A Review of Freshwater Fish Genetic Conservation Research and Practices in China

Sifa Li
Shanghai Fisheries University
334 Jun Gong Road
Shanghai, People's Republic of China

Abstract

China's natural aquatic diversity and traditional inland fisheries are threatened by the need to feed the most populous nation on earth. As the world's leader in aquaculture production, conservation strategies are extremely necessary to protect China's genetic resources. In this paper, the status of fish genetic resources and a relevant study in China are presented. Efforts toward genetic conservation of the major Chinese carp are described. The impact of the Three Gorges Dam is also considered.

Introduction

For thousands of years plants and animals have been domesticated and adapted to agriculture by intentional and unintentional genetic changes. In contrast, a few fish species (common carp, rainbow trout, Atlantic salmon) have been domesticated in a rather short period.

Aquaculture, the so-called "blue revolution," is now at the stage where genetic erosion is beginning to impact fish populations. It is essential to foresee, and if possible to forestall, a major loss of aquatic genetic resources. The strategies used to maintain those genetic resources will be significantly different from those used for plant crops.

Genetic conservation studies of fish began only recently in China. As the leading aquaculture producing country in the world, it is necessary to develop a genetic conservation program for aquatic organisms.

Overview of Freshwater Fish Genetic Resources in China

- **Genetic resources and their role in Chinese aquaculture**

China has a rich freshwater fishery resource. There are more than 800 species distributed throughout China. Among them, about 760 are pure freshwater fishes (subspecies), 60 are migrant and 21 are exotic food fishes. Less than 200 species contribute significantly to food production. Table 1 shows fish species found in the major river systems in China. These fishes are essential genetic resources for aquaculture development in China.

Chinese carp are the primary aquaculture species in China and the world (Table 2). In 1990, fisheries production in China reached 12.37 million tons, of which freshwater aquaculture accounted for 4.4 million tons. The filter feeding species (silver carp and bighead carp) accounted for 2.5 million tons and the herbivorous species (grass carp and blunt snout bream) accounted for 1 million

Table 1. Incomplete statistics of number of fish species (Spp.) in the major river systems of China. (--) refers to those species for which data is not available.

River	Zhujiang (Pearl)		Changjiang (Yangtze)		Huanghe (Yellow)		Heilonjiang (Amur)	
Family	Spp.	%	Spp.	%	Spp.	%	Spp.	%
Cyprinidae	167	45.1%	141	49.8%	84	55.6%	59	52.2%
Bagridae	23	6.2%	19	6.7%	6	4.0%	4	3.6%
Gobiidae	17	4.6%	12	4.2%	8	5.2%	3	2.7%
Cobitidae	28	7.6%	19	6.7%	18	11.7%	--	--
Salmonidae	--	--	1	--	--	--	11	9.8%
Homalopteridae	22	6.0%	15	5.3%	--	--	--	--
Salangidae	--	--	5	1.8%	8	5.2%	--	--
Acipenseridae	--	--	3	1.1%	--	--	2	1.8%
Others	121	32.7%	68	24.0%	29	18.3%	34	30.0%
Total	378	100.0%	283	100.0%	153	100.0%	113	100.0%

Table 2. The position of Chinese carp in fish culture production in China and the world.

Species	Rank	
	In China*	In World **
Silver carp	1	1
Grass carp	2	3
Bighead carp	3	4
Common carp	4	2
Black carp	5	
Crucian carp	6	
Blunt snout bream	7	

Source: * Bureau of Aquatic Products, Agriculture Ministry of China, 1991. ** FAO, 1990.

tons of the freshwater aquaculture production.

• **Loss of genetic resources**

Loss of biodiversity throughout China will severely limit future options for sustainable development of aquaculture and fisheries. Genetic diversity of fishes in China is decreasing as a result of loss of species and loss of genetic variability within species.

• **Loss of species**

With the rapid development of the country and the ever increasing demand for fish as food, aquatic ecosystems are under constant stress. This stress has resulted in the loss of many species.

One preliminary estimate states that there are approximately 100 fish species (9 orders, 24 families and 80 genera) that are either extinct, endangered or are under threatened status in China (Li 1991, cited in Li 1992). Extinct examples include *Cyprinus yilongenesis*, *Anabarilius albumops*, and *A. ploylepis*; endangered examples include *Schizothorax taliensis*, *S. biddulphi*, *Cyprinus longipectoralis*, *C. crassilabris*, *C. megalophthalmus*, *Barbodes exigiua*, *B. coggili*, *B. exigua*, *Psephurs gladius*, *Aspiorhynchus laticeps*, and *Macrura reevesi* and threatened examples include *Myxocyprinus asiaticus* and *Acipenser sinensis*.

