BEST MANAGEMENT PRACTICES TO REDUCE WATER POLLUTION: THE CASE OF MARICULTURE

Denise L. Stanley
California State University-Fullerton, USA

Keywords: water pollution, best management practices, mariculture, water exchange, biosecurity

Contents

Summary

Many agro-industries, including aquaculture and mariculture in particular, face water pollution problems. The consensus has moved away from regulatory approaches to the adoption of best management practices to reduce water pollution. Six best management practices for mariculture are reviewed here, followed by a focus on reduced water exchange. The private costs and benefits of adopting this technique are reviewed, followed by the analysis of data from a water exchange experiment carried out in Ecuador in 1996. Results suggest the practice does reduce diesel costs but leads to lower pond productivity, so that profits are not increased. Changes in the economic environment would make the practice more attractive to farmers. An approach of adopting several best management practices simultaneously is suggested so that productivity losses can be minimized. The article concludes with suggestions for future research to answer some of the outstanding questions around these new water management practices.

1. Introduction: Water Pollution and Agro-Industries

Water is used as both an input and as a medium of waste disposal in many industrial and commercial processes. There is growing attention to the relationship between numerous agro-industrial enterprises and the water resource systems of both developed and developing countries. Animal agriculture activities—hog farming, chicken production, and aquaculture—play an important role in many watersheds, and their impact on water pollution and quality has come under scrutiny. More emphasis has been placed on the fact that aquacultural products, for instance, are an important source of foreign exchange revenues, and some employment, in many developing countries.
Aquaculture is a water-intensive industry. Operators regularly take and return large amounts of water from nearby public waterways. A recent study by the Environmental Defense Fund estimates that channel catfish require 6470 cubic meters of water per metric ton of fish produced; while intensively-farmed shrimp require 29 000–43 000 cubic meters in aerated systems. This converts to some thirteen to twenty cubic meters of water needed for every pound of fish produced.

1.1 Shrimp Farming Dilemmas

One of the most important branches of aquaculture—shrimp farming in developing countries—has important water management concerns. For high-valued species such as shrimp, mariculture represents some 30 percent of the total worldwide production. Farm-raised shrimp production involves the acclimatizion and stocking of wild or laboratory seed in a pond, followed by a grow-out period. Pond operations range from small artisanal units of one hectare or less to larger agro-industrial enterprises over 1000 hectares. During the four-month production cycle, feeds, some fertilizers and pesticides, and pumped water are continuously added to the pond as the animals grow to around 20 grams each. Stocking and feeding rates determine whether the operation is classified as extensive, semi-intensive, or intensive. (Extensive operations have a low density of animal stocking, with little supplementary feeding and environmental management. In contrast, intensive systems require stocking ponds at a higher density with controlled feeding and higher investment costs.) After harvest the animals are cleaned, de-headed, and packed for export.

In this process mariculture operators take and return large amounts of water from nearby estuaries for pond filling, routine exchange, and replacement. (The "water budget" of any given aquaculture pond is a factor of the gains of water (in terms of precipitation, direct runoff, stream inflows, and groundwater flows) and the losses of water from the pond (due to evaporation, seepage, spillway discharge, and consumptive use).) Water exchange is necessary to maintain appropriate levels of toxic metabolic wastes, excess algae, water temperature, calcium, chloride, salinity, pH, ammonia, nitrite, carbon dioxide, suspended solids, and, particularly, dissolved oxygen and salinity in the ponds. Dissolved oxygen can be increased by tidal flows, water circulation, and diffusion through wind power or the mechanical aeration of paddle wheels, pumps, weirs, or blowers. Mechanical aeration may appear prohibitively expensive for many semi-intensive farm operations due to the irregularity of electricity and large pond design. Thus water exchange may serves as a substitute for aeration in many developing countries.

Shrimp pond effluents then occur from excessive precipitation and evaporation, discharges from routine water exchange to dilute pond nutrients, and discharges when the pond is drained. Waste levels are a function of the water input level, feeding and fertilizer regimes, and increase in the last quarter volume of pond discharge. Excess uneaten feeds, fertilizers, pesticides, antibiotics, and chlorine used for water purification lead to higher levels of estuary suspended solids, dissolved and particulate inorganic and organic nutrients (such as ammonia and nitrate, nitrogen, phosphorus, and hydrogen sulfide), phytoplankton, and biochemical oxygen demand. Some of the most drastic implications are hypernutrification and eutrophication of adjacent estuaries with pond effluents, and impingement of estuarine biota through pumping and escape of livestock.

Mariculture is one of many water users in a watershed that may have a positive or negative impact on estuarine water quality. Domestic human and industrial waste is an important source of pollution for common waterways in farm sites near urban centers. (Indeed, shrimp farmers often argue that their contribution to water quality is positive as waters flushed out of shrimp ponds are cleaner than up-stream source estuary waters. Some studies have found water quality upstream in the Choluteca River of Honduras to be worse than that downstream for several farms. Aquaculture as an industry tends to produce a higher volume, but lower concentration, of effluents than other activities.) Some operators now realize careful water management is necessary to enhance biosecurity and reduce the risk of disease transmission. Water pollution and environmental deterioration has reduced the profitability of some farms in several Asian countries. The crucial water quality problem is the combined effect of many mariculture operations on a single estuary. The severity of this pollution ultimately turns on the carrying capacity of the watershed, whether receiving waters can dilute industrial and human wastes, and at what point each actor pushes ecological parameters to critical levels.

