WHITE PAPERS

CONTENTS

Aquaculture Best Management Practices as a Possible Focus for Future PD/A CRSP Research

Claude E. Boyd
Department of Fisheries and Allied Aquacultures
Auburn University, Alabama

C. Wesley Wood
Department of Agronomy and Soils
Auburn University, Alabama

Aquaculture is growing rapidly in many areas of the world, and as with most rapidly growing activities, conflicts with other resource users are occurring. The conflicts involve mostly environmental and social issues. In some cases, conflicts result from poor planning or bad management by aquaculturists. There are also instances where poor planning and management by other resource users have negatively impacted aquaculture. Moreover, some critics of aquaculture do not have a good understanding of this industry and make uninformed and exaggerated claims about the problems caused by aquaculture.

Aquaculture is an essential activity. The world population is increasing rapidly, and about 20% of the animal protein available to the human population originates from fisheries products (Anonymous, 2000). Capture fisheries are apparently being exploited to the maximum and cannot be expected to provide additional aquatic food products. Aquaculture currently provides about 20% of the world's fisheries products, and it must increase production to keep up with the greater demand for fisheries products. It is anticipated that aquaculture will provide 20 to 40% of the world's fisheries products by 2010 (Anonymous, 2000).

In spite of the importance of aquaculture to world food supplies, its future will be diminished unless it improves its environmental and social image (Boyd and Tucker, 1998). Aquaculture, like other kinds of agriculture, is conducted on a variety of scales, and production methods vary greatly. Although aquaculture has been growing rapidly for several decades, site selection often is done in a haphazard way, design and construction procedures often are not based on sound engineering principles, and many producers do not employ efficient management systems. Environmental aspects are seldom considered, and in some parts of the world, aquaculture has been embroiled in social conflicts (Primavera, 1989).

It is interesting that aquaculture is a relatively disorganized activity, because a tremendous amount of research has been conducted on shrimp and fish farming. This research has resulted in highly efficient and environmentally responsible production methods, but the degree of adoption of this information by both small and large producers has been slow and incomplete.

Prospects for increasing world fisheries production through aquaculture would be greatly enhanced if fish and shrimp farmers adopted the most efficient and environmentally responsible production techniques available. It also would be helpful if production techniques were standardized as much as possible. In addition to improving performance, aquaculture would benefit from programs to improve its image with environmental advocacy groups, human rights organizations, and consumers (Boyd and Clay, 1998). Obviously, achievement of these objectives will require a great effort in research and development, extension, and public education and cooperation among many organizations with different and sometimes conflicting interests.

ENVIRONMENTAL ISSUES AS POSSIBLE NEW FOCUS

The fact that aquaculture can have undesirable environmental and social impacts if it is conducted improperly cannot be denied. Although there has been little restriction of production techniques in the past, there is increasing environmental awareness and national and international pressure from environmental activists and from the public for better environmental stewardship in aquaculture. These pressures will ultimately force governments to regulate aquaculture and are already influencing aquaculture in the United States. Although some states have regulated aquaculture under the National Pollution Discharge Elimination System of the Clean Water Act for more than a decade, the United States Environmental Protection Agency (EPA) has no national rule for effluent discharges. Thus, states are not required to regulate aquaculture effluents, and most states with a large aquaculture sector do not regulate them. The Environmental Defense Fund (EDF) prepared a document entitled "Murky Waters, the Environmental Effects of Aquaculture in the United States" (Goldburg and Triplett, 1997). The main recommendation of this document was that the EPA should regulate aquaculture under the Clean Water Act. The EDF convinced the EPA to embark upon a formal rule-making procedure for aquaculture effluents. This process is well underway; the draft rule is due in June 2002, and the final rule will be presented in June 2004 (Federal Register, 2000). When the EPA rule has been finalized, all states will be required by law to regulate aquaculture effluents.

Some other developed nations are ahead of the United States and already regulate all aquaculture facilities within their borders. It seems clear that nearly all nations with commercial aquaculture facilities will eventually develop and enforce some type of regulation. In the meantime, there will be increasing criticism of the environmental and social performance of aquaculture in nations where regulations do not exist or where regulations exist but are not enforced. Thus, many large aquaculture producers, aquaculture associations, aquaculture scientists, and regional, national, and international organizations involved with aquaculture realize that aquaculture should rapidly adopt more environmentally and socially responsible methods of aquaculture.

The Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP), which is supported by the United States Agency for International Development (USAID), has worked for many years developing better methods for producing fish and crustaceans in ponds (Egna, 1997). This aquaculture activity has been conducted in many countries. Because of its success, it has developed an international reputation as a source of data on pond aquaculture. Although the PD/A CRSP has conducted some studies related to aquaculture and the environment, its major focus has been on production techniques and the description of factors affecting production (Egna and Boyd, 1997). The PD/A CRSP is soon due to be renewed, and many participants of the

PD/A CRSP feel that there should be some change in the focus of the research and development effort if a renewal proposal is prepared.

Most people involved in efforts to improve the environmental and social performance of aquaculture think that the best short-term approach is to develop Best Management Practices (BMPs) for voluntary adoption by the aquaculture industry in countries where effective national aquaculture regulations are not expected in the near future. BMPs may also be used in programs to "eco-label" and certify aquaculture products, and they may even be the basis for national aquaculture regulations. Much activity has been initiated on BMPs for improving environmental and social responsibility in aquaculture, but even more remains to be done if BMPs are to be effective for the intended purpose. Thus, the "aquaculture and the environment" issue—with focus on identification of negative environmental impacts, development of BMPs for preventing these impacts, verification of the benefits of BMPs, and promotion of BMPs—appears to present an excellent opportunity for a new focus of the PD/A CRSP. This effort would be interdisciplinary, proactive, and diverse. It could encompass a wide variety of issues to include environmental impact assessment of various kinds of aquaculture in different countries, development of BMPs from existing data and from results of new studies, verification of BMPs, and efforts to enhance the implementation of BMPs. Work could be extended to include social issues, because both social and environmental concerns have been directed at aquaculture.

Although environmental assessment and BMPs have been widely used in environmental management, they are somewhat new in aquaculture. Thus, some information on these topics will be provided.

ENVIRONMENTAL ASSESSMENT

Environmental Impact Assessment (EIA) has been widely applied to identify possible negative environmental and social impacts of proposed projects. Many governments and lending agencies require EIA before approving projects or loans for projects. The procedure for conducting EIAs is fairly standard. The EIA typically requires a description of the project and determination of all regulations and permits that apply to it. The possible negative environmental and social impacts must be identified and alternatives for project development discussed. A mitigation plan for preventing or ameliorating possible negative impacts through design features, project layout, specified production methods, or other means are provided. Moreover, a monitoring program to verify that procedures recommended in the mitigation plan are preventing negative impacts is needed.