Compared to the ocean, inland rivers and lakes have simple fish faunas, lower biodiversity indices and a fish diversity that is very sensitive to ecosystem changes. The endemic fish species may suffer from the introduction of exotic species, destruction of specific habitats and overfishing.

The introduction of exotic species has impacted fish species in many areas of China. Introduction may also cause a loss of production. In Fuqiaohe Reservoir (2,000 ha), fry of the predatory fish *Elopichthys bambusa*, were accidentally introduced with major carp fry. The fish production decreased from 420 kg/ha in 1966 to 25 kg/ha in 1975. Certain species may be particularly susceptible to the introduction of exotics. In Buston Lake (960 km^2) in west China, *Perca fluviatilis* was introduced in the 1960s. They reproduced rapidly and preyed on the local species *Aspiorhychus laticeps*, which had previously dominated the lake's fish and are now rare.

Pollution from industry, habitat loss as a result of reservoir construction, building of facilities along shores of river and lakes, silt and sediment from land based forestry, agriculture and construction have affected fish resources throughout the world. Habitat loss on the Yangtze River, one of the most heavily exploited rivers in China, has significantly affected fish populations.

The Chinese sturgeon (*Acipenser sinensis*, Fig. 1) migrates between the ocean and river. The construction of Gouzhouba Dam in 1981 blocked its spawning migration route. This fish is no longer present in the upper reaches of the Yangtze River.

Chinese paddle fish (*Psephurus gladius*, Fig. 2) are distributed in the middle and lower reaches of the Yangtze River. Since the 1980s, its populations have sharply declined. The sampling data from June-August at the estuary of the Yangtze River is presented in Table 3.

Over-exploitation of many species is well-known and documented. The prized anadromous hilsa (*Macrura reevesi*, Fig. 3) provided 300,000-500,000 kg catch annually in Yangtze River before the 1970s. The highest

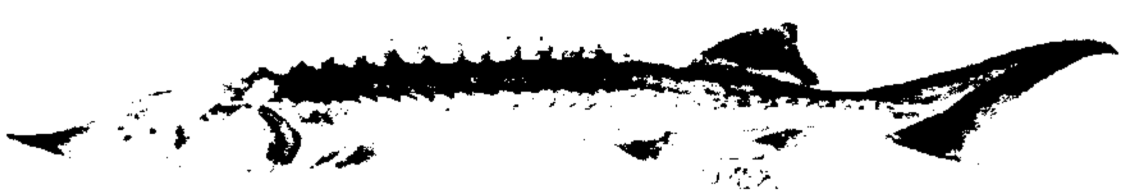

Figure 1. Chinese sturgeon (*Acipenser sinnensis*)

Table 3. Catch data for Chinese Paddle Fish in the Yangtze River Estuary (1983-1990)

Year	Number sampled
1983	587
1984	9
1985	84
1986	2
1988	5
1989	0
1990	0

yield reached 1,575,000 kg in 1974. It has now lost its significance in the Yangtze River fishery and has completely disappeared in the Qiantangjiang River (Zhou et al., Internal material, 1991).

Overfishing is the main reason for the reduction of fisheries resources in many lakes. For example, in catch composition small species and young age groups dominate the fishery. In Taihu lake (233,800 ha), the small fish, *Coila ectenes*, which has little market value, accounted for an average of 41.1% of the total aquatic production from 1980 to 1988. Another small but valuable species, ice fish, *Neosalanx tangkahkeii* accounted for 9.4% of the total production during the same period (Fig. 4, Cai 1990).

