Environmental Impact of Aquaculture: A Literature Review

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Abstract

Aquaculture has an enormous contribution to worldwide food production, being one of the fastest growing food sectors and a significant economic activity for many countries. In 2012, aquaculture contributed with 42.2% to total fish production. Due to the continuous growing of world population and of rising incomes and urbanization, aquaculture will continue this impressive development, being expected to overcome capture fisheries production till 2030. The continued growth of aquaculture contributes to increasing pressure on natural resources, water, feed and energy. Fish production generates considerable amounts of effluent which may have an adverse environmental impact. Generally, aquaculture effluents include uneaten feed, faeces and other organic and inorganic compounds. Because aquaculture depends largely upon a good aquatic environment, mainly the success of developing aquaculture needs to be related to it. In the context of the aquaculture expansion it is essential that the aquaculture technologies be ecologically sustainable and to respect environmental legislation. Mostly, the impact of aquaculture on environment mainly depends on reared fish species, rearing and management techniques, location and also, local environmental conditions. In this context, the aim of this present paper is to present a literature investigation regarding the world aquaculture status, together with its potential effects on the environment.

Keywords: environmental impact, sustainable aquaculture, aquaculture production systems.

Introduction

Fish is considered a food with a high nutritional value, providing an important source of protein and a wide variety of vitamins (such as D and B2-riboflavin), minerals (iron, zinc, iodine, magnesium, and potassium) and poly-unsaturated omega-3 fatty acids. According to the report of Food and Agriculture Organization from 2014, in the year 2010 fish accounted 16.7% of the global population's intake of animal protein and 6.5% of all protein consumed. Taking into consideration that world's population keeps growing during next decades and global life standards, respectively animal protein need rises, fish demand will certainly growth. Because the wild fish captures are already exploited at maximum level, a large part of those new demands must be satisfied through aquaculture activity. As a result, aquaculture has generated a great interest from the international scientific community, supplying the concerns regarding the increase of sustainability and profitability by different methods.

Aquaculture represents the farming of aquatic organisms including fish, mollusks, crustaceans and aquatic plants. According to the Food and Agriculture Organizations, 2014, aquaculture is the fastest growing animal food sector in the world. Food and Agriculture Organizations, (2000) mentioned that in the present, aquaculture supplies an estimated 49% of all fish that is consumed by humans globally and is expected to contribute to more than half of the global fish consumption till 2030.

Although aquaculture has many benefits (providing food and ensuring jobs for humans) a big concern which is facing it is represented by its environmental impact and water quality degradation. Acoording to Guangjun et al (2010), if this sector is not well managed we may experience some unreasonable phenomena such as: the random discharge of aquaculture wastewater, the abuse of medicines, and the escaping of aquatic animals, which have serious influences on the environment.

A. The state of World and EU Aquaculture. World food fish aquaculture production expanded at an average annual rate of 6.2% in the period 2000–2012, slower than in the periods 1980–1990 (10.8%) and 1990–2000 (9.5%). Between 1980 and 2012, world aquaculture production registered a slight increase with an average rate of 8.6 % per year. In a report published by Food and Agriculture Organizations (2014), in the year 2012, this sector reported a record registering almost 90.4 million tonnes, including 66.6 million tonnes of food fish and 23.8 million tonnes of aquatic algae, being estimated for 2013 a production of 70.5 million and 26.1 million tonnes, respectively. The World per capita apparent fish consumption increased from an average of 9.9 kg in the 1960s to 17.0 kg in the 2000s and 18.9 kg in 2010, with preliminary estimates for 2012 pointing towards further growth to 19.2 kg (Food and Agriculture Organizations, 2014).

The species that dominate world aquaculture are aquatic plants, shellfish, herbivorous fish and omnivorous fish. Also, a rapid increase is obvious for marine aquaculture of carnivorous species, especially salmon and shrimp and other marine finfish (Food and Agriculture Organizations, 2014). The most widespread type of aquaculture in the world is represented by the farming of tilapias, Pangasius and other cichlid species. (Food and Agriculture Organizations, 2014).

