Aquaculture Effluents and Water Pollution

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AQUACULTURE AND WATER POLLUTION

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ABSTRACT: Nearly 20% of world fisheries production comes from aquaculture, and the percentage will increase in the future. Aquaculture is done primarily in ponds, but some aquaculture is conducted in raceways, cages, and pens. Fertilizers, manures, and commercial, pelleted feed are used to stimulate production of fish, shrimp, and other aquatic organisms. Water discharged from aquaculture ponds and raceways is enriched in nutrients, organic matter, and suspended solids, and wastes from cages and pens also enter natural waters. There is concern over potential eutrophication of natural waters by aquaculture facilities. Several industrially-developed countries currently regulate aquaculture effluents, and the United States Environmental Protection Agency has initiated rule making for aquaculture effluents. The draft rule is due in June 2002 and the final rule in June 2004. Once the final rule is available, states must regulate aquaculture effluents at least as strictly as specified by the rule. In many tropical nations, regulations are lacking or ineffective. Possible methods for reducing the pollution potential of aquaculture include effluent limits, effluent treatment, and use of better management practices (BMPs) such as environmentally-friendly feeds, better feed management, more efficient mechanical aeration, reduction of effluent volume, and water reuse.

Key Terms: aquaculture, water pollution, effluents, water quality, ponds.

INTRODUCTION

Fisheries products are an important part of the world food supply providing about 15 to 20% of the protein needed in human diets (Gallagher, 2000). The catch of fisheries products from oceans and natural inland waters has apparently reached a sustainable annual limit of about 90 million metric tons, but some species are being overexploited and their catch is declining (Brown et al., 1998). The world population is growing, the demand for fisheries products is increasing, and aquaculture is the only method for bridging the gap between supply and demand of many aquaculture species. Aquaculture currently produces about 28 million metric tons of fish, shellfish, and other aquatic products or about 20% of total world fisheries output. Examples of successful aquaculture are channel catfish (*Ictalurus punctatus*) production in the southeastern United States and marine shrimp farming (*Penaeus* spp.) in many tropical and subtropical nations. Channel catfish farming has increased from a minor activity in the 1960's to reach an annual output of around 270,000 metric tons in 1999. Shrimp farming output has increased from about 80 thousand metric tons in 1984 to over 800,000 metric tons in 1999 (Rosenberry, 1999). Aquaculture provides almost 30% of the world shrimp supply.

Although aquaculture has been tremendously successful, there is doubt that it can keep up with the increasing demand for fisheries products (Boyd, 1999). Thus, the future of aquaculture should be bright for its products are in great demand, but in short supply. However, environmental advocate groups have expressed concerns over the impacts of aquaculture on the environment (Goldberg and Triplett, 1997; Naylor et al., 1998, 2000). Unless the aquaculture industry responds to these concerns in a positive way by developing more responsible production techniques, its future may be greatly diminished. The most frequent criticisms of aquaculture are listed in Table 1. Examples of these negative impacts can be found, but the bad examples are a result of poor management by some producers and inadequate regulation by governmental agencies in some countries. Aquaculture usually is conducted without causing serious environmental impacts. The greatest potential for negative environmental impacts in most types of aquaculture is water pollution, and the purpose of this report is to provide an overview of this topic.

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Table 1. Major Negative Environmental Impacts that Can Result from Aquaculture (Boyd and Tucker, 1998).

Infringement on wetlands and other sensitive aquatic habitats
Eutrophication of natural water by effluents
Excessive consumption of freshwater
Salinization of freshwater supplies
Sedimentation in natural waters
Introduction of non-native species
Release of residues of drugs, antibiotics, and other chemicals into natural aquatic ecosystems
Adverse effects on biodiversity of aquatic ecosystems