- **Loss of genetic diversity within species**

Genetic pools may be changed through selective fishing of the stock, selection and hybrid breeding and transplantation to new

Figure 2. Chinese paddle fish (*Psephurus gladius*)

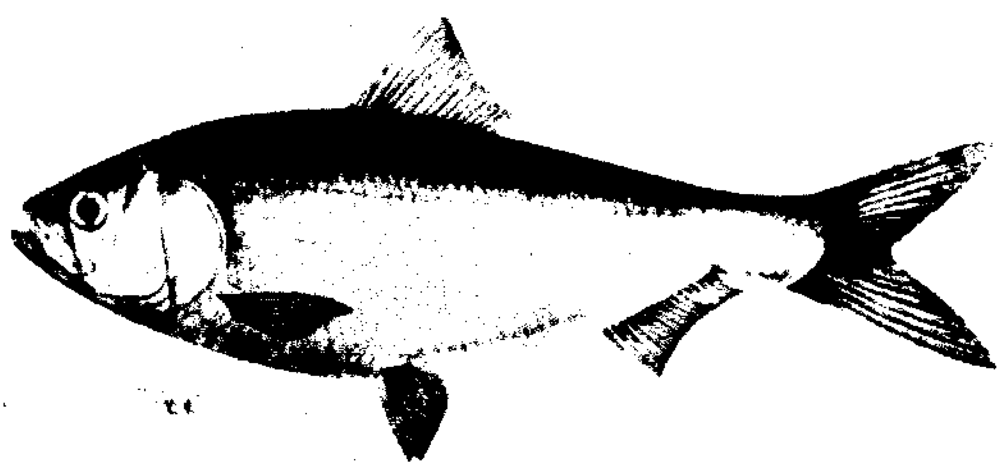

Figure 3. Hilsa (*Macrura reevesi*)

locations. Such changes may affect the resiliency of the species to environmental fluctuations, and finally, the production potential.

The Chinese have a tradition of using the productivity of the waters on a large scale through aquaculture. However, the decrease of the relevant gene pools due to intensification of aquaculture activities, extensive application of artificial reproduction and bioengineering techniques has posed a serious constraint to aquaculture development.

China produces more cultured freshwater fish than any other country. Aquaculture activities are being conducted in ponds, lakes, reservoirs and rivers. Due to stocking methods, escapes and unpredicted flooding, there are many opportunities for cultivated populations to enter natural waters. To meet the demand for aquacultured species in different areas of China, the transportation of fish fry and/or fingerlings is conducted on a large scale. There is concern that this may disturb local fish populations.

Since 1972, significant effort has been expended on fish hybridization, primarily for use of F_1 hybrid heterosis. Zhang et al. (1988) summarized crosses made among 25 fish species belonging to three orders. Emphasis was on use of F_1 hybrid heterosis in common carp. At least six crosses ("harvest carp," "Heyuan carp," "triple-cross carp," "Yue carp," "Furong carp" and "Ying carp") are widely cultured. However, it is not possible to estimate how many hybrids enter natural waters. The pure strain of common carp is difficult to find except in northeastern China.

The development of gene transfer as a means of improving cultured fish stocks is progressing rapidly. At least six research institutes in China are developing transgenic fish. Once these are released to farms, it will be virtually impossible to prevent them from escaping into natural systems. The subsequent impacts on native stocks and aquatic communities are presently unknown (Hallerman and Kapuscinski 1992).

Case Study of Genetic Variation and Conservation of Chinese Carp

- **Genetic evaluation of major Chinese carp**

Since the 1980s, studies on genetic resources and the conservation of important freshwater

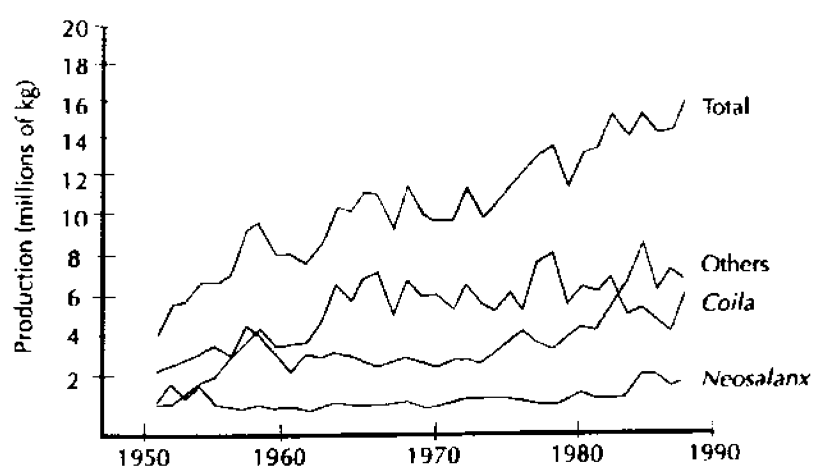

Figure 4. Production of the major species in Taihu lake

fishes have been conducted. Traditional farm fishes include the grass carp (*Ctenopharyngodon idellus*), black carp (*Mylopharyngodon piceus*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), and blunt snout bream (*Megalobrama amblycephala*). These fish are widely recognized as the most important species for farming in a wide range of aquaculture systems, including extensive and intensive, ponds, cages, pens, lakes and reservoirs.

