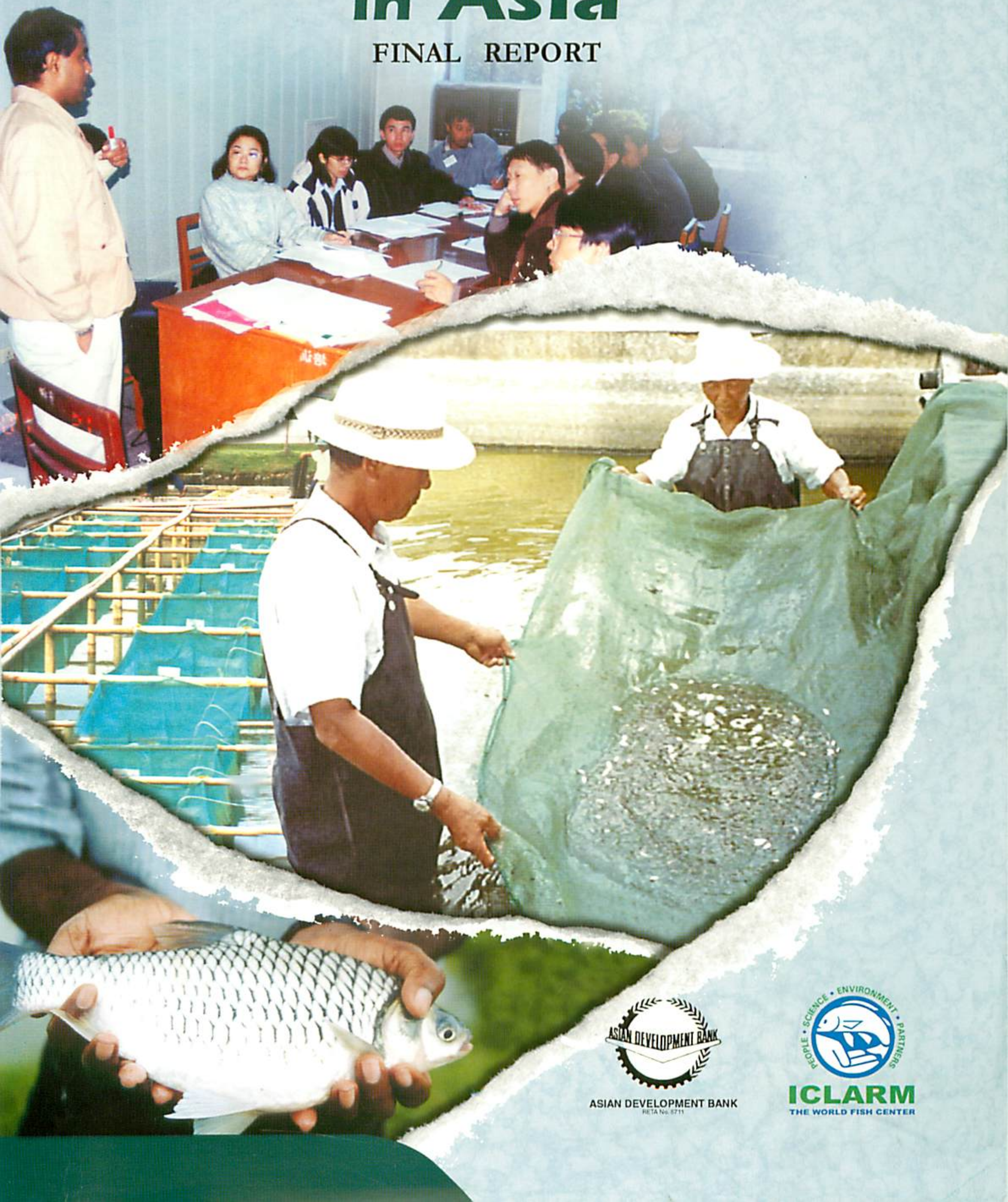
Genetic Improvement of Carp Species in Asia

FINAL REPORT



ASIAN DEVELOPMENT BANK
RETA No. 5711

ICLARM
THE WORLD FISH CENTER

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FINAL REPORT

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GENETIC IMPROVEMENT OF CARP SPECIES IN ASIA
(RETA 5711)

Final Report to the Asian Development Bank

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ICLARM - The World Fish Center

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GENETIC IMPROVEMENT OF CARP SPECIES IN ASIA

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Executive Summary - ADB RETA 5711: Genetic Improvement of Carp Species in Asia

ADB RETA 5711 on the Genetic Improvement of Carp Species in Asia showed that the growth performance of carps, the most cultured fish in the world, could be improved by 10% per generation of selection, based on the preliminary studies of 4 carp species in the 6 Developing Member Countries (DMCs) participating (Bangladesh, the People's Republic of China, India, Indonesia, Thailand and Vietnam). This is similar to the results obtained by earlier research on tilapia selection and indicates great promise of gains, through selective breeding, in efficiency of production and potential increase in supply of carp. The longer generation time of carps compared to, say, tilapia, means that these gains will only be demonstrated adequately through a further project phase and may not be realized on farm from just the successful though preliminary work of Phase I. The major potential impact of the present project is the transfer of breeding technologies and methods that will enable participating countries to carry out their own breeding programmes.

The project to date also provides an information base on carp genetic resources to underpin further long term selection efforts. It has documented the genetic and strain diversity and use in aquaculture of the 20 main native carp species raised in Asia.

Of the total world carp production, 95% is grown in Asia and the results of the socio-economic component of the study showed that carp farming is typically carried out in simple low input pond aquaculture, operated by small to medium scale farmers in rice-based farming systems. Carp farming in ponds and cages is profitable in all the countries and many farmers further increase profitability and lower their risks by adopting polyculture and integrated culture systems. The project showed that carp farming is not performing optimally. The causes of yield loss vary with farm and country but major factors are: lack of allocative efficiency and profit seeking behaviour of the farmers (40-60%) technical constraints especially poor water quality and disease (10-30%) and technical inefficiency (10-50%).

Carps are favoured by low income consumers because of their low price and good taste; in many areas, carps are the only source of affordable animal protein for the poor. Improvement in carp farming will benefit poor consumers.

The collaborative project on the genetic improvement of carps in Asia was planned to be implemented in two phases. The Bank has provided a Technical Assistance Grant (RETA No. 5711) of US$ 1.3 million to ICLARM for implementing the first phase of the Project from 1 June 1997 to 30 June 2000 in the six DMCs of the Bank. A no cost extension led to the research phase I being completed by 31 December 2000 not including the subsequent analyses presented in this final report. The current phase of the project was reviewed by two major review missions.
This report discusses the results of the first phase of the project and outlines the plan for the second phase.

The project has been successful in achieving all three of its objectives (see below and table). During the first phase of the project, research priorities (species for genetic improvement, farming environment, and traits) have been identified, genetic resource-bases have been evaluated, and growth rate for some of the priority species have been improved. Outputs include the development and publication of knowledge on existing carp genetic resources in the region, and the formation and training of national teams comprised of geneticists and socioeconomic scientists. The evaluation and priority setting has thus been based on both a knowledge of biophysical opportunity, market forces expressed through consumer and producer preferences and analysis of technical and other constraints. Thirdly and most importantly the carp genetic improvement programs have been initiated for carp species key to the different DMCs with early gains in growth performance of these species through family-based genetic selection procedures. These outputs are listed in the accompanying tables and developed in detail in the text of the report. They may be summarized as follows:

(i) *To assess the current status of Asian carp genetic resources for their use in aquaculture, and to bring together the existing technical skills and experience scattered throughout Asia to build strategic research partnerships and networks*: the project has systematically documented the carp genetic resources in the participating DMCs, as well as their evaluation and sustainable use in aquaculture. Three books will be published as a result of the project, two on characterization of resources, with one being a translation from the Chinese and the other being a completely new treatise on this subject. It is expected that at least eight scientific papers will be published by ICLARM and national partner scientists, reflecting both project results and the enhanced scientific capacity in socio-economic and quantitative genetic data analysis and use of statistical software provided by the project. Three regional training workshops were conducted during the phase I project to provide participants with overviews of quantitative genetic methods, applied carp breeding techniques, statistical and economic analyses and the use of computer programmes. These workshops also facilitated exchanges of ideas and research experiences among geneticists and socio-economists. Some participating scientists have used their advanced skills in analysis of the other projects in their institutes. Geneticists have shown initiative in other research methodologies and found ways to maximize use of resources, such as making their own floy tags (for fish identification) instead of buying them from commercial companies.

(ii) To develop criteria for prioritizing carp genetic research and set research priorities: Systematic documentation involved the collation of available information, including indigenous knowledge. Field surveys were made to understand regional supply systems and to estimate the demand for carps. ICLARM and its partners have (a) assessed how carp strains are valued by various groups; (b) estimated future demand by income groups; (c) analyzed the importance of various carp-based farming systems, (d) assessed the relative economic importance of various traits (including growth, disease resistance, tolerance to low dissolved oxygen and to poor soil and water conditions). Analyses of this information were based on field surveys and secondary information, and implemented by an ICLARM socio-economics and policy analyst, visiting scientists and local social scientists. The third book to be published will correlate the outcomes of this part of the study against a background review of the importance of carp farming in Asia.

Briefly, pond operators in China have the highest yield (12 085 kg/ha/growing season while Bangladesh, India, Thailand and northern Vietnam produce 3 262, 3 214, 3 780 and 3 647 kg/ha/growing season respectively. In Indonesia, cage culture produces significantly higher yields (1 010 kg/100m^2 than do running water systems (482 kg/100m^2). For pond polyculture, operating profit/hectare/production cycle is highest in China (US$ 3 448), followed by Thailand (US$ 1 471) and North Vietnam (US$ 1 390), and is lowest in India (US$ 589). In Indonesia, the operating profit under cage culture and running water systems are 155 and 176 US$/m^2, respectively. The use of polyculture and integrated culture systems shows not only profit-maximization by fish farmers, but also the farmers' tendency toward risk aversion.

Total yield losses due to various technical (both biotic and abiotic) constraints contribute from about 10% of the yield gap in India to about 30% of the yield gap in Vietnam. The results show that, overall, the two most important technical constraints to production are poor water quality and disease. This suggests that under most circumstances farmers would benefit generally from the use of improved strains of carp particularly those tolerant or resistant to these stresses. Disease is an important constraint in all countries but Bangladesh. Disease contributes to more than 30% of total estimated yield losses in China, India and Vietnam.

The results of the producer and consumer surveys for the different carp species have shown that preferences are shaped by a large number of factors which vary from country to country. Rankings of preferences by producers are as expected based on production characteristics, including rapid growth, high market value and better meat quality. Preferences are also based on size, colour and shape. Consumer preferences for particular fish are shaped by variables such as taste, price, availability and physical appearance. Desirable quality traits of fish include high dress-out percentage, large size, colour, body shape, flavour and high fat content. Preferences for these traits differ among countries, sometimes for the same species. Each country had a unique profile of preferences for traits, however, increases in growth and disease resistance are invariably preferred by producers in all countries for all species.

The carp species preferred for genetic improvement are catla (*Catla catla)* and silver barb (*Barbodes gonionotus*) in Bangladesh, common carp (*Cyprinus carpio*) in China focussing on rapid growth, better meat quality, tolerance to low dissolved oxygen and disease resistance. India has identified rohu (*Labeo rohita*) and common carp, for which rapid growth, high dress-out percentage, disease resistance (rohu) and late maturity (for common carp) are high on the list of traits for genetic improvement. Indonesians prefer common carp. In Thailand, the choice for genetic improvement for freshwater species is silver barb and common carp. In Vietnam, silver barb and common carp are preferred. The Vietnamese prefer species with rapid growth, high dress-out percentages and disease resistance.

(iii) *To identify potential genetic approaches and initiate location-specific strategic research and training in carp genetics leading to the development of high yielding carp strains:*
The overall goal of this project was to identify and stimulate research into the use of selective breeding, which has been successfully used with tilapias and salmonids to achieve impressive gains in growth and other traits. Genetic improvement experiments were successfully conducted for common carp in China, Thailand, India and Indonesia and Vietnam, for silver barb in Bangladesh, Thailand and Vietnam, for blunt snout bream (*Megalobrama amblycephala*) in China and for rohu in India. The project has developed improved silver barb in Bangladesh with 22% higher growth performance in 3 generations of selection, improved Jian Carp (a local strain of common carp, in China with further growth improvement of 6 to 12%, and improved blunt snout bream in China with 29% higher growth. Other participating countries have successfully initiated the genetic improvement experiments for growth improvement of priority species. The initial results show that the growth performance of carps can be improved by 10% per generation of selection. This range is similar to the anticipated improvement per generation in earlier projects with tilapia. This suggests that substantial gains can be made from the continued use of selective breeding strategies for the improvement of Asian carps based on genetically heterogeneous starting populations. These gains are not dependent upon genetic engineering. The longer generational cycle of carps compared with tilapias mean that full gains in growth performance from the work already commenced can only be completely realized in phase II. Experiments on inbreeding (in blunt snout bream in China) however showed that fish subjected intentionally to three generations of inbreeding showed 17% less growth than controls. These results clearly show that inbreeding resulting from poor broodstock management can lead to a loss of growth potential, raising the need for future improved lines of carps to be properly husbanded upon dissemination.

Impacts of the phase I carp genetic improvement project are given in the accompanying table by country.

During the first phase of the project, research priorities (species, farming environment and traits) have been identified, genetic resource-bases have been evaluated and growth rates for some of the priority species have been improved. Given the demonstrable gains in growth in Asian carps that can be produced by selective breeding methods, all the participating DMCs wish to develop this major opportunity for enhancing aquaculture in the region. All DMCs and ICLARM met during the final stages of the project. It was agreed to request that the Asian

Development Bank finance the next phase of the project under its CGIAR RETA programme. The proposed outline for the new phase is being forwarded for the consideration of the Bank with this report (p. 151).

The phase II activities describes research building on the teams and experiments started under phase I with seven sequential activities and outcomes:

- Economic valuation of priority traits and estimation of breeding values in multitrait selection,
- The continued improvement of selected carp strains and species,
- On-farm testing of the improved strains,
- Development of strategies for dissemination of improved carp breeds,
- Capacity strengthening of national partners,
- Assessment of the potential economic, social and environmental impacts of the improved breeds,
- The design of national carp breeding programs in the collaborating DMCs.

In all countries, as carp production is dominated by small and medium-scale farmers, the benefits from the adoption of improved carp strains developed under this project will be enjoyed by these groups of farmers. Given the semi-intensive and low external input culture systems of carp farming, the adoption of the improved carp strain is not expected to create environmental problems. As carps are consumed mainly by relatively poor people, due to their relatively low price, the adoption of improved carp strains will continue to benefit the poor consumers in Asian communities. The technical advances will allow teams of Asian scientists to continue collaboration in the improvement of the region's aquaculture and to mount research in the future to tackle major threats to the continued growth of the industry, and the food security it offers, through addressing diseases and other abiotic stresses.

Country	Achievements during Phase I	Issues to be addressed in Phase II
Bangladesh	▪ Three generations of selection for growth of silver barb were done. The cumulative genetic gain is about 22%. ▪ Catla and silver barb were identified as priority species for genetic improvement. ▪ Rapid growth, high reproductive performance, bright appearance (for catla), disease resistance (for silver barb) and high dress-out percentage (for silver barb) were identified as the priority traits for genetic improvement. ▪ Genetic resource-base of carps have been evaluated and documented. ▪ Catla broodstock were collected from three river systems. These genetic stocks will be used to derive the initial base population for future selection. ▪ Surveys of 540 fish producing households and 360 fish consuming households were conducted to identify priorities for carp genetic research. ▪ Research priorities (species for genetic improvement, farming environments, and traits) have been identified. ▪ Fingerlings of improved silver barb were disseminated to fish farmers (nursery and and grow-out operators in Mymensingh District) for on-farm testing. Results show that selected (improved) fish grew more rapidly and survived better than local strains. ▪ Twenty-four fish farmers were trained on "Culture of Genetically Improved Silver Barb".	▪ Improvement for growth of silver barb will be continued. ▪ Addition of other traits for selection (higher reproductive performance, higher dress-out percentage, and disease resistance) of silver barb will be considered for further selection. ▪ Selection of catla for growth, higher reproductive performance and color traits will be initiated. ▪ Improved silver barb will be tested in different farming systems under on-farm conditions. ▪ Strategies for dissemination of improved carp breeds will be developed. ▪ Potential economic, social and environmental impacts of the improved carp breeds will be assessed. ▪ National carp breeding program will be designed.

India	▪ Growth trials of rohu were conducted in 2 aquaculture systems (polyculture and monoculture). In polyculture, no significant difference in weight was found between crossbreeds and pure breeds. In monoculture, pure lines attained higher weights than cross breeds. ▪ Molecular genetic methods were used to characterize genetic variation in and among carp breeds, including crossbreeds of rohu, triploids and monosex populations of common carp. ▪ The usefulness of triploid common carp to control reproduction was demonstrated. ▪ Experiments on triploids showed that triploid fish have low gonadal somatic indices and high dress-out percentages which are very promising for commercial use. ▪ International cooperation has widened and improved common carp from Indonesia, Vietnam and Thailand was sent to India. ▪ The project has led to additional donors contributing to selection and improvement work and has affected policies in India. The Department of Fisheries has agreed to produce crossbreeds of catla and rohu to increase production and to keep separate breeding centers for Indian major carps and common carp to implement genetic improvement programs. ▪ The genetic resource-base of carps has been evaluated and documented. ▪ Surveys of 409 fish producing households and 682 fish consuming households were conducted to identify priorities for carp genetic research. ▪ Rohu and common carp were identified as priority species for genetic improvement.	▪ Genetic improvement of rohu will be continued. Disease resistance and high dress-out percentage will be incorporated in the breeding goal. ▪ Common carp will also be improved for other priority traits (late maturity and high dress-out percentage) ▪ Improved breeds of common carp and rohu will be evaluated in different farming conditions under on-farm trials. ▪ National carp breeding programmes will further be strengthened. ▪ Potential economic, social and environmental impacts of the improved carp breeds will be assessed. ▪ Strategies for dissemination of improved carp breeds will be developed ▪ Improved fish (common carp and rohu) will be disseminated to farmers.

	▪ Rapid growth, high dress-out percentage, disease resistance (rohu) and late maturity (for common carp) have been identified as the priority traits for genetic improvement of common carp and rohu.	
North Vietnam	▪ Two generations of selection for growth of common carp was done using family selection. About 5% genetic gain per generation was achieved. ▪ A methodology for rearing carp fry and fingerling in hapas was improved. This has provided advantages in using limited numbers of earthen ponds in the experiment. Farmers in the northern highland region have adopted this technology. ▪ Improved common carp fry and fingerlings were distributed to farmers for food production. ▪ The genetic quality of broodstock has been maintained and deposited at three national brood stock centers in Northern, Central and Southern Vietnam. ▪ Genetic resource-base of carps have been evaluated and documented. ▪ Surveys of 158 fish producing households and 514 fish consuming households were conducted to identify priorities for carp genetic research. ▪ Common carp was identified as the priority species for genetic improvement, and the identified priority traits are rapid growth, high dress-out percentages and disease resistance.	▪ Genetic improvement of common carp will be continued with the incorporation of 2 other identified priority traits (i.e., disease resistance and high dress-out percentage). ▪ Strategies for dissemination of improved carp breeds will be developed. ▪ Potential economic, social and environmental impacts of the improved carp breeds will be assessed.

South Vietnam	• Analysis of genotype by environment interaction was done for crosses of two domestic strains and three wild strains of silver barb from Mekong River. Pure breed, Tien Giang had a good performance in earthen ponds while pure breed Can Tho was excellent in rice fields. • A breeding programme for silver barb using a population base of communal brooders was initiated. • Silver barb from various locations of the Mekong Delta were collected. • Breeding methods for research were developed. These are use of hormone injections to induce and synchronize spawning of silver barb, development of conical plankton nets for incubation of fry and use of alcian blue injections and fin clipping to mark fingerlings in breeding experiments. • The genetic resource-base of carps has been evaluated and documented. • Surveys of 240 fish producing households and 318 fish consuming households were conducted to identify priorities for carp genetic research. • Silver barb was identified as the priority species for genetic improvement and the priority traits identified are rapid growth, high dress-out percentages and disease resistance.	• Selection for growth of silver barb will be continued with addition of other traits like disease resistance and high dress out percentage. • Potential economic, social and environmental impacts of the improved carp breeds will be assessed.