PRODUCTION TECHNIQUES

The majority of the world's aquaculture is conducted in freshwater and brackishwater ponds, but aquaculture species also are produced in raceways, cages, and net pens. Small fish and crustacean larvae normally are produced in hatcheries and used to stock grow-out facilities. Inorganic fertilizers and manures and other agricultural byproducts may be applied to ponds to increase the production of natural food organisms for aquaculture species. Even greater increase in the production of an aquaculture species can be achieved through the use of manufactured feeds. To illustrate, in channel catfish or marine shrimp farming, production in fertilized or manured ponds seldom will exceed 500 kg/ha. By providing manufactured feed to shrimp or catfish ponds, production can exceed 5,000 kg/ha (Boyd and Tucker, 1998), and feed-based aquaculture has become the standard production technique for many species. Aquaculture feeds are made from plant and fish meals fortified with minerals, vitamins, and other substances. Feeds usually are pelleted, and they contain 90 to 95% dry matter, 4 to 8% nitrogen (20 to 40% crude protein), and 1 to 1.5% phosphorus. Feeds normally are offered to culture animals one or more times per day, and daily feeding rate usually is 2 to 3% of the biomass of the culture animals. Ponds often contain 2,000 to 5,000 kg/ha of biomass near harvest, and daily feed input typically ranges from 40 to 150 kg/ha. Nutrients reaching pond water from feed applications stimulate heavy plankton blooms. Dissolved oxygen concentrations often are low at night as a result of plankton respiration, and mechanical aeration may be applied to prevent stress or mortality of the culture species from low dissolved oxygen concentration.

Ponds may be drained for harvest, or harvests may be done by seining without water drawdown. Even if harvest is done without draining ponds, after several years, ponds must be drained to repair earthen infrastructure (Boyd et al., 2000). Ponds also overflow after heavy rains, and most aquaculture ponds release effluents into natural water bodies.

Feeds usually are applied to raceways, cages, and net pens to encourage growth of the culture species. In raceways, water continually flows through the culture units to provide oxygen and flush metabolic wastes and uneaten feed from the production system. Uneaten feed and metabolic wastes enter directly into bodies of water used for cage and net pen culture. The density of animals in raceways may reach 200 kg/m^3, and even greater densities may be cultured in cages and pens. Mechanical aeration also may be applied in raceway, cage, or pen culture to increase the weight of animals that can be maintained per unit volume of culture space. Animals can be harvested without the necessity for draining raceways or water bodies into which cages or pens have been installed.

WASTE LOADS AND EFFLUENTS

Nutrient inputs and production levels are low in fertilized and manured ponds, and these ponds do not have as large a potential for water pollution as ponds to which feeds are applied. In feed-based aquaculture, the ratio of feed applied to net aquatic animal production is the feed conversion ratio (FCR). Typically, FCR is 1.5 to 2.5 in aquaculture ponds. At a FCR of 2.0, 2,000 kg of feed are applied and 1,000 kg of culture animal are harvested.

The difference between the input of material in the feed and the amount of material removed in the culture animals at harvest represents the waste load in the pond. Consider the production of 1,000 kg of channel catfish at an FCR = 1.8 with a feed containing 92% dry matter, 4.48% nitrogen, and 0.95% phosphorus. Feed input was 1,800 kg (1,656 kg dry matter), and it contained 80.6 kg nitrogen and 17.1 kg phosphorus. Channel catfish contained 23% dry matter, and the dry matter averaged 8.15% nitrogen and 1.42% phosphorus (Boyd and Tucker, 1998). Thus, at harvest, there were 230 kg catfish (dry weight) containing 18.7 kg nitrogen and 3.27 kg phosphorus. The waste loads were 1,426 kg dry matter, 61.9 kg nitrogen, and 13.83 kg phosphorus. Most of the dry matter load is carbon dioxide released by respiration of the culture species, but a part is feces and uneaten feed. The nitrogen and phosphorus loads include ammonia nitrogen, orthophosphate, and organic nitrogen and phosphorus in feces and uneaten feed.

Carbon, nitrogen, and phosphorus released into ponds are nutrients for phytoplankton growth. Boyd (1985) estimated that nutrients resulting from the production of 1,000 kg of channel catfish resulted in 2,500 kg dry phytoplankton. Ponds have a large capacity to assimilate organic matter and nutrients from feed. A study by Schwartz and Boyd (1994a) revealed that effluents from catfish ponds in Alabama contained 3.1% of carbon, 28.5% of nitrogen, and 7.0% of phosphorus initially applied to ponds in feed. Pond bottom soils do not accumulate large amounts of organic matter, and the loss of organic matter from ponds in effluents is a minor fraction of the organic matter applied in feed and produced in algal photosynthesis. Only a small amount of the organic matter is removed in fish at harvest, and most of the remainder is converted to carbon dioxide in microbial and fish respiration (Boyd, 1985). Nitrogen not harvested in fish or contained in effluent is lost primarily through ammonia volatilization from pond surfaces and denitrification (Gross et al., 2000). Phosphorus is strongly adsorbed by pond soils or precipitated directly from pond water as calcium phosphate (Masuda and Boyd, 1994).

