

I: OVERVIEW OF FISH FARMING

FISH FARMING CONCEPT

Fish farming is the raising of fish in managed unnatural aquatic ecosystems for profit. All aquacultural environments are unnatural ecosystems, because they do not exist as such in nature. They are inherently unstable and if left unmanaged, even for a brief period, will destabilize and begin transformation into more natural environments. The major components of all aquacultural ecosystems are the cultured organisms, the water environment, including all of its biological, chemical and physical characteristics, and the nutrient inputs. Management of the ecosystem components allows the aquaculturist to maintain stability in the culture system to achieve an aquacultural crop. The higher the aquaculturist's understanding and application of principles, the higher the effectiveness and efficiency and the lower the risks of producing the crop.

Figure I-1 is a simplistic illustration of the three basic components of fish farming enterprises. The thumb represents the market, which is the driving force and purpose for production. The three fingers together represent the primary managed components of the production ecosystem: fish stock, water environment and nutrients. The little finger represents business and production management; both are critical to competitively achieving the profit objective. Successful fish farm management involves the application of sound business management principles to maximize profits by matching market situations with optimized production options. Optimum production performance is achieved by maintaining a cost-conscious balance in the ecosystem between stock quality and quantity, nutrient input quality and quantity, and environmental quality.

AQUACULTURE SUSTAINABILITY

"Sustainable aquaculture" has recently become an ill-defined standard or goal to which all aquaculture technologies are to be measured. Although the term is yet to be properly defined and conceptualized, its general intent to minimize and even eliminate negative environmental impacts caused by aquaculture technologies has broad popular support inside and outside the industry. This manual defines "sustainable aquaculture" as "an adaptable aquaculture production technology system whose ecological and economic viability persists indefinitely." Markets determine aquaculture opportunity, and ecological and economical principles determine choices of aquaculture practices for packaging sustainable aquaculture technologies. This concept is strictly followed throughout the manual.