EXTENDED PROJECT SUMMARY

Although capture fisheries currently provide most of the aquatic production for human consumption, aquaculture will become more important as capture fisheries decline or stabilize. World fish production from all sources in 1999 was 137 million mt, including 43 million mt from aquaculture and 94 million mt from capture fisheries. Aquaculture production more than doubled between 1990 and 1999 (from 16.8 million mt in 1990 to 42.8 million mt in 1999; FAO 1999), while capture fisheries production increased only marginally (from 86.8 million mt in 1990 to 94.1 million mt in 1999; FAO 1999). Aquaculture has become the world's fastest growing food-producing sector, with a growth rate of 10% annually since 1984. Asia produces about 57% of the world's total aquaculture production, with China, India, Japan, Republic of Korea, the Philippines, Indonesia and Thailand as top producers within Asia.

Aquaculture benefits poor rural communities in many developing countries, because it enhances food security and improves the livelihoods of poor peoples. Increases in aquaculture production can be made through the development and adoption of new technology (e.g. improved management, better nutrition and genetic improvement of the strains used for culture) and improvements in the economic efficiency of fish farming operations. If farmers are reasonably efficient, then increases in productivity will require new inputs and the development and adoption of new technology (e.g. genetically improved carp strains and better fish farming technology) to increase fish production further. Given the relatively high technical efficiency of fish farmers in Asia and the evidence of genetic deterioration (including inbreeding depression) of culture stocks, genetic improvement can play a key role in increasing fish production in Asia.

Previously, the Genetic Improvement of Farmed Tilapia (GIFT) project (partially funded by the Asian Development Bank (ADB) under RETA No. 5279) and the Dissemination and Evaluation of Genetically Improved Tilapia in Asia (DEGITA) project (funded by ADB under RETA No. 5558) applied genetic improvement methods to tilapias and examined the effectiveness of improved strains in enhancing the efficiency of tilapia production among farmers. The use of genetic selection in the GIFT project was impressive. A gain of over 80% in growth was achieved after five generations of selection on families in a base population consisting of four genetically diverse strains of Nile tilapia.

In most Asian countries, however, carp are more important than tilapia in aquaculture. About 20 carp species are extensively cultured under a diverse variety of farming systems; all of these species are endemic to Asian waters. Several carp producing developing member countries (DMC's) of the Asian Development Bank approached ICLARM to initiate a 'GIFT-type' strategic research and training initiative on Asian carps. However, the target for genetic improvement of carps is complex because of the diversity of species farmed, farming systems and socioeconomic circumstances prevailing in the various Asian carp producing nations. Also, the generation intervals of most carp species are longer than those for tilapia - about two to three years in tropical environments. Finally, a fish breeder must choose between numerous commercially important traits that could be improved.

Given the complexity and time constraints of the carp genetic research, ICLARM submitted a proposal to the ADB for the implementation of a collaborative project on the genetic improvement of carps in Asia in two phases. Phase I would focus on determining research priorities and initiating research leading to the development of high yielding breeds and strains. Phase II would concentrate on (i) the continued development of improved breeds, (ii) dissemination and evaluation of improved carp species, and (iii) establishment of national carp breeding programmes. The ADB approved a collaborative project on the genetic improvement of carps in Asia for implementation in two phases, and provided a Technical Assistance Grant (RETA No. 5711) of US$ 1.3 million to ICLARM for implementing the first phase of the

Project from 1 June 1997 to 31 May 2000 in six DMCs of the Bank (namely, Bangladesh, People's Republic of China, India, Indonesia, Thailand and Vietnam). These countries were selected because they 1) are the major centres of carp species diversity and have high demand for carp, and 2) have national aquaculture strategies, reasonable research facilities and human resources. At the request of ICLARM and all the participating countries, the ADB granted a no cost extension of the project up to 31 December 2000. ICLARM and the six participating DMCs also contributed approximately US $1.3 million to match the grant of the bank for the implementation of the project.

The first phase of the project has the following objectives:

1. Assess the current status of Asian carp genetic resources for their use in aquaculture;
2. Bring together the existing technical skills and experience scattered throughout Asia and build strategic research partnerships and networks;
3. Analyze production and consumption of carps in Asia and identify research priorities and approaches, including species, farming systems and traits;
4. Identify potential genetic approaches, and initiate location-specific strategic research and training in carp genetics leading to the development of high yielding carp strains.

This final report discusses the results of the first phase of the project and outlines the plan for the second phase. The results are reported under the three main activities: (1) documentation of carp genetic resources, (2) socioeconomic analysis of production and consumption of carp and (3) carp genetic research.

Genetic resources of carp

South and South-East Asia encompass the world's highest diversity of carp species in the family Cyprinidae. These fish have been harvested from natural waters and used for aquaculture for centuries. However, carps have not been selectively bred to enhance growth and other important production traits. Many areas where aquaculture takes place are characterized by large river systems that flood annually. These areas have some of the highest human population densities and therefore tend to have highly disturbed environments in which natural populations are under threat. Consequently, attention has been paid in recent years to conservation and utilization of carp genetic resources in Asia.

Substantial information on carp genetic resources was collected and compiled in all the participating countries. This information on carp genetic resources in Asia is valuable in designing an appropriate carp genetic research programme in participating countries with due consideration to the fish biodiversity. It also provides a working knowledge base on present Asian carp genetic resources in aquaculture. A brief summary of carp genetic resources in different participating countries is presented below.

Bangladesh

Bangladesh has a rich diversity of fish species, with 296 fresh and brackish water species (including freshwater prawns) and 511 marine water species (including marine shrimps). Endemic carp species of Bangladesh can be sub-divided into two groups: Indian major carps, rohu (*Labeo rohita*), catla (*Catla catla*) and mrigal (*Cirrihinus mrigala*), and minor carps, Bata (*Labeo bata*), Reba (*Cyprinus reba*), Nandin (*Labeo nandina*) and Gonia (*Labeo gonius*). Most of the freshwater river systems and floodplains of the country are natural breeding grounds of these carps.

A number of exotic fishes have also been introduced since 1960, but these introductions have not been well documented. Introduced species include silver carp *(Hypophthalmichthys molitrix)*, bighead carp *(Aristichthys nobilis)*, grass carp *(Ctenopharyngodon idella)*, black carp

(Mylopharyngodon piceus), common carp *(Cyprinus carpio)*, mahseer *(Tor putitora)* and silver barb *(Puntius gonionotus)*.

Both indigenous and exotic carps are used in pond polyculture; some are also stocked in floodplains, rivers and reservoirs to enhance wild stocks. Bangladesh has a high human population density, which makes large demands on the environment for fish production and which threatens indigenous species.

India

India shares many species of fish with Bangladesh in the Ganges-Brahmaputra River system. The diverse Indian fish fauna includes about 9% of the world's 25,000 described species of fish. These species include a variety of marine, estuarine brackish water and freshwater species, many of which are economically important. The Ganga River system contains the largest diversity of freshwater fishes in the country. It is also the natural habitat for many commercially important species. Freshwater lakes also contain numerous fishes. About 544 species inhabit warm waters of the plains.

Carps are an important component of India's rich fish biodiversity. They not only support the inland capture fishery, but also contribute substantially to aquaculture production. The four major carps which contribute substantially to aquaculture production belong to three genera: *Catla, Cirrhinus* and *Labeo*. The important species belonging to these genera are: *C. catla, C. mrigala, C. reba, L. rohita, L. calbasu, L. dero, L. dyocheilus, L. fimbriatus, L. kontius, L. bata and L. gonius.*

Chinese silver carp and grass carp and different strains of common carp have been introduced into India and form an important component in polyculture of indigenous and exotic species. Bighead carp and black or snail carp *(M. piceus)* have also been introduced into India in recent years.

Displacement of wild stocks and high levels of introgression as a result of large-scale introduction of hatchery stock has been reported. Studies in some species have clearly indicated that the hatchery stocks differ greatly from wild stocks.

Some minor carps like *L. dero, L. dussumieri, L. fimbriatus* and *L. gonius* are on the endangered species list. Many of the endangered carps are from the peninsular region and some are endemic only to India. While the major carp species are not either endangered or threatened, they are prone to loss of genetic diversity and variability due to extinction of genetically distinct wild populations, escape and ranching of farmed seed and competition from exotic carps.

Thailand

Thailand has a rich diversity of carps in five subfamilies of the family Cyprinidae. At least 192 species of local and introduced carps have been recorded in Thailand. The indigenous carp species used in aquaculture are: silver barb *(P. gonionotus)*, jullien carp *(Probarbus jullieni)*, Jullien's mud carp *(Cirrhinus jullieni)*, soldier- river barb *(Cyclocheilichthys enoplos)*, *Leptobarbus hovenii, Catlacarpio siamensis* and *Osteochilus hasselti*. Of these, *P. gonionotus* is the most important and widely cultured species in ponds and rice fields.

In addition to the indigenous species mentioned above, eight species of carps have been introduced into Thailand and used in aquaculture. They are: common carp *(C. carpio)*, Chinese carps: silver carp *(H. molitrix)*, bighead carp *(A. nobilis)* and grass carp *(C. idella)* and Indian carps: rohu *(L. rohita)*, mrigal *(C. mrigala)* and catla *(Catla catla)*.

Due to programmes undertaken to restock reservoirs and other natural waters, genetic contamination of natural populations from hatchery populations was noted. The spatial genetic structure of *P. gonionotus* populations was studied. High genetic variability was observed in 12 natural populations from three rivers and 29 hatchery stocks from the different regions of Thailand studied. Allozyme data indicated three strains of common carp in Thailand.

Vietnam

Freshwater fish fauna of Vietnam comprise 544 species in 228 genera. Of these, only 11 species are common to North and South Vietnam. About 50 carp species are economically important. Approximately 28 indigenous fish species are being used in aquaculture production systems, of which, 9 species are native to the North, 14 species native to the South and 5 species distributed in both regions. Thirteen species of carps are widely used in aquaculture. These are: common carp, Vietnamese silver carp *(Hypophthalmichthys harmandi),* black carp, mud carp, *Squaliobalbus curriculus, Megalograma ferminalis, Spinibarbichthys denticulatus, Carassius auratus, P. gonionotus, Leptobarbus hoeveni, Puntius altus, Puntioplites protozysron* and *Osteochilus hasselti.*

In addition to the above indigenous species, some 18 freshwater fish species have been introduced into Vietnam for aquaculture. These include the carp species silver carp, bighead carp, grass carp, rohu, mrigal, catla and common carp. They account for over 90% of aquaculture production.

Based on morphology and colouration, eight varieties of common carp have been identified. Characterization of Chinese carps and Vietnamese silver carp has been carried out.

Indonesia

Indonesia consists of more than 17 500 islands, including five large islands—Sumatera, Java, Kalimantan, Sulawesi and Irian Jaya. Indonesia as a whole has a high level of freshwater fish species diversity, including 30 endemic species of fishes on Sumatera, 149 on Kalimantan, 12 on Java and 52 on Sulawesi. Freshwater fish have been cultured since the 14th century and have made a significant contribution to the farming economy. Several species of indigenous fishes, including Java carp, Nilem carp, jelawat, giant gourami, kissing gourami and walking catfish have more recently been used in culture.

Common carp is the most important cultured species in Indonesia. Other important cultured carp species are Nilem carp, and Java barb. In addition, kancera carp also has potential for production but has not yet been developed for culture.

Environmental conditions and farming systems differ from region to region and with this, common carp also exhibit variation in body colour and colour pattern on the body. Some well established stocks were selected on the basis of colour and given colour-specific names such as "Merah" (red) developed by farmers in East Java, "Majalaya" (dull green) in West Java, "Sinyonya" (yellow) and "Punten" (dark green). All stocks were hybridized under farming conditions. Geographical barriers may have split common carp stocks into several sub-populations, among which gene flow is restricted.

China

There are about 3,016 species of fish in China, of which 800 are from freshwater. Carps play a significant role in both capture fisheries and aquaculture. Some 22 species of carps are used in aquaculture. Ten species account for 80% of aquaculture production. Silver carp, bighead carp, grass carp, common carp, Crucian carp *(C. auratus),* wuchang fish, black carp *(M. piceus)* and mud carp *(Cirrhina moliterella),* and blunt snout bream *(Megalobrama amblycephala)* are the main species used in aquaculture. Silver carp, bighead carp, grass carp and black carp, known collectively as 'four Chinese farmed fish' contributed 6.719 million tons to aquaculture production. Silver carp, grass carp and black carp are distributed in the Yangtze, Pearl and Amur Rivers, while bighead carp is distributed in the Yangtze and Pearl Rivers. Seven stocks of Chinese carps (from farming stock) have been established in the Yangtze River basin. Common carp is the most domesticated species in China and many strains/varieties have been developed. Three subspecies of Crucian carp are cultured and ploidy level, body shape and production traits vary among subspecies and strains.

Production and consumption of carps in Asia: Implication for research priority

To ensure that the new carp strain(s) to be developed is(are) relevant for and acceptable to its users, it is necessary to understand, among others, the biophysical and socioeconomic environments within which it will be introduced. Thus the genetic research began after an extensive, objective and pragmatic research priority setting exercise, which considered both production and consumption of carps in Asia. The analysis was based on secondary information and on field survey data collected under this project from 2 025 fish producer households and 5 931 fish consumer households. For the survey of consumers, each household was visited four to twenty four times during the survey year to capture the seasonality in fish consumption.

Aquaculture industry in Asia

In Bangladesh, carps are by far the most important species in cultured (pond) fish production. Three major Indian carps, rohu (*Labeo rohita*), catla (*Catla catla*), mrigal (*Cirrihinus mrigala*) and one exotic carp, Silver carp (*Hypopthalmichthys molitrix*), together account for more than 78% of this production. About 91% of all fish species in the total pond culture are carps.

China has the longest history of freshwater aquaculture, dating to 5 B.C. and is the largest producer of aquatic products in the world. Although China has more than 800 freshwater fish species, carp species dominate freshwater capture fisheries production contributing about 80-90% of total production. Carps are also widely cultured, despite the introduction of numerous exotic freshwater species for culture. Eight of the 10 major carp species being cultured are of national economic importance, including black carp (*Mylopharyngodon piceus*), grass carp (*Ctenopharyngodon idella*), common carp (*Cyprinus carpio*), silver carp (*H. molitrix*), bighead (*Aristichthys nobilis*), Crucian carp (*Carassius auratus*) and Chinese bream (*Megalobrama amblycephala* and *Parabramis pekinesis*). Production of these eight species reached nearly 12 million tons in 1999 and together accounted for about 83% of the total freshwater aquaculture production. Aquaculture production in China increased on average 7.6% annually from 1990 to 1999. Growth in production of important species was 13.5% for black carp, 9.1% for grass carp, 1.5% for silver carp, 6.4% for common carp, 19.7% for Crucian carp and 39.5% for freshwater bream.

In India, traditionally, aquaculture farmers have used freshwater and coastal saline waters culture systems, characterized by low inputs and low production. However, aquaculture has been slowly transformed into a business activity during the last decade. Total aquaculture production has more than doubled from 686 260 mt in 1986 to 1,608,938 mt in 1995. Carps dominate aquaculture production in freshwater ponds, cages, pens and recirculating systems and production in inland fisheries. Carp production constituted about 44% of the total inland fishery production of 5.14 million mt in 1996. In aquaculture, however, only carp pond culture has reached commercial importance. The remaining production consists of experimental and small-scale production.

In Indonesia, aquaculture represents 16.5% of the total fisheries production (4 452 258 tons). Fisheries statistics for 1996 show that aquaculture production has increased more than production from capture fisheries. Aquaculture production consists of 9.1% in brackish water ponds, 4.1% in freshwater ponds, 1.0% in cages and 2.4% in paddy fields. Culture production grew by 8.4% annually for brackish water ponds, 7.4% for freshwater ponds, 2.4% for paddy fields between 1987 to 1996. The largest growth in production was for cage culture with 45.8% annual growth during this period. Presently, carp culture largely takes place in three environments: ponds, floating cages and rice fields. Cultured carps account for about 98% of all carps produced in the country. The common carp contributes more than 90% of the country's total carp production. Common carp production from aquaculture registered a moderately high annual growth of 12% from 1985 to 1994.

Fifteen species of fish and invertebrates are cultured in Thailand. In 1997, freshwater aquaculture amounted to 200,018 tons, including tilapia (33.9%), Thai silver barb (16.7%), common carp (6.1%), Chinese carp (0.4%), rohu (0.9%), mrigal (0.2%), catfish (25.6%), snakeskin gourami (6.5%) and others (9.8%). Fish farming is carried out in ponds, paddy fields, ditches and cages. Pond culture is by far the most popular culture method in terms of the number of farms and cultured area.

Traditional carp culture has been practiced for a long time in Vietnam by rice farmers who culture fish in rice fields and village ponds. The main cultured species are common carp and other indigenous species. In the 1960's, with the introduction of Chinese carps (silver carp, bighead carp, grass carp) together with induced breeding, freshwater fish culture entered into a new era. However, carp farming was not important to the rural economy of Vietnam until the early 1980's, following the introduction of Indian carps such as rohu, mrigal and catla. In 1996, carp culture contributed about 29% (0.40 million tons) to the total fish production (1.37 million tons). The Mekong River Delta plays a most important role in aquaculture, producing about 67% of the total aquaculture production.

Socioeconomic profile of carp farming in Asia

Carp farming in Asia is dominated by small-scale farmers operating in predominantly rice-based farming systems. Fish farming is not the primary occupation of most households, except in China and Indonesia. The pond system of farming and polyculture is common for all the countries, except for Indonesia where fish are grown in monoculture running water systems and cages. Integrated fish farming and rice fish farming constitute a major part of the aquaculture in Thailand and Vietnam. The average total area cultivated by a household ranges from 1.04 ha in South Vietnam to 4.24 ha in India. The average size of a fishpond varies from 0.2 ha in Bangladesh to 1.70 ha in China. Carp farms are operated mostly by private owners, except in China and North Vietnam, where a large proportion are owned by the state or by collectives. Carp farming is usually carried out by the male head of the family, except in Vietnam, where it is carried out by women on over 50% of the farms.

In pond polyculture systems, the average stocking density varies from 5,432 fish/ha in North Vietnam to 67,382 fish/ha in Thailand . The Indian major carps (rohu, catla and mrigal) are stocked the most in India and Bangladesh. In China, silver carp (28%), common carp (22%), grass carp (21%) and Crucian carps (15%) predominate. In Thailand, silver barb account for 40%, followed by tilapia (37%) and common carps (9%). In North and South Vietnam, silver carps (28%) and silver barb (20%) are cultured most. Thus, carps together account for a major share of stocked fish in all countries, except in Thailand, where tilapias constitute 35% of stocked fish. In Indonesia, stocking densities for monoculture in cages vary between 25-100 g/m^2. In the pond polyculture system in Bangladesh, China, India, Thailand and Vietnam, fish are raised for eight to 12 Months. While common carp are reared for only three to four months in the cage/running water monoculture system in Indonesia. Fingerlings are generally supplied by private and government hatcheries, except in China where fingerlings are produced by farmers themselves.

Pond operators in all the surveyed countries fertilize their ponds and also feed the fish, though the type and quantity of feeds varies among countries. Fish farmers in Bangladesh, India and Vietnam used relatively less supplementary feed and other inputs than did farmers in China and Thailand. Level of input use indicates that pond operators in these countries are culturing fish using a semi-intensive system.[1] In Indonesia, running water systems (RWS) are semi-intensive and intensive systems, whereas fish-rice culture is an extensive culture system.

The yield level, cost of production and profitability of carp farming vary widely in different countries, production environments, with differing input levels, culture practices and farming systems. Pond operators in China have the highest yield (12 085 kg/ha) while Bangladesh, India, Thailand and northern Vietnam produce 3 262, 3 214, 3 780 and 3 647 kg/ha respectively. In Indonesia, cage culture produces significantly higher yields (1 010 kg/m^2) than do running water systems (482 kg/m^2).

