Aquaculture and society in the new millennium

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Aquaculture as we know it at the beginning of the 21st century is a consolidation of more or less independent experiences. Carvings indicate that the Egyptians were cultivating fish at least 2,500 years ago. The Chinese claim to have been growing fish for centuries. The Romans had fishponds (*piscinae*). In the 14th century, the emperor Charles IV ordered all towns to build fish ponds to produce food, enhance the local environment and protect watersheds. Paleolithic Hawaiian Islanders isolated embayments for rearing fish in the sea. Whatever the original objective of these aquaculture initiatives was, from each evolved a set of concepts that, until quite recently, strongly influenced how aquaculture interacted with local society and the environment.

One could argue that modern, global aquaculture arose from these different local traditions only in the second half of the 20th century. Scientific evaluation of the integrated agriculture-aquaculture systems that had evolved in China began in the 1960s. The publication of two books in the 1970s, Traité de Pisciculture, Fourth Edition (Huet 1970) and Aquaculture: The Farming and Husbandry of Freshwater and Marine Organisms (Bardach *et al.* 1972) for the first time brought together for analysis and comparison the range of global aquaculture experiences. The World Aquaculture Society and the European Aquaculture Society were formed in the 1970s. The journal Aquaculture began in 1972. The Food and Agriculture Organization of the United Nations (FAO) began separate reporting of aquaculture statistics from capture fisheries statistics in the early 1980s.

These initiatives created, from disparate and isolated experiences, the international research and development (R&D) community that has worked together with industry to solve problems and produce average annual industrial growth rates of about 10 percent over the last 15 years, making aquaculture the fastest growing animal production sector in the world.

However, the environmental, social and economic landscape within which aquaculture has performed well up to now is changing. In particular, competition will increase as barriers to trade decline through the process of economic globalization. In addition, the negative environmental and social impacts of aquaculture that occur in some situations will increase public scrutiny and criticism that could well alter the policies that have so far fostered growth.

In addition to the regular status reports and prognostications produced by FAO, New (1999), Pedini (2000) and Masser (2000) have recently reviewed the major trends in aquaculture over the last decades and attempted to project these trends into the future. From those analyses, it is clear that changing dietary preferences, population growth and economic development will create a strong demand for aquaculture products for the foreseeable future. Inasmuch as the principal dataset for the analyses is the same – FAO - and because all the reviews resulted in similar predictions and concerns for the future, I will not revisit in depth the fish production statistics. Instead, I will focus on how trends in aquaculture development affect the lives of consumers and producers, and try to draw conclusions that might guide aquaculture development policy for the future.

Aquaculture and Food

Agriculture, in general, is different from most businesses because, in addition to generating jobs and income, it produces the food we absolutely must have to survive. Modern agriculture produces enough food to feed the world. The problem is distribution, or more precisely, the inequitable distribution of the financial resources necessary to obtain food.

Although globally fish are one of the most widely consumed sources of animal protein, in industrialized countries seafoods are generally regarded as luxury or specialty products. Prices for salmon, seabass, shrimp, oysters and other such high value commodities can rise or fall and the effects are on producer profit margins. In poorer countries of Africa, Asia and Latin America, fish are often a critically important part of the daily diet and in its absence people suffer from malnutrition, particularly protein deficiencies. Increasing population on those continents, coupled with declines in capture fisheries resulting from over-exploitation and environmental degradation, have rendered the people vulnerable to even minor perturbations in fish supply. Having said that, demand for fish, unlike agriculture of staple crops, is seldom a matter of life or death, but, rather an opportunity for profitable aquaculture.

Because of generally high demand, aquaculture is theoretically profitable in most countries where enterprise budgets have been calculated (Hatch and Hanson 1992). However, investors and farmers want to maximize their returns, not just profit margin. There are two general strategies for maximizing returns: 1) Produce a relatively small quantity of a high profit margin product (e.g., luxury seafood), 2) Produce a large quantity of a cheap product, what I call “commodities” in this paper.

In Africa and South Asia, more than 40 percent of the population lives on less than one US dollar per day; in East Asia

Table 1. Wholesale market value of major aquaculture products grown in 1998 in sub-Saharan Africa (SSA) in millions of US dollars (FAO 1999).

Commodity	Tons Produced	Value (SSA)	Value (Europe)
Cyprinds	2,921	1,880	591
Salmonids	1,769	2,830	2,898
Tilapia	12,238	1,706	4,001
Other freshwater finfish	10,860	2,170	691
Marine shrimp	5,626	7,053	14,367
Bivalve molluscs	3,169	2,058	1,076
Algae	3,153	274	346

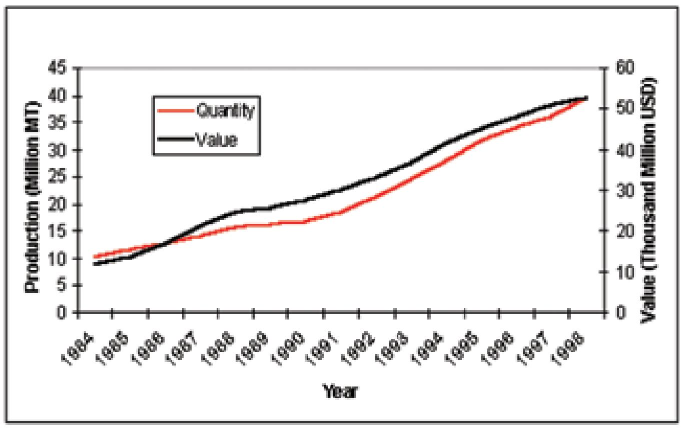

Fig. 1. Quantity and value of global aquaculture production from 1984 to 1998 (FAO 1999).