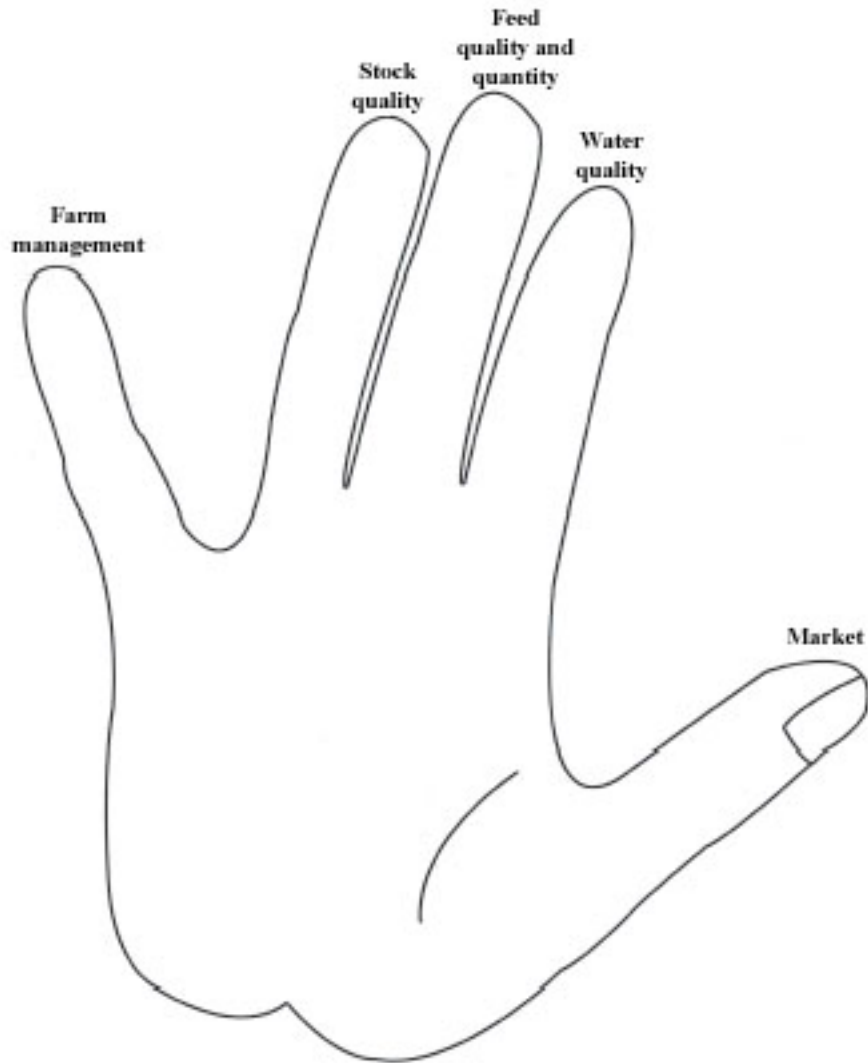


Figure 1-1. Hand illustration of the three basic components of fish farming enterprises.

WORLD FISH FARMING REVOLUTION

Fish farming is the business of agriculture in water. Fish farming technologies are developed and practiced for the same reasons as land-based agricultures; principally to supplement and replace naturally produced food supplies and provide economic benefits. Fish farming originated in China before or during the Yin Dynasty at least 3,100 years ago. However, it became a significant contributor to world food supplies and economies only during the last quarter century. As recently as 1955 world farmed fish production was <0.5 million metric tons (mmt), accounting for less than 1% of total capture and farm production. At that time the scientific basis of aquaculture was little understood and less applied. However, in 1995 world farmed fish production was 15 mmt and 20% of total world fish production (total aquaculture production of animals and plants in 1995 was 21 mmt and 19% of total combined capture and aquaculture production of 113 mmt). Fish farming technologies are now well developed and approaching the scientific levels of poultry, swine and other land-based farming technologies.

Table I-1. Levels of aquaculture technology based on quality of nutrient input.

Level	Description
1	No nutrients provided - stock-and-recapture fisheries where nursery produced stock are unmanaged between stocking and recapture
2	Organic farming - integrated animal/fish cultures, e.g. pig-cum-fish or duck-cum-fish, and fish cultures where manures and waste organic materials stimulate the base of the food chain and/or provide some direct nutrition
3	Ingredient feeds - oilseed meals, other feed ingredients or vegetation provide direct nutrition and enhancement of the food chain
4	Compound feeds - mixed ingredient feeds, nutritionally incomplete and usually physically unsuitable for use in water, provide the nutritional base
5	Nutritionally complete compressed feeds - formulated steam pelleted feeds, specifically manufactured for a certain species or species group and for use in water
6	Nutritionally complete extruded feeds - similar to compressed feeds of level 5, but with more specific formulation and extrusion processing to provide higher efficiency and water stability
7	Nutritionally refined extruded feeds - similar to extruded feeds of level 6, but formulated to be more efficient and to influence market qualities of the fed species, such as meat color, texture, flavor and nutrition (e.g. level of omega-3 fatty acids)

Aquacultures throughout the world are in revolution, rapidly expanding and undergoing change to higher technology levels. A distinct trend from low to high levels of aquaculture technologies is briefly summarized in Table I-1. Aquacultural technology systems determine the technology levels, which are built around the quality of nutrient inputs and necessary water quality management requirements to sustain environmentally sound and economically viable culture ecosystems. All the levels have some application in the world, but technologies meeting sustainable criteria are essentially limited to level 5 (compressed, steam pelleted feed) and level 6 (extruded pelleted feed). Level 1 (no nutrient inputs) is obsolete. Level 2 (organic farming) is also obsolete, except possibly for some economically depressed locations. Level 3 (ingredients) and level 4 (nutritionally incomplete compound feeds) are broadly practiced but doubtfully sustainable primarily because of environmental criteria. Level 7 technologies (refined feeds) are technically feasible but not yet economically viable except in special, limited situations. Prevalent in Asia, where over 80% of the world's fish are farmed, are levels 3 and 4 (ingredients and nutritionally incomplete compound feeds), but the revolution is occurring because of the broad, rapid adoption of levels 5 and 6 (nutritionally complete compressed and extruded pelleted feeds). In North America and Europe level 6 is almost exclusively applied to fish cultures. Based on the current rate of adoption in China, level 6 will be the world norm or standard by year 2005. Although both pond production of channel catfish in the United States and salmonid farm production in Europe are at level 6, the extruded feeds used in channel catfish productions are not as highly refined as extruded feeds used in salmonid farming. This will soon change and feeds for warmwater fishes in the United States, China and throughout the world will become even more refined than those now used for salmonids in Europe.