Blunt snout bream is a herbivorous species. It is distributed in several lakes along the Yangtze River. Since the 1960s, it has become a major species in pond and cage fish culture as its production reached 150,000 tons in 1991. A study of the morphological and biochemical genetic variation among different populations of blunt snout bream, supported by IDRC, has been conducted since 1985 in Shanghai Fisheries University (SFU). The results from three lakes and one tributary indicated that the mean proportion of polymorphism was 13.3-20.0%, the average heterozygosity was 0.0549-0.0851, and the Nei genetic distance was 0-0.0219 (Li et al. 1993).

SFU started a study on genetic resources of Chinese carp in 1982 under the support of a national government program and the International Foundation for Science (IFS). The research team included the SFU; Institute of Hydrobiology (IHB), Academia Sinica; Heilongjiang (= Amur) River Fisheries Research Institute (HRFI), Changjiang (= Yangtze) River Fisheries Research Institute (CRFI) and Zhujinag (= Pearl) River Fisheries Research Institute (ZRFI) of the Chinese Academy of Fisheries Science.

The major findings from this study from 1982 to 1989 were:

(1) There was significant intraspecific divergence in morphometric characters among populations of Chinese carp from the three Chinese rivers. The number of scales on the lateral line of silver carp and bighead carp decreases from northern to southern China (Li 1990; Li et al. 1990).

(2) There was biochemical genetic variation among the different populations of Chinese carp from the three rivers. The range of the average heterozygosity was 0.0484-0.0511 for silver carp, 0.1042-0.1133 for bighead and 0.0454-0.1076 for grass carp. The range in proportion of polymorphic loci was 11.8-23.5% for silver carp, 29.4 % for bighead and 20.0-33.3% for grass carp. The population in the south had a higher proportion of polymorphic loci than those in the north (Li 1990; Li et al. 1990).

The proportion of polymorphic loci and the average heterozygosity of wild Chinese carp is much higher than that of the grass carp introduced in the United States (Utter and Folmar 1978; Brummett et al. 1988).

(3) Under the same culture conditions, the growth rate of silver and bighead carp from the Changjiang River is 5-10% faster than those from the Zhujiang River (Li 1990; Li et al. 1990). Since the annual production of these two species exceeds 2 million tons, this is a major finding and of immediate applicability. In addition, the growth of the wild population of silver and bighead carp from both river systems were shown to be 5-10% faster than hatchery populations. This shows there was a negative response to the domestication process, which requires more attention and further study. This study also showed that genetic factors had a considerable effect on growth variation.

(4) Under culture conditions, silver carp and bighead carp from the Changjiang and Jhujiang Rivers reached maturity at the same time. Environmental factors had a major effect on their gonadal development and age of sexual maturity (Li et al. 1990).

(5) Fishery resources of silver and bighead carp have decreased in three major rivers. In the early 1980s, catches of marketable-sized fish were half of the catch in the 1950s, and the catch of natural fry was one-quarter of the catch in the 1960s. In recent years this decline in fishery resources has accelerated. The catches of silver and bighead carp fry are now insufficient to meet the demand from the limited number of original brooder farms.

Establishment of Fish Gene Banks

Since 1985, there has been an effort to learn how to conserve the genetic material of important freshwater fish species at the population, individual and cellular level. A few different methods have been investigated.

- **Live gene conservation banks**

A gene bank pond farm with a 24 ha area was set up in the Yangtze River Fisheries Research Institute in 1989-1990. Ten species including silver crucian carp (*Carassius auratus gibelio,*), mirror common carp, tilapia nilotica, tilapia aurea, Xingguo red common carp (*Cyprinus carpio singuonensis*), red purse common carp (*Cyprinus carpio wuyuanensis*), silver carp, bighead carp, grass carp and black carp have been preserved in these ponds. The effects of environmental factors on growth, metabolism, gonad development and fecundity of the fish were studied. The optimum environmental parameters, as well as reasonable stocking and rearing techniques were proposed to improve the management of these ponds.