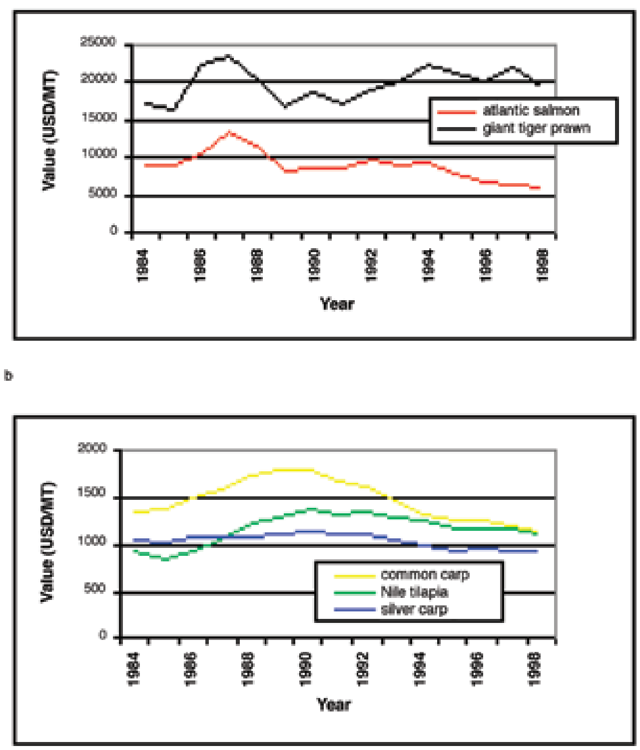

Fig. 2. Reported value of global aquaculture production (USD/MT) in 1998.

and Latin America that figure is about 25 percent (World Bank 2000). To mass produce low-value species at the lowest possible cost to feed these people, one would need to use systems based on low-cost inputs. Without chemicals, machinery, electricity and feeds, one could safely anticipate standing stocks at harvest of no more than 3,000 - 5,000 kg/ha depending on the species grown. To produce 14 kg of fish per person per year for the 10.5 million people who live in the African country of Malawi, for example, such a system would require between 28,000 and 46,000 hectares of land. If the 80 percent of the Malawian population that makes less than US$200 per household per year were able to spend 10 percent of total income on fish, a fish farmer could expect to gross about $1,500 per hectare. The same farmer, with the same system but targeting the wealthiest 10 percent of the population that lives in cities (average annual income of $12,000 per household), could theoretically gross some $60,000 per hectare (World Bank 1996).

This competition with wealthier markets, both locally and internationally, works against the production of cheap fish for the poor (Street and Sullivan 1985). For example, low-tech tilapia production can gross over $8,500 per hectare if the fish are sold in the African wholesale market (Table 1). Exported to Europe, the same fish are worth over twice as much. Producing shrimp for Europe instead of tilapia for Africa could increase gross receipts by over nine times. It takes a true philanthropist to ignore these figures and the investment pattern in Africa shows that philanthropy is taking a back seat to profits, even in situations where people are literally starving to death. In 1998, sub-Saharan African production of difficult-to-grow luxury mariculture products was almost the same, approximately 12,000 tons, as that of easy-to-rear tilapia (FAO 1999).

The role of aquaculture in food security has been a major concern of the industry for some time. Bridging the gap between fish supply and demand was the theme of the 1999 World Aquaculture Society annual meeting in Australia. From the point of view of food security, the most important recent trend in aquaculture has been the convergence of production and market value (Figure 1). Overall, the driving force behind the relative increase in production and decline in value appears to be declining prices for luxury (Figure 2a) and commodity (Figure 2b) products as markets are becoming saturated and competition is increasing. However, as the trend for tiger prawn in Figure 2a illustrates, these declines are related to specific market situations. The tiger prawn industry suffered serious technical problems resulting from self-pollution and disease in the early 1990s that reduced production and forced prices significantly higher, and from which the industry has not yet fully recovered.

Within the luxury products market, the industry's response to market saturation has been an attempt at species diversification and the production of more specialized products. In a recent survey, Abellan and Basurco (1999) found that Mediterranean countries involved in aquaculture are currently investigating 5-10 new species each. In addition, new marketing strategies and value added products are under consideration. With the large profits that are potentially possible from production of luxury products for wealthy markets, the scramble for technological advantage and market share will most likely produce further consolidation. However, unavoidable high overheads, such as rental of sites with access to good water, expensive hatchery technology and the cost of high-protein formulated feeds, will keep prices from declining to the point where these products can compete with lower value species in commodity markets for the foreseeable future.

Within the commodity markets, increases in production have brought wholesale prices down to about $1,000 per ton. At that price, lower income consumers may be beginning to benefit from commercial fish farming. However, most of the gains have come in China and a few other Asian countries where local demand is high and aquaculture has already become an important part of the food production system. It is worth noting that China, being the single largest producer of lower-priced commodity fish, developed most of its low-cost aquaculture under the command economy of the early 20th century, and the sustainability of those production systems in a globalized economy is questionable. In any case, the spread of the benefits of international trade to non-producing countries remain marginal.

In sub-Saharan Africa for example, prices for cyprinids and tilapia remain at about twice the $1,000 per ton level, despite high demand (Table 1). Notwithstanding almost 20 years of structural adjustment, the per capita economic growth rates of all but six of the 48 poorest countries remains below the theoretical three percent threshold for poverty reduction (World Bank 2000).

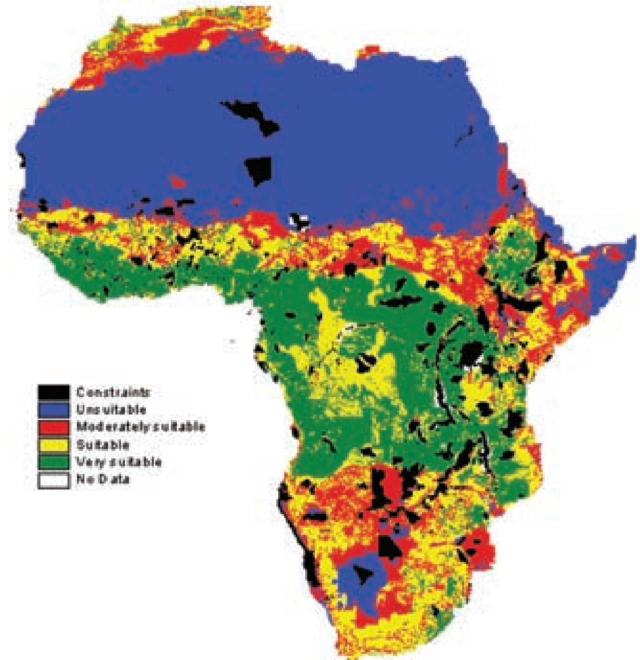

Fig. 3. FAO estimates indicate that 37 percent of sub-Saharan Africa range from moderately suitable to very suitable for small scale fish farming.