Presently, world farmed fish production is growing at an annual rate of approximately 13%, while capture production is essentially stable and possibly declining. Two factors stand out when considering the reasons for the remarkable growth of farmed fish production: 1) the high and growing market demand for fish, and 2) the development of aquacultural sciences, most specifically the advancement in understanding the principles of aquatic ecology, that have allowed development of practical, economically viable and scientifically-based production technologies that enable farmers to sustainably meet market demand. Farmed fish production could increase at a greater rate simply by accelerating production intensity, increasing area of conventional aquacultures, and by expanding into the vast natural waters of inland, coastal and inshore marine environments.

HUMAN POPULATIONS, FISH FARMING AND WORLD AQUAFOOD SUPPLIES

Government programs are designed to create jobs, generate income and make best use of resources in the community, and to produce food, and where appropriate, to help balance foreign exchange for the good of the total country. Aquaculture meets these goals throughout the world. However, internationally every government is challenged to balance a declining resource base with ever expanding human needs resulting primarily from ever increasing human population growth. Efforts throughout the world to curb human population growth have produced measured success. Rates of growth are declining in almost all countries of the world, including China and others of the most populous countries where rates are now below 2.0%. Nevertheless, world population continues to expand, presently at 90 million per year. Governments are concerned about how to feed, employ and otherwise provide services to so many new persons per year. They realize that as a direct result of human population increases:

1. Arable land area will decrease as competition for land resources increases. Arable land will be required for increased housing, roads, industry and other non-agricultural purposes even with major efforts to protect those lands.
2. National and international capture fishery yields appear to have stabilized at about 85 mmt because of overfishing as a direct result of increased competition for all fisheries resources. Already 65% of the world's fish stocks are considered overfished.
3. Some freshwater and marine fish stocks will disappear from the fishery. This has already occurred in some areas.
4. Capture success and effort in freshwater and shallow sea fisheries will decline to a principally subsistence level.
5. Employment throughout the fishery subsector will decline primarily because of a stabilizing and declining fishery and modernization of fishing technology. As a consequence, a socio-economic shift to other resources for employment alternatives will likely be necessary for a very large segment of the population.

Much more could be predicted regarding future population and fish supplies. However, the point is made that every nation's fishery resource is finite and cannot keep up with inevitable human

population growth. There are no solutions to that specific problem. However, aquacultural production is perhaps the most promising short term as well as long term means of increasing fish supplies, thereby supplementing and replacing components of the natural fishery.

FISH FARMING TRENDS IN CHINA

China accounts for approximately 60 percent of the world's total aquacultural production of freshwater fishes; therefore, it essentially represents the norm in the world's fish farming status. The table and growth curve in Fig. I-2 shows actual growth of freshwater fish farm production in China from 1955 through 1996 and projected through year 2000. China has long been known for high yielding, manure-based integrated, multiple species fish farming that reached a peak during the 1950s through 1970s. Economic efficiency of the traditional systems rapidly declined after 1978 when the government began reform away from a centrally planned economy to a market driven economy. A dynamic upturn in production began around 1980 partly because of farmers changing nutrient input bases from manures (level 2) to ingredients (level 3). The pace and magnitude of change were most prevalent in the coastal provinces within the Yangtze and Pearl river deltas. The change to a more reliable, economically competitive technology began a continuing trend throughout China toward higher level technology with corresponding decline in traditional integrated polycultures. Technologies were first changed only with changes in nutritional bases. Farm-made nutritionally incomplete compound feeds (level 4) were first used about 1985, but with the same mixed species as in the traditional technologies. The more innovative farmers realized that for them to be more competitive they would need to change species composition as well as nutritional bases from 6 or 7 species with low market demand to simpler cultures of 1 or 2 select species with high demand. By the early 1990s delta farmers were experimenting with pond cultures of only 1 to 3 higher valued species but with limited success primarily because of poor quality feeds and feeding practices.