From 1986 - 1990, Xingguo red common carp and red purse common carp gene bank ponds have been set up with 4 ha and 20 ha ponds, respectively. Each bank can supply hundreds of brooders and thousands of fingerlings of red carp. These two common carp are local strains developed under specific natural environments. They have a high potential for heterosis in hybridization.

A gene bank for blunt snout bream was set up in 1990 in Yuli Lake, with an area of 2,000 ha area combined with 5.5 ha ponds. A 300 ha natural spawning ground has been rehabilitated, and a fish screen has been built to prevent fish from escaping. This bank can protect the bream at a population level, and can produce 1500 brooder pairs, 1900 kg of fingerlings and 100 million fry annually.

- **Cryogenic gene bank**

Parallel to live fish collection from the wild, a fish spermatozoa cryopreservation bank has been set up at the National Laboratory of Freshwater Fish Germplasm Resources & Biotechnology (NLFFGRB). The sperm from eight economically important species (black carp, grass carp, silver carp, bighead carp, blunt snout bream, Xingguo red common carp, mirror common carp and silver crucian carp) have been stored.

Although cryopreserved sperm do not undergo changes during storage in liquid nitrogen, it represents only half the genome. The banked sperm of a stock might be less useful if the female of that strain were to become unavailable.

Genetic Conservation Program of the Yangtze River and Evaluation of Impact of the Three Gorges Dam

- **The importance of Yangtze River for fisheries**

The Changjiang River is the third longest river in the world. It originates in the Qinghai-Tibetan plateau (4000m elevation), flows through nine provinces and has a total length of about 6300 km. It enters the East China Sea on the north side of Shanghai. Its catchment covers an area of 364,000 km^2, and with favorable monsoon climate and good ecological conditions, an abundant fish composition has developed in the Chinese and Asian river systems. Among them, about 100 species are native to the Chinese plain rivers including grass carp, black carp, silver carp, bighead carp, *Elopichthys bambusa*, *Coreius heterodon*, white amur bream (*Parabramis pekinensis*), black bream (*Megalobrama terminalis*), blunt snout bream, and mandarin fish (*Siniperca chuatsi*).

Fish production from the Changjiang River basin accounts for 60% of the total freshwater fish production in China. It is the major source of wild brooders for artificial breeding and ensures the genetic variability of cultured Chinese carp.

In the early 1960s, it was estimated that the annual fry production of the four major carp species was 115 billion and that 200,000 spawning brooders of these four species were available. But only 17.3 billion fry were produced in 1980 (Survey Team of Spawning Grounds of Domestic Fishes in Changjiang River 1982) and today, resources have decreased even further.

The sturgeons (Chinese sturgeon), Changjiang sturgeon (*Acipenser dabryanus*), and Chinese paddle fish are all ranked as protected fish species in China. To rehabilitate the Chinese sturgeon, a hatchery was established below the Gouzhouba Dam. Artificial reproduction has been successful and the hatched fry and fingerlings have recently been released into the river. As a result, the population has been increased. After construction of the Three Gorges Dam, they may face a new challenge.

- **The construction of the Three Gorges Dam and an evaluation of its impact on fisheries resources**

The decision to construct the Three Gorges Dam on the Yangtze River was made in 1992. The principle reasons are to produce electric power, control flooding and improve navigation. As a result, a huge reservoir 175 meters high and 500-600 km in long will be created. Many evaluations of impact on the environment, including work on fisheries resources, have been completed, but the impact on the genetic resources of major cultured fish species has been ignored.

Through changed water flows, elimination of seasonal flooding and water temperature changes that presently trigger spawning, construction of the Yangtze High Dam will obliterate the major spawning grounds (downstream of the Gouzhouba Dam, Fig. 5) for carp in the most important part of the river. More problematic will be a reduction of flooded backwater areas, which form the nursery and fattening areas for fry and fingerlings of Chinese carp. This may result in a significant loss of genetic diversity from the single most important source of these fish in the world.

After spawning below the Gouzhouba Dam disappears, spawning might move downstream and the Swan oxbow would lose its function as a breeding and rearing area for Yangtze River fish.

The Yangtze River is the cradle of Chinese fish culture. It contains essential resources for the maintenance of Chinese carp genetic diversity. It is necessary to protect its resources so that China can maintain its position as the world's leader in aquaculture production, as well as maintain the most important freshwater fish genetic resource in the world.