This suggests that aquaculture species that are considered to be lower priced commodities in some countries, will continue to be available only to a relatively wealthy minority in others, thereby remaining out of reach for the foreseeable future for some sectors of the population with greatest need.

In the meantime, people need to eat, and since most of the poor people in the world eke a living from small scale family farms, it seems important to determine in which ways those farming systems can be made more productive. Because the farms produce food primarily for the family and only secondarily for sale in the cash economy, small scale farmers tend to manage for minimal costs and risks, rather than maximum production. Systems that return a profit from locally-marketed fish grown in small ponds fed with agricultural by-products may be attractive to this group of farmers. Cost of production of the fish is low because most inputs are wastes, and in most developing countries, where under-employment runs up to 80 percent, there are no realistic opportunities for the labor used for pond construction and feeding (Stewart 1993). In Malawi, Ghana and the Philippines, such systems have been able to double production and treble the cash income of small farms (Brummett and Noble 1995, Prein *et al*. 1996, Prein *et al*. 1999).

In addition, case studies from southern Africa indicate that, if done properly, fish farming of this type can be transferred into a broad range of small scale farming systems (Brummett and Noble 1995, Van der Mheen 1995). Using very conservative figures, FAO has recently estimated that 37 percent of sub-Saharan Africa, the continent with the poorest aquaculture and, arguably, the greatest need, is suitable for small scale fish farming (Figure 3; Aguilar-Manjarrez and Nath 1998). If production figures from relatively recent development projects are used, 35 percent of Africa's projected increased fish needs up to the year 2010 could be met by small scale fish farmers on only 0.5 percent of the total area potentially available.

Table 2. Major negative environmental impacts of global aquaculture.

Continent	Major Negative Impact
North America	Eutrophication of freshwaters; escape of exotic species
South America	Eutrophication of estuaries receiving shrimp farm effluents; mangrove destruction; escape of exotic species
Asia	Eutrophication of fresh and estuarine waters; extensive mangrove destruction; escape of exotic species
Europe	Eutrophication of freshwaters; sedimentation and fouling of seabed under marine cages; escape of exotic species
Africa	Escape of exotic species
Australia	Escape of exotic species
Oceania	Escape of exotic species

Aquaculture and the Environment

Agriculture, more than any other human activity, determines what the rural environment will look like. There are many possible scenarios, but at one extreme are relatively small, traditional family farms working land that has been in more or less continuous production for hundreds of years to produce a wide range of commodities for local markets. At the other end of the spectrum are industrialized, monocropping estates that cover thousands of contiguous hectares and operate on 3-5 year planning horizons to produce bulk products for international markets. In an unregulated market economy, the industrial agriculture end of the spectrum has a clear advantage in terms of profit margins and productivity and this has been reflected in the trend away from family farms. However, human economics is an imperfect distributor of costs and benefits and any form of agriculture that pushes environmental and social limits in order to be profitable, cannot be sustainable in the long term.

For example, thorough cost-benefit analyses of shrimp farms built in mangrove areas show strong negative returns to society (Primavera 1997). Such investments have resulted not only in destruction of sensitive mangrove forests, but also in significant loss of jobs and income, and sometimes even homes and livelihoods. Kautsky *et al*. (1997) cite a typical example from Thailand where the destruction of 100,000 hectares of mangroves for shrimp ponds caused an estimated loss in capture fisheries production of 800,000 tons over five years while only producing 120,000 tons of shrimp.

In countries with the wherewithal to pay, huge subsidies have been made to produce the sort of agriculture that society finds acceptable, such as the traditional farming communities one still sees in much of rural Europe. In the case of the US dust bowl, the federal government took sweeping action to curtail destructive practices and provide high-quality technical expertise to agriculture to prevent future abuses. The US Soil Conservation Service and the Tennessee Valley Authority were created. Land was set aside for hedgerows and barrage ponds to reduce soil erosion, as advised by Charles IV 600 years ago. Large investments were made in agricultural education, research and extension to help generate and transfer more productive and sustainable technology.

However, globalization is working against this system. Increased competition and the specter of decreased protection and/or other subsidies forces farmers to operate on smaller profit margins and larger volumes. Often, this means increased use of pesticides and chemical fertilizers, and reduction in methods that could limit soil erosion, including hedgerows, water storage reservoirs and fallows. In effect, environmental goods and services, as well as public health, are the new agriculture subsidies. Rather than paying taxes to support sustainable agriculture, we are now paying higher recreation and medical fees. We may also be mortgaging the land and water resources that future generations will need to feed themselves.

Environmental legislation alone is not a solution to these problems. Harsh penalties for environmental destruction fall disproportionately on smaller, family farms that cannot afford compliance with complex rules nor engage lawyers and lobbyists to fight regulation. As the marginal profitability of small scale agriculture declines, operators have increasing difficulty buying more expensive and productive technology. In industrialized countries, subsidy programs have been altered to maintain cosmetic compliance with free trade rules, but still help family farms out of this conundrum.

In developing countries that cannot afford lavish subsidies, the situation is somewhat different. Rather than being urban consumers, most of the populations in Africa, Asia and Latin America are rural, smallholding farmers. The bulk of the environmental degradation resulting from bad agriculture on these continents is the fault of people who are, in many cases, struggling less to increase their marginal profits, than to merely survive. Even if governments have the will to legislate against destructive farming practices, low operating budgets for agriculture support agencies mean there is little ability to enforce the law or even explain the problem to farmers in order to seek voluntary compliance. Miniscule public sector support also produces ineffective R&D institutions that, as a consequence, can provide productive and environmentally friendly technology to neither smallholders nor corporate agriculture. In the extreme case, the resulting decreased per capita food production increases political pressure in favor of any type of agriculture, no matter how destructive, just to avoid famine in the short term.