The EIA concept also can be applied to an entire industry to determine possible or actual impacts and to recommend ways of mitigating these impacts. For example, Tookwinas (1996) made an environmental assessment of the marine shrimp farming industry in Thailand and recommended BMPs for preventing negative environmental impacts. Boyd et al. (2000) made an assessment of channel catfish farming in Alabama. To illustrate the kinds of information that result from EIAs, the major findings of the channel catfish assessment are listed below:

1) Catfish farming in Alabama is conservative of water, and excluding storm overflow, about two pond volumes are intentionally discharged for each pond in 15 years.
2) Overflow from ponds following rains occurs mostly in winter and early spring when pond water quality is good and stream discharge volume is high.
3) Total suspended solids concentrations in pond effluents were high, and the main sources of total suspended solids were erosion of embankments, pond bottoms, and discharge ditches.
4) Concentrations of nitrogen and phosphorus in effluents were not high, but annual effluent loads of these two nutrients were greater than for typical row crops in Alabama.
5) Groundwater use by the industry is about 86,000 m^3d^{-1}, but seepage from ponds returns water to aquifers.
6) There is little use of medicated feeds.
7) Copper sulfate is used to control blue-green algae and off-flavor in ponds, but copper is rapidly lost from pond water.
8) Although sodium chloride is applied to ponds to control nitrite toxicity, stream- or groundwater salinization has not resulted from this practice.
9) Fertilizers are applied two or three times annually to fry and fingerling ponds and occasionally to grow-out ponds.
10) Hydrated lime is applied occasionally at 50 to 100 $kgha^{-1}$, but this does not cause high pH in pond waters or effluents.
11) Accumulated sediment removed from pond bottoms is used to repair embankments and not discarded outside ponds.
12) Sampling above and below catfish pond outfalls on eight streams revealed few differences in stream water quality.
13) Electricity used for pumping water and mechanical aeration is only 0.90 $kWhkg^{-1}$ of production.
14) Each ton of fishmeal used in feeds yields about 10 tons of dressed catfish.

The practices recommended to improve the environmental performance of channel catfish farming in Alabama also will be listed:

1) Establish grass cover on denuded areas of pond watersheds to minimize erosion.
2) Provide grass cover on the interior and exterior of pond embankments to minimize erosion.
3) Divert excess runoff from large watersheds away from ponds to minimize total suspended solids input to ponds.
4) Use stocking and feeding rates that do not lead to excessive phytoplankton blooms and serious water quality deterioration within ponds.
5) Avoid feeding more than the fish will eat in order to prevent accumulation of uneaten feed in ponds.
6) Use fertilizers only if necessary to promote plankton blooms.
7) Maintain storage capacity in ponds to capture rainfall and runoff and minimize the necessity to add water from wells.
8) Avoid deep-water discharge structures in ponds because surface waters usually are of higher quality than deeper waters.
9) Position mechanical aerators to minimize erosion of pond bottoms and embankments, but use adequate aeration to prevent low dissolved oxygen concentrations.

10) Avoid discharging water during final seining, and when ponds are completely drained, release the final volume of water as slowly as possible to minimize discharge of potential pollutants.
11) Where possible, construct check dams in farm ditches to retain discharge and allow solids to settle.
12) Do not leave ponds empty in winter, and shut valves when ponds are empty to prevent discharge of suspended solids after rains.
13) Close pond valves when renovating inside earthwork to prevent discharge of suspended solids after rains and to conserve water.
14) Use sediment removed from pond bottoms to repair earthwork rather than disposing of it outside of ponds to reduce potential erosion from the farm.
15) Extend drain pipes beyond toes of embankments to prevent erosion of the embankment by discharge.
16) Construct ditches with adequate hydraulic cross-sections and side-slopes to minimize erosion, and establish grass cover in ditches.
17) Install concrete structures or rip-rap to protect areas subject to erosion by rapidly flowing discharge.
18) Extend pipes that discharge directly into streams to prevent bank erosion.
19) Where possible, release pond effluents into natural wetlands to take advantage of natural water treatment.
20) Store materials such as fertilizers, lime, salt, and other pond amendments so that they are not washed into streams by rainfall.

The EIA of channel catfish farming (Boyd et al., 2000) is being used by the EPA as background information for development of a federal rule for regulating aquaculture effluents in the United States. It also is being used by a committee in the State of Alabama as the basis for development of a system of BMPs to be used in lieu of effluent standards for regulation of catfish farms by the Alabama Department of Environmental Management. Thus, environment assessments can be extremely important activities.

Environmental Management

The most advanced level of environmental management is the development and enforcement of rules and regulations regarding how activities should be conducted in order to provide environmental protection. In pond aquaculture, contamination of natural waters with nutrients, organic matter, and suspended solids in effluents usually is the major environmental concern. Pond aquaculture normally cannot be conducted without effluents, so the most advanced regulation would be to require aquaculture operations to reduce concentrations and loads of pollutants in effluents to levels that will not cause deterioration of water quality in receiving waters. However, many nations do not have or do not enforce environmental regulations for aquaculture. Thus, in such countries it would be highly desirable to encourage fish and shrimp farmers to voluntarily adopt practices that are environmentally and socially responsible.

Management Systems

Many industries have found that management procedures can be organized into a system to improve efficiency and enhance environmental and social performance. There has been some effort to develop systems approaches to aquacultural production, but there is much opportunity for improvement in this area. Management systems are most suitable for well-organized activities such as manufacturing and distribution, where procedures are clearly defined and usually standardized. Nevertheless, it should be possible to organize aquacultural production activities into systems. The systems would vary depending upon location, species, type of grow-out (ponds, cages, raceways, etc.), intensity of production, and other factors. In terrestrial agriculture, the best practices for conducting a particular activity are called Best Management Practices, and a sound management system to promote efficient, environmentally and socially responsible aquaculture could be based on BMPs. However, in terrestrial agriculture and particularly in concentrated animal feeding operations, BMPs are often a component of formal regulations (United States Environmental Protection Agency, 1995). In voluntary adoption of management systems to demonstrate environmental and social responsibility, BMPs usually are incorporated in Codes of Practice, which accompany Codes of Conduct.

CODES OF CONDUCT

A Code of Conduct usually is a short declaration containing several general statements about how the participants in some activity should conduct their affairs. For example, there can be codes about how meetings are held, how businesses should treat clients, or how a product should be manufactured. The Food and Agriculture Organization (FAO) of the United Nations (1997) developed a Code of Conduct for Responsible Fisheries, and this document contains a Code of Conduct for Responsible Aquaculture (Table 1). The FAO Code of Conduct is typical of Codes of Conduct in that it consists of a series of general statements on how aquaculture should be conducted. In the case of the FAO code, the statements are addressed to the governments of the world. However, an aquaculture association or an individual aquaculturist can adopt a modified version of the FAO Code of Conduct for Aquaculture. For example, the Global Aquaculture Alliance (GAA) is an organization of seafood importers, producers, aquaculture associations, and related businesses devoted to the responsible production of aquaculture products. The GAA modified the FAO Code of Conduct for Aquaculture to form their guiding principles, or Code of Conduct (Boyd, 1999).