Carp farming is a profitable activity in Asia. In pond polyculture, operating profit/hectare/production cycle is highest in China (US$ 3 448), followed by Thailand (US$ 1 471) and North Vietnam (US$ 1 390), and is lowest in India (US$ 589). In Indonesia, the operating profit under cage culture and running water systems are 155 and 176 US$/m^2, respectively. The use of polyculture and integrated culture systems shows not only profit-maximization by fish farmers, but also the farmers' tendency toward risk aversion.

Feed costs are important for pond culture in China and Thailand, which in these countries accounted for about 46% and 33% of the total cost, respectively. Feed costs are equally important for Indonesia's RWS and cage systems, accounting for more than 50% of the total cost. In Bangladesh and India, feed costs are not as high, accounting for only 14.2% and 15.7% of the total cost, respectively. Except for India, the proportional cost of fingerlings ranks second to feed costs for all countries.

The yield of fish farms differs greatly between countries and among farms in each country, even in China, where carps have been cultured for thousands of years. This project identified and quantified the possible constraints responsible for the gap between potential and actual yields of carp farms in Asia. The yield gap, defined as the difference between the potential and the actual farm yield, can be attributed to four factors: (1) profit-seeking behavior, that is, the desire of farmers to maximize profits rather than yields; (2) lack of allocative efficiency, that is, farmers use less than economically optimal level of inputs; (3) lack of technical efficiency; and (4) losses due to various biotic and abiotic factors.

Results show that the average yield of carp farms is much lower than the potential farm yields in Asia. The ratio of the average farm yield to the potential farm yield for carp farms ranges from about 0.25 in India to about 0.65 in Indonesia. A substantial proportion of yield gap (about 40 to 60%) is attributed to the lack of allocative efficiency and profit seeking behavior of the farmers. A stochastic production frontier with technical inefficiency effects model is specified and estimated for various countries to calculate loses due to technical inefficiency. The estimated technical efficiency of carp farming in Asia is generally high - 70% in Bangladesh, about 80% in Indonesia, 61% in India, and 58% in North Vietnam. Technical inefficiency accounts for about 10 to 50% of the yield gap in various countries.

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[1] Aquaculture can be broadly classified as extensive, having no feed or fertilizer inputs; semi-intensive, having some fertilizer and/or feed inputs; and intensive, largely reliant on feed inputs (Edwards et al. 1988; Edwards 1993; Pullin 1993b; Molnar et al. 1996). As these systems are conceptual stages in a continuum and in practice are modified to suit specific farm conditions, they are often categorized as modified extensive, modified semi-intensive and modified intensive etc. (Pillay 1997).

Total yield losses due to various technical (both biotic and abiotic) constraints contribute from about 10% of the yield gap in India to about 30% of the yield gap in Vietnam. The results show that, overall, the two most important technical constraints to production are poor water quality and disease. The contribution of poor water quality to total estimated yield losses ranges from around 12% in Thailand to about 70% in Bangladesh. Most important water quality related constraints are low dissolved oxygen in water, high turbidity of water and plankton blooms. Disease is an important constraint in all countries but Bangladesh. Disease contributes to more than 30% of total estimated yield losses in China, India and Vietnam. Soil acidity is an important constraint in Thailand and southern Vietnam.

The results of the survey indicate that in Bangladesh, producers currently prefer rohu, followed by silver carps, mrigal and catla. In China, producers prefer grass carps, then silver carps and Crucian carps. In India, rohu, catla and common carps are most preferred. In Thailand, farmers prefer silver barb and common carps. In North Vietnam, the first preference is for grass carps followed by common carps, silver carps and rohu each with equal ranking. In South Vietnam, farmers prefer silver carp, followed by grass carps and silver barb. Rankings of preferences by producers are based on production characteristics, including rapid growth, high market value and better meat quality. Preferences are also based on size, colour and shape.

Patterns of fish consumption and traits preferred by consumers

In addition to the preferences of producers, the choice of species and traits for genetic research also depends on consumers' preferences and tastes that shape the domestic market. Results of the survey of consumers show that patterns of expenditures on fish varies considerably among income groups in the various countries. In China, expenditure on Crucian carp is highest for all income groups (22-24%), due to both a high rate of consumption and high prices. In Thailand, the "very poor" income group's expenditure on fish is greatest on marine fishes and the expenditure of the other three income groups is mainly on snakehead. Silver barb is popular for the lower income groups in Thailand, expenditure on this fish is inversely proportional to income level. The pattern of fish expenditure in North Vietnam and South Vietnam is very different. The highest expenditure for all the income groups in South Vietnam is on snakehead, whereas in North Vietnam the highest expenditure is on rohu. In North Vietnam, the percentage share of expenditure on silver carp and mrigal is inversely related to income, but in South Vietnam expenditure on these species is similar in all income groups. Consumers in North Vietnam spend more on common carp as income increases, which differs from consumer behaviour in South Vietnam, China and Thailand.

Prices of fish varied among countries during the surveyed year (1998/99). In Bangladesh, rohu, catla and mrigal fetched the highest prices, ranging between US$ 0.94-1.44/kg. In China, Crucian carp (US$ 1.30/kg) fetched the highest prices, followed by black carp (US$ 1.28/kg) and common carp (US$ 1.07/kg) respectively. In India, the rohu, catla and mrigal were priced at US$ 0.80 to US$ 0.86/kg. In Thailand, the prices per kg were US$ 0.90 for common carp, US$ 0.72 for silver barb and US$ 0.69 for tilapia. Black carp and common carp cost the most in North Vietnam (US$ 1.38 and US$ 0.82/kg, respectively), whereas in South Vietnam, catla, silver barb and common carp had the highest value.

Consumer preferences for particular fish are shaped by variables such as taste, price, availability and physical appearance. The most preferred species in Bangladesh, as well as in India, is rohu, followed by catla and mrigal. Common carp is most preferred by consumers in Indonesia and South Vietnam. Snakehead and then silver carp are the most preferred species in South Vietnam. Consumers in North Vietnam rank grass carp as the most preferred species, followed by mud carp and common carp. Chinese consumers rank Crucian carp, grass carp and common carp in that order. In Thailand, the freshwater fish presently most preferred is tilapia, followed by snakehead and catfish. Silver barb is ranked fifth.

Another way of gauging preferences is to assess desirable qualities of fish. Traits include high dress-out percentage, large size, colour, body shape, flavour and high fat content. Preferences for these traits differ among countries, sometimes for the same species. For example, trait preferences vary considerably among the three most-preferred species in a country, except for rohu and catla in Bangladesh where colour and high dress-out percentage ranked first and second, respectively. Unlike Bangladeshi consumers, Indian consumers prefer the body shape and flavour of rohu and the larger size and higher fat content of catla over colour and higher dress-out percentage in these species. Like Indian consumers, body shape, size and flavour are among the traits the Chinese considered important in preferred species. High dress-out percentage, large size, better flavour and body shape are traits preferred by consumers in Thailand to select silver barb. Consumers in South Vietnam, however, mostly prefer fish with high fat content in some of the same species. High fat content is the most preferred trait of common carp among consumers in South Vietnam. Consumers in North Vietnam prefer the higher fat content of silver carp, but also its colour.

Implications for carp genetic research priorities

The above results indicate the lack of a universal set of species or preferred traits that might be used for genetic improvement. Each country had a unique profile of preferences for traits, although some traits are preferred in common among countries. For example, increases in growth and disease resistance are invariably preferred by producers in all countries for all species. In Bangladesh, catla and silver barb appeared to be important candidates for genetic improvement. Rapid growth, high reproductive performance, bright appearance (for catla), and high dress-out percentage (for silver barb) might be traits for genetic improvement. Traits high on the list for genetic improvement in common carp in China are rapid growth, better meat quality, tolerance to low dissolved oxygen and disease resistance. Indians have identified rohu and catla, for which rapid growth, high dress-out percentage, disease resistance (rohu) and late maturity (for common carp) are high on the list of traits for genetic improvement. Indonesians prefer common carp and would like to select for more rapid growth, higher dress-out percentages and greater resistance to diseases. In Thailand, the choice for genetic improvement for freshwater species is silver barb and common carp, for which rapid growth, high dress-out percentage and high survivability are important. In Vietnam, silver barb and common carp are preferred. The Vietnamese prefer species with rapid growth, high dress-out percentages and disease resistance.

Carp genetics research

Only a limited amount of research to characterize and improve carp species through selective breeding[2] and gene manipulation has been done, even though carps have long been an essential part of the economies of countries in South and Southeast Asia. The overall goal of this project was to identify and stimulate research into the use of selective breeding, which has been successfully used with tilapias and salmonids to achieve impressive gains in growth and other traits.

Genetic improvement experiments were successfully conducted for common carp in China, Thailand, India, Indonesia and Vietnam, for silver barb in Bangladesh, Thailand and Vietnam, for blunt snout bream in China and for rohu in India. A component of many of the studies in the present project concerned the marking of carps in some way to identify families, especially

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[2] Mass (or individual) selection involves the measurement and use as breeder of the best performers in a population without regard to family relationships. On the other hand, family selection entails the use of physical tags to identify families. Breeders are selected on the basis of family performance, not individual performance, and are selected from different families to prevent inbreeding. Mass selection may lead to inbreeding (mating between relatives) because family members cannot be identified and related individuals may inadvertently be mated with each other.

when individuals from different families are grown in common ponds. Molecular genetic markers can be used to assist selection, if markers can be found that are linked to the performance trait being selected. A study in India screened genetic variability in rohu in an attempt to find such markers.

Common carp

Common carp is a native of the temperate regions of Asia. However, it has been transplanted into scores of countries, so that it now enjoys the status of being a global fish and its culture is widespread. This fish grows rapidly and is suitable for many farming systems. The protein content of common carp is high and the production costs are relatively low.

In China, the culture of common carp presently faces various problems including reduced growth rate, increased disease susceptibility –(possibly from poor water supplies or from inbreeding) and declining economic return. Even so, production is reputed to reach more than one million mt annually for the Jian strain, alone. Therefore, common carp was selected by the Freshwater Fisheries Research Center, Wuxi as the major target for genetic improvement of growth performance and other attributes influencing economic value. Six trial groups: Jianhuang (Jian carpE × Huanghe carpΓ), Jianhe (Jian carpE × Hebao red carpΓ), Hebao, Huanghe and two groups of Jian carp (selected and unselected) were used in growth trials. Artificial insemination was used for matings between varieties. The different groups of fish were tested for growth in three replicates. In one generation, as much as 30% body weight gain over parental strains was made by hybrids in mono- and polyculture, while 6-9% gains were made by selection.

In India, common carp has become an increasingly important species for aquaculture in the Bangalore region. In static water, this fish becomes sexually mature before reaching a marketable size. Hence, sterility was induced through triploidy to control early sexual maturation and unwanted reproduction. These triploids were evaluated for use in aquaculture and enhanced fisheries. Triploid and control fish were tagged either with PIT tags or by fin cauterization. At the end of the experiment, weights of triploid and diploid common carp (pooled sex) were not significantly different. However, dress-out weights of triploids were significantly higher than those of normal diploids. An alternative to prevent early maturation and mating is the production of all-male populations through sex reversal. Experimental fish were fed methyl di-hydroxy testosterone to induce sex reversal. Treated fish (40 day large, 50 day small, 50 day large) had significantly greater numbers of males than did the untreated controls.

In Indonesia, the wide development of common carp culture has apparently led to inbreeding, which is capable of lowering the genetic quality. The objective of the present project was to establish a base population by conducting a diallele cross with four Indonesian strains and to estimate heterosis effects for maternal and production traits. Tags for individual fish are a major cost in communal stocking experiments, so tags were developed in Indonesia. Heterosis for growth was estimated in two production environments: earthen ponds at the Research Institution for Freshwater Fisheries and floating net cages. In 16 crosses of the strains rajadanu, wildan cianjur, sutisna kuningan and majalaya, offspring of rajadanu females and males had the highest larval and post-larval survival rates. Estimates of heterosis for growth and survival in a communal stocking pond ranged from –2% to 7%.

In Thailand, scientific assessments of growth potential and the potential for genetic enhancement of carp have been made only recently. The objective of this project was to evaluate growth performances of three purebred strains of common carp and their crossbreeds, including local Thai, Vietnamese and Indonesian strains. After marking, strains were reared communally and growth was measured monthly by sampling 30 fish/pond for each strain. Total length, body weight, body width and depth were measured. After 11 months, there was little difference in length between the local Thai and Vietnamese strains, but the local strain consistently weighed more. The Indonesian strain grew considerably faster and longer than the local Thai strain.

In North Vietnam, the primary objective of the breeding programme was to selectively breed a strain of common carp that grew rapidly, had high survival and maintained stable genetic quality from one generation to the next. The base population used for selection consisted of individuals from the sixth generation of a strain of common carp derived by mass selection for growth. One hundred families were initiated and individuals marked with PIT tags. After hatching, larvae were gathered in fine-meshed hapas and swim-up fry of each family were divided and stocked into three 1m^3 hapas. Fingerlings were marked by fin clipping and stocked communally in earthen ponds. After 5-6 months, survival rate and individual weights were measured for each family. Within these families, 20% of the largest individuals were selected for breeding. Survival rates of offspring were high (> 90%), but average weights differed significantly among families ($P < 0.05$). The average weight of fingerlings from selected parents was 18 g and was significantly greater ($P < 0.05$) than the mean weight of fingerlings from the unselected base population (14 g). However, the mean weights of these two groups were not significantly different from each other ($P > 0.05$) after three months of growth.

Silver barb

Silver barb are naturally distributed in the Mekong, Chao Phraya and Xe Bangfai basins, Malay Peninsula, Sumatra and Java. They are migratory fish that have only recently been domesticated for aquaculture on a large scale.

In Bangladesh, most hatcheries rear their own broodstock and usually do not add broodstock from natural populations or exchange breeders among the farms. Reduced fecundity and growth, morphological deformities and increased incidence of disease and mortality of hatchery carps and silver barb have been reported in recent years. A breeding programme was initiated with two wild strains of silver barb from Thailand and Indonesia and a local stock in Bangladesh. Diallele crosses of three strains were developed, followed by a programme of mass selection for growth. Individuals were marked with PIT tags and stocked communally. The F_1 crossbred group weighed 8% more than the control stock, the F_2 selected group weighed 2% more than the crossbred group and the F_3 selected group weighed 12% more than the F_2 generation. The average gain per generation after two generations of selection was 7%. However, growth of the 3rd generation of selected fish grew 22% more than the local control group (BXB). The present genetic improvement of silver barb through crossbreeding and selection can serve as a model for improving other carp species in Bangladesh.

Thailand has a long history of aquaculture, but selective breeding has been used only recently. The objective of the present project was to genetically improve silver barb. Two different base populations were used for genetic improvement. Genetic gain was determined from the selected strain and control population of the first generation from July 1999 to January 2000. The selected Chao Phraya strain grew significantly faster and survived significantly better than the control population. Growth experiments are continuing with the Mekong River fish population and the genetic gain from this experiment will be calculated later.

Silver barb is most important in central and southern areas of South Vietnam. The objective of this project was to evaluate growth of various strains of silver barb and to establish a suitable base population for conducting combined family and individual selection. Silver barb from various locations in the Mekong Delta are presently being propagated. To increase genetic variability in the initial base population to be used for selective breeding and to reduce inbreeding, silver barb broodstock included two domestic strains and three wild strains from the Mekong River. For identification of fish in communal rearing environments, different parts of fingerlings were marked with fluorescent dyes. The two domesticated groups showed varied results. The pure breed, Tien Giang, had a good performance in earthen ponds, whereas the pure breed, Can Tho, was excellent in rice fields. Evidence for genotype-environment interactions was examined in the various crosses, but only the pure bred Can Tho strain responded differently between the two environments. In 2000, a breeding programme of silver barb using a population base of communal brooders was initiated. Mass selection was used to improve growth.

Blunt snout bream

In China, systematic selection for desirable traits in blunt snout bream was started in 1986. The initial population for selection originated from the Yuni Lake (2000 ha) in Hubei province in 1985 and 1986. This population was used to establish two parallel groups for selection (line 1 and line 2) and one control group. Another reference control group was based on the original brood fish introduced from Liangzi Lake (26700 ha) in Hubei province in early 1998. The objective of the present project was to continue selection for increased growth rate, so that fish could reach an ideal market size of 500-600 g in their second year under normal culture conditions. Experimental populations were created with fish collected in Lake Yuni in 1985 and 1986. Comparisons of total length and body weight were made among four groups of 5th generation (F_5) blunt snout bream at one, two and three years of age. The average absolute weight gain of selected line II at two years improved 29% more than that of the control group; each generation improved by 5.8%. The F_3 inbred group showed 17% less growth than the control group. These results clearly show that inbreeding resulting from poor broodstock management can lead to a loss of growth potential. Support is required not only for designing and executing selective breeding schemes, but also for developing sound broodstock management practices among farmers.

Rohu

Rohu is one of the most common aquaculture species in India. These fish do not breed in confined waters and must be spawned artificially. The production of fingerlings currently does not follow any genetic guidelines in India, particularly in the management of brood fish, the maintenance of effective breeding numbers and the replenishment of broodstock. Consequently, the quality of hatchery-produced larvae appears to have declined, as indicated by poor survival and growth. The first objective was to produce crossbreeds of two populations to evaluate growth in different aquaculture systems. A second objective was to use molecular genetic markers to search for markers of desirable traits and to measure levels of inbreeding. The final average weights of crossbreeds in polyculture at two locations were slightly higher (but not significantly so) than final mean weights of the pure breeds. In monoculture, however, pure lines attained higher mean weights compared to crossbreeds. Unlike catla, the results of growth trials did not give a clear indication of genetic deterioration in rohu. The use of DNA fingerprinting to search for family-specific markers was unsuccessful. No locus provided genetic tags for the identification of individual fish that could be used for marker-assisted selection. However, distinct markers would not be expected after only a single generation of selection. Additionally, estimates of heterozygosities with RAPDs (randomly amplified polymorphic DNA) indicated that selectively bred fish populations had lost genetic diversity. This implies that an insufficient number of breeders was used in the selective breeding experiments.

Training and workshops

Three regional training workshops were conducted to provide participants with overviews of quantitative genetic methods, applied carp breeding techniques, statistical and economic analyses and the use of computer programmes. These workshops also facilitated exchanges of ideas and research experiences among geneticists and socio-economists.

Impacts of carp genetic improvement

Aquaculture is a rapidly growing industry in numerous Asian countries. The major potential impact of the present project is the transfer of breeding technologies and methods that will enable participating countries to carry out their own breeding programmes. These technologies will lead to the improvement of fish strains that can increase production by enhancing growth and survival and a more efficient use of materials available to carp growers, including poor farmers.

In Bangladesh, the improved silver barb (with about 22% higher growth compared to the existing strain) is expected to be adopted by poor farmers. A major influence of the present project also includes a better awareness of broodstock management practices to avoid inbreeding and the loss of genetic diversity in hatchery populations.

In China, this project led to several positive influences on research capacity and fish production. First, significant progress was made during the project to improve the growth of common carp (Jian). This strain is characterized by rapid growth with an average of 30% higher body weight over other local and introduced common carp varieties. The selective breeding during this project has further improved its growth performance by 6-12%. The use of these improved strains and hybrids can lead to better food security. Researchers greatly benefited from the exchange of information on the analysis of socioeconomic and genetic data, research methods and breeding technology. Under this project, ICLARM introduced to China for the first time the conceptual framework and methodology of socioeconomic research on aquaculture. An important result of this project has been that the Chinese government has paid more attention to carp genetics and breeding.

In India, the focus of the project was to use molecular genetic methods to characterize genetic variation in and among varieties of carps, including crossbreeds of rohu, triploids and monosex populations of common carp. One important result was the finding that inbreeding in experimental populations of rohu was not occurring at the same rate as inbreeding in catla. Although the selective breeding programme is not complete, small farmers will most likely adopt the improved strains to increase their production. Improved strains will also be stocked in reservoirs to boost the catch of fishermen who depend on fish for their livelihoods. This ADB funded project has led to additional funding from other donors and has influenced policies in India. As a result of this project the state Department of Fisheries has agreed to produce crossbreeds of catla and rohu to increase fish production. The Department has also agreed to keep separate breeding centres for Indian major carps and common carp to implement genetic improvement programmes.