The global distribution of aquaculture production in all regions and countries with different levels of economic development remains unbalanced. Asia dominates this production, accounting 88.39% of world aquaculture production in 2012, this being determined by the significant contribution of China (Food and Agriculture Organizations, 2014).

Compared to world aquaculture production, which continues to rise, European aquaculture is in a period of stagnation. EU contributions to world aquaculture production have been decreasing significantly over time in both volume and value terms, representing only 1.9% and 3.5% of world production in 2012. According to Eurostat 2014, aquaculture production by the European Union Member States was approximately 1.25 million tonnes of live weight in 2012, almost the same as in 2011. This represented a decline in aquaculture production of about 11% after the relative peak of 2000.

Mainly, the most valuable species produces in EU are Atlantic salmon, oysters, sea bream, sea bass and trout. The main species produced in freshwater is represented by trout. Also, carp is another important species mostly produced in Eastern Europe, where the main producer is Poland covering 39% in terms of total value (Food and Agriculture Organizations, 2014). According to Eurostat (2014) the three largest aquaculture producers among the EU Member States were Spain, the United Kingdom, and France, which together accounted for more than half (54%) of the EU aquaculture production in 2012.

Aquaculture production systems. Aquaculture systems can be classified in extensive, semi-intensive, intensive, or highly or super intensive depending upon the number of organisms grown per volume of water and the water source and supply. Extensive aquaculture is practiced without feed or fertilizer inputs. In semi-intensive aquaculture fertilizers can be added to increase the natural productivity and the water quality can be improved using additional aeration. In intensive aquaculture high densities are practiced using aeration, full feed, and chemical supplements, in order to promote the health of the organisms grown. In principal, freshwater aquaculture is practiced either in fish ponds, pens, cages or, on a limited scale, in rice paddies, in high flow-through tanks or in recirculating aquaculture systems (RAS), brackish aquaculture is done mainly in fish ponds located in coastal areas and marine culture employs either fish cages or substrates for mollusks and seaweeds such as stakes, ropes, and rafts (Food and Agriculture Organizations, Aquaculture Systems and Practices: a Selected Review, 1989).

Pond aquaculture. Pond aquaculture represented the oldest fish farming activity and involves maintaining the environmental conditions at the same level of the technological requirements of fishes. In these systems fish are raised at low densities, mainly because of lack of additional feeding, fish feeding on aquatic animals reared is strictly resulting from natural productivity and due to the difficulty to control water quality. Usually, in order to improve natural food are applied organic and inorganic fertilizers, which contribute to developing natural developing micro and macro flora, food that will support fish populations or other aquatic animals. Higher production can be obtained in the condition of supplementary feeding and higher stocking densities, but this supposes water aeration. According to SRAC (Southern Regional Aquaculture Center), Publication No. 163/1997, in a pond without aeration, it can be obtained from 226 kg to 680 kg of fish per 0.40 ha. Instead, in a pond with aeration, it can be obtained around 1133 kg to 1814 kg of fish per 0.40 ha. To increase the profitability of these systems is indicated to combine both fertilizer and supplementary feeding.

Between the main disadvantages of these systems, we emphasize: require large volumes of water, large land/pond area, due to the use of organic and inorganic fertilizers may appear eutrophication of the waters, incapacity to guarantee the safety of the product to consumer, because ponds systems are open-air there is always a risk of water contamination. But, according to Verdegem & Bosma (2009) if this systems succeed a better optimization of water consumption and feed management they could triple production without increasing freshwater usage. That's why, to increase the economic efficiency of this systems it`s crucial to optimize water consumption, a good solution being the integration into other production systems and also applying of a production management focused on sustainability.