The general principles in Codes of Conduct usually are expressed in more detailed Codes of Practice. Some organizations do not bother to produce a Code of Conduct and have only the Code of Practice.

The statements in Codes of Practice usually are called Best Management Practices (BMPs). In environmental management, practices considered to be the most practical and effective means of achieving a particular resource management goal, or to prevent one or more negative environmental impacts are called BMPs (Alabama Soil and Water Conservation Committee, 1995). Usually a single BMP will not solve a problem, and several BMPs must be used. Some do not like the term BMP for it implies that the best way of preventing a negative outcome is known. Of course, the term BMP only is intended to imply that the practice is the best way currently known for preventing the negative outcome. As technology advances, BMPs must be revised. Those who do not like the term BMP often refer to good management practices (GMPs). The term BMP is well established in agriculture and pollution abatement, so we see no reason for using GMP or some other term.

There currently is considerable interest in developing codes of practice to demonstrate dedication to environmental stewardship. These Codes of Conduct usually contain best management practices. For example, the GAA recently prepared codes of practice for nine different aspects of shrimp farming (Table 2). Each code contains several BMPs, as illustrated in Table 3. Many other organizations have developed codes of practice for aquaculture. A partial list of these organizations is provided below:

Belize Shrimp Farmers Association
Marine Shrimp Farming Industry of Thailand
Malaysian Department of Fisheries
Irish Salmon Farmers Association
British Trout Growers Association
Florida Department of Agriculture
State of Missouri
Global Aquaculture Alliance
Australian Prawn Producers Association

Several benefits can result from the application of Codes of Practice and BMPs. Adoption of BMPs can improve the environmental and social performance of shrimp farms and demonstrate that producers desire to conduct their activities in a responsible way. By publicizing the use of BMPs, it would be possible to counteract recent negative views about aquaculture expressed by environmental activist groups and improve its public image. In countries where governments are already considering the possibility of aquaculture regulations, an organized effort to formulate and implement BMPs that include collaboration with regulatory agencies, environmental interest groups, and other stakeholders would be a proactive approach. Proof of compliance with a formal BMP system might substitute for more formal regulations or be a major component of these regulations. The transfer of technology and new research findings to producers, and especially to small producers in third-world countries, is a difficult task. Organization of the best technology into a system of BMPs would be an excellent means of technology transfer. Some industries have created markets for products that are certified to have been produced by environmentally responsible methods. Compliance with a Code of Practice would be an essential component of a program to market a certified, eco-labeled aquaculture product.

There also are several problems associated with Codes of Practice. The development of a Code of Practice is a relatively easy task for aquaculture specialists because most of the better practices are known. However, studies have not been conducted with particular systems of BMPs to determine if their implementation will actually improve environmental protection and avoid social conflicts. Although aquaculture experts may agree that Codes of Practice will provide benefits, documentation of these benefits is needed to convince environmental advocacy groups and regulatory agencies. Adoption of Codes of Practice by producers also poses a problem. Unless the better practices are used by the producer, no benefits will result. The more progressive farmers may be receptive to voluntarily adopting Codes of Practice, but a large education program will probably be required to cause the general adoption of a Code of Practice within a given area. Adoption of the practices will require an investment in time, effort, and money, so some producers may refuse. Other producers may adopt the practices that are inexpensive or easy to implement and ignore the others. Furthermore, unless studies are conducted to ascertain how well producers comply with the program and the degree of adoption, there is no real proof that better practices are being used.

Codes of Practice tend to be brief descriptions of how some aspect of production should be conducted or a terse comment about how to avoid a negative impact. For example, there might be a practice stating that feed should be applied at reasonable rates to prevent overfeeding. This statement assumes that the farmer will know how to determine how much the culture species will eat. If the farmer already knows this, why is there widespread overfeeding in pond aquaculture? Details should be provided to explain why it is undesirable to overfeed, how to determine the optimum feeding rate, how to apply the feed so that it will be completely consumed, and what benefits will occur to the environment and to the farmer. For maximum effectiveness, a Code of Practice should be accompanied by an operations manual for implementation of the practices. This will be especially true for small producers who tend to be less technologically aware than larger producers.

The PD/A CRSP would no doubt be more interested in working with small- and medium-sized producers than with large producers. Therefore, particular attention would have to be given to developing systems of BMPs for small-scale aquaculture. Emanuel Polioudakis, an anthropologist, has considerable experience with an association of small shrimp farmers in Thailand. He prepared a report on the possible application of BMPs by small shrimp farmers. Many of the comments in this report would apply equally well to small fish farmers. Therefore, the report of Emanuel Polioudakis is attached as an appendix.

Conclusions

Issues related to the influence of aquaculture on the environment will become increasingly important in the future. Production techniques that are environmentally and socially responsible should be promoted and adopted by the aquaculture industry throughout the world. Most nations will eventually impose regulations to improve the environmental and social performance of aquaculture, but only a few nations currently have such regulations or are in the process of making them. In countries without aquaculture regulations, voluntary adoption of better management practices by producers is the only means of improving environmental and social responsibility. A large scientific effort will be required to develop and verify the effectiveness of systems of BMPs for use in different kinds of aquaculture and in different regions. The educational effort to promote BMPs among producers and the monitoring effort to determine the degree of adoption of BMPs by producers also would be considerable. The PD/A CRSP has developed a large database and amassed considerable expertise in pond aquaculture in developing nations. Thus, aquaculture and the environment with emphasis on development of BMPs to avoid negative impacts in pond aquaculture are a possible new focus for the PD/A CRSP.