The remainder of this article examines the methods farmers are using to enhance the profitability of their operations while reducing waste and effluents. Several best management practices (BMPs) to enhance water quality are reviewed, followed by a focus on reduced water exchange. The costs and benefits of this single practice are examined in Section 2. Section 3 reviews the research around this practice, followed by data from a 1996 farm trial in Ecuador. The short-run cost-benefit analysis suggests that the practice is marginally profitable, so a combination of best practices together could appear more attractive to producers. Section 4 offers an integrated approach to the joint implementation of best management practices. Section 5 then concludes and provides suggestions for future research.

2. Single Best Management Practices for Improved Mariculture Water Quality

Best management practices provide an alternative combination of resource use, conservation practices, and management techniques, which, when applied to a resource, result in the opportunity for a reasonable economic return within acceptable environmental standards. Best management practices have been offered as an alternative to the technology-based water standards mandated by the traditional “command-and-control” environmental regulatory system of many developed countries. The voluntary adoption of BMPs is seen as a more acceptable method of achieving similar environmental outcomes.

Regarding mariculture, at least six farm management practices can reduce the water effluent problem:

- Water filters, treatment plants
- Sludge removal
- Co-production
- Reduced stocking and feeding rates
- Treatment ponds
- Reduced water exchange

2.1 Filters, Treatment Plants, and Co-Production

The first three options have been widely studied in the US but may face barriers in developing country settings. Aquaculture water substances are diffuse so that many practical methods of effluent water treatment are precluded. Putting in filters at the level of fineness needed (or using sand filters) could be prohibitively expensive, and filters would only reduce the problem of suspended solids, not dissolved inorganic materials such as ammonia. Chemical treatment plants with reservoirs and feedback canals also are probably prohibitively expensive and suffer from location bias. However, there is growing discussion around the use of filters and treatment of incoming waters.

The second option of removing sludge deposits has been successfully completed in several South Carolina experiments, but this technique often requires the installation of expensive water jets, suction dredges and pumps, or drain ports. Co-production techniques (such as producing shrimps and oysters with sedimentation devices together to remove suspended solids and allow the bivalves to absorb algae) are starting to be used as a promising biological treatment method.

2.2 Stocking, Feeding, and Treatment Ponds

Better stocking, feeding, and fertilizer regimes are a fourth promising technique. Intensification of operations means using more inputs, with more potential for wastes to affect effluent water quality. So using higher-quality feeds, using feeding trays, and reducing feed levels may increase feed assimilation so the total level of wastes could be reduced. (Excessive feeding is a thorny problem since fish normally absorb only 30% of the feed; uneaten feed and shrimp feces decompose and produce more carbon dioxide, ammonia, phosphates, phytoplankton growth, and other metabolic wastes in pond water. Data from a Thailand experiment demonstrate that for every metric ton of feed in intensive shrimp culture, nearly 1250 kg. of organic matter, 117 kg. of nitrogen, and 28 kg. of phosphorus are produced as waste for a normal feed-conversion ratio of 2.) Lower feed conversion ratios would allow more of the nutrients and chemicals to be recovered in the shrimp and reduce effluent loadings. High stocking densities force much of the dietary intake of the shrimp to go into the pond water as metabolic wastes (carbon dioxide, phosphorus, and ammonia), which in turn lower dissolvable oxygen levels. These changes lead to obvious reductions in production costs and possibly higher revenues for shrimp farmers.

Changed feeding regimes complement a fifth technique—the use of settling basins. Numerous studies at Auburn University in Alabama of both freshwater catfish and brackish water mariculture demonstrate enhanced water quality benefits from allowing water to settle before discharge. Although the absorption of phytoplankton, dissolved substances, and nitrogen is minimal in settling ponds, some ammonia is absorbed in the pond soils, suspended solids are reduced, and sediments left in the ponds may actually fertilize the soil. Of course the settling rate is a function of the particle size, soil type, water turbulence, and salinity. Benefits from settling the water for just sixty minutes can be achieved in high saline environments, suggesting even greater benefits of this technique in brackish water mariculture.

Beyond these benefits to the general environment, farmers themselves may enjoy reduced disease risks and losses throughout the year if the water they are using in an estuary is cleaner. This would be the case if all farms jointly adopted effluent settling basins so that collective benefits could be felt across an estuary. Some farmers may prefer settling basins for incoming waters, rather than effluents, since they perceive the pollution effects of other industries to be a primary concern. Thus some confusion still exists around the efficacy of effluent settling basins.

