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Guidelines for aquaculture effluent management at the farm-level

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Abstract

Pressure from environmental groups will force most governments to impose effluent regulations on aquaculture. Shrimp and fish producers are concerned that these regulations will be unnecessarily restrictive and expensive. Most pond aquaculture cannot be conducted without discharge. Fish and shrimp farms tend to be concentrated in specific regions, but typically they are sprawling operations where large volumes of relatively dilute effluents are released at many points. Effluents from pond aquaculture resemble non-point sources of pollution more than point sources. Thus, application of traditional effluent treatment methods to meet effluent standards, as done for point source pollution, will be difficult or impossible. Many involved in aquaculture believe that application of best management practices (BMPs) could be a reasonable and affordable way to improve the quality and reduce the volume of pond effluents. During recent years, several organizations have suggested systems of BMPs for making pond aquaculture more environmentally responsible. These include international development organizations (Food and Agriculture Organization of the United Nations and International Finance Corporation), industry groups (Global Aquaculture Alliance, Australian Prawn Producers Association, Marine Shrimp Culture Industry of Thailand, and Alabama Catfish Producers), a research center (Coastal Resources Center, University of Rhode Island), and state agencies in the USA (Missouri Department of Natural Resources and Florida Department of Agriculture and Consumer Services). The contents of BMP documents presented by the different groups are remarkably similar. Although the BMP approach is largely a "paper list" at present, the topic is being discussed widely, and producers are becoming more aware of environmental issues. There is an obvious attempt by producers in Latin America, Asia, Australia, and the United States to improve production practices, and some producers are voluntarily adopting BMPs. Many shrimp producers in several nations have installed settling basins, and a few large shrimp farms monitor effluent quality. The Aquaculture Certification Council (ACC) plans to implement a certification program based primarily on compliance with BMPs during 2003. There also is considerable discussion among producers and

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governmental agencies in several nations regarding BMPs, and it is expected that regulatory programs based on BMPs will be forthcoming.

Keywords: Effluents; Sustainable aquaculture; Best management practices; Aquaculture ponds; Codes of conduct

1. Introduction

Aquaculture contributes significantly to the world food supply, providing around 30% of fisheries production (Anonymous, 2001). Because capture fisheries are being exploited to their sustainable limit and beyond, aquaculture is expected to continue to have an important role. Aquaculture has become large enough to have significant impacts on the environment and natural resources, and a number of concerns have been expressed by both environmental activists and scientists (Dierberg and Kiattisimukul, 1996; Goldburg and Triplett, 1997; Naylor et al., 1998, 2000). The most serious concerns are the following:

(a) Destruction of mangrove, wetlands, and other sensitive aquatic habitat by aquaculture projects;
(b) Conversion of agricultural land to ponds;
(c) Water pollution resulting from pond effluents;
(d) Excessive use of drugs, antibiotics, and other chemicals for aquatic animal disease control;
(e) Inefficient utilization of fish meal and other natural resources for fish and shrimp production;
(f) Salinization of land and water by effluents, seepage, and sediment from brackishwater ponds;
(g) Excessive use of ground water and other freshwater supplies for filling ponds;
(h) Spread of aquatic animal diseases from culture of organisms to native populations;
(i) Negative effects on biodiversity caused by escape of non-native species introduced for aquaculture, destruction of birds and other predators, and entrainment of aquatic organisms in pumps; and
(j) Conflicts with other resource users and disruption of nearby communities.

Of these and other possible negative impacts, water pollution by pond effluents is probably the most common complaint, and this concern has attracted the greatest official attention in most nations (Tookwinas, 1996; Boyd and Gautier, 2000; Boyd and Tucker, 2000).

Most shrimp and fish production is conducted in ponds, and ponds have effluents after heavy rains and when they are drained (Boyd and Queiroz, 2001). Water also is discharged from some ponds in response to water exchange. Although there is considerable interest in water reuse, or closed-cycle production systems, it currently is not technically or economically feasible to conduct most types of aquaculture without discharge.

