Carp Polyculture System in China: Challenges and Future Trends

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ABSTRACT: China has long been known for manure-based integrated multiple species fish farming technology. The traditional Chinese system of polyculture, stocking fish with fingerlings of different species of fish with different food habits, at a ratio determined by the quantity and quality of natural food available in the pond, has been practiced with a view to utilizing all the natural food available, thus maximizing fish production per unit area of pond surface. The Chinese major carps, such as silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Arigtichthys nobilis*), grass carp (*Ctenopharyngodon idella*), black carp (*Mylopharyngodon piceus*), mud carp (*Cirrhina molitorella*), Crucian carp (*Cyprinus carpio*) and common carp (*Cyprimus carpio*), are widely cultured in these ponds wherever traditional markets exist. The challenges faced by the Chinese system of polyculture include genetic degeneration of the Chinese major carps, deterioration of pond eco-systems, frequent occurrences of fish diseases, poor quality feeds, poor growth performance, environmental pollution and serious market competition. Aquaculture production technologies are experiencing a revolution, rapidly expanding and undergoing change to higher valued species and higher technology levels, due to pressures on the Chinese government and producers for improved economic and resource efficiency and for environmental concerns. In the 21st century, profitable and sustainable aquaculture will become the major concern for fish producers in China.

KEY WORDS: Chinese major carps, traditional polyculture system, profitable and sustainable aquaculture.

1. FISH PRODUCTION BY AQUACULTURE IN CHINA

Presently, fish and shellfish production in China is growing at an annual rate of approximately 10.5%, while production from capture fisheries is slowly declining because of over fishing and pollution (Yang et al., 2000). Since 1990, China has become the leading fish and shellfish producer in the world. Available statistics indicated the annual production of aquatic products was 31.3 kg per capita in 1998 (Yang et al., 2000). This ranks China above the average level in the world.

Aquaculture has developed rapidly in China, which accounts for approximately 67% of the total world aquaculture production. Figure 1 shows the production of fish and shellfish for the world and China, 1988-1997 (FAO, 1998). Figure 2 shows fish and shellfish culture as a percentage of total world aquaculture, 1988-1997 (FAO, 1998). In 1996, aquaculture contributed 18.61 million tons, or 56.6% of the total fish and shellfish production (Tu, 1998). Since then, China has become the first country for which aquaculture achieved a higher production than capture fisheries. The aquaculture growth in China is mainly driven by two factors: (1) increasing population (2) dwindling returns from marine capture fisheries.

China has a long history of freshwater aquaculture. The earliest record of freshwater aquaculture dates back to as early as 3000 years ago. The earliest monograph on fish culture, "Treatise on Pisciculture", was written by Fan Li in 473 B. C. Aquaculture techniques continued to improve and to increase in complexity through the centuries (Li, 1990), and the polyculture of fish first started in China in 618 A. D. In 1950, the total production from freshwater fisheries in the People's Republic of China was 360,000 tonnes from 380,000 ha, of which freshwater aquaculture represented 18%, or 64,800 tonnes. The success of artificial reproduction of Chinese carps in 1958-1960 greatly increased the availability of carp fry (Li, 1990). In 1959, total production from freshwater fisheries increased to 1.23 million tons, in which the contribution from aquaculture was 590, 400 tons, or 48%. As a result of the emphasis placed on fish production through aquaculture by the Chinese government, production increased steadily through the 1960s and 1970s.

A dynamic upturn in freshwater fish production began around 1980, as a result of the open policy promoted by the Chinese government and a change in nutrient input bases, from manures to agricultural by-products. The earliest trials on grass carp (*Ctenopharyngodon idella*) culture, using nutritionally incomplete compound feeds, were first conducted in 1972, but with the same mixed species as in the traditional polyculture technologies (Shi et al., 1998). Studies on the nutrient requirements and feed technology of the Chinese major carps were begun in 1981. In 1982, approximately 3 million ha were brought under freshwater aquaculture production, yielding 1.1 million metric tons. Polyculture in freshwater ponds, with a combined area of 910,000 ha, contributed 863,590 tons, or 78.5% of the total freshwater aquaculture production.

Profitability of the traditional polyculture system rapidly declined after 1986, when the Chinese government effectively conducted reform away from a centrally planned economy to a market-driven economy. Since then, demand increase for aquaculture products has been primarily for higher value, fed species - in contrast to the low value, filter species that dominated the traditional Chinese polyculture systems. Recently, farmers with foresight have realized that to be more competitive, they need to change the species composition of their polyculture systems, from six to nine species with low market value, to one or two select species with high value and market demand. Figure 3 shows the actual growth of freshwater aquaculture production in China, 1955-1996, and projected through 2000. (Schmittou et al., 1998).