References

Alabama Soil and Water Conservation Committee, 1995. Protecting water quality on Alabama's farms. Alabama Soil and Water Conservation Committee, Montgomery, Alabama.
Anonymous, 2000. Status of world aquaculture 2000. Aquaculture Magazine Buyer's Guide and Industry Directory 2000, 29:6–42.
Boyd, C.E., 1999. Codes of practice for responsible shrimp farming. Global Aquaculture Alliance, St. Louis, Missouri.
Boyd, C.E. and J.W. Clay, 1998. Shrimp aquaculture and the environment. Scientific American, June 1998, 278(6):42–49.
Boyd, C.E. and C.S. Tucker, 1998. Pond Aquaculture Water Quality Management. Kluwer Academic Publishers, Boston, Massachusetts, 700 pp.
Boyd, C.E., J. Queiroz, J. Lee, M. Rowan, G. Whitis, and A. Gross, 2000. Environmental assessment of channel catfish (*Ictalurus punctatus*) farming in Alabama. Journal of the World Aquaculture Society, 31:511–543.
Egna, H.S., 1997. History of the Pond Dynamics/Aquaculture Collaborative Research Support Program. In: H.S. Egna and C.E. Boyd (Editors), Dynamics of Pond Aquaculture. CRC Press, Boca Raton, Florida, pp. 19–52.
Egna, H.S. and C.E. Boyd (Editors), 1997. Dynamics of Pond Aquaculture. CRC Press, Boca Raton, Florida, 437 pp.
Federal Register, 2000. Environmental Protection Agency, Effluents Guidelines Plan. Federal Register: June 16, 2000 (Volume 65, Number 117), Office of the Federal Register, National Archives and Records Administration, Washington, D.C. pp. 37783–37788.
Food and Agriculture Organization (FAO) of the United Nations, 1997. Aquaculture development. FAO Technical Guidelines for Responsible Fisheries, FAO, Rome, Italy.
Goldburg, R. and T. Triplett, 1997. Murky waters: Environmental effects of aquaculture in the United States. Environmental Defense Fund, Washington, DC.
Primavera, J.H., 1989. The social, ecological, and economic implications of intensive shrimp farming. Asian Aquaculture, 11:1–6.
Tookwinas, S., 1996. Environmental impact assessment for intensive marine shrimp farming in Thailand. Thai Fisheries Gazette, 49:119–133.
United States Environmental Protection Agency, 1995. Guide manual on NPDES regulations for concentrated animal feeding operations. EPA 833-B-95-001. United States Environmental Protection Agency, Office of Water, Washington, DC.

Table 1. The Articles of the FAO Code Of Conduct for Aquaculture.

1) States should establish, maintain, and develop an appropriate legal and administrative framework which facilitates the development of responsible aquaculture.
2) States should promote responsible development and management of aquaculture, including an advance evaluation of the effects of aquaculture development on genetic diversity and ecosystem integrity, based on the best available scientific information.
3) States should produce and regularly update aquaculture development strategies and plans, as required, to ensure that aquaculture development is ecologically sustainable and to allow the rational use of resources shared by aquaculture and other activities.
4) States should ensure that the livelihoods of local communities, and their access to fishing grounds, are not negatively affected by aquaculture developments.
5) States should establish effective procedures specific to aquaculture to undertake appropriate environmental assessment and monitoring with the aim of minimizing adverse ecological changes and related economic and social consequences resulting from water extraction, land use, discharge of effluents, use of drugs and chemicals, and other aquaculture activities.
6) States should protect transboundary aquatic ecosystems by supporting responsible aquaculture practices within their national jurisdiction and by cooperation in the promotion of sustainable aquaculture practices.
7) States should, with due respect to their neighbouring States, and in accordance with international law, ensure responsible choice of species, siting and management of aquaculture activities which could affect transboundary aquatic ecosystems.
8) States should consult with their neighbouring States, as appropriate, before introducing non-indigenous species into transboundary aquatic ecosystems.
9) States should establish appropriate mechanisms, such as databases and information networks to collect, share and disseminate data related to their aquaculture activities to facilitate cooperation on planning for aquaculture development at the national, subregional, regional and global level.
10) States should cooperate in the development of appropriate mechanisms, when required, to monitor the impacts of inputs used in aquaculture.
11) States should converse genetic diversity and maintain integrity of aquatic communities and ecosystems by appropriate management. In particular, efforts should be undertaken to minimize the harmful effects of introducing non-native species or genetically altered stocks used for aquaculture including culture-based fisheries into waters, especially where there is a significant potential for the spread of such non-native species or genetically altered stocks into water under the jurisdiction of other States as well as waters under the jurisdiction of the States of origin. States should, whenever possible, promote steps to minimize adverse genetic, disease and other effects of escaped farmed fish on wild stocks.
12) States should cooperate in the elaboration, adoption and implementation of international Codes of Practice and procedures for introductions and transfers of aquatic organisms.
13) States should, in order to minimize risks of disease transfer and other adverse effects on wild and cultured stocks, encourage adoption of appropriate practices in the genetic improvement of broodstocks, the introduction of non-native species, and in

the production, sale and transport of eggs, larvae or fly, broodstock or other live materials. States should facilitate the preparation and implementation of appropriate national codes of practice and procedures to this effect.

14) States should promote the use of appropriate procedures for the selection of broodstock and the production of eggs, larvae and fry.
15) States should, where appropriate, promote research and, when feasible, the development of culture techniques for endangered species to protect, rehabilitate and enhance their stocks, taking into account the critical need to conserve genetic diversity of endangered species.
16) States should promote responsible aquaculture practices in support of rural communities, producer organizations, and fish farmers.
17) States should promote active participation of fishfarmers and their communities in the development of responsible aquaculture management practices.
18) States should promote efforts which improve selection and use of appropriate feeds, feed additives and fertilizers, including manures.
19) States should promote effective farm and fish health management practices favouring hygienic measures and vaccines. Safe, effective and minimal use of therapeutants, hormones and drugs, antibiotics and other disease control chemicals should be ensured.
20) States should regulate the use of chemical inputs in aquaculture which are hazardous to human health and the environment.
21) States should require that the disposal of wastes such as offal, sludge, dead or diseased fish, excess veterinary drugs and other hazardous chemical inputs does not constitute a hazard to human health and the environment.
22) States should ensure the food safety of aquaculture products and promote efforts which maintain product quality and improve their value through particular care before and during harvesting and on-site processing and in storage and transport of the products.

Table 2. List of Codes of Practice available from Global Aquaculture Alliance.

Mangroves
Site Evaluation
Design and Construction
Feeds and Feed Use
Shrimp Health Management
Therapeutic Agents and Other Chemicals
General Pond Operations
Effluents and Solid Wastes
Community and Employee Relations

Table 3. Global Aquaculture Alliance Management Practices for Mangrove Protection.

Purpose:

The Code is designed to foster greater environmental awareness within the shrimp farming industry to assure continued protection of mangrove forests from potentially adverse impacts of coastal aquaculture. Recognizing the multitude of different conditions impacting mangroves in different countries and regional locations, this Code is to be interpreted as a flexible set of criteria to be used to assist any and all interested parties in formulating codes, regulations, and principles for protecting mangrove forests.

The Code helps to achieve several of the "Guiding Principles of Responsible Aquaculture" by encouraging the following:

- The shrimp aquaculture industry will promote responsible and sustainable development and management practices ensuring the preservation of mangroves and the sustainability of shrimp aquaculture.
- Shrimp aquaculture industries will promote alternative development programs aimed at protecting mangroves while benefiting local communities in mangrove areas.
- Producers shall adhere to national and local regulations applicable to mangroves and to shrimp farming.

