacterial infection (Gram +)	Oral	50–100 mg kg^{-1} j^{-1}
Antiparasite	Organo-phosphates	Sea lice	Bath	0.5–2.0 mg l^{-1}
	Anthelmintics	Cestode	Oral	
Antiseptic	Formalin	External ailment (protozoan)	Bath	130–200 ml m^{-3}
	Malachite green	External ailment (fungi)	Bath	1–2 mg l^{-1}
	Chloramine	External ailment (bacteria)	Bath	2–15 mg l^{-1}

Table 2. Major chemotherapeutic agents used in aquaculture.

Name	Distributed	Released with the feed (Non-ingested)	Intake	Released with the feces (Non-digested)	Assimilated in the fish
Oxytetracycline	100	70	30	27	3
Oxolinic acid	100	70	30	18	12

Table 3. Mass balance of antibacterials in a salmonid farm (% of drug distributed in the feed).

The most widely used antibacterial substances are oxytetracycline, furazolidone, and oxolinic acid. Chloramphenicol has been banned from European countries for its effects on bacterial resistance. It is somehow difficult to know the quantities of antibacterial used, except in some countries.

In Norway, where monitoring is undertaken by the government, the amount of active substance per ton of salmon produced decreased from 0.4 kg in 1988 to 0.1 kg in 1996. The mass balance of two major antibacterials delivered via the feed is given in Table 3 for two important substances. Furthermore, the bulk of the product is lost into the environment.

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Biographical Sketch

Antoine Dosdat is a Senior Scientist at the French Institute for Marine Exploitation Research (IFREMER). He graduated from the French National Agronomic Institute and has been involved in Aquaculture Development Planning and Research since 1980. He conducted research on nutritional control of wastes in fish farming and he was the head of the Aquaculture team in the Mediterranean branch of IFREMER from 1996 to 2002. He is now Deputy Director for Science at Ifremer. He is a member of the ICES Working Group on "Environmental Interactions of Aquaculture".