Fertilizers and feeds are applied to ponds to promote shrimp and fish production, and normally, no more than 25% to 30% of the nitrogen and phosphorus applied to ponds in fertilizers and feeds is recovered in fish or shrimp at harvest (Boyd and Tucker, 1998). Ponds have a remarkable ability to assimilate nitrogen and phosphorus through physical, chemical, and biological processes (Schwartz and Boyd, 1994a). Nevertheless, ponds often have higher concentrations of nutrients, plankton, suspended solids, and oxygen demand than the water bodies into which they discharge (Schwartz and Boyd, 1994b). Thus, pond effluents are potential sources of pollution in receiving waters.

Because of coercion by environmental advocacy groups, many nations are beginning to make regulations for aquacultural effluents. Some European nations have made relatively strict regulations for cage and net pen fish culture. Australia has developed regulations for pond culture of fish and shrimp. The National Pollution Discharge Elimination System (NPDES) of the United States Clean Water Act has allowed individual states to apply NPDES permits to aquaculture effluents for many years. Most states with significant aquacultural production, however, have not required NPDES permits for aquaculture because the United States Environmental Protection Agency (USEPA) has made no federal rule for aquaculture effluents. The USEPA has initiated a rule-making procedure for aquaculture, and the final rule will be available on 30 June 2004 (Federal Register, 2000). After this, aquaculture projects in all states will be subject to regulation by the federal rule. Many tropical nations also have made aquaculture effluent regulations. Some examples are Belize, Brazil, Ecuador, India, Mexico, Oman, Thailand, and Venezuela.

Aquaculture associations are concerned about the possible effects of environmental criticisms on the markets for their products. There is a growing trend of environmental awareness by aquaculture associations, and they are promoting environmentally responsible production methods. There also is widespread interest in the economic advantages of products certified to be "environmentally friendly."

Effluent regulations mandated by governments often require compliance with water quality standards containing numerical criteria (Gallagher and Miller, 1996; Mackenthun, 1998). Alternatively, regulations sometimes are based mainly on mandated use of environmentally responsible practices (Gallagher and Miller, 1996; United States Environmental Protection Agency, 1995). Even when regulations are based solely on effluent standards, aquaculture producers will find it necessary to improve production methods in order to comply with water quality criteria in permits.

The purpose of this report is to discuss actions that have been initiated to improve the management of aquaculture farms for the purpose of preventing or lessening the pollution of natural waters by pond effluents. The focus is on international efforts, but examples from the United States also will be given.

2. Effluent standards and permits

Water quality regulations developed by governmental agencies usually have effluent standards and rules for issuing and enforcing permits for individual effluent outfalls (Goldsteen, 1999). Water quality standards are designed to prevent effluents from causing negative impacts on receiving waters (Gallagher and Miller, 1996; Boyd, 2000). Standards normally specify limits for selected water quality variables and may contain other restrictions. A water quality standard might contain the following water quality restrictions: pH, 6 to 9; dissolved oxygen, 5 mg/l or more; 5-day biochemical oxygen demand (BOD_5), 30 mg/l or less; total suspended solids, 50 mg/l or less. Sometimes, the standard also may place a restriction on discharge volume or restrict discharge volume indirectly by specifying a maximum daily load for a variable. To illustrate, the maximum daily volume might be 10,000 m^3/day, or the maximum BOD_5 load cannot exceed 100 kg/day. The load limit would restrict volume to 3333 m^3/day at a BOD_5 concentration limit of 30 mg/l, or restrict BOD_5 concentration to a maximum of only 10 mg/l at a maximum daily discharge. There may be qualitative criteria in standards, such as no discernable odor, no foam, or no visible plume at the outfall. Effluent permits often are issued on a case-by-case basis, and the numerical and qualitative criteria of the standard will depend upon the nature of the effluent and the characteristics of the receiving water. Sometimes, industry-wide general permits are issued for a particular activity. In this situation, permits for all operations will be similar. An effluent permit for a particular discharge point also will contain a list of numerical and qualitative criteria, and it also will give instructions on sampling, analysis, and reporting.

Sometimes, discharge permits only require the application of specific practices called best management practices (BMPs, to be discussed below), while others may contain both water quality standards and BMPs. Where BMPs are mandated, there will be an inspection procedure for verification and continuation of discharge permit validity (United States Environmental Protection Agency, 1995).