2. STATUS OF CARP CULTURE

The Chinese major carps, such as silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Arigtichthys nobilis*), grass carp, black carp (*Mylopharyngodon piceus*), mud carp (*Cirrhina molitorella*) and crucian carp (*Cyprinus carpio*), etc., have long been cultivated as the major species in freshwater ponds, lakes, and reservoirs (Li, 2001). In spite of rapid progress made in the culture of higher valued species over the last ten years, carp culture still plays a very important role in Chinese aquaculture. Pond polyculture makes substantial contributions to the overall fish production from the freshwater fisheries. Nearly 80% of the total freshwater fish production comes from carp (particularly silver carp, grass carp, and bighead carp) polyculture ponds (Li, 2001).

Pond fish culture characterized by polyculture and integrated fish farming systems represents the typical traditional and productive fishery conducted in China (Li, 1990). In traditional Chinese pond polyculture, the silver carp feeds on phytoplankton in the water column, the bighead consumes zooplankton, the grass carp eats supplemental vegetation, the black carp eats molluscs, and the mud carp and common carp (*Cyprinus carpio*) eat benthos/ detritus. The major carps are cultured together at a ratio determined by the quantity and quality of natural food available in the pond. Other species, such as crucian carp, wuchan fish (*Megalobrama amblycephala*) and tilapia (*Tilapia* spp.), etc., are also considered for pond cultivation. The embankments of the ponds are used for the production of vegetation. Some land is also reserved for the establishment of piggeries and duckeries, to integrate the culture of pigs and ducks with fish farming. Manure from pigs and ducks is used to fertil-

ize the ponds to generate high quantities of natural food for fish, thus making it possible to increase fish production per unit area of pond without much additional cost. Agricultural by-products, such as rapeseed cakes, rice and wheat bran; by-products of beer and wine industries, and the vegetation grown on the banks of the ponds are also used as fish feed. Figure 4 shows schematically the traditional Chinese system of polyculture.

China produces more than 480 billion freshwater fish fry (mainly Chinese carps) annually, of which at least 80% are hatchery produced (Li, 2001). Encouraged by the success of pond fish culture, the Chinese government, in its bid to improve the nutritional status of the increasing population and adjust the structure of agriculture, has turned to aquaculture, and in particular, to pond aquaculture. A policy has been drawn up to promote aquaculture development within the next five years in China.

3. MAJOR PROBLEMS IN THE CHINESE SYSTEM OF POLYCULTURE

With the rapid development of aquaculture, the major problems faced by polyculture in China include: genetic degeneration of the Chinese major carps, deterioration of pond ecosystems and environmental pollution, frequent occurrences of fish diseases caused by Aeromonas hydrophila, poor quality feeds, and market competition between producers of the same species.

3.1. Genetic degeneration of the chinese major carps

Traditionally, silver carp, bighead carp, grass carp, and black carp are referred to as the main cultivated fish in Chinese aquaculture. Improving the main cultivated fish through genetic research is a relatively new activity. Faster growth, higher yield, better feed conversion, and increased resistance to disease can all be improved through genetic manipulation (Jensen and Crews, 1997). Up to the present, most of the brooders of the main cultivated fish in China are derived from wild strains. Few producers work with mass selection or improved strains. Since it takes several generations of continuous culture to obtain a domesticated strain, almost no genetically improved strains have been obtained for the main cultivated fish in China. Because inbreeding and unsuitable genetic manipulation of carp are practiced by producers in some regions, indicators of genetic degeneration, such as slower growth, poor resistance to disease, and earlier maturation, have appeared. At the same time, wild strains are decreasing rapidly in natural bodies of water, partly because of over-fishing for initial stock of the main cultivated fish species.

3.2. Deterioration of pond ecosystems and environmental pollution

Traditional polyculture technology enables the productive potential of a body of water to be fully realized (Ye, 1984). The vertical water column, the natural food, and the mutual benefits between different species can be fully utilized through the stocking together of several species in reasonable proportions. With improved management of water quality and better input, such as fertilizer, artificial feed, and improved varieties of fingerlings, fish production per unit area may be substantially increased. The technical management and control of the pond ecosystem, however, is not easy and production risks are rather high. It is important to understand that Chinese traditional aquaculture differs in many aspects from the advanced aquaculture systems in industrialized countries. Water quality is an essential parameter for effective and disease-free aquaculture systems, but in quite a few fish farms there are no means to regulate and improve water quality (M.E. Nielsen et al., 2001).