In Indonesia, this project stimulated the development of a network to exchange information at annual meetings to evaluate the research progress and to confer on research problems. This project also stimulated the development of inexpensive, but reliable tags for use in the breeding programme. Other countries can also benefit from the development of these tags. Genetically selected broodstock has been distributed to the small farmers.

In Thailand, the Government increased its contribution to research in the fields of biotechnology for developing genetically improved breeds in aquatic species, gene banking for conservation of aquatic genetic resources and dissemination of genetically improved breeds in aquatic species to public and private sectors. The Government has also increased budgets for production and dissemination of genetically improved breeds to grow-out operations. Several areas of research have benefited from this project and will benefit farmers through increased production. One such area has been a better understanding of selection methods to improve fish breeds, including not only the development of breeding schemes, but also improved methods of broodstock management. Gains from these selection experiments will produce fish that will increase the production of silver barb in Thailand.

In North Vietnam at RIA-1, the project provided an opportunity to learn many technical aspects of fish culture and, in particular, how to design and conduct breeding experiments. This three year project was successful in several areas of research. The successes of this project have influenced how research is conducted at RIA-1 and elsewhere in Vietnam. Some of the improved common carp fry and fingerlings were distributed to farmers for food production. The present project also stimulated the development of dissemination procedures. In South Vietnam at RIA-2, researchers focused on the improvement of silver barb. The Project stimulated the development of breeding methods for research. The project also stimulated the improvement of brood stock management. In the coming year, about two million silver barb fry will be distributed to private hatcheries and to farmers.

In all countries, as carp production is dominated by small and medium-scale farmers, the benefits from the adoption of improved carp strains developed under this project will be enjoyed by these groups of farmers. Given the semi-intensive and low external input culture systems of carp farming, the adoption of the improved carp strain is not expected to create environmental problems. As carps are consumed mainly by relatively poor people, due to their relatively low price, the adoption of improved carp strains will also benefit the poor consumers.

Follow-up activities

Fish breeding is a long process. The important sequential steps to be followed in developing a practical and sustainable fish-breeding programme are: 1) identification and prioritization of species, target environments and traits, 2) systematic documentation and evaluation of available genetic resources and choice of a genetic base, 3) development of a breeding strategy, 4) development of selection criteria and evaluation (including tagging), 5) development of improved strain through successive generations of selection, 6) dissemination of improved strain, and 7) impact assessment. During the first phase of the project, research priorities (species, farming environment and traits) have been identified, genetic resource-bases have been evaluated and growth rates for some of the priority species have been improved. In order to sustain the gain achieved during the first phase of the project, genetic improvement of key species should be continued with the incorporation of other important priority traits in the breeding goal. All the participating members including ICLARM met during the Sixth Steering Committee meeting of the International Network of Genetics in Aquaculture held in Hanoi, Vietnam from 8 to 10 May 2001.It was agreed to request that the Asian Development Bank finance the next phase of the project under its CGIAR RETA programme. The proposed outline can be found in this report (p. 127).

1. INTRODUCTION

Background and rationale

Until recently, capture fisheries have provided most of the aquatic production for human consumption. However, many fisheries are declining or have reached maximum yields. A large portion of global aquatic production now comes from aquaculture, which has been the world's fastest growing food-producing sector for nearly 20 years, with a growth rate of 11% annually since 1984 (FAO 2001). As aquaculture expands, it will play an increasingly important role in enhancing food security and in filling shortages from declining or stable capture fisheries. Aquaculture benefits poor rural communities in most developing countries because it can be practiced by poor farmers without a large capital outlay.

Over one billion people in developing countries depend on fish as the primary source of animal protein. In Asia and the Pacific region, fish provides about 50 to 70% of animal protein and contributes substantially to the economies of the DMCs. Since 1990 the gap between the demand for and supply of food fish has been rapidly widening due to limited production from overexploited capture fisheries, destructive fishing practices and from the increasing demands of a rapidly growing population. FAO predicts that the world will require fish supplies of about 91 million tonnes to maintain consumption at its current level (13.0 kg/capita/year in live-weight equivalent). The contribution of marine and freshwater capture fisheries is unlikely to increase above 60 million tonnes/year. Consequently, the balance of 31 million tonnes required by the year 2010 will have to come from aquaculture. This implies a doubling of the estimated 1993 aquaculture production of nearly 16 million tonnes. Most of this production will come from the culture of freshwater fishes, largely carps and tilapias, in developing Asian countries. These species form the mainstay of many small-scale aquaculture enterprises in tropical developing countries. Genetic improvement has a tremendous potential for improving and sustaining aquaculture production in these countries.

Recognizing the importance of genetic improvement in increasing aquaculture production, the Asian Development Bank (ADB) and the United Nations Development Programme (UNDP) supported ICLARM and its partners in 1988 with funds to establish a collaborative aquaculture research project on Genetic Improvement of Farmed Tilapia (GIFT)[1]. The GIFT project on Nile tilapia was the first major initiative in applied fish genetics and breeding in tropical aquaculture. Within four years, the project developed the world's first strain of genetically improved Nile tilapia. This project demonstrated that enormous gains in production were possible from selective breeding; five generations of selection produced a strain that grows 85% faster than unselected Philippine stocks. The successes of the GIFT project spawned the Bank-supported project on the Dissemination and Evaluation of Genetically Improved Tilapias in Asia (DEGITA)[2], which assessed the social, economic and environmental impacts of GIFT fish in Bangladesh, Peoples Republic of China, the Philippines, Thailand and Vietnam in preparation for the development of national tilapia breeding programmes. The achievements of the GIFT project have also led to the establishment of an International Network on Genetics in Aquaculture (INGA)[3], and the start of a Philippines national tilapia breeding programme with active private sector participation.

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[1] GIFT Phase I financed by the Bank RETA No. 5279 and the UNDP Project No. INT/88/019; Phase I successfully accomplished in August 1992. GIFT Phase II with UNDP funds (Project No. GLO/90/016) was completed in December 1997.

[2] RETA No. 5558; initiated in June 1994 and was successfully completed in June 1997.

[3] Formally established in July 1993. At present, INGA involves 13 member countries; 9 of which are Bank DMCs: Bangladesh, People's Republic of China, Fiji, India, Indonesia, Malaysia, the Philippines, Thailand and Vietnam. ICLARM is the member-coordinator.

Encouraged by the impressive results of the GIFT and the DEGITA projects, the major carp-producing developing member countries (DMCs) of the Bank approached ICLARM to initiate a 'GIFT-type' strategic research and training initiative on Asian carps, which are the most cultured fish in the world. World carp Production in 1999 was 11.6 million tonnes, about 22% of the world's total aquaculture production and about 51% of the world' freshwater aquaculture production. Asia accounts for about 95% of the world carp production. About 20 carp species are extensively cultured under a diverse variety of farming systems; all of these species are endemic to Asian waters. They are favoured by low-income Asian consumers because of taste and relatively low prices; in many areas, carps are the only source of affordable animal protein to the poor. Carp culture in Asia typically involves simple, low input pond culture, operated by small farmers in a predominantly rice-based farming system. Much of the production by low-income carp farmers is consumed at home. Competition for natural resources (land, water) or external inputs (manure, fertilizer, feed) is generally low.

Genetic principles can be used to improve culture production in two ways. The first is to avoid the negative effects of inbreeding. In some cases, levels of production are similar to those expected from wild stocks, and there is evidence of genetic deterioration for some strains. The application of genetic principles to the culture of carps has only recently started, but can be important in increasing or maintaining production. The second way in which genetics can improve production is through the selective breeding of superior strains that grow more rapidly or have improved market characteristics. However, the genetic improvement of carps is complex because of the diversity of species, farming systems and socioeconomic scenarios prevailing in the various Asian carp producing nations. Also, generation times of most carp species are longer than those for tilapia - about two to three years in tropical environments. Furthermore, a fish breeder must choose among numerous commercially important traits that could be improved. Finally, the development of an improved strain must be followed by the development of a dissemination strategy to provide fish to poor farmers.

Given the complexity and time constraints of the carp genetic research, ICLARM submitted a proposal to the ADB for the implementation of a collaborative project on the genetic improvement of carps in Asia in two phases. Phase I would focus on determining research priorities and initiating research leading to the development of high yielding breeds and strains. Phase II would concentrate on (i) the continued development of improved breeds, (ii) dissemination and evaluation of improved carp species, and (iii) establishment of national carp breeding programmes. The ADB approved a collaborative project on the genetic improvement of carps in Asia for implementation in two phases, and provided a Technical Assistance Grant (RETA No. 5711) of US$ 1.3 million to ICLARM for implementing the first phase of the Project from 1 June 1997 to 31 May 2000 in six DMCs of the Bank (namely, Bangladesh, People's Republic of China, India, Indonesia, Thailand and Vietnam). These countries were selected because they 1) are the major centres of carp species diversity and have high demand for carp, and 2) have national aquaculture strategies, reasonable research facilities and human resources. At the request of ICLARM and all the participating countries, the ADB granted a no cost extension of the project up to 31 December 2000. ICLARM and the six participating DMCs also contributed approximately US $1.3 million to match the grant of the bank for the implementation of the project.

ICLARM has submitted the following reports to the Bank: 1) project inception report, 2) semi-annual progress reports of project activities, and 3) semi-annual statements of account of project expenditures. This final report discusses the results of the first phase of the project and outlines the plan for the second phase. The results are reported under the three main activities: (1) documentation of carp genetic resources, (2) socioeconomic analysis of production and consumption of carp, and (3) carp genetic research. Appendix 1 shows the other publications/books being prepared based on the findings of this project.

Objectives and scope of the project

The Project seeks to build on previous genetic improvements of carps for aquaculture. The first step is to establish priorities for species, farming systems and breeding goals for the DMCs of the Bank. The next step is to conduct strategic research and training activities on the basis of these priorities with the National Aquatic Research Institutions (NARIs).

The Project has the following objectives:

1. assess the current status of Asian carp genetic resources for their use in aquaculture, bring together the existing technical skills and experience scattered throughout Asia and build strategic research partnerships and networks,
2. develop criteria for prioritizing carp genetic research and set research priorities,
3. identify potential genetic approaches and initiate location-specific strategic research and training in carp genetics leading to the development of high yielding carp strains.

Following the patterns of the GIFT and DEGITA projects, the Project established a systematic approach to genetic improvement of carps, linking biodiversity and the development of national fish breeding programmes. These activities included (a) systematic documentation of carp genetic resources, their evaluation and sustainable use in aquaculture; (b) prioritization of species, farming systems and breeding goals; (c) research design activities based on identified priorities; and (d) initiation of research activities leading to the development of high yielding strains.

Systematic documentation involved the collation of available information, including indigenous knowledge. Field surveys were made to understand regional supply systems and to estimate the demand for carps. ICLARM and its partners have (a) assessed how carp strains are valued by various groups; (b) estimated future demand by income groups; (c) analyzed the importance of various carp-based farming systems, (d) assessed the relative economic importance of various traits (including growth, disease resistance, tolerance to low dissolved oxygen and to poor soil and water conditions). Analyses of this information were based on field surveys and secondary information, and implemented by an ICLARM socio-economics and policy analyst, visiting scientists and local social scientists.

Training workshops were conducted to provide participants with overviews of statistical and economic analyses and the use of computer programmes. Workshops also included quantitative genetic methods for research prioritization and applied carp breeding techniques. These workshops also facilitated exchanges of ideas and research experiences among geneticists and socio-economists.

Implementation

The project was administered by ICLARM in partnership with selected national aquatic research institutes (NARIs) in six DMCs. The project was headed by ICLARM's Programme Leader for Germplasm Enhancement and Breeding (now called the Biodiversity and Genetic Resources Research), who had overall responsibility for planning and implementation. He was assisted by the ICLARM Director of International Relations, who is concurrently the Research Coordinator for the International Network on Genetics in Aquaculture, and a fisheries economist. The Project began in November 1997 and was completed in December 2000.

National teams were responsible for particular field activities and consisted of a geneticist, a social scientist and an ecologist. These teams maintained close contact with farmer groups and with government and non-government organizations working in aquaculture research and development. The list of scientists, from ICLARM and NARIs, participated in implementing the project activities is given in Appendix 2.

The Asian Development Bank reviewed the project through two review missions and has monitored project activities regularly. ICLARM's senior management and the Programme Committee of the Board of Trustees reviewed the project periodically as part of regular assessments of projects implemented by ICLARM. Project activities were also presented and discussed at the annual Steering Committee meetings of the INGA.

2. GENETIC RESOURCES OF CARPS

Introduction

Freshwater fish culture has a large potential to meet the domestic demand for low-cost protein for food and for export to foreign markets. Several key elements are required for the successful development of fish culture. Fish must grow rapidly and be suitable for domestication. The reproductive cycle of the fish must be conducive to culture and in polyculture, species should have complementary diets to avoid competition. A ready market for the fish should be available and fish should be easily transported to the market.

South and Southeast Asia have a diverse fauna of fish (see Table 2.1 for common and scientific names). This diversity results from the copious amounts of water from seasonal monsoons. This area also has a rich tradition of aquaculture and a high level of fish consumption. The extent of freshwater fish resources in the six countries participating in the Carps project will be outlined in this section. The focus will be on the most important fishes in the various countries, but with an emphasis on species collectively known as carps. Information on carp resources varies greatly among countries. Hence the information presented here ranges from basic descriptions of species to descriptions of strains arising from crossbreeding or chromosomal manipulations.

Climate

The climates of South and Southeast Asia are dominated by tropical monsoons, driven by moist southwest and northeast surface winds. From mid-May to October a low atmospheric pressure system develops over Asia and draws in winds from the Indian Ocean saturated with water. The major trough of low pressure, the intertropical convergence zone (ITCZ), moves northward in July and August to 25-30°N bringing warm temperatures, high humidity, thick cloud cover and frequent rainfall. The summer southwest monsoons begin first in southern India and move northward to Bangladesh, then eastward to Burma, Thailand, Cambodia and Vietnam. Rainfall can be variable in June and July because of anticyclonic circulation, but intensifies in August and October. Over 200 mm/month of rain can fall in some areas.

During the northern Hemisphere winter, continental cooling creates high atmospheric pressure and pushes the ITCZ southward. This shift brings largely dry northeast monsoons to Asia, except for peninsular Thailand, Malaysia, South India and parts of Indonesia and the Philippines, which can experience increased rainfall from November to March. Tropical cyclones and typhoons often occur during the transition between these two weather patterns.

Geography

The countries collaborating in the project are situated in South and Southeast Asia, areas that are generally characterized by large river systems that flood annually. These areas have some of the highest population densities, and therefore tend to have highly disturbed environments. These countries are generally located in the tropics, an equatorial area defined by average temperatures exceeding 18°C. Northern areas of India and Bangladesh occur in the subtropics and the northern areas of China reach into temperate areas. In northern areas, cold temperatures may limit aquaculture activities.

Freshwater fish farming is largely found in lowland areas that are often part of large flood plains. The major rivers in these areas include the Ganges, Brahmaputra river system, the Chao Phraya River, Mekong River and Changjiang River. Water is usually plentiful because of high levels of rainfall, although suitable water may not always be available for aquaculture because of the seasonality of rainfall and pollution. Rivers often carry a large sediment load because of sharp drops from high interior plateaus, high-intensity rainfall and frequent landslides. Human activities, including deforestation and mismanagement of land and water resources, also contribute to the limited supplies of suitable water for aquaculture in some areas.

India and Bangladesh

India and Bangladesh share many of the same species of fishes and some northern areas are climatically and topologically similar, because of the large Ganges-Brahmaputra River system. A rich native fish fauna has been harvested for centuries in both countries, but only recently have some species of carps been domesticated. These countries are amongst the largest human populations, which make large demands on the environment.

India

In India, a diverse fish fauna includes about 9% of the world's 25,000 described species of fish. These species include a variety of marine, estuarine/brackish water and freshwater species, many of which are economically important. About 1 440 species inhabit the marine environment. Freshwater fishes occur in the Ganga and Brahmaputra river networks and in the North, the East and West Coasts, rivers network in southern areas. The Ganga River system contains the largest diversity of freshwater fishes in the country. It is also the natural habitat for many commercially important species, including the Indian major carps. Freshwater lakes also contain numerous fishes. About 544 species inhabit warm waters of the plains. In addition to the major carps catla, rohu, mrigal and kalbasu, several minor (peninsular) carps and catfishes are important species that are fished or cultured.

Over 70% of the people in India live in rural areas and work in agriculture. Until the 1960s, India depended on other nations to meet the demand for some food grains. However, with the establishment of Agricultural Research Institutes, much progress has been made toward independence, and new technologies and culture systems have been developed, especially in the past four decades. Several landscape transformations were made to attain these goals. The construction of multipurpose dams for flood control and irrigation diverted the courses of many rivers. Although this contributed to the development of agriculture, enabling the farmers to produce two or three crops a year, these activities changed the natural habitats of many commercially important fishes, including the major carps and some anadromous species, which migrate from sea to rivers to breed. One response was to embark on the stock enhancement of fish populations in rivers, lakes and reservoirs with hatchery-produced fish. However, as most hatcheries produce fingerlings without following principles of genetic or resource management, these activities may be detrimental in the long run to remaining natural populations.

Another response to declining abundances has been to explore the value of cryopreservation of gametes and embryos. Protocols have been developed for successful preservation of milt of common carp and Indian major carps at NBFGR and CIFA in India. Cryopreserved milt of rohu ware viable after 8-9 years of preservation. The development of cryopreservation techniques may be essential for conserving some endangered species. Cryopreservation may also be an effective tool to overcome the problem of transporting live seed and may replace the maintenance of brood fish, particularly males. Using this approach, female brood fish are maintained *in situ* and cryopreserved milt is used to fertilize eggs.

Cold-water fisheries are in waters with temperatures of 0–20°C and include about 21 indigenous and seven exotic species harvested commercially and for sport. Common indigenous cold-water fish species include *Acrossocheilus hexagonalfps*, *Basilius bende*, *B. bola*, *B. galensis*, *Labeo dero*, *Schizothorax kumaonensis*, *S. richardsonii*, *Tor putitora* and *T. yor*. The most important exotic fishes include the game fishes, brown trout (*Salmo trutta fario*), Atlantic salmon (*S. salar*), brook trout (*Salvelinus fontinalis*), sockeye salmon (*Onchorhynchus nerka*) and rainbow trout (*O. mykiss*). These fisheries are largely undeveloped.

Several methods, including hybridization, selective breeding, and chromosomal manipulation, have been used in India to genetically improve various species of carps. Ponniah (1997) reported that cross-breeding of farmed common carp at Bilaspur, Himachel Pradesh with cryopreserved sperm from wild common carp stocks of Ooty and Rewalsar were carried out to identify strains that would perform better than local stocks. The results indicated that Rewalsar stocks were superior to the others. As many as six inter-specific and 13 inter-generic hybrids have been produced and evaluated for culture traits. In the 1980s, chromosome manipulation led to the successful induction of gynogenesis and polyploidy (triploidy and tetraploidy) in Indian major carps. In the early 1990s, the long-awaited selective breeding programme was initiated on rohu in collaboration with AKVAFORSK in Norway and is being continued. A base population was constructed with fish from five northern rivers, including the Ganga, Gomati, Yamuna, Sutlej and the Brahmaputra rivers and from the CIFA farm stock. Family selection is being used in this breeding project. Only two generations of selection have been completed as females of rohu mature at two years of age. The third generation was produced in 2000. An average selection response of over 20% has been estimated for the second-generation of selection.

Molecular genetics methods have been used to estimate genetic relatedness among species and strains. These include the electrophoretic analysis of allozymes and restriction fragment length polymorphism (RFLP) analysis of mitochondrial DNA (mtDNA). A recent characterization of allozyme variability in rohu stocks showed that the level of genetic variability in base populations used for the selection project was similar to the level of variability in wild stocks and no genetic contamination from other species was detected. Protocols have been developed for genetic stock identification with RFLP analysis of mtDNA. Other studies have employed the analysis of microsatellite loci to differentiate catla broodstock in hatcheries in Karnataka State from wild and other hatchery stocks. These results show that, despite being initiated from common sources, hatchery populations in Karnataka are distinct from one another, most likely because of genetic drift or selection.