Effluent permits have been required by the government for some aquaculture operations in the United States and other developed nations. Some developing nations have already developed effluent standards for aquaculture, and possibly, a few permits have been issued. The aquaculture effluent rule now being developed in the United States is expected to contain some numerical standards but to be based primarily on BMPs (Boyd and Tucker, 2000; Boyd and Hulcher, 2001). Many developing nations often adopt regulations similar to those used in the United States. Thus, the final form of the aquaculture effluent rule now being developed by USEPA may have far reaching effects on governmental regulations for aquaculture in other nations.

The development of aquaculture regulations does not assure that the regulations will be applied at the farm level. The effort to enforce compliance with effluent permits would be a difficult and expensive activity in many nations. Ideally, a producer would be issued either an individual or general permit, and the effluent would have to be monitored according to a specific schedule. Usually, the farmer would be responsible for monitoring and would either make the analyses on farm or send the samples to a qualified laboratory. The farmer also would be responsible for reporting results to the permitting agency. The agency would evaluate the report and decide if the farm is in compliance. The agency also would be responsible for enforcing cases of non-compliance. Moreover, the permitting agency would have to check a sample of farms periodically to assure that analyses are being done in the proper manner and that reports are accurate.

In a developed country such as the United States where aquaculture farms are not extremely numerous, the financial resources and personnel needed to issue permits, review and verify monitoring and reporting efforts, and provide enforcement usually would be available. Most of the aquaculture in the world is conducted in developing countries and

Table 1
Initial and target water quality standards for shrimp farm effluents recommended by the Global Aquaculture Alliance (Boyd and Gautier, 2000)

Variable	Initial standard	Target standard
pH (standard units)	6.0–9.5	6.0–9.0
Total suspended solids (mg/l)	100 or less	50 or less
Total phosphorus (mg/l)	0.5 or less	0.3 or less
Total ammonia nitrogen (mg/l)	5 or less	3 or less
5-Day biochemical oxygen demand (mg/l)	50 or less	30 or less
Dissolved oxygen (mg/l)	4 or more	5 or more

especially in Asia. In the major aquaculture nations of Asia, there are tens of thousands of small farms operated by individuals with relatively little technical knowledge. The large personnel and financial requirements would make it virtually impossible for these nations to effectively regulate aquaculture effluents by application of traditional effluent standards.

At least two non-governmental organizations have made effluent standards for aquaculture. The Global Aquaculture Alliance (GAA) is an international aquaculture organization promoting environmentally responsible production. It suggests that members use environmentally responsible culture methods to comply with effluent standards (Table 1). The GAA standards consist of initial, rather lenient limits, and stricter target limits with which the member should comply within 5 years (Boyd and Gautier, 2000). The International Finance Corporation (IFC) sometimes provides low interest loans to aquaculture projects in developing countries. The IFC requires compliance with water quality standards (International Finance Corporation, 1998). The standards that have been required for farm effluents apparently are the same ones required for fish processing operations (Table 2). Of course, the GAA program is just being initiated, and only a few aquaculture facilities are funded by IFC.

It is important to note that when governmental or other organizations require compliance with effluent permits and standards, these organizations do not usually mandate what procedures must be used to achieve compliance. If the effluent does not comply with the permit or standards, it must be treated by some procedure that will improve its quality or management changes must be made that will result in higher quality effluent.

Table 2
Liquid effluent standards suggested by the International Finance Corporation (1998)

Parameter/pollutant	Maximum value
pH	6 to 9
BOD_5	50 mg/l
Oil and grease	10 mg/l
Total suspended solids	50 mg/l
Coliforms	Less than 400 MPN/100 ml (MPN = Most Probable Number)
Temperature increase	Less than or equal to 3 °C[a]

[a] The effluent should result in a temperature increase of no more than 3 °C at the edge of the zone where initial mixing and dilution take place. Where the zone is not defined, use 100 m from the point of discharge.