Management Practices:

It shall be the objective of all adherents to this Code to not harm mangrove ecosystems, and whenever possible, to preserve and even enhance the biodiversity of these ecosystems. The following practices will ensure the protection of mangrove ecosystems:

1) New shrimp farms should not be developed within mangrove ecosystems.
2) Realizing that some mangrove must be removed for canals when new shrimp farms are sited behind mangroves, a reforestation commitment of no net loss of mangroves shall be initiated.
3) Farms already in operation will continue ongoing environmental assessments to recognize and mitigate any possible negative impacts on mangrove ecosystems.
4) All non-organic and solid waste materials should be disposed of in an environmentally responsible manner, and waste water and sediments shall be discharged in manners not detrimental to mangroves.
5) The shrimp aquaculture industry pledges to work in concert with governments to develop sound regulations to enhance the conservation of mangroves including regulations regarding restoration of mangrove areas when old farms located in former mangroves are decommissioned.
6) The shrimp aquaculture industry will promote measures to ensure the continued livelihood of local communities that depend upon mangrove resources.

Biotechnology, Genetics, and Disease Issues in Aquaculture

Christopher Brown
Marine Biology Program
Florida International University
North Miami, Florida, USA

Amrit Bart
Aquaculture and Aquatic Resources Management
Asian Institute of Technology
Pathumthani, Thailand

Executive Summary

Applications of biotechnology in human health, medicine, and agriculture have been increasing rapidly in recent years. The development of a variety of materials capable of promoting increased agricultural production has led many to believe that this approach can provide a viable means of solving major economic problems, possibly including some of the constraints and limitations on world food production by aquaculture.

Technical progress in emerging technologies can be expected to become available globally for agricultural and aquacultural applications. The biotechnology industry is believed to be approaching profitability; growth in investment, employment, and revenues has been brisk, doubling within the past six years (Ernst and Young, 2000). Opportunities to address disease problems and to produce aquaculture crops more efficiently by the manipulation of the genomes of culture subjects are among the likely areas in which progress can be expected reasonably quickly.

Applications of biotechnology in aquaculture require a significant and sustained investment in research and development. Disease resistance, growth limitations, reproductive success, adaptation of wild stocks to farm conditions, and other issues can potentially be resolved by a clear understanding of cellular or molecular processes. This would call for the development of databases on selected species, which, for the most part, are presently unavailable. It would also require a shift of resources from more conventional applied science in order to redirect energy to this promising new technology.

Public perception of problems associated with biotechnology has added a layer of complications to the technical challenges inherent in its application. The degree to which farmers and consumers will be willing to work with genetically modified or manipulated animals remains to be seen and must be taken into consideration. Other less controversial biotechnology applications should be developed vigorously. Resource-poor farmers and consumers must be included in the debate and decision-making about biotechnological introductions in aquaculture. Extension and outreach channels should be used to help inform farmers and the public about the distinctions between the numerous non-invasive uses of DNA-based tools and technology, at least until currently exaggerated public perceptions that genetic engineering is a threat have been dispelled.

INTRODUCTION—BIOTECHNOLOGY TRENDS

Biotechnology has been defined differently by various users of the term, but in general it refers to the application of molecular techniques for purposes of solving problems or making products. It is not generally considered to be synonymous with genetic engineering. Some critics claim biotechnology is a solution looking for a problem. In the agriculture sector, problems are real and momentous.

The US is the largest producer of crops (72% of global production) whose performance has been improved by biotechnological tools. The US biotechnology industry has expanded rapidly over the past few years as a result of both private investment and public-sector support of technology development. Reflecting the impressive growth in number and size of commercial biotechnology firms, this industry has had an increasingly significant economic impact in the United States; revenues in 1999 amounted to $20 billion, which is considered unprofitable (Ernst and Young, 2000). Of this $20 billion, approximately $2.3 billion is attributed to direct revenues from Agricultural Biotechnology.

Biotechnology revenues can be amplified by the type of analyses invoked; considering indirect sources of revenue such as generation of taxes, revenues of companies selling supplies and goods to biotechnology companies, and research and development expenditures, the economic impact of biotechnology might be estimated at closer to $67 billion. Industry and stock market analysts generally interpret these trends as indications that investors remain confident about the future potential of biotechnology and view its current unprofitability as a temporary condition.

A primary emphasis in commercial biotechnology is the development of pharmaceuticals intended for human health applications. Agriculture applications include the production of genetically manipulated crops that are fast-growing and resistant to disease, drought, insects, and other problems that compromise the harvest. The use of these crops and ancillary biotech products can help decrease expenditures on fuels, chemicals, and water while increasing production.

Aquaculture can be viewed as an emerging science currently burdened by a wide range of problems, not the least of which is our rather limited knowledge base of many of the organisms that we wish to domesticate. Aquaculture has grown at a rapid pace and is predicted to continue to do so as world dependence on farmed animal protein continues to expand. For these reasons it is essential that problems currently faced by aquafarmers be addressed, including growth rate and hatchery issues, health and disease, and other problems. Based in part on what is being accomplished in medical and field crop biotechnology, many of these appear to be the sort of limitations to production that might be resolved through biotechnology.

OPPORTUNITIES FOR CONTRIBUTIONS OF BIOTECHNOLOGY TO AQUACULTURE

According to a report of the National Science and Technology Council (1995), the predicted infusion of biotechnology into aquaculture will "improve the health, reproduction, development, growth, and well-being of cultured aquatic organisms" and will lead to "environmentally sensitive, sustainable systems that will enable significant commercialization..." The use of genetic manipulations, it is argued (NSTC, 1995), could improve production efficiency and product quality, leading to benefits for producers, consumers, and society. This, of course, is one of many points of view on the subject, and the reader is reminded that these arguments were drafted before the highly publicized uproar over the detection of Starlink corn in Taco Bell taco shells. The unauthorized incorporation of genetically engineered corn, with enhanced pesticidal capabilities, into human food has underscored the need to apply this technology in a controlled manner. It has also galvanized opponents of biotechnology to some extent; one need not search the Internet extensively to find a call for a ban on genetic engineering. Environmental groups, consumer advocates, and even churches have taken up the cause of banning genetic engineering.

A sensible and sensitive approach to the application of biotechnology would appear to be most useful at this point. Technology development must take consumer sensitivities into account, even if the concerns being expressed appear to be out of proportion to the threat. There is no need to develop technology that the intended end-users do not want, and there is nothing to be gained by stepping into the center of a raging controversy. Consideration of the specific areas of biotechnology applications suggests a productive course of action.

Biotechnology is too potent a solution to shun because of its currently tarnished image. The potential improvement of the human condition that hangs in the balance suggests that applying the best available technology to stabilizing the production of protein in the developing world is worth some risk, although any potential risks can be minimized by enhanced biosafety and food safety regulations. As underscored by the Starlink debacle, regulations must also be accompanied by accountability and enforcement.

Some biotechnology applications, such as the use of DNA technology to assess and maintain genetic diversity or to guide a selective breeding program, can be carried out without manipulating the genome. The use of biotechnology to gain an understanding of and eventually better control over regulatory processes—growth, development, reproduction, and disease resistance—should be pursued and will have considerable long-term benefits. Detection and diagnosis of pathogens, vaccines, and other disease control and exclusion measures can be developed in consumer-friendly ways. All efforts should be made to expand our knowledge base of cultured aquatic animals and to apply biotechnology in tackling the most difficult problems while remaining aware of the fact that many people may not be comfortable with the idea of consuming genetically engineered food.