Concentrations of some water quality variables are higher in pond effluents than in receiving water bodies. Schwartz and Boyd (1994b) measured average concentrations of selected water quality variables in surface water of Alabama channel catfish ponds over a 2-year period (Table 2). These data are representative of effluents resulting from storm overflow or initial drawdown of pond water levels before harvest (Boyd et al., 2000). However, the last 20 to 25% of effluent discharged from channel catfish ponds has much higher concentrations of total suspended solids, total nitrogen, total phosphorus, and 5-day biochemical oxygen demand than storm overflow and initial draining effluent (Schwartz and Boyd 1994a). The average concentrations of these variables in the final effluent during fish harvest were: total suspended solids, 1,027 mg/L; 5-day biochemical oxygen demand, 31.8 mg/L; total phosphorus, 1.59 mg/L; total nitrogen, 9.58 mg/L.

Table 2. Average Concentrations ± Standard Deviations of Selected Water Quality Variables in Surface Waters of Channel Catfish Ponds and in Effluents from Shrimp Ponds.

Variable	Channel Catfish	Shrimp
pH (standard units)	8.2 ± 0.5	8.1 ± 0.4
Dissolved oxygen (mg/L)	8.8 ± 1.2	6.1 ± 1.3
Total suspended solids (mg/L)	70 ± 24	164 ± 238
Total ammonia nitrogen (mg/L)	1.09 ± 0.54	0.52 ± 0.59
Total nitrogen (mg/L)	6.44 ± 1.84	3.05 ± 3.15
Total phosphorus (mg/L)	0.25 ± 0.11	0.37 ± 0.33
Biochemical oxygen demand (5-day) (mg/L)	9.42 ± 3.8	10.3 ± 8.1

Boyd and Gautier (2001) summarized data from 17 studies of shrimp farm effluents (Table 2). Concentrations were similar to those reported for channel catfish pond effluents, and highest concentrations of most variables occurred in effluents released during shrimp harvest. The highest observed concentrations for selected variables were as follows: total suspended solids, 3,671 mg/L; biochemical oxygen demand, 50.7 mg/L; total phosphorus, 110 mg/L; total nitrogen, 2,600 mg/L. These peak concentrations were observed in effluents from highly intensive shrimp ponds where large amounts of organic sediment that accumulated in pond bottoms were resuspended during shrimp harvest.

The pH of pond effluents will seldom be below 6, because ponds are treated with agricultural limestone to prevent low pH that is harmful to fish and shrimp. The pH in aquaculture ponds increases during the day as carbon dioxide is removed from the water by phytoplankton for use in photosynthesis, but it decreases at night when carbon dioxide from respiration accumulates in absence of photosynthesis. Ponds typically have dense phytoplankton blooms and daily pH fluctuations of 6.5 to 9.5 are not uncommon. Dissolved oxygen concentrations also are higher in the daytime than at night because of photosynthesis by phytoplankton. Daytime concentrations of dissolved oxygen often exceed 10 mg/L, but concentrations may fall to 2 or 3 mg/L at night in ponds without mechanical aeration. Thus, high pH in effluents is more common during daylight hours, while low dissolved oxygen concentration in effluents is more common at night.