3. Codes of conduct

A large number of producer associations, governmental fishery agencies, international development organizations, environmental non-government organizations (NGOs), and others have formulated codes of conduct for aquaculture (Table 3). A code of conduct in its most basic form is a set of guiding principles consisting of broad statements about how management and other operational activities should be conducted. Most aquaculture codes reference the Code of Conduct for Responsible Fisheries presented by the Food and Agriculture Organization (FAO) of the United Nations (FAO, 1995, 1997) and the general principles of the codes usually reflect those of the FAO code. Most codes do not have any legal authority, and adoption usually is voluntary. In fact, codes may be developed in circumstances where either governmental regulations do not exist or are not enforced. The purpose of codes usually is to demonstrate environmental stewardship for purposes of improving the image of an industry. This is certainly one of the purposes in aquaculture.

Codes of conduct usually are supplemented by codes of practices that are basically a list of BMPS. These BMPs can be implemented in voluntary efforts to improve environmental performance, but it should be noted that all BMPs listed may not be fully applicable on all farms. The codes of practices also allow producers to cooperate with environmental agencies in developing formal governmental regulations based on BMPs (Boyd and Tucker, 2000; Boyd and Hulcher, 2001).

4. Best management practices

In environmental management, practices used to prevent water pollution and other negative environmental impacts are called best management practices and usually are referred to as BMPs (Hairston et al., 1995). A BMP is considered to be the best available and practical means of preventing a particular environmental impact while still allowing production to be conducted in an economically efficient manner. The word "best" is not intended to imply that a particular BMP will always be the best practice. The "best" practices must be selected based on site characteristics, and as technology advances, BMPs

Table 3
Partial list of organizations that have prepared codes of conduct for aquaculture

Alabama Catfish producers	Global Aquaculture Alliance
Agro Eco Consultancy	Industrial Shrimp Action Network
Aquaculture Foundation of India	Irish Salmon Growers Association
Australia Aquaculture Forum	Malaysia Department of Fisheries
Australian Prawn Farmers Association	Marine Shrimp Farming Industry of Thailand
British Columbia Salmon Farmers' Association	Missouri Department of Natural Resources
British Trout Association	Naturland
Catfish Farmers of America	Ornamental Fish Industry (United Kingdom)
Coastal Resources Center (University of Rhode Island)	Shrimp Farming Industry of Belize
Florida Department of Agriculture and Consumer Services	Soil Association (United Kingdom)
Food and Agriculture Organization of the United Nations	

must be revised to reflect new knowledge. Some workers do not like the term BMP and insist on referring to good management practices (GMPs) or better management practices. Nevertheless, the term BMP is acceptable terminology in environmental management, and its use should be encouraged over GMP or other acronyms. It should be emphasized that a BMP is seldom applied alone. A system of several BMPs usually must be installed to prevent water pollution and achieve resource management goals.

There has been widespread application of BMPs in traditional agriculture to prevent soil erosion and resulting turbidity and sedimentation in streams and other water bodies. In the United States, BMPs are the main feature of regulations of animal feed lot operations (AFOs) and concentrated animal feed lot operations (CAFOs). BMPs are most commonly associated with agriculture and other activities that cause non-point sources of pollution. However, BMPs also may be included in standard NPDES permits for non-agricultural, point source effluents (Gallagher and Miller, 1996).

There are many BMPs available for use in aquaculture, so a simple listing of BMPs is not useful. It is customary to group BMPs according to specific operations or objectives. Two groups of BMPs for aquaculture will be provided for illustration. Erosion of pond watersheds, embankments, bottoms, and discharge canals may be a significant source of suspended soil particles in effluents. These particles can increase turbidity and cause sedimentation in receiving waters. Some BMPs that may be adopted to prevent erosion are as follows:

(a) Use proper slopes and compaction to minimize erosion potential on embankments;
(b) Design discharge structures and canals to prevent erosion by impact of water or scouring by excessive water velocity;
(c) Provide vegetative cover on embankments and above water slopes of canals to prevent erosion;
(d) Provide grass cover on watersheds and gravel on farm roads and tops of embankments to prevent erosion;
(e) Position aerators to prevent erosion of insides of embankments and pond bottoms by aerator-induced water currents;
(f) Do not leave the drain open in empty ponds to prevent rainfall erosion and discharge of suspended solids;
(g) Do not allow livestock to walk on pond embankments or to wade in ponds; and
(h) Do not remove sediment from ponds and place in spoil piles on embankments or surrounding area; Use sediment to repair pond embankments or dispose of it in a responsible manner.