Biotechnology—Implications for the Developing World

Global projections indicate that poverty, child malnutrition, and micronutrient deficiencies will persist through 2020 in less developed countries (Smith and Haddad, 2000). Demand for meat products and feedgrain will exceed domestic production, exacerbated by poor yield rate, particularly from poor farmers. In part this is a result of import competition for lower-priced food from industrialized countries. Modern aquaculture, believed to contribute to poverty alleviation and improve child malnutrition in rural parts of developing countries (Edwards, 2000), could use biotechnology to help increase efficiency by overcoming production obstacles. Public sector research is essential for assuring that molecular biology–based science serves the needs of poor farmers and consumers. Unlike conventional new technology, which lies in the public domain, processes used in modern biotechnology are increasingly subjected to intellectual property protections, along with resulting products. The dominant role of the private sector in modern agricultural biotechnology research, which is focused exclusively on industrialized countries and large-scale farming, will deprive poor people of the benefits of biotechnology.

Furthermore, if the opposition to biotechnology in industrialized countries leads to the stoppage of biotechnological studies, developing countries are not likely to receive scientific and financial support for their research. This would be unfortunate because it would again deny research in poorer countries, thus negatively affecting the opportunity to reduce poverty and child malnutrition.

SUGGESTED COURSE OF ACTION

Biotechnology tools should be applied wisely to aquaculture problems with the goal of increasing our mastery of health management and food production without the avoidable encumbrance of public outrage. Modest applications of biotechnology can pay off in the short term through specific technical developments and also in the longer term through the general expansion of our knowledge base of tilapia and other domesticated fishes. It is likely that concerns over genetically altered fish may eventually go the same way as the belief that is was heresy to argue that the earth revolves around the sun. In the meantime, work that is done in the public interest must be guided by the interests and concerns of that same body of people.

The social costs of particularly invasive science, such as the production of fish with heterogeneous DNA, should be considered on a case-by-case basis. Likewise, the practical limitations imposed by consumer skepticism and environmental protection suggest a cautious entry into the aquaculture biotechnology arena. It might be argued that the social costs of poverty should be weighed against these concerns, but the recommendation here is not a ban or even avoidance of controversial science but a stepwise development of aquaculture biotechnology, designed to give consumers and farmers time to become comfortable with this technology. Much of what biotechnology has to offer can be applied immediately. The development of diagnostic tools for aquaculture management—e.g., DNA-based indicators of the presence of pathogens, production of inducing hormones for spawning, genetic markers in selective breeding, *in situ* hybridization, and gene expression studies—can be used now, with minimal risk of arousing organized opposition. With the knowledge that consumers are always cautious and skeptical with new technology, we can proceed with the vigorous development of tools and biotechnical applications without forcing the issue of genetic engineering. It is probably only a matter of time before the benefits of biotechnology become apparent to consumers.

REFERENCES

Edwards, P., 2000. Aquaculture, poverty impacts and livelihoods. ODI Natural Resource Perspectives, 56:4 pp. (Available at <www.odi.org.uk/nrp/56.html>.)

Ernst and Young Economic Consulting and Quantitative Analysis, 2000. The Economic Contributions of the Biotechnology Industry to the US Economy. A report prepared for the Biotechnology Industry Organization. (Available at <www.bio.org/new/ernstyoung.pdf>.)

National Science and Technology Council, 1995. Biotechnology for the 21st Century: New Horizons, Stock Number 038-000-00590-1 US Government Printing Office, Washington, DC, 89 pp.

Pinstrup-Anderson, P., and Cohen, M.J. 2000. Agricultural biotechnology: Risks and opportunities for the developing country food security. International Journal of Biotechnology, 2(1-2-3): 145–163.

Smith, L.C. and L. Haddad, 2000. Overcoming child nutrition in developing countries: Past achievements and future choices. 2020 Vision for Food, Agriculture, and the Environment Discussion Paper 30, pp. 30-32 IFPRI, Washington, DC.

INDIGENOUS FISH SPECIES AND BIODIVERSITY

Amrit Bart
Aquaculture and Aquatic Resource Management
Asian Institute of Technology
Pathumthani, Thailand

THE PROBLEM

Rural poor populations of many developing nations need a sustainable mode of food production. Small-scale fish farming has provided a much-needed protein source to the rural poor. Introduced fish species have been shown to be problematic because they have displaced local indigenous species, inbred within species and/or crossbred with local species, and are susceptible to environmental stresses and local pathogens. Adequate studies of indigenous species with culture potential in captivity are lacking.

BACKGROUND

During the last ten years global aquaculture production has increased steadily at a rate of 20% per annum, faster than any other agriculture sector, contributing over US$50 billion to the general economy. Most of this production has come from fewer than ten farmed species. The potential for the further growth of aquaculture lies in the ability to explore new species that can be grown in a sustainable manner. There are over 2,000 species of marine and freshwater fish with various levels of potential for cultivation.

Discussion of the potential impact of cultivating introduced (exotic) species and/or domesticated indigenous species on local biodiversity has generated a great deal of interest and concern among biodiversity advocates. Because of this concern there is a strong interest in Southeast Asia towards developing indigenous species for aquaculture to either replace the established culture of exotic species and/or diversify the species currently cultured.

Past surveys of species diversity in the Mekong River Basin have resulted in a number of reports indicating a large number of species with the potential for aquaculture. However, there has been no indigenous species cultured at a commercial level with the exception of *Pangasius hypophthlamus.*

The threat that exotic species pose to native species' diversity provides the strongest support for the need to promote and culture indigenous species. Many non-native populations of Chinese and Indian carps, catfishes, and tilapias have been reported in rivers and lakes of the Mekong River Basin. Similar intrusion of exotic species has been described in Lake Victoria of Africa, inland waters of Fiji, and the Philippines.

In addition, non-sustainability of introduced species compounds the effects on diversity. Introduced species over multiple generations tend to inbreed due to a small founder population or a small effective breeding population, leading to decreased culture performance. A recently publicized project, the GIFT (Genetically Improved Farm Tilapia) Foundation in the Philippines, has demonstrated the weakness of the uncontrolled introduction of tilapia, an exotic species to the region. Out-crossing of tilapia has resulted in significantly higher growth performance. Similarly, grass carp and rohu introduced to North Vietnam during the 1980s have become problematic to resource-poor fish farmers. Grass carp and rohu comprise nearly 100% of the species cultivated in the northern mountains. Chronic viral infections (red spot disease) prevalent in grass carp have nearly destroyed this species and have now spread into rohu populations. Further, rohu, a primary culture species, is exhibiting inbreeding depression (slow growth and lower fecundity) throughout Cambodia, Laos, and Vietnam.