Aquaculture in Raceway. Raceway, also known as a flow-through system, represents enclosed systems which are based on the continuous water flowing through the culture tanks. Because in these systems water enters at one end and flows through the raceway in a plug flow manner, the best water quality exist only at the head of the tank, where the water enters, and then deteriorates along the axis of the raceway toward the outlet (Timmons and Ebeling, 2013). In comparison with the ponds these systems have several advantages, as higher stocking densities, improved water quality, feeding and harvesting are done more easily, less off flavor and an easier way to control disease problems. Fish metabolites are carried out with the effluent while settleable particulate wastes can be collected by settling or less frequently by other means of filtration. Optionally, this type of systems can be integrated into agricultural production, a fraction of the waste process water used in the irrigation of different agricultural areas.

Between the main environmental concerns of these systems we mention eutrophication as the main consequence of increased nutrient loadings (faecal and uneaten food waste), the use of chemicals to control parasites and disease. Also, a big disadvantage of raceways is related to the needs of constant flows of water with a high quality.

Cages and Pens. Cages are boxes shaped enclosure which floats, is suspended, or sits on the bottom of a larger water body. Usually, the cages size varied from 1.0 m^3 to 1,000 m^3. Usually, pens are much larger and serve as enclosures to hold organism for grown. In pens, organisms have free access to the bottom within the enclosed area. Growing and production of farmed aquatic organisms in caged enclosures has been a relatively recent aquaculture innovation. Primarily, these systems have been associated with the culture of salmonids, but due to the rapid expansion of aquaculture in the last 20 years this sector has grown very rapidly. Generally, cage culture is suitable for the growing of carnivorous species with a high economic value (Atlantic salmon, Coho salmon and Chinook salmon Japanese amberjack, red seabream, yellow croaker, European seabass, gilthead seabream, cobia, rainbow trout, Mandarin fish) (Tacon A. et al 2007).

The main advantages of cage culture are associated with the use of existing water and the fact that doesn`t require land ownership, the related capital costs being quite low making this technology the most economical culture. Also, a big advantage it`s represented by the possibility to move into optimal rearing environments and sheltered areas.

Between the disadvantages of the system, we mention the fact that these systems are permanently exposed to foul weather conditions making impossible the controlling of physical-chemical water and also the environmental impact on water quality generated by these systems. Also, according to Sugiura et al (2000) and Tacon A. et al (2007), cage cultures are vulnerable to poaching and vandalism and to higher risks of fish escaping.

Aquaculture in recirculating systems (RAS). Recirculating Aquaculture Systems are used for fish farming or other aquatic organisms by reusing the water in the production by mechanical, biological chemical filtration sterilization, oxygenation, and other treatment steps. That's why RAS systems represent an alternative to pond aquaculture due to low water consumption (Verdegem et al 2006) better opportunities for waste management and recycling of nutrients (Piedrahita, 2003) and due to the easy way to control the spread of disease (Summerfelt et al 2009; Tal et al 2009). RAS are intensive production systems than most other types of traditional aquaculture systems (Timmons and Ebeling, 2013) and are the most compatible with environmental sustainability (Martins et al 2010), due to the production of small quantities of wastes and of water reuse. However, the main disadvantages of these systems are high capital and operational costs and requirements for very careful operational management. That's why this type of systems are justified only for growing high-value species such as sturgeon, pike, perch, eel, catfish, tilapia, etc.

B. Impacts of aquaculture on the environment. Due to rapid expansion and to continued pressure on natural water resources, energy and feed, aquaculture can produce different impacts on the environment. Aquaculture can exert both positive impact and negative on the environment. Usually, the quality and quantity of waste from aquaculture, as well as the environmental impacts of aquaculture, vary with farmed species, the management practices used and location of the production system but also on feed quality and management (feed composition, feed ration and feeding method) (Preston et al 1997; Wang et al 2005; Podemski C.L. and Blanchfield P.J. 2006). Among the major effects of aquaculture on the environment in this paper we refer to:

- Effluent discharges;
- Effects of other discharges from aquaculture (e.g. fertilizers, chemicals, and medicines);
- Escapes from fish farms and potential effects on wild populations.