A specifically designed pond production technology was tested in China in the early 1990s and promoted to farmers beginning in 1995. That technology, designated as "80:20" pond fish culture, was rapidly and broadly adopted by progressive farmers establishing levels 5 and 6 in China. It is the only technology for pond growout being promoted and supported by the China government through agencies of the Ministry of Agriculture. Chinese farmers can no longer afford integrated, manure-based systems simply because they are not economical, and the China government can no longer afford them because they are too destructive to the environment. The traditional and ingredient-based technologies (levels 2 and 3) do not meet either "sustainable aquaculture" test of economic viability or environmental soundness. Technologies based on nutritionally incomplete compound feeds (level 4) are still marginally "sustainable", while technologies based on high quality feeds (levels 5 and 6), such as the new 80-20 technology, are "sustainable".

Aquafeed quality and use in China are rapidly increasing. Although most aquafeeds presently produced are nutritionally and/or physically suitable for level 4 technology, nutritionally complete feeds, meeting international quality standards and suitable for level 5 and 6 technologies, are now available from different mills throughout the deltas and other major fish farming areas of China. The prevailing aquafeed use trend is toward high quality manufactured

feeds produced in large mills and away from lower quality feeds produced on farms and in small mills.

In 1996 over 5 million tons of commercially produced compound feeds were used to produce about 2 million tons of fish or about 16 percent of China's total freshwater fish farm production of 12.5 million tons. Farm-made feed production volume in China is unknown, but NEC estimated that 40 percent of total aquaculture production (5.41 million of 13.53 million tons of aquaculture production) in 1995 was produced with an approximate total of 13 million tons of commercial and farm-made compound feeds. However, new level 5 freshwater pond and cage fish production technologies, requiring high nutritional and physical quality feeds, are rapidly being adopted and diffused in China primarily because they are technologically and economically superior to traditional, lower level technologies. Per annum demand for high quality freshwater fish feeds is projected to be about 12 million tons by year 2000. The projection is based on the current successful promotion of level 5 and 6 technologies by the national and provincial governments, the availability of higher quantity and quality feeds from newly constructed aquafeed mills, increasing consumer income and demand for higher quality fish, and an expanding free market driven economy for farmers. Farm production of freshwater fish is projected to be over 15 million tons in year 2000, which is a conservative estimate considering that this would represent only a 37 percent increase over 1996 freshwater fish production of 10.94 million tons and the current growth rate has been steady at about 15 percent per annum for the past decade (Fig. I-2).