Besides pumping charges, the main cost of settling ponds is the land required for the settling basin. Taking a one hectare pond out of production for one cycle may represent losses of some US$500–2500, as will be seen below. Settling basins generally must be twice the size of the pond itself. Alternatively, a separate construction may be developed from existing canals. In either case, farmers may resist basins in areas where land is highly valued. A cheaper option would be to use natural wetlands (e.g. mangroves) or constructed wetlands as a discharge area—however, the amount of wetlands needed may be quite large.

2.3 Reduced Water Exchange

The sixth alternative—reduced water exchange—may be the easiest individual practice to change since it involves almost a zero increase in fixed costs and direct reductions in operating costs. "Reduced exchange" involves many variations—from lowering the daily rate, to reusing water in a nearby pond, to complete recycling and elimination of water exchange. Overall less estuary water is taken in and flushed out, so environmental benefits may follow.

-
-
-

Bibliography

Beveridge M. Phillips M., and Clarke R. (1991). A quantitative and qualitative assessment of wastes from aquatic animal production. In D. Brune and J. Tomasso, eds. Aquaculture and Water Quality, *Advances in World Aquaculture* **3**, 506-533. Baton Rouge, LA: World Aquaculture Society. [This year of the book series focuses on effluents and aquaculture water management strategies.]

Boyd C. (1982, 1990). *Water Quality Management for Pond Fish Culture*, **7 & 9**, 171-179 & 303-306. Amsterdam: Elsevier Scientific Publishing. Updated as *Water Quality for Ponds in Aquaculture.* [This is a comprehensive textbook of water management for aquaculture in general.]

Boyd, C. and Tucker, C. (1998). Pond Aquaculture Water Quality Management, **14**, 541-575._Boston: Kluwer Academic Press.

Browdy C. and Hopkins J. S., eds. (1995). *Swimming Through Troubled Water: Proceedings of the Special Session on Shrimp Farming.* (Annual Meeting of the World Aquaculture Society, San Diego, CA, 1995.) Baton Rouge, LA: World Aquaculture Society. [This conference abstract continues the earlier presentation of industry managers and researchers on strategies to reduce the environmental impact of shrimp farming.]

Chamberlin G., Villalon J., and Wyban J., eds. (1992*). Proceedings of the Special Session on Shrimp Farming.* (Annual Meeting of the World Aquaculture Society, Orlando, FL, 1992. Baton Rouge.) Los Angeles: World Aquaculture Society. [This conference abstract contains important comments by shrimp farm managers and researchers about a variety of water quality issues.]

Dierberg F. and Kiattisimkul W. (1996). Issues, Impacts and Implications of Shrimp Aquaculture in Thailand, *Environmental Management* **20**, 649–666. [This is one of the often-cited articles on mariculture water pollution and experimental techniques in Asia.]

Enga H. and Boyd C. (1997). *Dynamics of Pond Aquaculture*, **7**, 163-200, Boca Raton, FL: CRC Press. [This is an updated pond management textbook, with special attention to environmental issues and regulatory approaches in the U.S.)

Goldburg R. and Tirplett T. (1997). *Murky Waters: Environmental Effects of Aquaculture in the United States*, **2**, 33-48. Report for the Environmental Defense Fund, October. [This non-governmental organization report discusses how aquacultural enterprises interact with the natural environment and what are some of the negative side-effects as well as strategies for change.]

Hopkins J. S. (1996). Aquaculture sustainability: avoiding the pitfalls of the green revolution, *World Aquaculture* **27**, 13–15. [This widely-cited journal article provides an overview of the common water pollution problems of shrimp farming and the South Carolina experiments with reduced water exchange.]

Hopkins J., Hamilton R., Sandifer P., Browdy C., and Stokes A. (1993). Effect of water exchange rate on production, water quality, effluent characteristics and nitrogen budgets of intensive shrimp ponds*. Journal of the World Aquaculture Society* **24**, 304–320. [This journal article provides the details of an important South Carolina experiment with reduced water exchange.]

Rosenberry B. (1997). *World Shrimp Farming 1997 (and various years)*. San Diego, CA: Shrimp News International. [This yearly report provides an overview of trends in the worldwide shrimp farming industry as well as news from farmers' experiments and production outcomes.]

Sandifer P., and Hopkins J. S. (1995). Progress Toward an Environmentally-Friendly, Pond-Based Shrimp Mariculture System. *Aquaculture Engineering*, **14**, 1–30. [This article is a discussion of a wide-range of practices to reduce the environmental impacts of shrimp farming, with an emphasis on closed recirculating systems.]

Biographical Sketch

Denise Stanley teaches at California State University-Fullerton and completed her Ph.D. at the University of Wisconsin in 1996. Previous to this she studied in England and worked with a variety of non-governmental organizations in Central America and the Caribbean. Dr. Stanley specializes in development economics and the application of environmental economics in developing countries. Her recent publications have appeared in a variety of economics and interdisciplinary journals, as well as edited book chapters. Her research program has emphasized the environmental and economic impacts of natural-resource based export industries such as mariculture and non-timber forest products. She is interested in the promotion of sustainable development techniques and policies and a variety of topics in applied microeconomics.