Effluent discharges. Aquaculture effluents contain dissolved and suspended solids that have biochemical oxygen demand (BOD), ammonia and nutrients phosphorus (P) and nitrogen (N) that are derived from fish excretion, faeces, and uneaten feed, and specific organic or inorganic compounds (i.e. therapeutics). Between all these components a special attention is directed towards nitrogen and phosphorus which are considered the main pollutants of intensive aquaculture (Hakanson et al., 1998). These components are a real source of pollution and if they are developed at high level can cause of eutrophication (González et al 2008), resulting in occurrence of the harmful algal blooms (Pearl H. W. 1997; Goldburg Rebeca and Tracy Triplett et al 1997) and the depletion of oxygen due to the increase of microbial activities (Diaz et al 2008).

It is obviously that feeding is the main source of waste output from aquaculture, due to the high amounts in fishmeal (FM) which is rich in P. In fact, Ackefors, (1999) said that the content of phosphorus and nitrogen in the feed and the feed conversion rates are most important in assessing environmental impacts of aquaculture. According to Jackson et al (2003) and Schneider et al (2005) only 20% to the cultured organism is retained as biomass while the rest is incorporated into the water column or sediment. Moreover, Pierhadrita, (2003) says that nitrogen and phosphorus retention range between 10-49% and 17-40% respectively, while from faeces N and P are released from 3.6% to 35% and 15% to 70% respectively. Lastly, dissolved N and P excretions range from 37% to 70% respectively. Nowadays, modern aquaculture is based mostly on the feeding of manufactured feeds (extruded pellets) reducing the phosphorus excretion. For example, in a diet for salmon, with 40% protein, 30% lipids, 13% carbohydrate and a energy content of 19.2 MJ kg-1, the nitrogen content is around 7%, aspect which makes possible to use fat for energy (instead of protein) and excreted of smaller volumes of nitrogen compounds (Pillay, 2004). That`s why it is very important to know the ingredients from the feeds and to balance these nutrient in order to improve the nutritional quality. Cho et al (1991), says that the goal of aquaculture is to produce feed very well suited to the nutritional needs of the fish so that the maximum growth can be achieved with minimum waste, particularly phosphorus and nitrogen. So, according to Youssouf A. et al (2012), a way to reduce P waste produced by aquaculture is to replace the FM with FM substitutes that contain lower P, without affecting the growth performance of fish. Also, Ayoola A. (2010) suggest that a possible alternative of protein sources, can be represented by animal proteins from rendering or slaughter, plant protein concentrates and novel proteins such as algae, yeast, dried distillers grains with soluble (DDGS) and insect meal.

Besides feed composition, others factor responsible for pollution effluent from aquaculture is the type of the culture systems and the practiced stocking densities. In general, the effluent resulting from aquaculture raceway is more polluted in comparison with ponds effluent, cages and pens, mainly because water passes quickly through raceways and dissolved and suspended matter are flushed out. Generally, wastes emitted from cages and raceways are quickly diluted but also can generate changes in sediment structure and function (Beveridge M. et al., 1997). On the other hand effluent from RAS systems, it is around 10% (daily water exchange) of total system volume per day, but RAS produce a concentrated waste.

Another important issue which will receive increasing attention is the practice stocking densities. High stocking densities suppose the concentration of many organisms in a low water volume, increasing the waste productions and thus increasing the concentration of phosphorus and nitrogen compounds from water. Also, not all fish species have similar metabolism having different capacities to process energy and nutrients, and that`s why choosing the suitable species for growth and the suitably grown system can be a good solution to protect the environment. Also, Manoochehri et al (2010), mentioned as a measure to reduce nutrient wastes or to avoid or reduce any negative environmental impacts a careful monitoring and management of aquaculture effluents.