Of course, the above list is not exhaustive, and many other BMPs could be added. A producer would adopt only those BMPs appropriate for the particular site and operation.

Pond effluents contain nutrients that may cause eutrophication of receiving water bodies. Nutrient loads in effluents may be minimized through application of the following BMPs:

(a) Use fertilizers only as needed to maintain phytoplankton blooms;
(b) Select stocking and feeding rates that do not exceed the assimilation capacity of ponds;

(c) Feeds should be of high quality, water stable, and contain no more nitrogen and phosphorus than necessary;
(d) Apply feeds conservatively to avoid overfeeding and to assure that as much of the feed is consumed as possible;
(e) Do not use water exchange or reduce water exchange rates as much as possible;
(f) In intensive aquaculture, apply enough mechanical aeration to prevent chronically low dissolved oxygen concentration and to promote nitrification and other aerobic, natural water purification processes;
(g) Provide storage volume for heavy rainfall to minimize storm overflow;
(h) Deep water release structures should not be installed in ponds, for they discharge lower quality water from near pond bottoms;
(i) Where possible, seine-harvest fish without partially or completely draining ponds;
(j) Where possible, discharge pond draining effluent through a settling basin or a vegetated ditch; and
(k) Reuse water where possible.

As for erosion control BMPs, this selection of BMPs for nutrient management is only a partial list.

Many of the presentations of aquaculture BMPs are simply lists of suggested practices as in the examples above. The presentation of BMPs as brief statements leaves the producer to decide upon the method of implementation. It is desirable to present the BMPs in a document that contains suggestions, guidelines, and specifications for implementation. For example, the GAA prepared a series of codes of practices for use by shrimp farmers (Boyd, 1999). The codes of practices deal with nine selected topics, e.g., mangroves, feed practices, effluents and solid wastes, etc., each with a list of suggested BMPs. The GAA also prepared an implementation document that leads the producer through the steps necessary to execute the BMPs.

The Alabama Catfish Producers Association, Auburn University, Alabama Department of Environmental Management (ADEM), and the United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS) cooperated to develop BMPs for channel catfish farming in Alabama (Boyd and Hulcher, 2001). These BMPs were presented as a series of 15 NRCS Alabama Conservation Practice Guide Sheets (Auburn University and Natural Resources Conservation Service, 2002). Each guide sheet provides a discussion of the objectives of the practices, a list of the practices, implementation notes, and references. The BMPs will be maintained by NRCS, and ADEM will refer to the BMPs as necessary in their rules for regulation of aquaculture effluents in Alabama. The Florida Department of Agriculture and Consumer Services also made a BMP document for aquaculture that includes guidelines for implementation. Many codes of conduct and practices programs for aquaculture, however, do not include specific suggestions for implementation of BMPs (Boyd et al., 2001).

The use of BMPs as a basis for formal governmental regulation of aquaculture effluents in developing countries appears more feasible than application of effluent standards and permits. Although it would require considerable effort to enforce a regulatory system based on BMPs, the amount of resources, manpower, and expertise would be much less than for enforcement of effluent permits with water quality criteria. It should be possible by an annual inspection by a qualified professional to determine if BMPs have been implemented on a farm. Of course, specific rules must be established about the actions to be taken in case of non-compliance, just as is necessary in enforcement of effluent permits.

5. Certification

Some organizations allow producers to adopt environment management systems (EMS) based on record-keeping and BMPs and be certified as following the EMS. A good example is the International Standards Organization (ISO) 14001 Environmental Management System Standards (von Zharen, 1996). The standards for performance in aquaculture for the ISO 14001 must be provided by the producer. Basically, the producer makes an EMS, and ISO inspects the farm and verifies whether or not the EMS has been implemented. Compliance with the EMS permits ISO certification. Obviously, a code of conduct and practices program with BMPs could serve as the basis for ISO 14001 certification.

The GAA and ACC are collaborating to develop a certification program for shrimp aquaculture, in which shrimp will be certified as being produced according to specific standards. Several organizations such as Naturland (Germany) and the Soil Association (United Kingdom) have programs for organic certification of aquatic animal production. Although organic certification is for a much different purpose than environmental certification by ACC, the requirements for organic certification include some BMPs for protection of the environment.