Some attempts have been made, at the National Institute of Immunology (NII) New Delhi, to introduce the human growth hormone gene into the embryos of rohu. DNA analysis from gill tissue of the surviving embryos showed that only two embryos appeared to contain the transgene. Other attempts at gene transfer have focused on zebra fish with variable success.

The Indian Government has set developmental priorities in the order of agriculture, animal husbandry and fisheries. Much attention was initially focused on developing genetic-based technologies for plants and farm animals, but recently aquaculture has received priority for development. Several aquaculture technologies, such as extensive, semi-intensive and intensive aquaculture, have already been developed which are designed for marginal, middle order farmers and also industrialists. Utilizing improved strains and better management, farmers are now able to produce 4-10 t fish/ha/yr, whereas unimproved extensive agriculture yields on average only 0.6 t/ha/yr. The improvement of key species through genetic methods will be an important step in establishing a viable aquaculture industry in India.

Bangladesh

The landscape of Bangladesh is dominated by the deltas of the Ganges, Brahmaputra and Meghna rivers. Inland water resources of the country cover an area of 4 339 694 ha, including open and closed water bodies. The major inland open water bodies consist of floodplains, rivers and tributaries, natural depressions and lakes. Closed water bodies include ponds, oxbow lakes and coastal ponds for shrimp farming. The country has a rich diversity of fish species, with 296 fresh and brackish water species (including freshwater prawns) and 511 marine water species (including marine shrimps). The current level of fish and shrimp production (1997-98) in Bangladesh is 1.46 m tons, 42.1% of which comes from inland open water capture, 18.6% from marine capture and 39.3% from aquaculture. The country has a large number of private and public hatcheries.

Endemic carp species of Bangladesh can be divided into two sub-groups: major carps (Catla, Rohu, Mrigal and Calbasu) and minor carps (Bata, Reba, Nandin and Gonia). Most of the freshwater river systems and floodplains of the country are natural breeding grounds of these carps. These species occur in deep pools of the Padma-Brahmaputra River System (Padma, Jamuna, Arial Khan, Kumar and Old Brahmaputra rivers) and Halda River System in Chittagong. They breed naturally during monsoon floods in inundated landscapes and in flowing waters. Species belonging to the minor carps inhabit small rivers and floodplains, including the shallow freshwater zones of the northeastern (Mymensingh, Netrokona and Mohanganj), southwestern (Faridpur and Jessore) and northwestern (greater Rajshahi area) floodplains. They grow to maturity within 10–12 months.

Exotic fishes, mostly Chinese carps, have been introduced since 1960, but these introductions have not been well documented. Introduced species include silver carp, grass carp, bighead carp, black carp, common carp, silver barb and mahseer. Both indigenous and exotic carps are used in pond polyculture and some are stocked in floodplains, rivers and reservoirs to enhance wild stocks.

In recent years, natural fish stocks have declined in Bangladesh due to the deterioration of aquatic habitats and the construction of embankments, dams and river closures for flood protection. Over-exploitation, diversion of water for irrigation, siltation, reclamation of land for human settlement, pollution and destruction of mangroves have also contributed to the decline of fish stocks. Many of these hydrological changes have influenced fish migration, reproduction and survival. As a result, many fish populations are threatened. The IUCN, Bangladesh (1998) listed 57 threatened or endangered freshwater fish species in the country, of these 11 belong to the family Cyprinidae.

Thailand, Vietnam and Indonesia

Thailand, southern Vietnam and Indonesia lie predominately in the humid tropics and experience large amounts of rainfall from the seasonal monsoons. Northern Vietnam has a more subtropical climate.

Thailand

In Thailand, fish have been an important component of the diet, making up most of the protein intake from animal sources. The country has a large network of rivers and canals, as well as swamps and reservoirs. During monsoons fish follow floodwaters from main rivers into canals and small streams, then into ditches, swamps and paddy fields. Fishing is most intense as floodwaters recede. This fishery is most developed in the central plains where large areas are flooded each year and where trap ponds are used to capture fish. The use of these ponds has given way to aquaculture, which in early years depended on the import of fry from China. Although catfish (*Pangasius* spp. and *Clarias* spp.) and snakehead are the main fishes used in freshwater culture, the culture of carps is nevertheless substantial and well established.

The country has a rich diversity of carps in five subfamilies of the family Cyprinidae. At least 192 species of local and introduced carps have been recorded in Thailand. Much of this diversity is associated with the Mekong River System. In addition to endemic species, several species have been introduced for culture, including common carp, Crucian carp, grass carp, silver carp, rohu and mrigal Total freshwater culture has risen from 48,000 t in 1981 to 196,000 t in 1995. In 1995, about 16% of the total freshwater culture production consisted of carps.

Common carp--This more temperate introduced species is establishing a foothold in Thailand. Common carp appear to spawn naturally in the cooler waters of the Mekong River where they are tolerant to turbid and contaminated waters. They are omnivorous, consuming a wide variety of plant and animal matter. These fish are usually marketed fresh.

Silver Barb--This fish is common throughout Thailand and inhabits mid-water to benthic waters in rivers, streams, floodplains and occasionally in reservoirs, where it appears to prefer standing water. This fish moves into flooded forest areas where it feeds on plant and animal material. This fish is also usually marketed fresh.

Vietnam

Vietnam has a history of small-scale aquaculture reaching back 300-400 years. Most aquaculture activity takes place in coastal plains, since the majority of the country is mountainous. The hydrological conditions in southern Vietnam results from the prevailing monsoon environment. For example, the annual variation in amplitude of the lower Mekong River between the dry and rainy season is 1:30 and large scale flooding is common with a peak in August-September. The life cycles of fish in this area depend on the annual cycle of flooding. Many fish remain in rice fields and depressions and provide a rich harvest of a wide variety of fishes. Fish products provide a large proportion of the total animal protein in the diet of the peoples of Vietnam. In 1997, freshwater fish production was about 434,000 mt, an increase of 170% over production in 1980. In the Mekong Delta, fish may provide 50-80% of dietary protein, but much less in other parts of the country.

Only a limited amount of information is available on carp resources in Vietnam, because few surveys have been undertaken in the country. Several species of carps have been introduced or domesticated in Vietnam. Important species include big head, silver carp and major Indian carps such as rohu, mrigal, and catla. Common carp, grass carp, bighead, silver carp and mud carp are most important in northern areas of Vietnam. Silver barb is most important in central and southern areas.

Common carp--Among the carps, common carp is one of the most important fishes in North Vietnam being readily marketable at good prices. Fry are readily available from hatcheries with naturally spawning broodstock and this species grows quickly to marketable size in about three months, when it is usually marketed live.

Grass carp--Grass carp are often used in polyculture because they feed on the bottom of ponds. They are in high demand and fetch prices that are near to those for common carp. One drawback of this species is that spawning in culture must usually be induced, and larvae and fry require special care. This fish also grows rapidly, reaching marketable size in three to four months. This fish is also generally marketed live.

Silver carp--Silver carp are especially suited to polyculture, because they feed only on nanoplankton and avoid competition with other fishes for food. However, they fetch lower market prices than do common and grass carps.

Indonesia

Indonesia consists of more than 17,500 islands, including five large islands—Sumatera, Java, Kalimantan, Sulawesi and Irian Jaya. Indonesia as a whole has a high level of freshwater fish species diversity, including 30 endemic species of fishes on Sumatera, 149 on Kalimantan, 12 on Java and 52 on Sulawesi. Freshwater fishes have been cultured since the 14th century and have made a significant contribution to the farming economy. Several species of indigenous fishes, including Java carp, nilem carp, jelawat, giant gourami, kissing gourami and walking catfish have been used in culture. In 1996, the production of cultured freshwater and brackish water fishes reached 733,000 t or about 16.5% of the total fish production. The demand for fish by 2007 is expected to be about 5.8 million tons from within the country and about 1.5 million tons for export. The maximum sustainable yield of the marine capture fishery is about 6.7 million tons and the shortfall will have to be met with aquaculture. Cyprinid fishes have the greatest potential for culture and include common carp, Java carp, nilem carp and jelawat carp, which have already been cultured to various extents. Carps contributed about 62% of the total cultured production in 1997 (Table 2.2). In addition, kancera carp also has potential for production, but has not yet been developed for culture.

Common carp--This fish was apparently introduced into Indonesia from China in the 18th Century. Following this initial introduction, additional carp strains were introduced from Taiwan and Japan and from Europe (Galician, Frankisia and German strains). In the early 1900s, introductions of various strains of carps were widespread throughout Indonesia. These strains were often hybridized to improve production traits and collectively are now known as Indonesian local common carps. Presently, common carp is cultured in all the provinces of Indonesia comprising 50.8% of the total fish production (146,672 t in 1997) which represents the highest proportion of fish production in Indonesia. By 1994, Indonesia ranked second, to China, in the world's production of carps.

Several strains of common carp have been developed, each with characteristic colour, body shape and market traits. In temperate areas, common carp mature in 3-4 years, but in the tropics they commonly mature at 1.5-2 years. After hatching, the yolk sac is absorbed in 2-4 days. Larvae feed on zooplankton and bacteria. Adults are omnivorous, feeding on bottom organisms and filtering organisms from pond mud.

Molecular genetic and experimental breeding methods also confirm that Indonesian common carps have moderate levels of genetic variability. These studies include surveys of genetic variation with allozyme electrophoresis, RAPD and breeding studies to determine the Mendelian inheritance of traits, such as colour and scale morphology. Estimates of allozyme heterozygosity range from 5.6% to 9.6% and these values are typical of outbred freshwater fishes.

Hybrid crosses between strains to improve growth and survival have led to variable results. Culture trials in floating cages in different environments and in monoculture and polyculture generally show that aeration increases production and that polyculture reduces growth of common carp below that in monoculture. Growth trials in rice field systems were used to evaluate the effects of pesticides on fish. Resistance to water-borne diseases and the effects of antibiotics on reducing infection has also been evaluated.

Several studies have been carried out on common carp nutrition to find ways of accelerating growth and to hasten maturity. An increase in the vitamin E content of feeds shortened the time to natural spawning and led to good larval hatching rates. Comparisons between protein, fat and vitamin enhanced feed and commercially available pellets showed substantial increases in the proportions of mature fish with enhanced food. Protein enhanced feeds also increased the growth and survival rates of larvae.

Several strains of common carps have been reared in government hatcheries. At the hatchery in Singaparna, West Java, fingerling production varies between 400,000 and 600,000 fingerlings/ha/year. At the hatchery in Cangkringan-Yogyakarta production varies between 30,000 to 50,000 ha/year. The highest production of fingerlings at these hatcheries generally occurs during the first half of the year. Fingerlings are also produced by farmers, who practice at least some form of selection of broodstock for breeding. Generally twice as many males as females are used in a spawning. A survey of farmers indicated that 10-50 females are kept as broodstock and that fast growing fish are chosen as candidate breeders. Broodstock are usually spawned five or six times or until they reach a body weight of 8 kg. Local and Majalaya strains of common carps are used the most in intensive aquaculture (floating net cages and running water systems).

Java barb (silver barb)--Females mature at the end of their 1st year, whereas males mature at about 6-8 months of age. Fish spawn throughout the year when reared in ponds, but in cage culture they spawn at the beginning of the rainy season. Java barb larvae are largely herbivorous, consuming phytoplankton, but also small zooplankton. Larger larvae switch to feeding on filamentous algae and aquatic weeds. Four kinds of Java barb are cultured in Indonesia and include common Java barb, albino Java barb (rare), silap Java barb and kumpay Java barb (also rare). Natural populations of Java barb inhabit open fresh and brackish waters, including rivers, swamps and lakes and are able to tolerate salinities up to 7 ppt.

Little information exists on levels of morphological and genetic variability in this species in Indonesia, chiefly because it is a low-value fish and has not been extensively cultured. Most research has centred on spawning biology, hatching and nutrition. Studies have been made to assess the best levels of hormone treatment to achieve the best spawning response and to evaluate the influence of salinity and pH on hatching. Several studies have been made to evaluate various feeding regimens, including comparisons of different feeds and organic fertilizers.

Java barb are cultured in several areas in Indonesia, including Java, Sumatera, Kalimantan, Sulawesi, West and East Nusa Tenggara and Irian Jaya. The production of Java barb was 23,213 t in 1997, or about 18% of the total production of freshwater fishes in culture. Production from the capture fisheries at this time was about 17,715 t, which represented 6.2% of the total open-water fisheries production. Intensive culture has not yet been developed, because the low market price of this fish is not sufficient to offset the cost of feed. However, this fish is important to low income consumers.

Nilem carp--These carps are commonly found in rivers and swamps throughout Indonesia and may be suitable for culture in ponds. Fish mature at one year of age and breeding occurs in the rainy season in natural populations, but could possibly occur throughout the year under culture conditions. The optimal temperatures for growth, range from 18-28°C and fish are best cultured at altitudes between 400-800 m in high water flow ponds provided with a supply of clean water. Colour variability indicates the existence of two strains: a blackish brown or green brown variety and a red or reddish variety. The production of nilem carp in 1997 was 10.3 t or about 3.7% of the total production of freshwater fish culture in Indonesia. Farmers have cultured this carp for several years, and demand for it is high among low-income consumers. However, intensive culture has not been developed because of the low price of the fish.

Several studies have been made to evaluate various aspects of the biology of nilem carp that potentially relate to production. Several experiments have been designed to evaluate the use of hormones to stimulate spawning. Ponds with substrates consisting of weeds appear to enhance larval survival, as compared to sand and gravel substrates. Hapas made of pralon fiber also produced high rates of hatching. Experiments have also been conducted to induce gynogenesis with irradiated spermatozoa. Research activities have not yet contributed to an increase in the production of this fish.

Jelawat--This fish is indigenous to Sumatera and Kalimantan and is commonly found from mid-flood plain levels to up-river areas. This fish is also found in rivers of Malaysia, Vietnam, Thailand and Cambodia. The larvae and juveniles are herbivorous, but adults tend to be omnivorous. Fish mature when males reach about 30 cm and when females reach about 40 cm; females spawn buoyant eggs in estuaries during the rainy season. Research activities have centred on culture trials, on evaluations of various feeds and on the use of hormone treatments to enhance spawning. However, the culture of this fish has not yet been optimized and no genetic improvement has been attempted. Production reached 5 836 t in 1997 and contributed to about 2% to the total production of the open-water fishery in Indonesia. Additional, but poorly documented, production also occurs in hatcheries, which are rapidly being developed for this species. This fish can be cultured to satisfy a large export demand to Malaysia.

Kancera carp--This fish is found in Sumatera, Java, Malaysia, Burma, Thailand and Indochina. In some areas of Indonesia the fish are considered to be mystical and deified as a 'god fish'. This fish is omnivorous and matures at about 20-25 cm in length. Spawning takes place during the rainy season. This fish can be raised to sexual maturity on high protein diets and in clean flowing water. Adults can be artificially spawned by injections of hormones. Experimental culture has been used to successfully raise newly hatched larvae on plankton and post larvae on artificial feeds. This fish is supplied to the market from the capture fishery and has a high economic value. Culture technology for this fish has not been developed, although researchers believe the fish has a high potential for aquaculture.

China

China encompasses areas with tropical, subtropical and temperate climates that influence species used in aquaculture and rates of growth and maturation of these fish. The landscape includes large river basins with seasonal flooding from the southeastern monsoons, as well as mountainous regions with high plateaus. Aquaculture takes place chiefly on the coastal plains, but also in river valleys and higher inland areas. The country extends over 40° of latitude and harbors a large diversity of endemic fishes. About 410 species of carps in 110 genera inhabit the water bodies of China, and 20-30 of these species are cultured in ponds, lakes, rivers, reservoirs and paddy fields throughout China. In addition to carp culture, carp production in natural waters is also important and together accounts for about 90% of the total production of freshwater species (Li and Mathias 1994).

Silver Carp--These fish are among the largest and fastest growing carps in China. They are naturally distributed in the Changjiang, Zhujiang, Heilongjiang and Red river basins and are most important in Chinese freshwater aquaculture. Silver carp are plankton feeders and live in the upper layers of water. In culture, they can be fed suspended soybean milk particles. They usually reach reproductive maturity in three years, depending on average temperatures, and migrate from lakes and rivers to the main tributaries of rivers to spawn in spring and early summer. Juveniles enter small tributaries to feed and grow. In the Changjiang River, silver carp can grow to about 0.5, 2 and 4 kg in their 1st, 2nd and 3rd years, respectively.

Bighead Carp--This species is distributed chiefly in the Changjiang and Zhujiang rivers and is the second most important freshwater species for aquaculture production in China. These fish tend to inhabit upper layers of water, but not surface waters as silver carp do, and feed on phyto- and zooplankton by gill filtration. These fish usually mature in their fourth year and spawn in the main tributaries of rivers. Bighead carp commonly grow to 0,5, 2.5, 7.5 and 10 kg by 1, 2, 3 and 4 years of age respectively. After several years these fish can grow to 50 kg.

Grass Carp--This fish is widely distributed throughout China in shallow water bodies with abundant submerged grasses. It is the third most important freshwater fish in China. Juveniles feed on zooplankton, but adults switch to such aquatic plants as *Wolffia* and *Lemna,* but also feed on other aquatic plants and land grasses. These fish are aggressive feeders and feed on most commercial feeds. They mature at four years of age and spawn large numbers of buoyant eggs that float at the water's surface. Grass carp can grow to 0.8, 3.5 and 5 kg by years 1, 2, and 3 respectively. The meat quality of grass carp is considered to be better than the meat of silver or bighead carp.

Black Carp--These fish are most abundant in the Changjiang River and in the southern plains, but less common in northern areas. This fish is a bottom dweller, feeding on zooplankton as juveniles then switching to small mollusks, insect larvae and shrimps. In culture, they will feed on a variety of commercial feeds. These fish can reach 7.5 kg in three years and mature in their 4th year.

Common Carp--This species most likely originated in temperate regions of the Middle East and were introduced to China, Japan and Europe. The natural distribution of common carp lies between 35-50°N and below an altitude of about 300 m. However common carp originated in China, this species has been cultivated there for at least 2,400 years. Common carps have been used in culture because they are widely distributed and highly adaptable. The various strains of common carp exhibit a wide range of morphological variability that has been achieved through breeding and crossbreeding. Examples include scattered mirror carp, mirror carp, *Cyprinus carpio wuyuanesnsis*, *C. c. singuonensis* and jian carp, among many others. Common carp are the fourth most important freshwater fish in Chinese aquaculture production.

Common carp are the most widely distributed of the carps in China because of their resistance to cold temperature, high alkalinity and low levels of oxygen. They live and feed in vegetated shallow rivers and lakes in summer, but move to deeper waters in winter. Juveniles feed on zooplankton, but adults are typically omnivorous feeding on small mollusks, insects and worms, as well as aquatic plants. In culture they feed on a variety of commercial feeds. These fish spawn adhesive eggs in shallow grassy areas in spring, beginning in their 2nd year. They grow rapidly and reach about 2 kg at reproductive maturity during their 2nd year.

Crucian Carp--This species is similar to common carp in morphology and time to reproductive maturity. They feed in shallow areas with aquatic plants during the warmer seasons, but overwinter in deeper water. These fish can reach reproductive maturity in one year, but more commonly in two years, and spawn eggs that adhere to vegetation. They are omnivorous, feeding on zooplankton, algae and plant shoots, a large proportion of their diet is made up of detritus and feeds not used by other carps. Crucian carp are slower growing than other carps, but their meat is considered to be of a high quality. Crucian carp are the fifth most important species in terms of production in China.

Blunt Snout Bream--This species is a native of the Changjiang River and inhabits vegetated water bodies in mid water, where it is herbivorous, feeding on grasses, algae, detritus and some zooplankton. Blunt snout bream grow quickly reaching about 30 cm in two years, at reproductive maturity. In culture, it can be fed a variety of foods. This fish is cultured increasingly for its desirable meat quality and resistance to disease.

Small Scale Fish--This species lives in mid-water in flowing streams and rivers, where it feeds on aquatic plants, algae, epiphytic diatoms, detritus and aquatic insects. It reaches reproductive maturity in its 2nd year and spawns adhesive eggs. It first spawns at about 0.5 kg (23 cm). This fish also yields high quality meat and has recently become widely distributed.