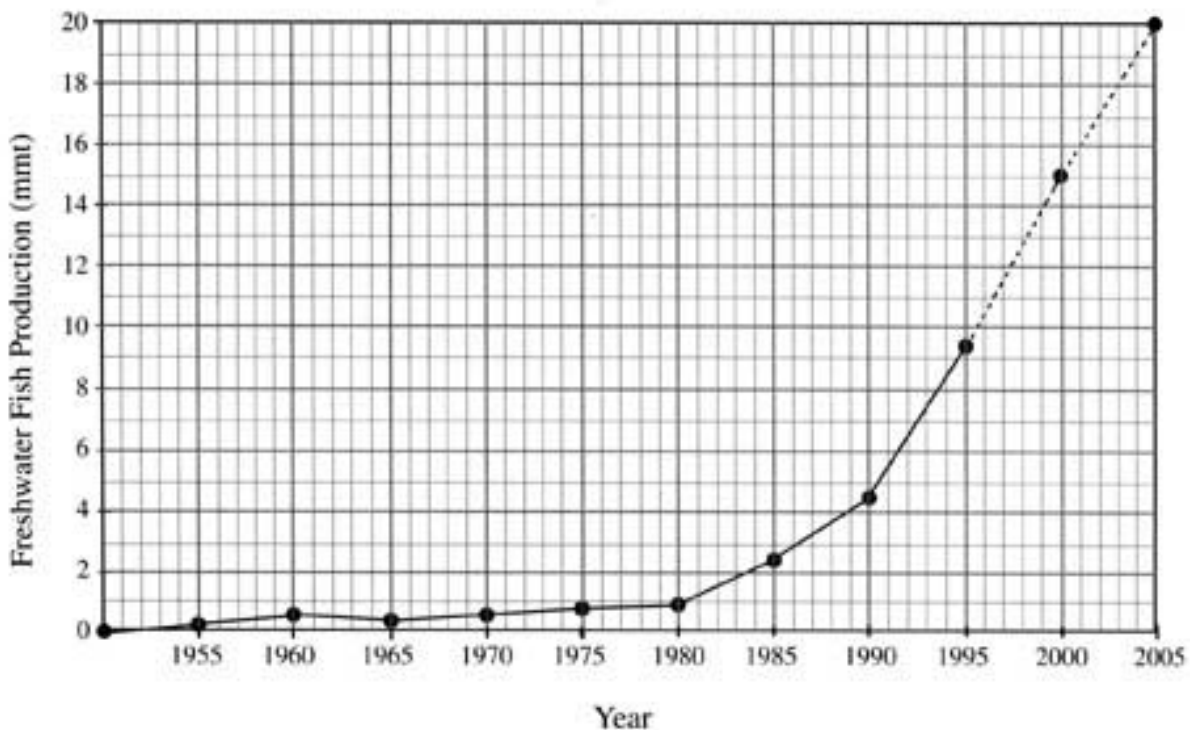


Figure I-2. Freshwater fish aquaculture production in China at 5-year intervals from 1955 through 2000.

WORLD FISH FARMING THROUGH YEAR 2000

It is inevitable that the world fish farming revolution will continue well into the next decade, and the trend from low to high level production technologies, requiring higher nutritional and physical quality feeds, will also continue. The rates of those changes are uncertain, and will vary between regions of the world because of unequal constraint variables. Although these constraints will tend to slow expansion, they will also tend to force change to higher quality feeds characteristic of higher technology levels and greater sustainability. Numerous constraints exist, and internationally the principal constraints are similar and related to environmental impact and feed quality and quantity.

Environmental degradation, caused by effluents from aquaculture environments, has become a major concern in all the aquaculture production areas of the world. Perhaps most of the criticism has been directed toward fish cage and shrimp pond cultures. Cage culture techniques are criticized for generating high concentrations of organic matter in open water ecosystems due to accumulation of fecal wastes and unconsumed feeds. Pond shrimp producers are criticized for their "slash and burn" tactics of intensively producing in newly developed areas for a 2- to 3-year period, then moving to new sites leaving behind seriously altered and polluted environments.

China continues to experience major negative consequences of both fish cage and pond shrimp aquacultural practices. In Hebei province during two days in August, 1995, over 12,000 tons of caged fish were reported killed as a result of an overturn in a reservoir made eutrophic by mismanaged cage fish culture. Similar reports are common from elsewhere in China. In 1991 China was the leading pond shrimp exporter in the world, but production collapsed in 1993 and further declined in 1994. Total production plummeted more than 70 percent from 220,000 tons in 1991 to 64,000 tons in 1994 (final figures will show a further decline in 1995 and 1996). The collapse was attributed to diseases, but diseases were only the manifestation of degraded water quality caused by both poor feeds and feed management. Perhaps even more significant in China than caged fish and pond shrimp are effluents from fish ponds. China has over 1.9 million hectares of ponds, and traditional production technologies, regardless of level, depend on periodic flushing of the ponds with environmental waters to reduce waste loading. The wastes generated in the culture environment then become part of the external environment to impact on nature, other fish farms and other human uses of the environment. Such technological systems are neither ecologically nor economically sustainable, and will have to be stopped within a few years through government and farmer cooperation.

Feed quality and quantity may be the most important of all constraints. Essentially all environmental problems associated with all world aquacultures are directly related to feed quality and quantity. Improving feed quality to provide only the nutrients the fish require and are able to utilize would greatly reduce the magnitude of pollution and lessen their effects within and outside the culture ecosystem. These improvements will inevitably occur either through enforced government regulations or "clean up or close up" economic necessity at the farm level. Model examples of government regulations exist in the trout and salmon industry in Europe. The maximum pollutant discharge units in Table I-2 are possible only with relatively highly refined feeds and rigid feeding programs specific for the culture situation. These include the

specific fish group (e.g. species, size) and environmental conditions (e.g. facility type, temperature, oxygen level). Feed formulation and manufacturing technologies already exist to achieve regulatory requirements for maximum pollutant discharges with such feeds used in any culture environment.