Recently, a research study has been proposed by the author to the Ministry of Agriculture to address current issues that may affect the genetic diversity within the Yangtze River. The proposed research will focus on:

(1) Evaluating the potential impact of the Three Gorges Dam on the genetic resources of major Chinese carp,

(2) Maintaining the genetic diversity of major Chinese carp of the Yangtze River by establishing a series of reserves (Fig. 5) along the Yangtze River and a gene bank at SFU,

(3) Designing a sustainable management systems and ensuring preservation of the genetic resources that are available for production,

(4) Providing fish and germplasm to national and/or international research programs and to fish farms by distributing Yangtze stock of Chinese carp through the National Committee of Aquatic Varieties Certification (NCAVC) and the Yangtze River Wild Fish Stock Utilization Program (YRWFSUP).

- **Current research**

Since 1991, a national research program has been carried out under the title, "Natural Ecological Bank of Genetic Resources of Major Chinese carp in Yangtze River." This program has focused on three goals.

> Establish an isolated conservation area for major Chinese carp

Louheko oxbow is located at the middle reach of the Yangtze River and forms a

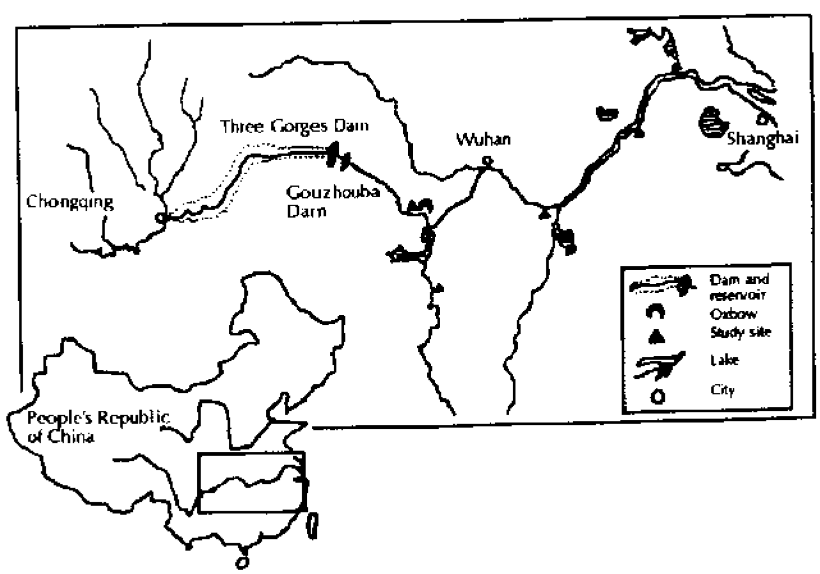

Figure 5. The middle and lower stream of the Yangtze River, Gouzhouba Dam, Three Gorges Dam, Swan oxbow and five study sites.

20,000-ha area. This oxbow is completely isolated from the Yangtze River. The wild fry are collected from the river and nursed in ponds in their first year and stocked into the oxbow in their second year. This conservation bank will support wild fish brooders for the hatcheries.

> Establish an open conservation area for major Chinese carp

The Swan oxbow was formed in the 1970s and remains open to the Yangtze River and has an area of 1200 ha. The major Chinese carp migrate between the oxbow and river. Swan oxbow will be used as a conservation area to keep a sufficient amount of fish to supply brooders to the hatchery. It will also be used as a window to observe the genetic variation of major Chinese carp affected by the changing environment of the Yangtze River; particularly after the damming of Three Gorges valley.

> Establish a genetic standard for major Chinese carp

In contrast to well-developed fish culture techniques, which date back thousands of years, genetic improvement of Chinese carp has so far remained almost untouched by recent biological advances. This is due to several reasons.