Consequently, examples of unsustainable agriculture are widespread. In Latin America, over 10 million hectares of rainforest have been cut and transformed into very marginally productive cattle ranches (Barbier *et al*. 1995, McNeely *et al*. 1995). In Asia, over 30 million hectares of forest have been destroyed to make way for unsustainable shrimp farms (McNeely *et al*. 1995). The environmental situation in Asia is so bad that the aquaculture sector alone has polluted itself into estimated annual revenue losses of more than $3 billion (ADB/NACA 1996) to say nothing of the destruction of natural aquatic ecosystems. Slash and burn cropping now contributes to the one million hectares of deforestation that is estimated to occur each year in Africa. One hundred and forty-two million hectares of rain fed cropland in sub-Saharan Africa have become desertified as a result of agriculture. Salinization of irrigated land affects another five million hectares (WRI/IIED 1988). Compared with other agriculture sectors, the contribution of aquaculture to environmental degradation is small, but it may be growing (Table 2).

In an attempt to address these problems without disrupting flows of food and money, farmers with the financial wherewithal will invest in marginal improvements in efficiency that lead to increased competitiveness and decreased environmental impact. The trends that have been identified in recent reviews of the environmental impacts of aquaculture will probably be:

- Decreased reliance upon fishmeal in diets,
- Increased efficiency in feed formulation in terms of pellet stability and nutritional content,

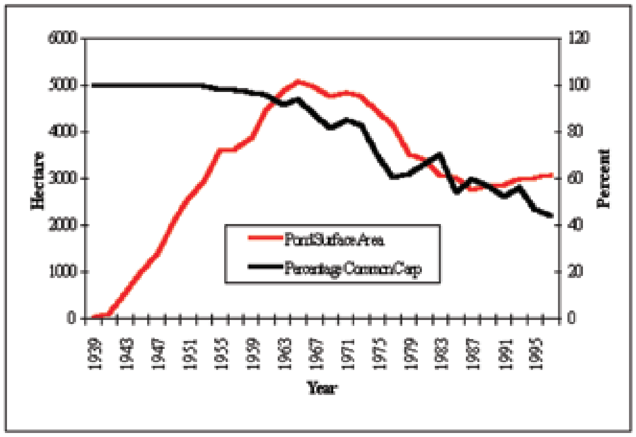

Fig. 4. Level of investment in Israeli aquaculture (indicated by pond surface area) relative to the diversity of species grown. From 1939 to 1953, common carp was the sole culture species. From 1955 to 1969, tilapias and mullets were added to the basic common carp system to improve efficiency in a market that was becoming increasingly competitive (the number of farmers decline from 88 in 1967 to 60 in 1985). From 1971 to 1985, additional species of carp were added. With the introduction of salmonids and striped bass in the late 1980s, level of investment and number of farmers once again began to rise up to 72 in 1977 (Dill and Ben Tuvia 1988), Sarig 1989 and 1996, Snovsky and Shapiro 1999).

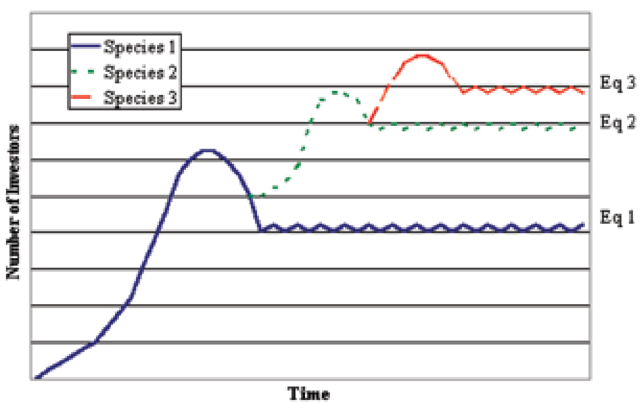

Fig. 5. A theoretical model of how the continual domestication of new species can enhance levels of employment and investment in aquaculture. Equilibrium 1 is the point where the initial aquaculture industry stabilizes with the culture of one main species. Equilibrium 2, based on the domestication of a second species, has taken advantage of existing infrastructure to add quickly but marginally to investment levels. At Equilibrium 3, even less of an increment has been added, but opportunities for employment and investment have been further increased.

- Containment and recycling of wastes in cage and flow-through systems,
- Increased water and land use efficiency in land-based systems,
- Changes in the type, and reductions in the extent of chemical use, and
- Containment and genetic manipulations to minimize the effects of escapees on indigenous fish populations.

An additional step that could be taken to minimize environmental impacts and increase the positive image of aquaculture would be to shift away from the luxury products that have heretofore dominated the aquaculture industry outside of some Asian countries, toward fish that feed lower on the food chain and might be affordable by lower income consumers. The production of such species in integrated farming systems that recycle agricultural byproducts through fish ponds would further lower costs and increase environmental sustainability (Brummett and Noble 1995, Kautsky *et al*. 1997).

Another choice that would reduce negative environmental impacts would be to focus on indigenous species for culture. While most successful aquaculture industries are based on local species, many poor countries of Asia, Africa and Latin America have been searching for quick fixes to their aquaculture development problems by importing exotic species from locations where farming of those species is already established. Those fish routinely escape from their culture units, often replacing indigenous species or severely altering local ecosystems (McNeely *et al*. 1995, Lever 1996). With increasing local and international pressure to safeguard biodiversity, I anticipate an increased interest in the development of indigenous species for aquaculture as more countries come into compliance with the Code of Conduct for Responsible Fisheries (FAO 1995) and the Convention on Biological Diversity (1994).

Aquaculture and the Economy

Even if the ecological consequences of aquaculture escapees do not affect government policy, the track record of aquaculture-related introductions shows that bringing in exotic species to get quick results seldom produces the desired result. Of 212 international introductions into Africa of freshwater fishes for aquaculture, only 33 (16 percent) were found to have resulted in the establishment of an industry with output of more than 10 tons per year in 1997 (FAO 1999). Of these, 10 (30 percent) were of common carp (*Cyprinus carpio*) from Asia and Europe and seven (21 percent) were of Nile tilapia (*Oreochromis niloticus*) from other African countries. The case of Zambia, where 39 introductions resulted in sustained aquaculture of only Nile tilapia and common carp (Thys Van den Audenaerde 1994), is typical. Production of those two species in 1997 was only 133 and 275 tons, compared with 2680 and 1010 tons for the indigenous *O. andersonii* and *Tilapia rendalli*. In total, exotic species account for only 15 percent of African aquaculture output (Bartley and Casal 1998). In Asia, the powerhouse of world aquaculture, 517 introductions have resulted in a total contribution of only five percent to total output (Garibaldi 1996).