Mud Carp--This species is native to southern China, where it requires warm temperatures to survive and grow. Like small scale fish, mud carp scrape epiphytic algae and plant detritus from the bottom. They grow to 250 and 500 g in two and four years, respectively. These fish reach reproductive maturity in their 2nd year and spawn from about April to September. They are most important to aquaculture production in southern China.

Conclusions

Southeast Asia encompasses the highest diversity of carp species in the world. These fish have been harvested from natural waters and used in aquaculture for centuries. However, except for some morphological traits, carps have not been selectively bred to enhance growth and other commercially important traits. The particular species available for culture in each region depend to a large extent on climatic conditions and on adaptations of carp species to these conditions. Life-history variables also play a role in the choice of species for domestication.

Species should have the potential to grow rapidly and to have reproductive biologies that are conducive to propagation in artificial systems. The choice of species also depends to some extent on the traditions and tastes that shape the domestic market.

Table 2.1. Common and Scientific names of fishes appearing in this report.

Common name	Latin name	Country
Bata	*Labeo bata*	Bangladesh
Bighead	*Aristichthys nobilis*	Bangladesh, China, Thailand, Vietnam,
Black carp	*Mylopharyngodon piceus*	Bangladesh, China
Blunt snout bream	*Megalobrama amblyocephala*	China
Calbasu	*Labeo calbasu*	Bangladesh
Catfish	*Pangasius hypopthalmus*	Indonesia, China
Catla	*Cyprinus catla*	Bangladesh, China, Vietnam
Chinese carp	*Ctenopharyngodon iddelus*	China, Thailand
Common carp	*Cyprinus carpio var. communis*	China, India, Bangladesh, Vietnam, Thailand, Indonesia
Crucian carp	*Carassius auratus*	China
Grass carp	*Ctenopharyngodon idella*	Indonesia, Vietnam, China
Java carp/barb	*Puntius javanicus*	Indonesia
Nilem carp	*Osteochilus hasselti*	Indonesia
Jelawat	*Leptobarbus hoeveni*	Indonesia, Malaysia, Cambodia, Vietnam, Thailand
Giant gourami	*Osphronemus goramy*	Indonesia
Gonia	*Labeo gonius*	Bangladesh
Hilsa shad	*Tenualosa ilisha*	Bangladesh
Kancera	*Tor soro*	Indonesia
Kissing gourami	*Helostoma teminckii*	Indonesia
Mahseer	*Tor putitora*	Bangladesh
Mirror carp	*Cyprinus carpio var. specularis*	Bangladesh
Mrigal	*Cyprinus mrigala*	Bangladesh, India
Mud carp	*Cirrhina molitrorella*	China
Nandin	*Labeo nandina*	Bangladesh
Reba	*Cyprinus reba*	Bangladesh
Rohu	*Labeo rohita*	Bangladesh, India
Sand goby	*Oxyeleotris marmoratus*	Thailand
Sepat siam	*Trichogaster pectoralis*	Thailand
Shingi	*Heteropneustes fossilis*	Bangladesh
Silver barb	*Barbodes gonionotus*	Bangladesh, Vietnam, Thailand
Silver carp	*Hypopthalmichthyes molitrix*	Indonesia, Bangladesh, Vietnam
Small scale fish	*Plagiognathops micrrolepis*	China
Snakehead	*Channa striatus*	Thailand
Striped catfish	*Pangasius sutchi*	Thailand
Striped snakehead	*Ophicephalus striatus*	Thailand
Walking catfish	*Clarias batrachus*	Indonesia, Thailand

Table 2.2. Production (t) of cultured fishes in Indonesia in 1997 (DGF, 1999).

Species	Type of culture			Total	
	Ponds	Cages	Rice fields	Metric tons	%
Common carp	63.9	11.6	71.2	146.7	50.2
Nile tilapia	17.2	8.8	2.1	28.1	9.6
Catfish	23.2	0.8	0.9	24.2	8.3
Java barb	15.3	0.2	8.3	23.9	8.2
Mozambique tilapia	16.3	3.3	2.7	22.3	7.6
Nilem carp	9.9	0.2	0.7	10.8	3.7
Giant gourami	8.0	0.6	0.1	8.7	3.0
Kissing gourami	5.6	0.04	0.02	5.7	1.9
Snakeskin gourami	2.7	0.05	0.4	3.2	1.1
River eels	1.7	0.09	0.03	1.8	0.6
Others	8.0	1.2	7.8	16.9	5.8
Total	171.8	26.2	91.3	292.3	100.0

3. AQUACULTURE IN ASIA

Introduction

World fish production from all sources in 1999 was 137 million mt, comprising 43 million mt from aquaculture and 94 million mt from capture fisheries. Aquaculture production more than doubled between 1990 and 1999 (from 16.8 million mt in 1990 to 42.8 million mt in 1999; FAO 2000), while capture fisheries production increased only marginally (from 86.8 million mt in 1990 to 94.1 in 1999; FAO 2000). Asia produces about 91% of the world's total aquaculture production. Thus, aquaculture in Asia is a promising and leading component of world fisheries. The potential of aquaculture to meet the challenges of providing food security and to generate employment and foreign exchange is reflected in its rapid expansion of about 10% annually since 1984. In comparison, livestock production has increased by 5% annually and capture fisheries have increased by only 1.6 % annually during the same period (Rana 1997).

Asia's contribution to the world's aquaculture production has increased over the last decade (Tacon 1997). The top seven aquaculture-producing countries in the world are China, India, Japan, Republic of Korea, Philippines, Indonesia and Thailand. Freshwater fish production from aquaculture for several Asian countries is presented in Table 3.1. World production of freshwater fish from aquaculture was 19 390 284 mt in 1999, of which China contributed about 73 %. India contributed 10%, Bangladesh 3%, Vietnam 2%, Indonesia and Thailand 1% each and the Philippines 0.5% of the total world freshwater fish production from aquaculture. Vietnam achieved the highest annual growth in freshwater aquaculture (16%), followed by China (14%), Bangladesh (12%), Thailand (11%), and Indonesia (5%) from 1989 to 1999. The Philippines achieved a negligible growth rate (1%) during this period. World freshwater aquaculture grew by 11% annually.

The freshwater aquaculture industry in selected Asian countries

Bangladesh

Fisheries contribute about 80% of the national animal protein intake, 5% of the Gross Domestic Product (GDP) and more than 12% of export earnings. In 1999, total fisheries production was 1,552,417 mt from 4,047,316 ha of inland capture fisheries (rivers and estuaries, forest area [Sundarban], *beels*, Kaptai lake and flood lands), 4,409,157 ha of inland culture fisheries (ponds, *baors* and shrimp farms) and 0.1666 million km^2 of marine waters (marine capture fisheries) (Gupta et al. 1997). Total fish production included 41.8% from inland capture fisheries, 38.2% from inland culture fisheries (ponds: 32.2%, *baors*: 0.2% and shrimp farms: 5.8%) and 19.9% from marine capture fisheries. In recent years, aquaculture production has increased more than capture fisheries. Per-hectare productivity in aquaculture is 2.3 mt/ha/year for ponds, 0.644 mt/ha/year for *baors* and 0.637 mt/ha/year for shrimp farms (DOF 2000).

Carps are by far the most important species in cultured (pond) fish production. Three major Indian carps, rohu (*Labeo rohita*), catla (*Catla catla*), mrigal (*Cirrihinus mrigala*) and one exotic carp, silver carp (*Hypopthalmichthys molitrix*), together account for more than 78% of pond production. About 91% of all fish species in pond culture are carps (Table 3.2). Polyculture of carps in ponds is the most widely used practice in Bangladesh. Other culture systems include carp culture in *baors* and shrimp culture in brackish water ponds. Fish are also cultured in rice fields and in conjunction with poultry. Cage and pen culture are almost absent. Pond culture may be rated as moderate, semi-intensive (high fingerling stocking rate and low use of feed and fertilizer). Species stocked are mostly rohu and silver barb (Table 3.2). Over the last decade, inland-water fish production increased by 5.7% annually, yielding annual increases of 4.7% in open-water fish production, 8.5% of closed water catches and 8.2 % of pond fish production (Alam 2000).

China

China has the longest history of freshwater aquaculture, dating back to 5 B.C. and is the largest producer of aquatic products in the world. Aquatic production reached 39.1 million mt in 1999 (Huang et al. 2000). Culture fisheries production increased from 7.7% in 1950 to 56.3% in 1997. Over the same period, capture fisheries have declined from 99.3% to 43.4% (Huang et al. 2000). Cultured fisheries grew rapidly during the reform periods (12.5% from 1979 to1984; 13.6% from 1985 to 1995 and 8.5 % from 1996 to 1997) in comparison to the pre-reform (1970-78) period. Culture production in freshwater increased by 3.7% in the pre-reform period to 15.8%, 12.2% and 11.8% in the first, second and third reform periods, respectively. Freshwater fish production currently contributes about 43% of the total fish production. In 1995, total freshwater fish production reached 10.8 million tons, of which 87% came from aquaculture and 13% from capture fisheries (Gupta et al. 1997).

Although China has more than 800 freshwater fish species, carp species dominate freshwater capture fisheries production contributing about 80-90% of the total. Carps are also widely cultured, despite the introduction of numerous exotic freshwater species for culture. Eight of the 10 major carp species being cultured are of national economic importance, including black carp (*Mylopharyngodon piceus*), grass carp (*Ctenopharyngodon idella*), common carp (*Cyprinus carpio*), silver carp (*H. molitrix*), bighead (*Aristichthys nobilis*), crucian carp (*Carassius auratus*) and Chinese bream (*Megalobrama amblycephala* and *Parabramis pekinesis*). Production of these eight species reached nearly 12 million tons in 1999 and together accounted for about 83% of the total freshwater aquaculture production. Aquaculture production in China increased 7.6% annually on average from 1990 to 1999. Growth in production of important species was 13.5% for black carp, 9.1% for grass carp, 1.5% for silver carp, 6.4% for common carp, 19.7% for crucian carp and 39.5% for freshwater bream (Huang et al. 2000)

Aquaculture systems reflect variation in the country's natural environments and socio-economic backgrounds. Currently, polyculture is used most for culturing carps, but carp monoculture is becoming popular for intensive culture in cages, ponds and running water systems. Culture environments include ponds, lakes, brooks, reservoirs and paddy fields, in a total area of
4 955 000 ha and comprising 1 994 000 ha in ponds, 880 000 ha in lakes, 1 568 000 ha in brooks, 371 000 ha in reservoirs, 1 586 000 ha in rice and paddy fields and 142 000 ha in other freshwater bodies. Most production is in ponds (4 474 kg/ha), followed by brooks (1 623 kg/ha), lakes (921 kg/ha) and reservoirs (743 kg/ha). Culture fisheries in China are very intensive. Stocking is relatively high with good use of feed and fertilizer. Carp culture takes place on state owned, collective, family-owned and private commercial farms.

India

India is endowed with natural resources suitable for aquaculture. It has 8 085 km of coastline, 164,000 km of rivers and canals, 1.97 million reservoirs, 2.2 million ha of ponds and tanks, 1.3 million ha of *beels*, oxbow lakes and swamps and 1.4 million ha of brackish water. Traditionally, aquaculture farmers have used freshwater and coastal saline water culture systems, characterized by low inputs and low production. However, aquaculture has been slowly transformed into a business activity during the last decade. Total aquaculture production has increased more than two times from 686,260 mt in 1986 to 1,608,938 mt in 1995.

Carps dominate aquaculture production in freshwater ponds, cages, pens and recirculating systems and production in inland fisheries. Carp production constituted about 44% of the total inland fishery production of 5.14 million mt in 1996. In aquaculture, however, only carp pond culture has reached commercial importance. The remaining production consists of experimental and small-scale production. The national production of carps cultured in ponds has increased from 900 kg/ha/yr in 1984-85 to 2130 kg/ha/yr in 1994-95. Polyculture takes place in three systems, extensive, semi-intensive or intensive. Stocking rate is high in India (18 408 fish/ha). Culture may be considered moderately semi-intensive as it is limited by low applications of feed and fertilizer.

Indonesia

The culture of freshwater fishes in Indonesia dates back to the 14th century. Presently, carp culture largely takes place in three environments: ponds, floating cages and rice fields. Fisheries statistics for 1996 (DGF 1999) showed that aquaculture represented 16.5% of the total fisheries production (4,452,258 tons). Contributions to aquaculture production consisted of 9.1% in brackish water ponds, 4.1% in freshwater ponds, 1.0% in cages and 2.4% in paddy fields. Culture production has increased more than production from capture fisheries. Culture production grew at 8.4% annually for brackish water ponds, 7.4% for freshwater ponds and 2.4% for paddy fields from 1987 to 1996. The largest growth in production took place for cage ponds with 45.8% annual growth during this period (DGF 1999).

Carps are the most important cultured species in Indonesia and include two types: common carp and Nilem carp, and Java barb. Indonesia is the world's third largest producer of common carps after China and the USSR. Carps are produced through culture and capture fisheries. Cultured carps account for about 98% of all carps produced in the country (DGF 1998). Common carp production from aquaculture registered a moderately high annual growth of 12% from 1985 to 1994.

Thailand

Thailand has had freshwater aquaculture for a long time. Initially only a few species were cultured, including common carp, sepat siam and striped catfish. Such culture practices were confined to the Bangkok area. Up to 1951, Chinese carp, walking catfish and striped snakehead were introduced and an extensive culture extension scheme was implemented. Within a short period, a large number of ponds had either been constructed or converted from the old ones for fish farming. Several idle swamps were also converted and operated by the farmers. After 1963, fish culture developed rapidly due in part to breakthroughs in artificial breeding by hormone injection.

Fifteen species of fish and invertebrates are cultured in Thailand. The 1997 statistics show that freshwater aquaculture amounted to 200 018 mt, including tilapia (33.9%), Thai silver barb (16.7%), common carp (6.1%), Chinese carp (0.4%), rohu (0.9%), mrigal (0.2%), catfish (25.6%), snakeskin gourami (6.5%) and others (9.8%) (Thailand, Department of Fisheries 2000).

Fish farming is carried out in ponds, paddy fields, ditches and cages. Pond culture is by far most popular in terms of the number of farms and cultured area. Farmers stock ponds densely and use supplementary feeds and fertilizers. Cage culture is the most productive of the farming methods. The use of monoculture or polyculture varies according to species. Monoculture is used for carnivorous species, such as walking catfish, snakehead fish, the freshwater prawn (*Macrobrachium rosenbergi*), catfish and the sand goby, while omnivorous species like tilapia, silver barb, common carp, Chinese carp and mrigal are cultured together. In addition, fish culture integrated with pig, poultry and rice farming, among others is also practised to some extent.

Vietnam

Traditional carp culture has been practiced in Vietnam for a long time by rice farmers who culture fish in rice fields and village ponds. The main cultured species were common carp and other indigenous species. In the 1960s, with the introduction of Chinese carps (silver carp, bighead carp and grass carp) together with induced breeding, freshwater fish culture entered into a new era. However, carp farming was not important to the rural economy of Vietnam until the early 1980s, following the introduction of Indian carps such as rohu, mrigal and catla. In 1996, carp culture contributed about 29% (0.40 million tons) to the total fish production (1.37 million tons). The Mekong River Delta plays a most important role in aquaculture, producing about 67% of the total aquaculture production.

Carps are mainly cultured in polyculture systems. The main species are Chinese carps (silver carp, grass carp and bighead carp), Indian carps (rohu, mrigal), and local fish species (catfish, common carp). The culture system is primarily semi-intensive with the use of only minimal amounts of fertilizers, rice bran and other agricultural on-farm and off-farm byproducts. In addition, an integrated VAC system (V: garden, A: fish pond, C: livestock) is also common in the Red River Delta.

Table 3.1. Freshwater fish production* from aquaculture of the selected countries and the world (in metric ton).

Year	Bangladesh		China		India		Indonesia		Philippines		Thailand		Vietnam		World
1989	156,333	(2.16)	4,170,030	(57.69)	976,500	(13.51)	197,695	(2.74)	77,842	(1.08)	91,491	(1.27)	120,187	(1.66)	7,228,143
1990	165,087	(2.16)	4,459,100	(58.47)	982,136	(12.88)	212,821	(2.79)	81,126	(1.06)	97,659	(1.28)	112,076	(1.47)	7,626,007
1991	182,493	(2.32)	4,625,900	(58.68)	1,185,261	(15.04)	194,351	(2.47)	87,844	(1.11)	122,936	(1.56)	111,504	(1.41)	7,882,616
1992	189,863	(2.14)	5,337,900	(60.11)	1,348,644	(15.19)	212,937	(2.40)	116,439	(1.31)	141,606	(1.59)	110,099	(1.24)	8,880,924
1993	191,698	(1.90)	6,472,599	(64.23)	1,354,702	(13.44)	245,100	(2.43)	113,663	(1.13)	161,630	(1.60)	120,061	(1.19)	10,077,785
1994	218,048	(1.87)	7,896,594	(67.85)	1,436,628	(12.34)	255,308	(2.19)	119,888	(1.03)	177,790	(1.53)	149,556	(1.29)	11,638,587
1995	269,742	(1.98)	9,407,600	(69.15)	1,588,799	(11.68)	279,845	(2.06)	97,664	(0.72)	200,782	(1.48)	370,128	(2.72)	13,605,534
1996	302,140	(1.96)	10,989,505	(71.38)	1,688,330	(10.97)	328,763	(2.14)	91,233	(0.59)	229,266	(1.49)	348,649	(2.26)	15,396,066
1997	347,197	(2.04)	12,366,559	(72.72)	1,795,240	(10.56)	292,288	(1.72)	105,425	(0.62)	240,118	(1.41)	342,622	(2.01)	17,006,425
1998	420,162	(2.32)	13,219,136	(73.01)	1,946,809	(10.75)	276,047	(1.52)	86,880	(0.48)	240,001	(1.33)	359,000	(1.98)	18,105,203
1999	512,134	(2.64)	14,219,740	(73.33)	1,919,565	(9.90)	289,550	(1.49)	97,276	(0.50)	256,417	(1.32)	407,820	(2.10)	19,390,284
Growth rate	11.70		13.86		2.24		4.70		1.18		10.85		15.97		11.00

*Figures inside parentheses indicate freshwater fish production from aquaculture as a percentage of world production.

Table 3.2. Production by industry (mt) and fish species in the aquaculture industries of Asia.

Bangladesh	China	India	Indonesia	Thailand	Vietnam
Total production	Share of fisheries in	Total production	Total production	Total production (1996)	Total production
1,552,417	agriculture output: 10%	(1996-97) 5,140,000	4,452,258	3,549,000	1,546,000
	(increasing over the years)			Marine	Import 2,823
Inland capture: 41.83%		Capture: 67%	Capture 3,719,163	capture 2,786,000	Export 195,276
Inland culture : 38.21%	Total production (1997)	Culture: 33%	(84%)	culture 326,000	
Marine capture: 19.96%	361,018,000		Aquaculture 733,095		Per capita
		Environment:	(16%)	Freshwater	consumption 17.4 kg
Major cultured species:	Marine	Freshwater		capture 208,000	
rohu, catla, mrigal, silver	culture 7,911,000	culture	Aquaculture types	culture 229,000	Important cultured
carp, silver barb, common	capture 13,853,000	capture	Ponds, cages, rice fields		species:
carp	Freshwater 12,368,000	Marine		Important species	Chinese carps
	capture 1,886,000	culture	Production	Common carp, Thai	silver carp
Production annual growth		capture	Ponds 171.768	silver barb, Chinese	grass carp
86/87-95/96:	Aquaculture production		Cages 26.186	carp, rohu carp,	bighead
Open water: 4.68%	growth 1990-99:	Important Species in	Rice fields 91.334	mrigala carp, tilapia,	Indian carp
Closed water: 8.53%	Total: 7.6%	aquaculture:		catfish, snakeskin	rohu
Ponds : 8.18% Total	black carp 13.5%	rohu, catla, mrigal,	Culture Species:	gourami,	catla
: 4.88%	grass carp 9.1%	silver carp, grass	Common carp, Java		Local
	silver carp 1.5%	carp, common	barb, Nilem carp	Average annual growth	catfish
	common carp 6.4%	carp		(1981-97) 10.35%	common carp
	crucian carp 19.7%		Common carp production	Carp growth 14.10%	
	fresh bream 39.5%		Annual growth 12.00%	Common carp 21.73%	
				Silver barb 14.88%	
				Chinese carp 12.85%	

Sources: India (FAO 1998), Bangladesh (DOF 2000), Indonesia (DGF 1999), Indonesia (Indonesian Fisheries Statistics 1996), China (China Agriculture Yearbook, Miao et al. (2000), Thailand (Department of Fisheries, Thailand).