6. Farm-level status and prospectus for effluent management

Aquaculture has a high profile because it usually is densely concentrated in specific areas and because profits can be much greater than for traditional agricultural crops. It has attracted the attention of powerful environmental groups in developed countries, and these groups have worked hard to convince governments to impose environmental regulations. In developing countries, environmental groups have focused almost entirely on aquaculture for export and mainly on shrimp farming. They have complained to local governments, but the focus has been on trying to convince consumers in developed countries that imported shrimp, salmon, and certain other aquatic products have a bad environmental record (Naylor et al., 1998, 2000).

Developed nations have either already developed or are developing aquaculture effluent regulations. Environmental advocacy groups will make sure that the regulations will be enforced. In a few years, most farms in developed countries will have to comply with the regulations. Of course, it is likely that farms below a given size, or farms operated by certain methods, may be exempt from effluent regulations.

The situation in developing nations is much less certain, and most of the world's aquaculture is in these nations. In spite of the recent worldwide concern over environmental issues in aquaculture, the preparation of codes of conduct by many organizations, and the development of aquaculture effluent regulations by several nations, relatively little has changed. Some large farms have been issued effluent permits, a few farms have voluntarily adopted BMPs, and even fewer farms have been certified for environmentally responsible operation. It is likely that many large fish and shrimp farms producing export products will adopt BMPs and some of these businesses also will seek environmental certification from one or more certifying bodies in order to protect their image among environmentally aware consumers. Some governments, such as Thailand, may succeed in enticing small-scale shrimp and fish farmers to produce certified aquaculture products for export.

It seems unlikely that governments in developing countries soon will be able to regulate aquaculture effluents effectively through effluent permits with standards or by mandated adoption of BMPs. Most of the world's aquaculture is in Asia and is directed to domestic markets. Consumers in these markets have much less interest in the environmental record of a product than in its cost. The powerful environmental NGOs have scant interest in domestic markets in developing nations. There is little opportunity for funding such efforts, and their image would suffer if they were perceived to interfere with the livelihood of small-scale farmers. Moreover, governments simply do not have the resources necessary to undertake the task of regulating effluents from many small farms.

The United States and most other developed nations will regulate aquaculture effluents. If this process is not done in a fair and reasonable manner, it could force many producers out of business. This would increase the demand for imported aquaculture products, and increase the possibilities for negative environmental impacts in tropical nations. Of course, the environmental NGOs will continue to complain, but they only will be able to influence aquaculture operations in developed countries and possibly the markets for shrimp, salmon, and other imported species.

Nevertheless, there are some positives related to aquaculture and the environment. Because of the controversy, producers are becoming more environmentally aware. I have seen many instances of farmers using better practices because they became aware of the consequences of their former methods. These farmers usually are leaders, and some of their neighbors may follow them. Nevertheless, there has been considerable effort in the United States and other countries to encourage the adoption of BMPs in traditional agriculture, and similar problems can be expected in aquaculture. Discussions with experts on BMPs for row-crops revealed that adoption of BMPs does not occur spontaneously. Farmers tend to be reluctant to change management practices, and they do not respond well to coercion. Fear of failing to comply with regulations (breaking the law) or threats of market losses because of consumer rejection of products produced by practices harmful to the environment have not resulted in willing and widespread adoption of BMPs. Even inducements based on subsidies to offset the cost of implementing BMPS often do not result in satisfactory implementation of BMPs.

The best inducement is when adoption of BMPs clearly increases profit. Thus, BMPs should be related back to farm economic performance. For example, suppose that the BMPs are to lower stocking rates and use better feed management. The lower stocking rates and smaller feed inputs will result in better water quality, less stress, faster growth, better feed conversion ratios, and less waste produced. However, this scenario also will increase efficiency and profits. Another example is the storage of rainfall in ponds to avoid overflow. Less overflow means that less water will need to be pumped into ponds to maintain water levels. A reduction in pump operation will reduce costs and increase profits. Probably, the most beneficial approach to encouraging use of BMPs is to promote better environmental education of producers rather than to try to regulate effluents. The education should consider the environmental benefits of BMPs, but it should focus on the greater profits that would accrue to farmers. This is certainly the case in developing nations.

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