On the other hand, however, the advantages of culturing indigenous species result in species that are generally more tolerant to local environmental stresses. Broodfish for domestication and replacement can be obtained from local wild stock to prevent inbreeding and promote out-crossing. Indigenous knowledge of culture practices can be exploited to optimize production. Indigenous people have preferences associated with culture and taste of indigenous species, making culture practices of local species more sustainable.

Additionally, native species display an extraordinary potential for aquaculture. In the Red River Delta, Mai Dinh Yen (1983) identified 203 species and subspecies, of which 51 were new species. A recent MRC (Mekong River Commission)–sanctioned project identified and described 19 species with the highest potential for culture based on natural habitat and behavior. Even a handful of these species developed for culture would significantly add not only to the livelihood of rural poor farmers, but also to commercial aquaculture.

Proposal

- Screen, identify and rank potential aquaculture species in South and Southeast Asia.
- Develop strategies to propagate and rear them in captivity.
- Examine wider market acceptance and export potential of these species.
- Develop and conduct studies to examine the impact of indigenous domesticated species on local biodiversity.

Literature Cited

Mai Dinh Yen, 1983. Classification of freshwater fishes in Vietnam. Published by Nha Xuat ban khola hoc ky thuat, Hanoi, Vietnam.

SEED PRODUCTION: THE FIRST STEP IN SUCCESSFUL AQUACULTURE

Ronald P. Phelps
Department of Fisheries and Allied Aquacultures
Auburn University
Alabama, USA

Amrit Bart
Aquaculture and Aquatic Resource Management
Asian Institute of Technology
Pathumthani, Thailand

Seed production is an essential component in the successful production of any organism. Seed should be available in a reliable quality and quantity to enable the producer to begin production in anticipation of resource availability, seasonal changes, and market demand. Many types of aquaculture had their beginnings by capturing seed from the wild, but using wild-caught seed presents several limitations. Availability is typically seasonal and may vary considerably from year to year. As shrimp culture on the Pacific coast of the Americas was developing, the availability of post-larvae would vary from year to year depending on the currents and El Niño. This led to wide price fluctuations in seed and often to ponds going unstocked for lack of seed. Similar climate effects can be seen with migratory fishes, which depend on strong stream flows to stimulate spawning. Some years the rains come early, others late, and some years not enough. Such variability makes it difficult to provide seed on a predictable basis.

Variability in quality is another issue with wild-caught seed. The seed collected is genetically predisposed for survival in the wild and is not selected for growth and survival in an aquaculture setting. By being dependent on wild-caught seed there is no opportunity for domestication and selection. Wild stocks often have many genetic traits that through selection can result in an organism better suited for aquaculture. But without control over the life history of the organism in a culture setting, such selection is difficult.

There are a number of other issues associated with wild-caught seed including disease control, size variability, and difficulties in separating desirable and undesirable seed. One issue with collecting seed from the wild that has both biological and social considerations is the effect on the environment. Although difficult to document, the perception often is that intense collection of seed from the wild is depleting natural stocks for the benefit of only a small sector of the population. This perception is difficult to counter and can be an obstacle to aquaculture development in many parts of the world. China is undergoing a rapid expansion of marine finfish culture. In 1998, it had grown to 100,000 MT and in 1999 was 200,000 MT. This rapid expansion has been dependent on capture of wild seed stock and indiscriminate trawling to provide trash fish for feeding of the fish being cultured. This trawling is quickly depleting the resource and soon will result in a scarcity of trash fish for use as feed and create a shortage of fingerlings to stock the cages. The trash fish needed for feeding can be replaced by formulated feeds, but the cage culture industry in China will still collapse unless there are significant advancements in hatchery technology to meet the seed demand.

Many times in the history of aquaculture, advancement has been bottlenecked because of seed-related issues, and once that bottleneck was overcome there was rapid growth. Culture of Chinese carp is one of the oldest forms of aquaculture, but it was restricted to areas of China where seed could be collected and distributed. Its production remained restricted for thousands of years until the 1950s when induced spawning techniques were developed. Bighead, grass, and silver carp will mature in ponds but will not reproduce. They require a long stretch of turbulent flowing water that cannot be duplicated in the hatchery to reproduce naturally. In the 1950s, Chinese scientists developed hormone-induced spawning procedures that allowed seed to be produced under controlled conditions. As a result of their work, these valuable aquaculture species have become available worldwide.

The establishment of induced spawning was a significant breakthrough not only for these species, but opened the door for the production of a number of other fish species that would not spawn naturally in a hatchery. As a result of developing induced spawning techniques, it has become possible to produce several species of basses, *Clarias*, *Colossoma*, flounders, *Lates*, *Panganius*, and sturgeons.

In some species the problem is having the fish reproduce under controlled conditions. For others, the problem is how to prevent their reproduction during the production period. This is a common problem in several species of centrarchids and cichlids. Tilapia was first considered a miracle fish because of its rapid growth and hardiness. However, one of its advantages, being able to reproduce naturally in ponds, is also one of its principal disadvantages. Initial production trials with tilapia gave high yields, but the average size fish produced was small (Swingle, 1960). A variety of techniques have been tried to control reproduction, but each has its limitations. Predator fish were stocked along with tilapia to consume any reproduction. But this requires producing two species of fish with the predator often not as hardy as tilapia and results in a more limited production (Dunseth and Bayne, 1978). In some settings, manually separating the sexes proved practical. Popma et al. (1984) developed a system for monosex production of tilapia, but half of the fingerling production had to be discarded once they reached a sexable size. To produce seed, this system required both land and labor that could have been better used elsewhere. The production of monosex tilapia through intraspecific hybridization was adopted as a commercial practice in the 1960s and 1970s but did not prove to be practical. However, these efforts set the stage for the future growth of tilapia production once a practical method to control reproduction was established.

With tilapia and many other fishes, the gonads are undifferentiated at hatch and the development of the gonad can be controlled by the administration of exogenous steroids. This technique became widely adopted after the work of Guerrero (1975) and Shelton et al. (1978). From 1970 to 1980 tilapia production grew 64%, while from 1980 to 1990, it increased 105%. The demand for tilapia continues to accelerate. In the US in 1994, an estimated 32.1 million lbs. of processed tilapia were imported. In 2000 the forecast is that 120 to 130 million lbs. will be imported (USDA, 2000). This rapid growth has been due in large part to the development of a practical seed production technique for controlling production. The commercial industry which now has developed could not exist without being able to direct the sexual development of tilapia.

Marine fish culture has been one of the most rapidly expanding forms of aquaculture in the last decade. A few examples of that rapid growth are given in the following table based on FAO data (FAO, 1998).