There are a number of existing problems with traditional polyculture technology. Pond water quality may deteriorate because of the large amount of organic matter input into these systems. Large amounts of silt may also be deposited on the pond bottom, caused by erosion of pond dikes and by adding manure and other ingredients. In addition, wastes generated in the polyculture system can impact natural bodies of water through efflu-

ents. Further complications arise if the outside water source has been industrially polluted, as in some regions, rendering water exchange an ineffective measure to improve pond water quality. Thus, there are many more problems concerning water quality and pond bottom mud now existing than there were before with the traditional polyculture technology.

3.3. Frequent occurrences of fish diseases caused by Aeromonas hydrophila

Fish disease is the major risk factor in commercial aquaculture with millions of dollars lost annually, and in Asia, disease has emerged as a major constraint to the sustainable development of aquaculture (FAO 1997, Shariff 1998). Aeromonas hydrophila has been recovered from a wide range of freshwater fish species worldwide (Austin & Adams 1996). Fish bacterial septicaemia has been a severe infectious disease in main cultivated freshwater fish throughout China since 1989 (Qian et al., 1997). The major Chinese carp, including crucian carp, silver carp, bighead carp, and blunt-snout bream are the most sensitive species to this disease. Hundreds of bacterial strains have been isolated from diseased fish. Most of the isolates were Aeromonas hydrophila (Chen et al., 1997). Sakazaki et al. (1984) reported that Shimada identified two major subgroups of A. hydrophila, strains TPS-30 and PBJS-76, which belonged to two serotypes, O:9 and O:97, respectively (reported in Qian et al., 1997). Recently, Aeromonas hydrophila has been recognized as a common organism associated with disease outbreaks in aquaculture in China (M. E. Nielsen, 2001). A. Hydrophila is more abundant in waters with a high organic load than in relatively unpolluted water (Jeney & Jeney 1995). Frequent occurrences of this disease in summer are probably due to high stress in this period (e.g. high temperature, low DO content and heavy parasite infections etc.). High mortality of fish and a resulting low profit or loss of income can be caused by outbreaks of the disease (Qian et al., 1997).

3.4. Poor quality feeds

The main feed used for Chinese traditional polyculture includes fresh organic ingredients and nutritionally incomplete compound pellets with unsatisfactory physical properties. Some problems such as coarsely ground ingredients, poor water stability and shortage of the actual quantity of vitamins for the compressed pellets can be found among the products of feed manufacturers. Overfeeding is observed to be much more common than underfeeding, especially among farmers with limited experience of using high quality feeds (H. R. Schmittou et al, 1998). Large amounts of feed wastes released into the water, together with poor feeding practices, can result in critical water quality deterioration of pond ecosystems. On the other hand, limited success has been achieved by using compound pellets, mainly because of the diversity of species in the polyculture system. For improving feed efficiency, fish farmers are realizing the need to move to a feed-based production system and to switch to high quality manufactured feeds. However, it is probably unrealistic to expect one type of compound pellets to meet the nutrient requirements of several different species of fish.

3.5. Market competition between producers of the same species

Pond polyculture of the major carps is a relatively profitable undertaking requiring low investment, with low costs and quick results, in comparison with rice planting and animal husbandry. In recent years, freshwater fish culture has been considered one of the main ways for improving the standard of living for people in rural areas. Many farmers have gradually directed their efforts to the development of aquaculture. The economic efficiency of the traditional systems, however, rapidly declines when production of the major carps is greater than market demands. As a result, market competition has become more intense between producers of the same species since 1986. Careful attention to the quality of farmed fish (nutritional value, texture, appearance, freedom from residues, parasites and pathogens, etc.) is also required (Michael B New, 1997). The development of new products and the marketing promotion of fish as a healthy food are essential for the continued success of Chinese aquaculture.

4. FUTURE SOLUTIONS

4.1. Improving Chinese major carps through genetic selection

Results from research on genetic selection for silver carp have been encouraging. The semi-domesticated strains of silver carp have shown better growth rates than wild strains (Zhejiang Institute of Freshwater Fisheries, unpublished). In addition, Chinese scientists have carried out some work on selection, strain identification, and evaluation of the major carps (Li, 2001). For the sustainable development of carp culture, producers should practise mass selection and try to obtain improved strains for crossbreeding. In particular, carp producers should not inbreed their stocks. Wild carp stocks are important resources for future genetic improvement programmes (R.S.V. Pullin, 1986). Effective measures should be adopted to protect from the threats from pollution and from fish and water transfers. It is also recommended that researchers conduct further genetic studies on crossbreeding, hybridization, polyploidy, sex reversing, and gene-splicing to improve growth rates, feed conversion rates, and disease resistance of the major carps.