The main reason why exotics have failed to produce rapid growth of the aquaculture sector in developing countries is because the germplasm being cultivated is only one, and not usually the most important, constraint to development. Far more important than lack of species are:

- Poor infrastructure, such as bad telephones, bad roads, irregular air service and unreliable electricity (Coche *et al*. 1994).
- The lack of essential inputs such as feeds, fertilizers, chemicals, fuel and spare parts, or volatile prices associated with them (Williams 1997).
- Inequality of incomes and consequent political instability (UNDP 1998).
- Poor market development and marketing infrastructure (Hecht 1997, Masser 2000).
- The lack of the necessary R&D to backstop industrial growth (Lazard *et al*. 1991).

In addition to having basic infrastructure and more-or-less stable government, countries where aquaculture has been successful have a history of strong direct linkage between research and farmers. Since the internationalization of aquaculture research and development (R&D) in the 1970s, there has evolved a high degree of uniformity and specialization within specific agro-ecological zones. States on cold oceans with sufficiently protected areas along their shores produce salmon. Tropical countries with suitable coastal areas produce shrimp. Throughout the Mississippi delta in the US, farmers with bottomland are growing channel catfish. Concomitant with specialization has been a convergence of technology so that systems vary little from place to place. Typically, pioneering entrepreneurs and R&D institutions supported by public funds have worked together to overcome technological and marketing problems. When technology is standardized and shown to be profitable, investors pour in.

Inasmuch as all investors are competing in very similar, if not the same markets, economic viability comes to rely increasingly on smaller and smaller profit margins. Such cycles have resulted in large numbers of dropouts as ventures with comparative advantage for a particular species increase production and push prices below the break-even point for others. While some go out of business as a result of production inefficiency, many others are simply victims of circumstance. Increasing efficiency and reduced numbers of farms means fewer jobs. Some bankrupt installations are sold to competitors, but others are simply abandoned for lack of a buyer in a saturated market. The Norwegian Atlantic salmon and the US channel catfish industries have followed this general pattern, as, indeed, have many other agro-businesses (Forster 1999).

The Israeli common carp industry provides an example of such change (Figure 4). Until 1965, virtually all of Israel's aquaculture production was of common carp. From 1965 to 1991, efficiency increases led to improvements in average yield, which, in turn, precipitated a decline in total area under water of 2,200 hectares and a decline in the number of farming businesses from 88 to 55. During the entire period of declining participation, annual production steadily increased from 10,000 to 15,000 tons.

Figure 5 presents a model for how total aquaculture output might be enhanced while keeping more investors and laborers in the industry. As production and the number of farmers increases, market limits or increases in efficiency favor some producers who come to dominate the market for a particular species. Without alternative markets, less competitive producers begin to fall out with associated loss of employment and waste of developed infrastructure. Equilibrium 1 is the level of investment supported by a highly efficient, single species industry. With alternative species and markets, additional investment and employment can be supported (Equilibria 2 and 3), although overlap among producers will probably mean lower overall investment levels for each new species added. On the other hand, run-in to full market exploitation should become shorter as more experienced farmers lead the transition to each successive new species.

Because the markets for many species overlap (Brummett 2000), this model would produce the greatest benefits if new species actually increase the overall size of the market, access new markets or in some special cases, replace a high value species for which the capture fishery is in decline. In Israel, for example, polyculture of cyprinids and tilapia served largely to increase yield, but did not develop new markets. Only when striped bass and salmonids were introduced did new consumers start to buy fish. This example underscores the importance of market analysis and planning prior to making major investments in the development of new species.

Another example is the rapid growth and collapse of the South African clariid catfish industry. Scientists and farmers working together fostered rapid expansion from 10 tons in 1987 to 1,200 tons in 1990. The industry, however, collapsed to 150 tons in 1992 due to inadequate market development (Hecht 1997).

Diversification to support stable industrial development is not a radical idea and has been a component of successful aquaculture development in many countries (Corbin and Young 1997). Israel (Figure 4) has been steadily increasing the number of species under cultivation. In 1967, when the decline in farm numbers began, three species were grown on Israeli farms. The decline reversed in 1991 when government increased its role in R&D and encouraged the domestication of new species (Mires 1995). By 1998 there were at least 14 species being cultured (Dill and Ben-Tuvia 1988, FAO 1999, Sarig 1989 and 1996) and new investments were being made even while the carp industry was still consolidating (Mires 1995).

When US aquaculture was in its infancy and no one knew which technologies were going to prove the most successful, research centers studied at least 16 finfish species, including eight exotics, for application in US warmwater aquaculture and numerous others for marine and coldwater applications.

Since 1985, Norway has developed successful commercial systems for at least five new species (FAO 1999). At least 26 new species are currently being domesticated for Mediterranean mariculture (Abellan and Basurco 1999).

Conclusions

Globalization and new standards for environmental and social responsibility on the part of aquaculture have changed the context in which the industry will function in the next millennium. These changes will be most noticeable in countries with short histories of democracy, those very countries in which most new demand for aquaculture products will be generated by increasing population and economic development.

If aquaculture responds to the deregulation and open markets of the 21st century in the same way as other agro-industries did in the last century, bigger, more vertically integrated farms will increase their market share. These farms will focus on larger markets for a limited number of species in forms that are easy to pack and ship. Ultimately, a small number of very large producers will produce huge quantities of a few species that can be grown in extensive and highly automated facilities either far offshore in the oceans or in large tracts of earthen ponds built in areas with abundant freshwater, some of which might well be located in countries that are currently not major aquaculture producers. Eventually, such farms may come close to feeding the masses with fish, possibly even before the end of the century.

Smaller farms, to survive, will have to capture niche and local markets, often by growing and selling specialty products, such as live fish, or locally favored species. As overall global wealth increases, the viability and number of these farms and the species they grow will also increase. The small farms will benefit from lower prices of equipment, feed and other inputs developed by, or for, the big corporate farms. They will be located near big cities where high profit margins can be realized through sale of fresh products to wealthy households, restaurants and hotels.