Species	MT produced, 1987	MT produced, 1996
European sea bass	1096	21,090
Gilthead sea bream	973	32,727
Mangrove red snapper	288	15,313
Turbot	65	2,588

This rapid growth has been due in part to being able to overcome the bottleneck of seed production. Gilthead sea bream is a highly valued fish throughout the Mediterranean, whose culture was limited until hatchery techniques were improved. In the 1960s and '70s, some of the initial research was conducted regarding the reproduction of this species. The fish could be reproduced successfully but larval survival was very low (approximately 1%). Survival remained low until advances in larval nutrition and other aspects of early life history were made. As improvements in larval survival—now over 15%—have taken place, a rapidly expanding industry has developed.

Appropriate seed production technology is not only an issue in finfish culture but also in culture of algae, crustaceans, and mollusks. The red seaweed "Nori," *Porphyra*, has been grown in Japan since the early 17th century, depending on a natural settling of seedlings on substrate provided by the producer (Nash and Nagasawa, 2000). In 1949 Kathleen Drew figured out the life history of *Porphyra umbilicalis*, and in 1960 Fusao Ohta was able to adapt that knowledge into a production system. Nori production grew from 100,000 MT to over 400,000 MT in 30 years. Shrimp culture has been a major beneficiary of improved hatchery technology. Seed of species such as *Penaeus vannamei* are now provided mainly through hatcheries while 20 years ago were much more dependent on wild-caught seed.

Seed availability continues to be a limitation for aquaculture growth throughout much of the world. Production of tilapia in Thailand, which produces approximately 76,400 $Mtyr^{-1}$, is constrained by shortages of fingerlings (Vannuccini, 1998). Likewise, availability of tilapia fingerlings in Honduras is one of the major factors limiting aquaculture development (Molnar and Lovshin, 1995). The culture of marine fish, particularly in the tropics and sub-tropics, is bottlenecked by the lack of seed. China, which produces 200,000 MT of marine fish in cages, is heavily dependent on wild-caught seed. This is also common for the culture of many species throughout Southeast Asia. Technology for seed production of groupers and snappers is in its infancy but once these limitations are overcome, their culture may expand at rates exceeding those seen with sea bream and sea bass.

Even the catfish industry in the US is restricted because of seed availability issues. Channel catfish represent over 99% of the total production, but there is a better production alternative. The hybrid between a channel catfish female and a blue catfish male is a much more desirable fish for production. The hybrid, whose potential was first recognized in the 1970s (Yant et al., 1975), has a 10 to 20% faster growth rate, is easier to harvest, and is more resistant to some of the major diseases common in channel catfish. The problem is that the two species of fish do not hybridize naturally very readily. Techniques to induce spawning are successful, but egg and fry survival is low. If hybrid catfish fingerlings would be available in adequate numbers it would be possible to increase catfish production 45,000 $Mtyr^{-1}$ without adding any acreage or increasing the demand for water.

On occasions, the issue is not the lack of a seed production technology but the lack of an appropriate technology for a particular set of producers. This is often the case with small-scale tilapia producers. The use of methyltestosterone is the best available technology for producing monosex tilapia, but access to that technology is an issue for small-scale producers. Likewise, hormone-induced spawning may be the only method to provide seed of certain species, but that technology often cannot be implemented by resource-limited producers. Multiple packages of seed production technology need to be available to meet the needs of those wanting to be aquaculturists.

How to provide seed to small-scale producers often becomes not only a question of technology but a development issue as well. For the purpose of this paper, the target audience is considered to be individuals capable of participating in a cash economy. The issue then becomes how to provide a form of seed that can be produced economically with inputs that are reasonably accessible to the producer. Whether producers purchase or produce their own seed involves not only technical but also economic and social issues. Government institutions often are the source of seed in the initial stages of introducing a new aquaculture production system. If the system is to be adopted, the private sector must become seed providers as soon as possible. It is this period of transition when adoption of a new production practice often flounders. Government programs cannot provide the reliable quantities of seed needed, and the private sector has yet to adopt the seed production technology. Best seed production technology must always be reviewed to determine if it is technically sound and environmentally appropriate, but just as importantly, if it is economically viable and socially acceptable. The costs of seed are often 20% or more of the total production costs to bring a fish to a market size. Reductions in seed production costs are often the key to successful aquaculture development. These reductions in costs can come about as a better understanding of the life history of an animal is gained and appropriate technologies are developed to let us control that life history.

Viable seed production technology is essential for aquaculture development. This can be accomplished through reducing the seed costs of species currently being produced, or developing the technology to allow additional species to be cultured. Many seed production technologies have worldwide application as there are similarities in species being cultured and in market demand. More specific seed production technologies often must be developed to meet specific needs at a more local level.

References

Dunseth, D.R. and D.R. Bayne, 1978. Recruitment control and production of *Tilapia aurea* (Steindacher) with the predator *Cichlasoma managuense* (Gunther). Aquaculture, 14:383–390.

FAO Fisheries Department, Fisheries Information, Data and Statistics Unit, 1998. Aquaculture Production Statistics, 1987–1996. Food and Agriculture Organization of the United Nations, Rome.
Guerrero III, R.D., 1975. Use of androgens for the production of all-male *Tilapia aurea* (Steindachner). Trans. Amer. Fish. Soc., 104:342–348.
Molnar, J. and L. Lovshin, 1995. Socioeconomic dimensions of aquaculture development in Honduras. Paper presented to the Annual Meeting of the Rural Sociology Society, Washington, DC.
Nash, C.E. and A. Nagasawa, 2000. Sumiyoshi fishermen remember their angel. World Aquacult., 31(2):39–42.
Popma, T.J., F.E. Ross, B.L. Nerrie, and J.R. Bowman, 1984. The Development of Commercial Farming of Tilapia in Jamaica 1979–1983. Research and Development Series No. 31. International Center for Aquaculture, Alabama Agricultural Experiment Station, Auburn University, Alabama, USA.
Shelton, W.L., K.D. Hopkins, and G.L. Jensen, 1978. Use of hormones to produce monosex tilapia. In: R.O. Smitherman, W.L. Shelton, and J.L. Grover (Editors). Culture of Exotic Fishes Symposium Proceedings. Fish Culture Section, American Fisheries Society, Auburn, Alabama, USA, pp. 10–33.
Swingle, H.S., 1960. Comparative evaluation of two tilapia as pondfishes in Alabama. Trans. Amer. Fish. Soc., 89:142–148.
USDA Economics Research Service, 2000. Aquaculture Outlook, Accessed 19 July 2001. Internet. URL: <usda.mannlib.cornell.edu/reports/erssor/livestock/ldp-aqs/2000/aqs1200.pdf> 14 pp.
Vannuccini, S., 1998. Western world—The focus of new tilapia market. INFOFISH International, 4/98:20–24.
Yant, D.R., R.O. Smitherman, and O.L. Green, 1975. Production of hybrid (blue x channel) catfish in catfish ponds. Proceedings of the Annual Conference of SEAFWA, Southeastern Association of Fish and Wild. Agen., 29:82–86.