4.2. Vaccination for the prevention of motile Aeromonad septicaemia

Fish vaccination is considered to be an effective method for preventing infectious diseases, but there are few descriptions of fish bacteria in China. An early fish vaccine used in China was the tissue-homogenized vaccine for haemorrhage in grass carp, made from the internal organs of diseased fish and inactivated with formalin (Chen et al., 1997). Recently, a good deal of work on the development of bacterial vaccines for the prevention of motile *Aeromonad septicaemia* of the major carps has been done at the Zhejiang Institute of Freshwater Fisheries. With the popularization of the vaccination techniques, instead of using antibiotics and other drugs, the survival rate of the major carps may be improved and adverse environmental impacts on natural and aquaculture ecosystems may be reduced as well.

4.3. Use of nutritionally complete compressed feeds for the Chinese major carps

Feeds for the Chinese major carps cultured in ponds should be nutritionally complete and balanced. Nutritionists have conducted extensive research on the nutrient requirements for the Chinese major carps. A feed-based system, which combines traditional Chinese polyculture and U. S. monoculture technology, has been developed by the American Soybean Association. In this system, termed 80: 20 pond fish culture, approximately 80% of the harvest weight comes from only one high value, high consumer demand species that consumes the feed, and the other 20% comes from "service species" such as silver carp, which help clean the water, and mandarin fish (*Siniperca chuatsi*), which control wild fish and other competitors (H. R. Schmittou et al, 1998). Together with proper feeding practices, feeding the major species (the 80%-group fish) a nutritionally complete and high physical quality compressed feed results in better feed conversion, faster growth, and higher profits than those obtainable in traditional polyculture systems. This type of feed-based system has much less impact on the environment than traditional polyculture technology. Thus, it also fulfils a major requirement of sustainable aquaculture. Demand for high quality, extruded aquafeeds will increase, led by economic and environmental concerns. The future production increases will be obtained mainly from better management and use of high quality feeds. Moreover, with the world`s fish meal supply which is stagnating due to over-fishing and limiting availability of natural fish stocks, efforts should be continuously made for the replacement and/or partly replacement of fish meal in the aquafeed by soybean meal: a cheaper source of protein with a more stable supply than fish meal.

4.4. Water treatment system for water supply and drainage canals of fish farms

For each fish farm in China, a canal system is constructed to serve as water supply and for drainage. In most cases, the system of water supply to the ponds, both for initial filling and for periodic topping off, is operated by

strategically located pump stations. Some small portable pumps are used to empty ponds, when necessary. Introducing a water treatment system which includes biological and mechanical filters for water supply and drainage canals of the fish farms may ensure the quality of the water source for the initial filling, and regulate the effluent quality within specific criteria. The filters can capture suspended solids from water and simultaneously provide a large surface area for cultures of bacteria (*Nitrosomonas* sp. and *Nitrobacter* sp.) which remove dissolved nitrogenous wastes. For fish ponds that have been cultivated for many years, the bottom mud that has accumulated in the pond should be dug up and used to repair dikes or to enrich agricultural croplands.

4.5. Processing of the Chinese major carps and improving culture techniques

The population of China now totals over 1.2 billion. Traditionally, people like buying live fish, but the techniques for delivering live fish to the markets are currently available only for short distances from the farms. Thus, the market for Chinese major carps is relatively limited. Limited success has been achieved in the processing of the Chinese major carps. Promotion of the market for the processed products is to be strengthened in the future. If the producers are able to sell the processed products, such as fish fillets, iced fresh fish, and frozen products, in the supermarket or through other commercial channels, the fish market will be expanded rapidly. From the point of view of improving the traditional culture techniques, a fish culture strategy referred as stocking and harvesting in rotation should be implemented widely in future. The rotation method begins by stocking pond with several size classes of each fish species cultured. Throughout the growing season, fish reaching market size are captured once in every two to three months. At the same time, additional fingerlings are added to replace the fishes removed (Li, 1990). Thus, a consistent supply of the Chinese major carps can be maintained to meet the demand of customers all year round.

With the improving nutritional status of the Chinese people, however, consumer demands are changing. In response, market-driven aquaculture production technologies in China are undergoing a revolution, rapidly expanding and changing from an emphasis on the Chinese major carps to higher valued species, and higher technology levels for improved economic and resource efficiency and for environmental concerns. In the 21st century, profitable and sustainable aquaculture will be the major target for Chinese fish producers.

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Figure Legends

Figure 1. Production of fish and shellfish, World and China, 1988-1997 (FAO, 1998).
Figure 2. Fish and shellfish cultured in China as a percentage of world aquaculture, 1988-1997 (FAO, 1998).
Figure 3. Growth of freshwater aquaculture production in China, 1955-1996, and projected through 2005. (from Schmittou, 1998).
Figure 4. The traditional Chinese system of polyculture.