While the bulk of overall employment will be in the processing and marketing of the fish grown on the large farms, the majority of fish culture jobs will be in the small scale, specialized sector. The total fish production from such farms may be modest, but farm-level economic impact produces wider economic growth. Delgado *et al*. (1998) reviewed results from Burkina Faso, Niger, Senegal and Zambia and found that "…even small increments to rural incomes that are widely distributed can make large net additions to growth and improve food security." Winkleman (1998), in a review of agriculture policy impacts in developing countries, identified interventions that lead to improved incomes at the level of the rural farmer and resource manager as "having a larger impact on countrywide income than increases in any other sector."

Making small-scale, market-oriented aquaculture viable will not require a revolution. Rather, it will require an evolutionary approach that adapts technology to local and idiosyncratic opportunities, gradually increasing production and efficiency over time. The strategy for aquaculture development that created the American catfish, the European salmon and the Asia and Latin American shrimp industries would again serve as a strong and direct linkage between the international R&D community and entrepreneurial farmers.

Industrial aquaculture, as it continues to specialize and consolidate, may eventually find a way to sustainably produce large quantities of fish at low cost. If the potential of the lower-income producers can also be realized through the concerted efforts of policymakers, scientists and farmers, both poor and wealthy fish farmers and poor and wealthy consumers can participate in reaping the benefits of a changing global society.

Notes

[1]International Center for Living Aquatic Resources Management (ICLARM), Yaoundé, Cameroon.

References

Abellan, E. and B. Basurco, editors. 1999. Marine finfish species diversification: current situation and prospects in Mediterranean aquaculture. Centre International de Hautes Etudes Agronomique Méditerranéennes, Paris, France.

ADB/NACA. 1996. Report on a regional study and workshop on aquaculture sustainability and the environment. Asian Development Bank (ADB) and Network of Aquaculture Centers in Asia (NACA), Bangkok, Thailand.

Aguilar-Manjarrez, J. and S.S. Nath. 1998. A strategic reassessment of fish farming potential in Africa. CIFA Technical Paper 32. Food and Agriculture Organization of the United Nations, Rome, Italy.

Barbier, E.B. , G. Brown, S. Dalmazzone, C. Folke, M. Gadgil, N. Hanley, C.S. Holling, W.H. Lesser, K.-G. Mäler, P. Mason, T. Panayotou, C. Perrings, R.K. Turner and M. Wells. 1995. The economic value of biodiversity. Pages 823-914 In V.H. Heywood, editor. Global Biodiversity Assessment. United Nations Environment Program. Cambridge University Press, Cambridge, UK.

Bardach, J.E., J.H. Ryther and W.O. McLarney. 1972. Aquaculture: the farming and husbandry of freshwater and marine organisms. Wiley-Interscience, New York, USA.

Bartley, D. and C.V. Casal. 1998. Impacts of introductions on the conservation and sustainable use of aquatic biodiversity. FAO Aquaculture Newsletter 20:15-19.

Beveridge, M.C.M., M.J. Phillips and D.J. Macintosh. 1997. Aquaculture and the environment: the supply of and demand for environmental goods and services by Asian aquaculture and the implications for sustainability. Aquaculture Research 28(10):797-807.

Brummett, R.E. 2000. Factors influencing fish prices in Southern Malawi. Aquaculture 186:243-251.

Brummett, R.E. and R. Noble. 1995. Aquaculture for African smallholders. ICLARM Technical Report 46. International Center for Living Aquatic Resources Management, Penang, Malaysia.

Coche, A.G., B.A. Haight and M.M.J. Vincke. 1994. Aquaculture development and research in sub-Saharan Africa. CIFA Technical Paper 23. Food and Agriculture Organization of the United Nations, Rome, Italy.

Convention on Biological Diversity. 1994. UNEP/CBD/94/1. United Nations Environment Program, Nairobi, Kenya.

Corbin, J.S. and L.G.L. Young. 1997. Planning, regulation and administration of sustainable aquaculture. Pages 201-233 In J.E. Bardach, editor. Sustainable Aquaculture. John Wiley & Sons, New York, New York, USA.

Delgado, C.L., J. Hopkins and V.A. Kelly. 1998. Agricultural growth linkages in sub-Saharan Africa. Research Report 107. International Food Policy Research Institute, Washington, DC, USA.

Dill, W.A. and A. Ben-Tuvia. 1988. The inland fisheries of Israel. Bamidgeh 40: 75-104.

FAO. 1995. Code of conduct for responsible fisheries. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO. 1997. Aquaculture production statistics 1986-1995. Fisheries Circular 815, Revision 9. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO. 1999. FISHSTAT electronic database. Food and Agriculture Organization of the United Nations, Rome, Italy.

Forster, J. 1999. Aquaculture chickens, salmon – a case study. World Aquaculture 30(3): 33-70.

Garibaldi, L. 1996. List of animal species used in aquaculture. Fisheries Circular 914. Food and Agriculture Organization of the United Nations, Rome, Italy.

Hatch, L.U. and T.R. Hanson. 1992. Economic viability of farm diversification through tropical freshwater aquaculture in less developed countries. International Center for Aquaculture, Auburn University, Auburn, Alabama, USA.

Hecht, T. 1997. A review of the development of clariid catfish culture in Southern Africa. Pages 26-27 In H.W. Van der Mheen and B.A. Haight, editors. Report of the technical consultation on species for small reservoir fisheries and aquaculture in Southern Africa. ALCOM Report 19. Food and Agriculture Organization of the United Nations, Rome, Italy.

Huet, M. 1970. Traité de Pisciculture (4th Edition). Editions Ch. De Wyngaert, Brussels, Belgium.

Kautsky, N., H. Berg, C. Folke, J. Larsson and M. Troell. 1997. Ecological footprint for assessment of resource use and development limitations in shrimp and tilapia aquaculture. Aquaculture Research 28(10):753-766.