Profile of carp producers in Asia

Socio-demography of carp farmers

The socio-demographic characteristics of the carp producers in selected countries of Asia are presented in Table 3.3, which includes details on age, gender, sources of income and occupation. The average age of the farmers ranges from 40 to 52 years. Except in South Vietnam, carp farming is usually carried out by the male head of the family. In Vietnam, the participation of women in aquaculture is as high as 56 and 50% (for North and South Vietnam, respectively). This indicates that carp farming can be undertaken by women and is potentially gender neutral. The average educational level of the farmers varies from only four years in Thailand to 12 years in China. The higher educational achievement in China has perhaps enhanced production. In India, 32.7 % of farmers were illiterate, a factor which may explain this country's lower level of production. Fish farming is not the primary occupation of the household in most countries, except in China and Indonesia. Fish farming is the primary occupation of 43% of the households that were surveyed in India. This may be due to the large number of fishing households surveyed in Andhra Pradesh, in which 95% of households depend fully on fish culture for a livelihood. In many other states, such as Orissa, Uttar Pradesh, farmers also depend on fish culture for subsistence.

Experience in carp farming is an important factor influencing the fishery production; carp producers in China had the most experience (15 years) with the least in India (6 years). The average annual gross household income of the farmers is as low as US$ 1 612 in Bangladesh to as high as
US$ 98 627 in China, followed by US$ 11 272 in Thailand and US$ 8 907 in India. Average gross household income of Chinese farmers (US$ 17 321) was the highest, followed by the Thai farmers (US$ 11 172), among the selected countries. In China, the average gross income of state owned, collective and co-operative farmers is US$ 149 135, US$ 184 963 and US$ 53 179, respectively. In general, the gross household income of the carp farmers is above the national average income. Fish culture contributes up to 80% in India and as low as 15% in Bangladesh to household income. The contribution of carp farming to household incomes in India varies among the states, 15% in Orissa, but 95% in Andhra Pradesh.

General characteristics of carp farmers and carp farming

Table 3.4 presents the general characteristics of the carp farms with pond systems in the selected Asian countries. Carp farms are operated mostly by private owners, except in China and North Vietnam, where a large proportion of farms are owned by the state or by collectives. In India, the Irrigation Department owns about 30% of common water bodies, which are used by the Fisheries Department for stocking. Joint ownership is common in India, Thailand and Vietnam.

The size of culture ponds varies from one country to the next. The average total area cultivated by a household is as high as 4.24 ha in India and as low as 1.04 ha in South Vietnam. In China, the size of a family-based farm is only 3.6 ha, on average. State-owned large-scale farms can be as large as 131 ha. The farm area allocated to fishponds is 31% in North Vietnam, followed by 23.5% in India and 26% in Thailand. The average size of a fishpond in China is 1.70 ha in China, 1.21 ha in Thailand and 1.16 ha North Vietnam. The average size of a fishpond is only 0.20 ha in Bangladesh, since these ponds are largely natural water bodies, which are used for various purposes in addition to stocking with fish. The average water depth of fishponds during dry season is as low as 0.9 meters in South Vietnam and as high as 2.9 meters in India. In India, farmers maintain higher water levels (4.8 meters) during the wet season, compared to other countries. The pond system of farming and polyculture is common to all the countries, except for Indonesia where fish are grown in running water systems and cages. In South Vietnam, 30%

of the farmers practice monoculture. Integrated fish farming and rice fish farming constitute a major part of the aquaculture in Thailand and Vietnam.

Stocking Characteristics

Carp farming practices, including stocking density, allocations of species, sources and size of fingerlings, are presented in Table 3.5 for selected countries. The average stocking density in fishponds is highest in Thailand (67 382/ha), followed by South Vietnam (28 200/ha) and China (26 470/ha). The Indian major carps (rohu, catla and mrigal) account for the largest proportion of stocked fish in India and Bangladesh. Silver carps and silver barbs are next most important in Bangladesh. In China, crucian carps (35%) and common carps (20%) predominate. In Thailand, silver barb account for 40% of stocked fish, followed by tilapia (37%) and common carps (9%). In North and South Vietnam, silver carps (28%) and silver barb (20%) are used most, followed by common carps, which contribute 17% in South Vietnam. Thus, carps together account for a major share of stocked fish in all countries, except in Thailand, where tilapias constitute 35% of stocked fish. Nevertheless, common carps and silver carps are common in all these countries.

In all countries, fingerlings are supplied by private and government hatcheries, except in China where the fingerlings are produced by farmers themselves. In Thailand, private hatcheries provide 74% of the total supply of fingerlings, followed by 61% in India and 55% in North Vietnam. In Indonesia, where only common carps are stocked in cages and running water systems, 48-55% of the total supply of fingerlings comes from government hatcheries. Middlemen play an important role in supplying fingerlings for cage culture in Indonesia.

Fingerling size at stocking influences yield in ponds. Stocking size is expressed in different units in the selected countries. Tables 3.6 and 3.7 list the size (g and cm) of fingerlings/ha. The average size of fingerlings varies among countries and among species. Stocking size varies between 1-5 cm with an average of 3 cm for Indian Major carps in India and Bangladesh. In China, stocking sizes vary between 20-250 g for silver carp and up to 1 kg for black carps which represents the largest stocking size for Asia. Similarly, in North Vietnam stocking sizes are large, ranging from 63 g for silver carp to 382 g for black carp. In South Vietnam stocking sizes are smaller, ranging from 1.2 g for rohu to 5.3 g for bighead carps. In Indonesia, stocking densities for intensive monoculture in cages vary between 25-100 g/m^2. Table 3.7 shows fingerling size in cm. Stocking sizes are similar for Bangladesh, India and Thailand, ranging from 1-5 cm with an average of 3 cm. In South Vietnam farmers stock the smallest fingerlings.

Producers' preference ranking for different species

Rankings of preferences of producers for stocking of various species appear in Table 3.8. In Bangladesh, producers ranked rohu as the most preferred species followed by silver carps, mrigal and catla. In China, producers ranked grass carps highest, followed by silver carps and crucian carps. In India, rohu, catla and common carps were most preferred. In Thailand, farmers primarily preferred tilapia, but, among carps they preferred silver barb and common carps most. In North Vietnam, first preference was for grass carps followed by common carps, silver carps and rohu each with equal ranking. In South Vietnam, farmers preferred silver carp most, followed by grass carps and silver barb.

Reasons for preferences of species

Reasons for species preferred by the producers appear in Table 3.9. Rapid growth, high market value and better meat quality were important reasons mentioned by farmers. In Bangladesh, rohu was preferred because of its higher market price, which reflects consumer preference. Farmers in Bangladesh preferred silver carp due to its rapid growth. In China, growth was the major factor for selecting grass carps, silver carps and big head carps. The Chinese farmers also mentioned that better meat quality is a crucial factor for selecting crucian carps and Chinese carps. In India, a majority of the farmers preferred catla and rohu because of their higher market prices and common carp because of more rapid growth. Farmers in Thailand preferred silver barb due to its higher growth and ease of culture. Farmers of North Vietnam preferred grass carps due to more rapid growth, followed by rohu. The reason for preferring silver carps and common carps in South Vietnam was their more rapid growth.

Traits preferred by producers

Sizes, colours and shapes of the carps preferred by producers are presented in Table 3.10. Farmers in Bangladesh and India preferred fish one kilogram in size, whereas Thai farmers were willing to grow fish to half that size. Farmers had differing preferences in colour and shape. The preferred colour for rohu by the Bangladesh farmers was bright and reddish, but Indian farmers preferred brown fish. Thai farmers preferred white rohu. Farmers in India and Thailand preferred different shapes of rohu. Indian farmers favored long and thin fish bodies, but Thai farmers preferred shorter and thicker bodies.

For all the species, the most preferred size was one kg/fish in Bangladesh and India, except for silver barb in Bangladesh. Farmers using the running-water system in Indonesia preferred smaller sizes for common carps (> 2 fish/kg) compared to India and Thailand, where the preferred size was one to two/kg. Preferences of cage farmers in Indonesia were similar to those of farmers in Thailand and India. Farmers in Bangladesh and Thailand preferred similar shapes of silver carps.

Future outlook for carp farming

Attitudes toward continuing carp farming were positive in the selected countries (Table 3.11). Many producers in Thailand, China and India are willing to try the new strains if made available. The majority of farmers in Thailand are willing to expand the area under carp farming and to continue the existing mode of operation.

Conclusions

The profile of carp producers and production systems varies between the countries. Farmers in China with better educational backgrounds and greater experience have a higher proportion of their income generated through fish farming. Although the average proportion of income from carp farming for Indian farmers is 79%, income from carp farming varies considerably among states. The gross household income of the Chinese farmers is the highest, followed by Thai farmers. The area under fish culture as a proportion of the total farm area varies between 20-30% among the selected countries. The average size of fishponds ranges between 0.2 ha in Bangladesh to 1.7 ha in China. Farms are mostly privately owned, except in China and North Vietnam, where state ownership plays an important role.

The average stocking density per hectare varies between 5,432 fingerlings in North Vietnam to 66,927 fingerlings in Thailand. However, the proportion of carps in the total stocking constitutes only about 60% in Thailand and 49% in South Vietnam. The ranking of producers' preferences showed that rohu, catla, grass carps and silver carps were some of the most preferred species in Asia. The reasons were more rapid growth and better market prices. Producer preferences for fish, size, colour and shape varied among countries. However, there is more uniformity among farmers in size preferences (1-2/kg). Carp producers in general are willing to try new strains and continue with existing production operations.

Table 3.3. Socio-demographic characteristics of carp producers in Asia (pond system).

Items	Bangladesh	China	India	Indonesia		Thailand	Vietnam	
				RWS	Cages		North	South
Sampled farm households	540	383	409	40	71	284	158	240
Age (years)	45		47	46.55	40.87	49.77	43	52
Gender (%)								
Male	100	100	87			95.10	43.90	51.4
Female			13			4.90	56.10	48.6
Education (years)	8	12	7.42	7.43	8.07	4.35	8.80	6.00
Illiterates (%)	11		32.70			1.80		4.35
Primary Occupation (%)								
Fish culture	9.0	100	43.7	92.5	94.4	20.1	2.0	7.9
Crop farming	65.0		41.1	2.5	1.4	60.6	87.4	44.6
Animal farming	2.0		2.2		4.2	7.0	10.6	0.8
Others	24.0		12.5	5.0		12.3		46.70
Experience in carp farming (yrs)	13	15	6	13	5		10	7
Gross household income (US dollars)	1,612	17,321[a]	8,907			11,272	2,878	3,142
Income Sources (%)								
Fish culture	14.93	64.00	79.66			20.01	27.6	27.58
Crop farming	28.93	3.00	13.10			13.03	29.4	58.15
Animal farming	3.19	3.00	0.03			48.41	27.30	14.20
Hatchery and seed Production		20.00	6.35				6.20	
Business and salaries	32.55	6.00	0.55				7.40	
Others	20.00	4.00				18.55	0.10	0.08
Average household size (no.)	5.5	3.5	8.00	3.35	3.73	4.65	5.00	5.81

[a] The gross income of China refers only to family based farms. The average gross income of co-operative and state owned farms ranges from US$ 53,179 to 149,135.

Table 3.4. General characteristics of carp farming in Asia.

Items	Bangladesh	China	India	Indonesia		Thailand	Vietnam	
				RWS	Cages		North	South
Total Area (ha)		3.59[a]	4.24	2.29	2.87	3.98	3.67	1.04
Crop land (%)		8.55[b]	24.76			50.80	43.30	80.69
Water spread area (%)		83.11	44.85			26.04	47.9	18.11
Fish-pond area (%)		17.95	23.51			25.63	31.60	7.94
Homestead area (%)			1.20			5.06	4.80	3.40
Animal farming						0.73		
Unutilized area			5.45				3.90	
Others			0.25			4.40		
Size of the fish pond (ha)	0.20	1.70	0.87			1.21	1.16	0.82
Fish farm area by tenure (%)								
Privately owned	100	41.10	62.6	100	100	90.10	35	95.70
State owned		29.60	29.30			0.70	45	0.57
Collective		29.30	2.20			8.50	17.8	
Rented in			6.80			0.70		3.73
Others			1.20				2.2	
Type of operation (%)								
Single ownership	86.70	100	71.00	100	100	85.40	88	99.12
Joint ownership			26.90			14.60	22	0.88
Lease operated	13.30							
Water depth (meters)	2.28	2.10	3.00	0.90	2.04			
Dry season	1.30		2.90			1.27	1.56	0.93
Wet season	4.25		4.78			2.12	2.44	1.37
Farming duration (months)	9-12	8-11	8-12	3-4	3-4	5-12		
Rearing type (%)								
Seasonal	26.30		13			8.50	8.10	41.42
Perennial	73.70	100	87	100	100	91.50	91.90	58.48
Pond system								
Monoculture	100	4.20	100	100	100	8.50	1.8	30.50
Polyculture		92.30				91.50	98.20	69.50
Mono+polyculture		3.50						
Cage culture								
Monoculture								33.33
Polyculture								66.67
Rice fish farming								
Monoculture						100		12.90
Polyculture								87.10

[a] The average total area refers to small-scale farms. For large-scale state owned farms it is 131.80 ha.

[b] The percentage of pond area refers to the water-spread area.

Table 3.5. Carp farming practices in Asia.

Items	Bangladesh	China	India	Indonesia		Thailand	Vietnam	
				RWS	Cages		North	South
Average stocking density*	10,261	27,867	18,408	56.5	136.56	67,328	5,432	28,200
Species composition (%)								
Rohu	24.10		31.00			4.93	22.90	0.11
Catla	16.13		26.06					0.01
Mrigal	16.45		17.77			4.47	7.40	2.68
Common carps	2.21	21.90	6.44	100	100	8.37	4.90	17.30
Grass carps	2.80	20.90	4.18				8.70	1.54
Silver carps	19.68	27.96	7.17				28.10	2.83
Silver barb	13.04					39.88		20.00
Kalbasu	0.55							
Big head carps		8.97					2.30	4.33
Chinese bream		3.11						
Crucian carp		14.93						
Mirror carps	2.28							
Black carps		0.69						
Tilapia						36.76		
Others	2.74	2.23	6.85			4.26	25.70	51.20
Source of fingerlings (%)								
Own	5	90	0.54	2.50	5.72	4.03	23.60	2
Private hatchery	40		61.85	42.50	13.46	74.20	54.50	79
Government hatchery	20		25.00	55.00	48.08	21.77	7.90	11
Middlemen and others	35	10	13.00		32.09		13.80	8

* For Indonesia, stocking density is in kg/100 m^2, while the others are in pcs/ha

Table 3.6. Size of fingerlings during stocking (gm).

	China	Indonesia		N.Vietnam
		RWS	Cages	
Size of fingerlings at stocking				
Rohu	--			64
Catla	--			--
Mrigal	--			65
Common carp	15-50	25-100	25-100	68
Grass carp	50-500			171
Silver carp	20-250			63
Silver barb	--			--
Crucian carp	1-50			--
Black carp	50-1000			--
Bighead	20-250			382
Chinese bream	20-250			210
Others	8-50			

Table 3.7. Size of fingerlings during stocking (cm).

	Bangladesh	India	Thailand	S. Vietnam
Size of fingerling at stocking				
Rohu	3-5	1-5	2.44	1.20
Catla	3-5	1-5	--	1.25
Mrigal	3-5	1-5	2.12	2.38
Common carp	2.5-4	1-5	2.25	1.84
Grass carp	2-4	1-5	--	2.03
Silver carp	3-4	6-10	--	1.81
Silver barb	2-4		1.95	3.34
Chinese carp	-		2.13	--
Bighead	-			--
Others	-			5.30

Table 3.8. Producer's preference for freshwater species in Asia.

Rank	Bangladesh	China	India	Thailand	North Vietnam	South Vietnam
1	Rohu	Grass carps	Rohu	Tilapia	Grass carps	Catla
2	Silver carp	Silver carps	Catla	Silver barb	Rohu/Mrigal/	Common carps
3	Mrigal	Crucian carps	Common carps	Catfish	Common carps/	Silver barb
4	Catla	Bighead carps	Grass carps	Rohu/Mrigal	Silver carps/	Rohu
5	Silver barb	Common carps	Mrigal	Chinese carps	Tilapia	Mrigal
6	Common	Chinese bream	Silver carps		Black carp	Bighead carps
7	carps	Black carps				Silver carps
8	Grass carps					
	Kalbasu					

Table 3.9. Reasons for preferring particular species.

Countries	Species	Reasons
Bangladesh	Rohu	Higher market price
	Silver carp	Good flavour/taste
	Silver barb	Higher growth
China	Grass carp	Higher growth
	Big head carp	
	Common carp	
India	Catla	Higher market price
	Rohu	Higher growth
Thailand	Silver barb	Higher market price
	Rohu	Higher growth
	Common carp	
South Vietnam	Silver carp	Higher growth
	Common carp	
North Vietnam	Grass carp	Higher market price
	Common carp	Higher growth

Table 3.10. Preferred size, colour and shape of the most preferred species.

Species trait	Bangladesh	China	India	Indonesia		Thailand	N.Vietnam
				RWS	Cages		
Rohu							
Size (no/kg)	1		1			<2	
Colour	Bright & reddish		Brown			White	Bright
Shape	Long & thick		Long & thin			Short & thick	Short & thick
Catla							
Size(no/kg)	1		1				
Colour	Bright & reddish		Brown				
Shape	Short & thick		Short & thick				
Mrigal							
Size(no/kg)	1		1			<2	
Colour	Bright		Brown			White	Black green
Shape	Long & thick		Long & thin			Long & thin	Short & thick
Common Carps							
Size(no/kg)	1	1	1	>2	<2		
Colour	Bright & yellow	Reddish	Reddish	Greenish	Greenish	Silver/ Green/ Grey	Bright
Shape		Short & thick	Short & thick	Short & high back	Short & high back	Short & thick	Short & deep
Silver barb							
Size(no/kg)	3					2-3	
Colour	White					White	Bright
Shape	Short & thick					Short & thick	Short & thick
Silver Carps							
Size(no/kg)	<1	2				<2	
Colour	Silver white	Silver white				White	Silver
Shape	Long & thick	Short & thick				Short & thick	Short & thick

Table 3.11. Farmers' attitudes toward carp farming (%).

Items	China	India	Thailand	N.Vietnam	S.Vietnam
Expand		11.10	75.30	2.40	33.11
Continue		75.00	11.30	54.10	66.22
Shift to other species		1.00			4.5
Change species combination		1.30			12.30
Increase stocking density		0.50		8.1	8.70
Increase feed use		9.50		14.40	8.00
Willingness to try new breed	95	46.70	43.30		

Costs, return and profitability of carp culture

Farming in Asia

This section provides an overview of the structure of inputs-outputs, costs-returns and profitability of carp production in participating countries. Average inputs-outputs were summarized for various culture practices and species used by farmers in the participating countries.

Input and yield levels

Table 3.12 shows levels of inputs used and yields of various culture systems for countries in this study. Fish farmers in Bangladesh, India and Vietnam used relatively less supplementary feed and other inputs in comparison to farmers of China and Thailand. Levels of input indicate that an extensive mode of operation was used in most fish farms in Bangladesh and India. In China, most farms practice at least semi-intensive fish culture. In Indonesia, running water systems are basically semi-intensive and intensive systems, whereas fish-rice culture is an extensive system (Kontara and Maswardi 1999). The RWS and cage culture systems require large inputs consisting of the supply of fingerlings, feed and labour. On the other hand, pond culture systems used various types of inputs, such as fingerlings, feed, fertilizers, chemicals, pesticides and labour. Average stocking densities in ponds ranged from 10,261 to 136,406 fish·ha^{-1}. For pond-culture systems, feeds included commercial feeds, rice bran, oil cake and other feeds. Both organic and inorganic fertilizers were used. Lime was only used in Bangladesh and Thailand.