EFFLUENT TREATMENT

The most feasible methods for treating aquaculture effluents appear to be sedimentation, constructed wetlands, or water treatment reservoirs with water reuse. Sedimentation is not effective in removing phytoplankton and detritus from effluents, but coarse suspended mineral particles can be removed by sedimentation if a hydraulic residence time (HRT) of 8 to 12 hours is provided (Boyd et al., 2000). Water from a production pond for channel catfish in Hale County, Alabama, was passed through a constructed wetland consisting of two cells, one planted with California bulrush (*Scirpus californicus*) and giant cutgrass (*Zizaniopsis miliacea*) and one planted with Halifax maidencane (*Panicum hemitomon*). The removal of potential pollutants from water flowing through the wetland was determined for 1-, 2-, 3-, and 4-day HRTs, with hydraulic loading rates of 77-91 L/m^2 of wetland per day. Concentrations of potential pollutants were much lower in effluent from the wetland than in influent from the channel catfish ponds. The following reductions in concentrations were recorded: total ammonia nitrogen, 1-81%; nitrite-nitrogen, 43-98%; nitrate-nitrogen, 51-75%; total Kjeldahl nitrogen, 45-61%; total phosphorus, 59-84%; biochemical oxygen demand, 37-67%; suspended solids, 75-87%; volatile suspended solids, 68-91%; and settleable solids, 57-100%. Overall performance of the wetland was best when operated with a 4-day HRT in the vegetative season, but good removal of potential pollutants was achieved for shorter HRTs and when vegetation was dormant. However, Seok et al. (1995) found that a settling basin provided almost as much improvement in aquaculture pond effluent quality as wetlands did. Settling basins are cheaper to construct and operate than wetlands.

Water from production ponds may be discharged into a reservoir for treatment by natural physical, chemical, and biological processes. Several studies have shown that aquaculture pond effluents held for 7 to 10 days in reservoirs improves drastically in quality and can be reused in production ponds (Boyd and Tucker, 1998; McIntosh, 1999). Some commercial aquaculture facilities have applied mechanical aeration in treatment reservoirs to increase their effectiveness, and at other facilities, constructed wetlands have been incorporated with treatment reservoirs. Water treatment and reuse is highly desirable because it conserves water and reduces effluent volume.

EFFLUENT REGULATIONS

United States

The United States Environmental Protection Agency is drafting an aquaculture effluent rule due in June 2004 (Federal Register, 2000). This rule possibly will have concentration limits for key water quality variables, but it is almost certain to require BMPs. The BMPs would be management procedures to lower concentrations of water quality variables and reduce effluent volumes in order to lessen pollution loads in aquaculture effluents. It is expected that the BMPs will include practices on watersheds to reduce erosion and to prevent excessive runoff into ponds, practices to prevent erosion and suspension of solids in ponds and effluent discharge routes, practices to prevent overfeeding, and practices to improve water quality in ponds. It may be possible to treat pond effluents in sedimentation basins in some types of aquaculture. However, in channel catfish farming the size of settling basins necessary for treatment of effluents appears prohibitive unless restricted to the final 15 to 20% of pond draining effluent (Boyd and Queiroz 2001).

Feed management and sedimentation have been used to improve the quality of effluent from raceways. However, the only technique available for reducing the pollution potential of cage and net pen culture is feed management.

Other Countries

Strict effluent regulations have been developed in many European nations, Australia, and Canada. These regulations often have concentration, volume, or load restrictions for pond effluents, and they usually are strictly enforced. In other countries, regulations have either not been developed or they have been developed and not enforced. However, because of the concern expressed by environmental advocacy groups, fish and shrimp farmers in many countries are worried that environmental issues may influence the value and demand for aquaculture products. Thus, many aquaculture organizations are promoting environmental education for producers and developing more "environmentally-responsible" production techniques for use by their members. These production techniques usually are presented to farmers as Codes of Practices for responsible aquaculture for voluntary adoption. The Codes of Practice usually contain best management practices (BMPs) designed to accomplish the following:

1. Reduce input of nutrients and organic matter into ponds through better fertilization and feeding practices.
2. Improve water quality in ponds through reasonable stocking and feeding rates, aiming to maintain optimal alkalinity of water and soil pH, and mechanical aeration to maintain adequate dissolved oxygen.
3. Minimize the use of drugs, antibiotics, and other chemicals for disease control and to focus on reduction in stress as the major feature of aquatic animal health management.
4. Water reuse and recirculation to minimize effluent volume

5. Discharge of effluents through settling basins or wetlands where possible.

In addition to BMPs related to water quality and effluents, Codes of Practice also suggest BMPs for preventing other negative environmental impacts of aquaculture (Boyd, 1999).

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