Lazard, J., Y. Lecomte, B. Stomal and J.-Y. Weigel. 1991. Pisciculture en Afrique sub-Saharienne. Ministère de la Coopération et du Développement, Paris, France.
Lever, C. 1996. Naturalized fishes of the world. Academic Press, London, UK.
Masser, M. 2000. The status and future of inland aquaculture. World Aquaculture 31(3):34-62.
McNeely, J.A., M. Gadgil, C. Levèque, C. Padoch and K. Redford. 1995. Human influences on biodiversity. Pages 711-821 In V.H. Heywood, editor. Global Biodiversity Assessment. United Nations Environment Program. Cambridge University Press, Cambridge, UK.
Mires, D. 1995. Israel's aquaculture 1995: recent developments and future prospects. Bamidgeh 47:78-83.
New, M. 1999. Global aquaculture: current trends and challenges for the 21st century. World Aquaculture 30(1):8-79.
Pedini, M. 2000. Bridging the gap: can aquaculture meet the additional demand for fishery products? FAO Fisheries and Aquaculture Newsletter 24:4-9.
Prein, M., J.K. Ofori and C. Lightfoot, editors. 1996. Research for the future development of aquaculture in Ghana. ICLARM Conference Proceedings 42, International Center for Living Aquatic Resources Management, Penang, Malaysia.
Prein, M., M.A.P. Bimbao, T.S. Lopez and R. Oficial. 1999. Upland integrated aquaculture-agriculture systems in forest buffer zone management. Final Project Report, International Center for Living Aquatic Resources Management, Penang, Malaysia.
Primavera, J.H. 1997. Socio-economic impacts of shrimp culture. Aquaculture Research 28(10):815-827.
Sarig, S. 1989. The fish culture industry in Israel in 1988. Bamidgeh 41:50-57.
Sarig, S. 1996. The fish culture industry in Israel in 1995. Bamidgeh 48:158-164.
Snovsky, G. and J. Shapiro, editors. 1999. The fisheries and aquaculture of Israel 1998 in figures. Ministry of Agriculture, Department of Fisheries, Tiberias, Israel.
Stewart, J.A. 1993. The economic viability of aquaculture in Malawi. Institute of Aquaculture, University of Stirling, Stirling, UK.
Street, D.R. and G.M. Sullivan. 1985. Equity considerations for fishery market technology in developing countries: aquaculture alternatives. Journal of the World Mariculture Society 16:169-177.
Thys Van den Audenaerde, D.F.E. 1994. Introduction of aquatic species into Zambian
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Calendar

May 19-23, 2003 — **Salvador, Brazil**

World Aquaculture 2003 will take place at the Bahia Convention Center. It will be the International Annual Conference & Exposition of WAS in conjunction with various other associations, industry, and government sponsors. Contact: Director of Conferences, Tel: +1-760-432-4270; Fax: +1-760-432-4275; Email: worldaqua@aol.com.

May – 1 June 2003 — **Singapore**

Aquarama '03. This conference will be the 3rd World Conference on Ornamental Fish Culture and will focus on advanced technology with respect to ornamental fish culture. There will be a number of sessions covering biotechnology, new species production, culture of freshwater ornamentals, culture of marine ornamentals, new developments, and challenges facing the industry. A large number of exhibitors from around the world will also be displaying their products. More information can be found at www.aquarama.com.sg.

June 16-18, 2003 — **Boise, Idaho USA**

Propagated Fish in Resource Management. This special symposium of the American Fisheries Society will be held at the Doubletree Riverside Hotel in Boise. It should be of interest to those who are interested in the role cultured fish can play in fisheries management. For further information, contact: Vincent Mudrak, Warm Springs Fish Technology Center, Route 1, Box 515, Warm Springs, GA 31830; Tel: +1-706-655-3382; E-mail: Vincent_Mudrak@fws.gov or Gary Carmichael, Doe Run Farms & Conservation, 700 Oelsen Road, Doe Run MO 63637; Tel: +1-573-760-0458; E-Mail: Carmichael_Gary@Yahoo.com

August 8-12, 2003 — **Trondheim, Norway**

Aquaculture Europe 2003 Conference and Workshop. This event, with the theme "Beyond Monoculture," will be held prior to the Aqua Nor exhibition. In addition to the European Aquaculture venue, the Aquaculture subcommittee of the FAO Committee on Fisheries will be holding its second session in Trondheim at about the same time, so there will be many opportunities for aquaculturists to obtain information and network. Additional information can be obtained on the internet at http://www.easonline.org or you may contact the EAS at Tel: +32-59-32-38-59; Fax: +32-59-32-10-05; or e-mail: ae2003@aquaculture.cc

August 10-14, 2003 — **Quebec City, Canada**

133rd Annual Meeting of the American Fisheries Society. For information, contact Betsy Fritz by e-mail: bfritz@fisheries.org or tel: +1-301-897-8616 ext. 212.

December 3-5, 2003 — **Sydney Convention Center, Australia**

Aquaculture Australia will be launched late this year by *Fish Farming International*. The Sydney Convention and Exhibition Centre at Darling Harbor will be the venue. Commercialization of aquaculture will provide focus for the meeting. Further information can be obtained from Sue Hill, Exhibition Sales Manager, Heighway Events, Telephone House, 69-77 Paul Street, London EC2A 4LQ, United Kingdom. Tel/Fax: +44 (0)20 7017 4516/4537; e-mail: sue.hill@informa.com.

September 22-25, 2003 — **Bangkok, Thailand**

Asian-Pacific Aquaculture, 2003 will be held at the Miracle Grand Convention Center. The conference will focus on the latest advances and problems facing shrimp, finfish, and mollusc culture, along with management quality. For more information, contact John Cooksey, Director of Conferences at 2423 Fallbrook Place, Escondido, California USA; Tel: +1-760-432-4270; Fax: +1-760-432-4275; E-mail: worldaqua@aol.com.

March 1-5, 2004 — **Honolulu, Hawaii USA**

Aquaculture 2004. The triennial International Annual Conference & Exposition of the World Aquaculture Society with the National Shellfisheries Association, Fish Culture Section of the American Fisheries Society, National Aquaculture Association and U.S. Aquculture Suppliers Association will be held at the Hawaii Convention Center. Contact: Director of Conferences, Tel: +1-760-432-4270; Fax: +1-760-432-4275; Email: worldaqua@aol.com.

May 9-13, 2005 — **Nusa Dua Beach, Bali, Indonesia**

WORLD AQUACULTURE 2005. Contact: Director of Conferences, Tel: +1-760-432-4270; Fax: +1-760-432-4275; Email: worldaqua@aol.com.

May 9-13, 2006 — **Florence, Italy**

AQUA 2006. Contact: Director of Conferences, Tel: +1-760-432-4270; Fax: +1-760-432-4275; Email: worldaqua@aol.com.