> Chinese carp have a long generation time (4-6 years) and require big ponds to grow and mature properly,

> The farming of Chinese carp was based primarily on the use of wild seed until the breakthrough of induced breeding in the 1960s,

> There has been a lack of genetic skills in China until recently,

> There has been a lack of sufficient funding to support long-term genetic research

In 1986, a national program was started to establish genetic standards for major Chinese carp. The propagation of fry by thousands of hatcheries in China reaching 140 billion a year, and the transportation of these fish throughout the country, prompted the study. Its goal is to establish genotypic and phenotypic criteria for the sustainable use of genetic resources and the healthy development of aquaculture in China. These standards are for government, scientists and managers to use in the different levels of hatchery and farm production, and for monitoring and controlling the quality of the product. This study, now under the direction of the Shanghai Fisheries University, should be completed by 1995

Responses from the Chinese Fisheries Community to the Genetic Conservation Issue

In China, there is a rich diversity of freshwater fishes and there are strong national movements both for genetic improvement and genetic conservation. It is well recognized that the application of genetic principles to aquaculture is far behind that of agriculture or animal husbandry. Conservation of genetic resources will bring long-term benefits to the development of aquaculture in China and the world. Due to rapidly changing socioeconomics and a changing environment (for example, the construction of the Three Gorges Dam and the expansion of industry in the countryside), genetic conservation strategies are necessary to protect genetic resources. Several relevant events are mentioned below.

In 1988, the National Laboratory of Freshwater Fish Germplasm and Biotechnique (NLFFGB) was established. It reflects a growing national concern for the conservation of aquatic genetic resources from the government and fisheries community.

The Yangtze River Wild Fish Stock Utilization Program (YRWFSUP) was organized in 1991. It is a collective organization formed by people interested in the utilization and protection of the wild Chinese carp stocks of the Yangtze River. Now it involves about 30 fish farms, research institutes and administrative extension agencies.

The National Committee of Aquatic Varieties Certification (NCAVC) was established in 1991 under the Ministry of Agriculture. The NCAVC is planning to set up 15 national farms for wild and domesticated fish and crab broodstock to protect and produce better strains under certification and authorization.

In 1992, the Aquatic Genetic Resources Laboratory(AGRL) at Shanghai Fisheries University was established. Its major targets are genetic variation of natural hatchery populations, conservation of genetic resources and international cooperation in aquatic genetic diversity and conservation.

Acknowledgments

I wish to express my gratitude to Drs. B. Ayles and J. Mathias for their constructive comments and English help with the manuscript.

Literature Cited

Brummett, R. E., R. O. Smitherman and R. A. Dunham. 1988. Isozyme expression in bighead carp, silver carp and their reciprocal hybrids. *Aquaculture* 70: 21-28.

Bureau of Aquatic Products, Agriculture Ministry of China: 1991. Production Yearbook of Aquatic Products. (In: Chinese)

Cai, R. K. 1990. Study on the integrate development and utilization of fishing in Taihu Lake. 79-96. In Freshwater Fisheries Research Center: Selected papers of Freshwater Fisheries Research. Science Press. Beijing (In Chinese with English abstract)

FAO: 1990. FAO Production Yearbook. FAO, Rome, Italy. 136 pp.

Hallerman, E. M. and A. R. Kapuscinski. 1992. Ecological implications of using transgenic fishes in aquaculture. ICES Mar. Sci. Symp. 194: 56-66.

Li, S. and S. Xu. 1988. Fish Culture and Capture in Reservoirs. Shanghai Scientific and Technological Publishers. 398 pp. (In: Chinese)

Li, S. 1990. Genetic evaluation of Chinese carp. AMBIO 19(8): 411-415.

Li, S. 1992. Protection of rare aquatic wild animals in China. Presented at FAO Expert Consultation on Utilization and Conservation for Aquatic Genetic Resources (Grottaferrata, Italy, November, 1992).

Li, S., W. Cai and B. Zhou. 1993. Variation in Morphology and biochemical genetic markers among populations of blunt snout bream (*Megalobrama amblycephala*). *Aquaculture* 111 (In press).

Li, S., L. Wu, J. Wang, Q. Chou and Y. Chen. 1990. Comprehensive Genetic Study on Chinese carp. Shanghai Scientific & Technical Publisher. 229 pp. (In: Chinese with English abstract)

Survey Team of Spawning Grounds of Domestic fishes in Changjiang River. 1982. A survey on the spawning groups of the "four famous Chinese carp" in the Changjiang River after being dammed by the key water control project at Gouzhouba. *Journal of Fisheries of China*. 6(40): 287-305. (In: Chinese with English abstract)

Utter, F. and L. Folmar. 1978. Protein systems of grass carp: Allelic variate and their application to management of introduced population. *Transaction of the American Fisheries Society*. 107(1): 129-134.

Zhang, X. Z., Q.R. Chou, S.L. Chen and W.Y. You. 1988. Fish Genetics and Breeding. Agriculture Publishers. Beijing, 250pp (In: Chinese).