Effects of other discharges from aquaculture (e.g. fertilizers, chemicals, and medicines). Besides the wastes, aquaculture effluents may contain chemicals (fertilizers, disinfectants and chemotherapeutants pesticides, antibiotics). Usually, fertilizers are used in aquaculture ponds, in order to increase the primary productivity by stimulating the phytoplankton growth. For that, a very important aspect is to establish the needed doses. These doses may be determined only from the knowledge of the chemical composition of the water and the physical-chemical characteristics of its bottom. Generally, in aquaculture are used organic fertilizers or inorganic fertilizers, or a combination of both. Inorganic fertilizers are an inorganic compound which contains nitrogen, phosphorus, and potassium. However, fertilizers, whether they are artificial or organic, can cause serious problems if they contaminate water or are added in excess, contributing to the deterioration of water quality and implicit to discharged effluents.

According to Okomoda V. (2011), in modern aquaculture, especially in high stocking density aquaculture, to prevent diseases, eliminate harmful biota, disinfect and restrain polluted and damaged water, multiple chemicals and medicines are used. In the lasts years, the use of antibiotics has grown, even their use remains still controversial. Generally, the antibiotics are incorporated in fish pellets and due to uneaten feed go straight into water and bottom. Also, they can enter in water through faeces and by urine excretion. In fact, there are researchers who indicate the approximately 70-80% of the drug ends up in the environment (Samuelsen, Torsvik and Erik, 1992; Lalumera et al 2004). Mainly, in aquaculture antibiotics are used for therapeutic purposes and as prophylactic agents (Zheng et al 2012), the most frequent fish infections treated with antibiotics are skin ulcers, diarrhea and blood sepsis (Food and Agriculture Organizations, 2005).

Although their use is carefully indicated, there are cases when their discharge into the aquatic environment can lead to serious damages, due to the fact that they came in direct contact with water and soil. (Boxall 2004). These risks are associated with the direct toxic effects (on benthic micro and meiofauna, algae, plankton and other aquatic organisms) and more subtle effects including potential modification of bacterial communities (and the promotion of antibiotic-resistant organisms) (Marine Strategy Framework Directive, 2015). However, the use of antibiotics in aquaculture remains still difficult, because they must be administered directly into the water, and that's why should be taken into account a number of considerations such as environmental integrity, the safety of fish and the aquatic products intended for human consumption.

Escapes from fish farms and potential effects on wild populations represent another big issue of aquaculture, with detrimental effects on the environment. According to a report published by The

Scottish Association for Marine Science and Napier University Scottish Executive Central Research Unit in 2002, escapees from fish farms may interbreed with wild population resulting in losses of genetic variability, including loss of naturally selected adaptations, thus leading to reduced fitness and performance. Also, escaping of fish from farms can be responsible for the spreading diseases and others pathogens. It is necessary for a better understand the relationships between disease and both as a means of preventing environmental economically serious disease outbreaks and indirectly promoting the need for better environmental management (Pullin et al 1993). In cases of cages, pens or other systems which release the untreated effluent directly into the water the possibility of transmitting diseases to wild fish stocks is quite high. The main way of introducing diseases is the transfer of infected farmed juveniles to these systems, or through infected food equipment, and through water streams (Ruiz et al 2000, Murray et al 2005, Salama et al 2011).

Conclusions

Aquaculture represents the sector with an important economic activity being situated on top of the food production industry. Increasing customer demand for aquaculture products, together with increasing environmental and also, the costs associated with land and water will determinate the producers to develop their technological facilities or to implement new solutions in order to assure the practice of high stocking densities and to meet the market demands while taking into consideration environmental protection.

In order to protect the environment, aquaculture activities must be conducted sustainably, with minimal impact on the environment. In fact, the aquaculture industry is already working on this requirement, which in many countries has reached an impasse. In conclusion, to develop a sustainable growth of aquaculture is needed to be profitability, economic development and to practice a good waste management. There are many measures which can be taking in order to reduce the environmental impact of aquaculture, as: reducing as much as possible food losses, the adoption of management strategies of discharged effluents, like the utilization of the recirculating systems or systems with low or zero water exchange, the revalorization of the wastes by integrating in hydroponic systems for plants production or for composting for garden applications. Also, it is important to ensure sustainable sourcing of feed, to avoid escapes by adopting technical standards, to minimize biodiversity impacts and to reduce the impact of chemicals and medicine use, particularly antibiotics.

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