May 19-23, 2008 — **Busan, Korea**

WORLD AQUACULTURE 2008. Contact: Director of Conferences, Tel: +1-760-432-4270; Fax: +1-760-432-4275; Email: worldaqua@aol.com.

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techniques and the development of new ones. Brazil is also expected to increase fisheries exportation, reaching new international markets and creating a strong production sector with competitive and integrated segments of economic, social and ecological dimensions, besides increasing employment opportunities. The final objective, however, should be the preservation of biodiversity allied with sustainable aquaculture production (Queiroz *et al*. 2002).

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References

Araujo-Lima, C.A.R.M. and M. Goulding. 1997. So fruitful a fish. Ecology, conservation, and aquaculture of the Amazon's tambaqui, Columbia University Press, New York, New York, USA. 192. p.

Cavero, B.A.S., R. Roubach, M. Pereira-Filho, D. R. Ituassú, R. Crescêncio and A. L. Gandra. 2002. Potential for cage culture of pirarucu (*Arapaima gigas*) in the Amazon region. Global Aquaculture Advocate, 5: 59-60, 01 Oct.

Chao, N.L., P. Petry, G. Prang, L. Sonneschien and M. Tlusty, eds. 2001. Conservation and management of ornamental fish resources of the Rio Negro Basin, Amazonia, Brazil. (Projeto Piaba), Universidade do Amazonas/Bio-Amazonia Conservation International, Manaus. 310 p.

CIDASC (Companhia Integrada de Desenvolvimento Agrícola de Santa Catarina). 1997.

FAO - Organização das Nações Unidas para Agricultura e Alimentação. 2000. El estado mundial de la pesca y la acuicultura, 2000. Viale delle Rome, Italy.

FAO - Organização das Nações Unidas para Agricultura e Alimentação. 2001. Retrieved January 10, from Fishery Country Profile. http://www.fao.org/fi/fcp/en/BRA/profile.htm. Viale delle Roma, Italia.

IBGE (Instituto Brasileiro de Geografia e Estatística). 2002. Retrieved January 10, from http://www.ibge.gov.br.

Kitamura, P. C., R. B. Lopes, F. G. Castro Jr. and J. F. Queiroz. 1999. Avaliação Ambiental e Econômica dos Lagos de Pesca Esportiva na Bacia do Rio Piracicaba. Boletim da Indústria Animal. Nova Odessa – SP, 56 (1): pp. 95 - 107.

Lovshin, L. L. and J. E. P. Cyrino. 1998. Status of commercial fresh water fish culture in Brazil. World Aquaculture 29(3): 23-39.

Lovshin, L. L., R. Wallace, F. Kubitza and R. B. Barthem. 1997. Capture fishery and aquaculture potential in the state of Amapá, Brazil. International Center for Aquaculture and Aquatic Environments/ Auburn University. 61 p.

Melo, L. A. S., A. C. U. Izel and F. M. Rodrigues. 2001. Criação de tambaqui (*Colossoma macropomum*) em viveiros de argila/barragens no Estado do Amazonas. Embrapa Amazônia Ocidental, Manaus. 25 pp.

MDIC/SECEX. Análise das Informações de Comércio Exterior via Internet, ALICE-Web, Secretaria de Comércio Exterior (SECEX), do Ministério do Desenvolvimento, Indústria e Comércio Exterior. 2001. Retrieved January 15, from http://aliceweb.mdic.gov.br.

Queiroz, J. F., B. Bernardino, N. Castagnolli, J. E. P. Cyrino, P. C. Kitamura, J. N. P. Lourenço, J. D. Scorvo and W. C. Valenti. 2002. A Embrapa e a Aqüicultura: Demandas e Prioridades de Pesquisa VI Congresso Venezolano de Acuicultura, III Seminario Internacional Para El Desarrollo de La Acuicultura Continental En La Amazônia, II Congresso Nacional de Camaronicultura, San Cristobal, Edo. Tachira, Venezuela.

Val, A.L., P.R. Rolim and H. Rabelo. 2000. Situação atual da aqüicultura na região norte. In: "Aqüicultura no Brasil. Bases para um desenvolvimento sustentável". In: W.C. Valenti; C.R. Poli; J.A. Pereira and J.R. Borghetti, eds. CNPq / Ministério da Ciência e Tecnologia, Brasília. 248-266 pp.

Valenti, W. C. 2000. Aquaculture for sustainable development. In: "Aqüicultura no Brasil. Bases para um desenvolvimento sustentável" In:W.C. Valenti, C.R. Poli, J.A. Pereira and J.R. Borghetti, eds. CNPq / Ministério da Ciência e Tecnologia, Brasília. pp. 17-24.

(Continued from page 59)

waters, and their importance for aquaculture and fisheries. ALCOM Field Document 24, Food and Agriculture Organization of the United Nations, Rome, Italy.

UNDP. 1998. Overcoming human poverty. United Nations Development Programme, New York, USA.

Van der Mheen, H.W. and B.A. Haight, editors. 1997. Report of the technical consultation on species for small reservoir fisheries and aquaculture in Southern Africa. ALCOM Report 19. Food and Agriculture Organization of the United Nations, Rome, Italy.

Van der Mheen, H. 1995. Report of the technical consultation on extension methods for smallholder fish farming in southern Africa. ALCOM Report 21. Food and Agriculture Organization of the United Nations, Rome, Italy.

Winkelmann, D.L. 1998. CGIAR Activities and goals: tracing the connections. Issues in Agriculture. The Consultative Group for International Agricultural Research, World Bank, Washington, DC, USA.

Williams, M.J. 1997. Aquaculture and sustainable food security in the developing world. Pages 15-51 In J.E. Bardach, editor. Sustainable Aquaculture. John Wiley & Sons, New York.

World Bank. 1996. Malawi: human resources and poverty. Report 15437-MAI. Southern Africa Department, World Bank, Washington, D.C.

World Bank. 2000. Entering the 21st century: world development report 1999/2000. Oxford University Press, New York, USA.

WRI/IIED. 1988. World resources 1988-1989: a report by the World Resources Institute (WRI) and the International Institute for Environment and Development (IIED). Basic Books Inc., New York, USA.