Increasing feed quality is synonymous with lowering of maximum pollution units as in Table I-2, and this is a worldwide trend even in Europe which is already producing the world's highest quality commercial feeds. Technology exists for higher quality feeds, but how high the quality will actually reach is a question of optimum or balance between cost and benefits. Producers in Europe have found that high quality feeds have high costs but their benefits are also high. Within limits as feed quality increases, required feed quantity decreases, water quality management decreases, incidence and severity of disease decreases, feed transportation and storage costs decrease, and other benefits accrue that are directly related to improved feed quality.

Table I-2. Summary of some 1991 maximum regulatory limits for feeds and pollutants discharged from fish farms in Denmark.

Item	Maximum unit
Regulatory requirement for feed:	
Feed efficiency (FCR)	1.0
Undigested nutrients	32.0 %
Phosphorus (P)	0.9 %
Dust	1.0 %
Permissible pollutant discharge limits:	
Organic matter (BOD)	1.00 mg/l
Suspended solids (SS)	3.00 mg/l
Phosphorus (P)	0.05 mg/l
Ammonia (NH ₃ -H)	0.40 mg/l
Total nitrogen (N)	0.60 mg/l

The following numbered paragraphs contain a summary of causes, trends and projections for continuation of the fish farming revolution through year 2000:

1. World demand for Aquafeed products is increasing at a rapid rate, fueled in part by rapidly increasing standards of living in Asian countries. Demand will continue increasing indefinitely into the next century just on the strength of world population growth, which is now at approximately 90 million people per annum.
2. World supply of marine captured Aquafeed has stabilized at around 85 mmt/yr, and supplies are projected to remain steady and certainly decline on a per capita basis.
3. Aquaculture is the only means of meeting increased world demand for Aquafeed.
4. On average world aquacultures are technologically and economically below optimum; some are environmentally degrading and most are resourcefully inefficient.
5. Aquacultural production technologies are rapidly expanding and advancing to higher levels because of pressures on governments and producers for improved economic and resource efficiency and for environmental concerns.
6. Among numerous constraints to world aquaculture expansion and technological improvement, and perhaps the most limiting of all constraints, is the problem of seriously limited availability of nutritional and physical quality feeds specifically manufactured for specific species and their culture situations.
7. This feed constraint can only be solved by the aquafeed industry, and at the moment the industry does not appear to either be prepared to meet the challenge or have a vision of their

opportunity. While new aquafeed mills are being built, production and marketing practices appear substandard relative to other industries, especially in areas of product quality and user education.

8. Technologies for formulation and manufacture of optimum nutritional and physical quality aquafeeds are not a limiting factor for most cultured species; aquafeed research is well ahead of the aquafeed industry and so are the poultry and livestock feed industries.
9. Research has already developed presently or potentially practical aquafeed technologies for least cost formulations, for lowering feed conversions below 1.0, for use of synthetic amino acids and enzymes for improving specific nutrient digestibility, for controlling color, extending shelf life, and fortifying omega-3 fatty acids in the aquaproduct, and for other production and marketing benefits.
10. Although numerous constraints exist, the opportunities are such that the trends of rapidly expanding and modernizing aquacultural technologies will continue, and aquafeed formulation and manufacture will continue to improve but likely at limiting rates to aquacultural development.

OVERCOMING CONSTRAINTS

Education and information are foremost in overcoming constraints to modernizing world aquacultures. East Asia is the center of aquacultural production and market demand while North America and Europe are the centers of aquacultural research, advanced technologies and information. Feed-based technologies are within the capability of most of the aquaculture industry throughout East Asia, and there is already a generally felt need for adopting them. However, feed-based technologies are being adopted well below their potential primarily because adequate information is not available to producers, feed manufacturers, administrators and educators. Governments offer research and extension services, but generally in name only without adequately trained people or sufficient budgets. Feed manufacturers are producing "aquafeeds" that do not approach minimum nutritional and physical quality standards. Administrators tend to promote causes and projects without coordinated program support. International and national development agencies continue to promote integrated and similar production systems that are no longer either ecologically or economically viable. These and numerous similar problems have one common cause -- inadequate knowledge and information base. Technical education is the one common solution.

Constraints limiting modernization and expansion of aquacultural technologies are identified but methods to overcome them are less understood. Significant action roles are identifiable for several sectors including the respective governments, producers, feed industry, entrepreneurs, post harvest businesses and consumers. Governments must take leadership in coordinating the actions of others and directly providing education, information and development capital.