Yields vary considerably among countries. This can be attributed to the variability in input intensity, culture practices and the production environments and systems. China showed significantly higher yields than those of Bangladesh, India, Thailand and North Vietnam. In India, production estimates should be best examined for each state, due to the differences in farming practices among states. Veerina et al. (1993) reported that in some parts of India farmers have successfully adopted semi-intensive culture, yielding an average annual production of 6-8 t/ha using organic and inorganic fertilizers as well as plant-based diets, such as rice bran, cotton seed meal, de-oiled bran and ground nut cake as supplementary feeds. In general, yields of carps in India and Bangladesh are similar, whereas yields in Thailand and North Vietnam are higher, but similar to each other. In Indonesia, cage culture produces significantly higher yields than does RWS.

Cost and returns

Costs and returns are expressed in US$, based on the exchange rates of local currencies during the survey. Various definitions of fish culture profitability are used here, depending upon the types of costs deducted from gross revenues. Hence, profitability of freshwater fish production was measured in terms of operating profit, rate of return over variable cost and ratio of operating profit to variable cost. As fixed costs are not available from other countries, only variable costs were included in the cost-and-return analysis. Data from China and Thailand showed that fixed costs accounted for about 10% of the total cost. Dey et al. (2000b) reported that fixed costs in freshwater culture in these countries accounted for about 9–35% of the total cost. In Bangladesh and Vietnam, as fixed costs are relatively important (McConnel and Dillon 1997), the use of gross margin is considered to be a good measure of profitability (Dey et al. 2000b). As with yield levels, the cost and returns of fish production vary widely with different production environments, input levels, culture practices and farming systems.

Table 3.13 lists the cost and returns and profitability of carp production. Freshwater farms in participating countries had average total receipts ranging from US$ 1,715.12/ha (Bangladesh) to US$ 10,797.11/ha (China) for ponds. RWS and cages in Indonesia had total receipts of US$ 506.89/100 m^2 and US$ 872.97/100 m^2, respectively. Operating profit per hectare per production cycle was highest in China (US$ 3,448.08), followed by Thailand (US$ 1,470.70) and North Vietnam (US$ 1,398.57), and was lowest in India (US$ 589.31).

Several factors influence profitability in both the short and long term. A positive operating profit for freshwater fish production ensures continuation of operations in the short-term. However, this assumes that if fixed assets are liquidated no undue loss is incurred or that farmers do not switch to other farming activities. Long-term prospects for freshwater fish production can be seen by including fixed costs in calculating profit. Rates of return over costs is close to 150%, except for Bangladesh, Thailand, North Vietnam and cage culture in the Philippines, which were over 200%. Cost per unit of output (the break-even price) implies that the country with the lowest cost in producing a unit of output (US$/kg) is more productive and cost effective. Since the cost per unit of output and the unit output price is lowest in Bangladesh and Thailand, farmers in these countries appear to be more productive and cost effective than farmers in other countries. The low level of production and low cost efficiency of carp production in Indonesia was unexpected. This may be more apparent than real, since the survey in Indonesia was conducted during a monetary crisis, which affected operational financing of culture activities. The limited financial base of fish producers prevents them from adopting efficient technologies for RWS and cage culture, that is, critical inputs for stocking and feeding cannot be applied at an appropriate level.

Feed costs were an important component of the total cost of pond culture in China and Thailand, accounting for about 46% and 33% of the total cost, respectively (Table 3.14). Feed costs were equally important for Indonesia's RWS and cage systems, accounting for more than 50% of the total cost. In Bangladesh and India, feed costs are not as high, at only 14.2% and 15.7% of the total cost, respectively. Except for India, the proportional cost of fingerlings ranked second to feed costs for all countries. This indicates that higher feeding rates compensate for low stocking rates in the total production. In general, higher yields are produced from higher stocking and feeding rates.

Investments in freshwater farming are considerably less risky than many other types of investments. The survey included a risk element, because both successful and unsuccessful farms were included in the survey. In most cases, investments in fish farming are considered to be low-risk investments. The use of polyculture and integrated culture systems shows not only the profit-maximization behaviour of fish farmers, but also the farmers' tendency toward risk aversion. To reduce costs of feed, farmers used various kinds of feed, including rice bran, kitchen waste and oil cake. Commercial feeds were used sparingly, except in China and Thailand.

Total factor productivity

Production measures, such as yield, operating profit, rate of return and cost per unit output, as used above, are only partial measures of production. These measures of production arebiased due to different input and output prices) between countries. We used the total factor productivity (TFP) indexes, specifically the interspatial Tornqvist (TI) index to compare differences in production among countries. This index accounts for differences in input and output price among countries, and is defined following Dey et al. (2000b) as:

$$TI_{ij} = \mathrm{Ln}\left[\frac{Q_i}{Q_j}\right] - \frac{1}{2}\sum_k \mathrm{Ln}\left[\frac{X_{ki}}{X_{kj}}\right]\left(s_{ki} + s_{kj}\right) \qquad (1)$$

where
TI_{ij} = Inter-spatial Tornqvist Index,
Q_i = Output quantity of country i,
X_{ki} = Quantity of input k in the production process of country i,
s_{ki} = kth input cost share of country i.

The exponentiation of TI_{ij} gives the difference in production between countries i and j. The equivalent dual cost index can be expressed as:

$$-TI_{ij} = \mathrm{Ln}\left[\frac{C_i}{C_j}\right] - \mathrm{Ln}\left[\frac{Q_i}{Q_j}\right] - \frac{1}{2}\sum_k (S_{ki} - S_{kj})\mathrm{Ln}\left[\frac{P_{ki}}{P_{kj}}\right] \qquad (2)$$

where
C_i = total cost of production for country i,
P_{ki} = prices of input k in country i.

The exponentiation of $-TI_{ij}$ in equation 2 gives the difference in production between two countries in terms of cost and indicates how much a unit of output would cost (more or less) relative to another country. We first estimated the dual cost index, then the production (primal) index negating the dual cost index. To correct for different product-species combinations among countries, production value was used in addition to production quantity as a measure of output in equation 2.

Table 3.15 summarizes the results of the total factor productivity analysis. TFP indexes were computed for polyculture ponds in Bangladesh, China, India and North Vietnam using polyculture ponds in Thailand for comparison. Only farmers in Bangladesh incurred lower (30%) costs per hectare but also lower yields (27%) than did farmers in Thailand. Farmers in India incurred 76% higher costs per hectare than did farmers in Thailand, but had 9% lower production value and 15% lower production quantity. Farmers in North Vietnam had 4% lower production yields (by quantity), but slightly higher production values, because they enjoy higher output prices than do farmers in Thailand. Only farmers in China had higher production quantity yields (230%) (Table 3.16 and 3.17). Farmers in these four countries experience higher weighted input costs than do farmers in Thailand. Another way to view these results is to measure production in terms of a standardized input cost. If farmers in these countries experienced the same input costs, comparable to those in Thailand, they could produce 8% (China) to 243% (North Vietnam) more. Production by farmers in North Vietnam and China will cost 71% and 3% less than production in Thailand, respectively. Estimated production indexes based on production values show that, if farmers in these countries incurred the same input costs as in Thailand, they could generate higher production values, ranging from 31% in India to 260% in North Vietnam. Production in North Vietnam and India will cost 24% and 72% less than the production in Thailand, respectively, to generate the same production value. These results imply that assuming the same input costs, farmers in Thailand appear to be less productive and farmers in North Vietnam more productive. Dey et al. (2000), who used dual cost indexes based on production value with the Philippines as a comparison, showed that for pond polyculture China was most productive, while Thailand had the highest production quantity, followed by China and Bangladesh. For tilapia monoculture in ponds and cages, China was more productive than the Philippines. To achieve similar relative production to Bangladesh fish farmers, farmers in Thailand must increase yields by 12%. In the same manner, to achieve equivalent production to Indian farmers, farmers in Thailand must increase yields by 77%.

Table 3.12. Inputs and outputs of carp producers in participating Asian countries, 2000.

Category	Bangladesh	China	India	Indonesia		Thailand	N.Vietnam
				RWS	Cage		
Yield (kg/ha)	3,262.11	12,085.20	3,214.07	481.68	1,009.52	3,779.71	3,647.00
Seed/Fry [a]	10,261.00	27,867.00	18,408.00	56.50	136.57	67,328.00	5,432.00
Feed	2,232.37	38,251.05	9,035.80	807.99	1,493.90	10,989.48	1,724.50
Rice bran (kg/ha)	1,727.70	442.50	8,243.52			2,019.92	1,724.50
Commercial feed (kg/ha)		19,219.80		807.99	1,493.90	1,229.13	
Oil cake (kg/ha)	504.67	16,380.00	474.00				
Other		2,208.75	318.28			7,740.43	
Fertilizer	725.22	2,292.60	5,606.96	-	-	2,909.58	1,875.00
Organic (kg/ha)	438.86	1,170.75	5,469.93			2,680.90	1,875.00
Inorganic (kg/ha)	286.36	1,121.85	137.03			228.68	
TSP	65.30						
Urea	221.06	150.00	55.99				
Other		971.85	81.04	-	-		
Lime	92.99					285.03	65.00
Medical/Chemical/Pest.		1,353.60	18.54	-	-	1.70	
Labour (Man-Days/ha)	323.52	292.51	277.27	64.80	187.20	159.21	132.60
Family labour	184.41		150.21				122.00
Hired labour	139.11	6,830.25	127.06				10.60
Land rent		6,614.85					118.30
Fuel/Electricity		2,503.95				131.28	
Other	316.19	921.00				620.52	234.70

[a] Seed was a kg/100m^2 in Indonesia while other was in no./ha.

Table 3.13. Costs and Returns of carp fish producers in participating countries, 2000 (US$/ha).

Category	Bangladesh	China[2]	India	Indonesia		Thailand	N.Vietnam
				RWS	Cage		
Gross returns	1,715.12	10,797.11	2,124.53	506.89	872.97	2,343.42	2,374.07
Average price of fish produced	0.53	0.89	0.66	1.05	0.86	0.62	0.65
Yield (kg/ha)	3,262.11	12,085.20	3,214.07	481.68	1,009.52	3,779.71	3,647.00
Variable costs	611.00	7,349.00	1,535.00	352.00	697.00	873.00	976.00
Seed/Fry	84.48	2,153.82	777.60	84.17	202.93	195.85	246.4
Feed	124.27	3,750.35	248.43	242.27	389.72	390.09	281.2
Rice bran	59.65		179.21			153.31	267.9
Commercial feed						179.00	
Oil cake	64.62		29.94				
Other			39.28			57.78	13.3
Fertilizer	69.33	146.59	88.42			60.42	87.1
Organic	30.35		66.21			101.27	
Inorganic	38.98		22.21			81.62	87.1
Lime	10.22					6.12	7.6
Medical/Chemical/Pest		156.94	45.73	0.30	1.49	1.42	118.3
Labor	322.82	731.27	375.04	25.02	102.34	167.35	234.70
Family labour	176.35		194.87			155.02	215.94
Hired labour	146.47		180.17			12.33	18.76
Fuel/Electricity		288.23				17.57	
Other	0.18	121.83		0.23	0.67	33.90	0.20
Total cost	611.30	7,349.03	1,535.22	351.99	697.15	872.72	975.50
Operating profit[3]	1,103.82	3,448.08	589.31	154.90	175.82	1,470.70	1,398.57
Rate of return over variable cost (%)	280.57	146.92	138.39	144.01	125.22	268.52	243.37
Ratio of operating profit to variable cost	1.81	0.47	0.38	0.44	0.25	1.69	1.43
Cost per kg (Variable cost/yield)	0.19	0.61	0.48	0.73	0.69	0.23	0.27

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[1] All figures are average of each country figure and values are in US $/ha, but Indonesia's figures are in US$/100 m2.

A US$ 1.00 equals Taka 49 (Bangladesh), CNY 8.1 (China), Rs 46 (India), Rp 7,000 (Indonesia), Baht 38 (Thailand) and VND 14,000 (Vietnam).

[2] Average farm gate price was calculated from survey data (CNY 7/kg) and average inputs-outputs were calculated from China's country report.

[3] Operating profit=Total revenue – Variable cost.

Table 3.14. Input cost percentage of the total cost in each participating country.

Category	Bangladesh	China	India	Indonesia		Thailand	N.Vietnam
				RWS	Cage		
Variable costs	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Seed/Fry	13.82	29.31	50.65	23.91	29.11	22.44	25.26
Feed	20.33	51.03	16.18	68.83	55.90	44.70	28.83
Rice bran	9.76	0.00	11.67	0.00	0.00	17.57	27.46
Commercial feed	0.00	0.00	0.00	0.00	0.00	20.51	0.00
Oil Cake	10.57	0.00	1.95	0.00	0.00	0.00	0.00
Other	0.00	0.00	2.56	0.00	0.00	6.62	1.36
Fertilizer	11.34	1.99	5.76	0.00	0.00	6.92	8.93
Organic	4.96	0.00	4.31	0.00	0.00	11.60	0.00
Inorganic	6.38	0.00	1.45	0.00	0.00	9.35	8.93
Lime	1.67	0.00	0.00	0.00	0.00	0.70	0.78
Medical/Chemical/Pest.	0.00	2.14	2.98	0.09	0.21	0.16	12.13
Labor	52.81	9.95	24.43	7.11	14.68	19.18	24.06
Family labour	28.85	0.00	12.69	0.00	0.00	17.76	22.14
Hired labour	23.96	0.00	11.74	0.00	0.00	1.41	1.92
Fuel/Electricity	0.00	3.92	0.00	0.00	0.00	2.01	0.00
Other	0.03	1.66	0.00	0.07	0.10	3.88	0.02

Table 3.15. Total factor productivity of carp polyculture production system in selected Asian countries.

	Bangladesh	China	India	N. Vietnam
% Difference in cost (US$/ha)	70.05	842.08	175.91	111.78
% Difference in production value (US$/ha)	73.19	460.74	90.66	101.31
% Difference in production quantity (US$/ha)	86.31	330.55	85.03	96.49
% Difference in weighted input prices	152.69	274.65	253.65	397.25
Productivity index based on production value:				
Cost index	0.63	0.67	0.76	0.28
Production index	1.60	1.50	1.31	3.60
Productivity index based on production quantity:				
Cost index	0.53	0.93	0.82	0.29
Production index	1.88	1.08	1.23	3.43

Note: Thailand is used as the reference country.

Yield gap and yield loss analysis

Introduction

The six participating countries are the largest and most technologically advanced producers of carps in Asia and the rest of the world. Various culture technologies and carp strains and varieties have been developed or introduced to these countries. The adoption of carps has greatly improved farm fish production. However, a large difference in the production levels exists among farms in each country and between countries, even in China, where carps have been cultured for thousands of years.

In this section, we identify the present yield gap and yield losses caused by various factors in the six participating countries. The results provide guidance to develop a strategy to further improve the production of carp culture in Asia and the world. These results identified the important traits that could be improved by genetic methods to increase the production quantity and output quality.

Yield gap analysis

Yield gap analysis has been used in agriculture for many years. Yield gap studies can demonstrate how closely farm yields are to the maximal potential yield with the available technology. They can also suggest how to improve production more efficiently through the extension of present available technology or study or by developing new technologies.

Three definitions of yield gap are found in the literature. Yield gap I is defined as the gap between experimental yield and the yield obtained by the farmers. Yield gap II is the gap between the experimental yield and the maximal potential yield, given a particular technology. Yield gap III is the gap between potential yield and actual yield obtained by the farmers. Use of yield gap III is more appropriate to farmers in developing countries, as many are unable to adopt methods used to achieve experimental yields. This is due to various factors, including a lack of knowledge of the technology, lack of capital, credit access and low input use.

As mentioned earlier, use of the yield gap III definition appears to be the most suitable to our study; but this definition still has some inherent problems. The use of a single maximum yield from the sample is not wise as it may be an outlier, and hence may exaggerate the magnitude of the yield gap. To overcome this problem, we have adjusted the definition and used the average of the top 5% of the total sample as the maximal yield.

The result of yield gap analysis of carp culture by level of farming intensity among countries appears in Table 3.16. The overall average yield gap in carp culture of the six countries examined is 65% of the potential yield. This yield gap is considerably larger than the country specific rice yield gaps estimated in "Rice Research in Asia" by IRRI in the early 1990s (Evenson et al. 1996). This can be explained by two factors. Firstly, compared with rice cultivation, carp culture is carried out under a more complex environment. That is, farm fish production is more influenced by the environmental conditions than is rice cultivation. Secondly, unlike plant crop production, the progress of which is visible, the progress of an aquaculture crop cannot be as easily monitored, as interactions among species, water and the influence of feed and other inputs are less visible. Polyculture of carps is also more difficult to monitor than monoculture. Carp culture is also a relatively new practice compared to rice cultivation in many countries, so that dissemination of technologies and extension is much less effective than with crop farming.

Comparisons among the different countries indicate that on average Indonesia has the smallest yield gap for carp culture. Whereas, countries with large amounts of environmental variation and a diversity of culture systems, such as Bangladesh, China, India and Thailand, have relatively higher yield gaps. The average of the ratio of yield gap to the potential yield is between 54-79% in all countries, except Indonesia. Unexpectedly, this yield gap ratio declines as the farming intensity level increases (except in Thailand and India). At medium and high intensities the gap varies among countries. Theoretically, the yield gap should narrow as the intensity level increases, as cultivation requires a higher standard of management, better culture conditions and higher input levels.

Yield loss analysis

To explain the yield gap in present carp culture in the six different countries, we made a yield loss analysis. It was expected that the yield loss analysis would provide insights into identifying priority areas for further genetic research to improve production. Two kinds of factors, environmental and fish related, were identified by biologists and included in the study. The financial loss caused by different factors was estimated, based on the producer survey data. The results of this analysis are presented in Table 3.17. The results of the Indonesian study could not be incorporated into this analysis because data collection differed from that in other countries.

The reported total annual financial loss caused by various environmental and fish-related factors ranged from US$243 (Bangladesh) to US$1,691 (China). Financial loss as a percentage of the total yield was highest in North Vietnam and Thailand (53 and 54%, respectively) and lowest in Bangladesh (14%). Such large differences mainly result from factors included in the study by different countries or institutions. Considering the average yield gap of about 65% of the potential yield, the result of the yield loss explained only a small portion of the gap. Such a result can be explained by three reasons. Firstly, not all socioeconomic factors were included in the study. Variation in inputs within different farming intensity levels was still large and resulted in a large amount of variation in the production level. Secondly, the losses from environmental factors, including floods, typhoons and droughts, were variously reported in some countries. The present yield gap is caused largely by these factors in most countries. Finally, it is difficult for fish farmers to accurately identify and report yield losses from some factors, such as reduced growth of fish and disease.

Proportions of various factors contributing to loss appear in Table 3.18. This table shows that water quantity and quality (specifically, high turbidity and low dissolved oxygen) and diseases (bacterial and viral) are factors contributing most to yield loss. Soil problems and extreme temperatures also contribute to the total yield loss among farmers in Thailand. Among the important factors contributing to total yield loss, low dissolved oxygen and disease are related to both the fish and management. Improved farm management can reduce the likelihood of low dissolved oxygen and outbreaks of disease. But, it is not possible to avoid losses from these factors in today's carp culture practices, especially with the tendency to increase the farming intensity level. Therefore, genetic research should be initiated to develop strains of fish that are tolerant to low dissolved oxygen. Apart from tolerance to low dissolved oxygen and resistance to disease, other problems such as intolerance to extreme temperatures may also be solved through genetic research. A closer examination of the data, however, shows that genetic gains may be able to reduce the total loss by only 18%. On the other hand, 80% of the total loss can be reduced by better management and more careful selection of sites for carp farms (Table 3.18).

Table 3.16. Yield gap in carp culture by intensity level across the participating countries.

Intensity Level[a]	Bangladesh	China	India	Indonesia	Thailand	N.Vietnam
Low intensity						
No. of farms	295	122	96	39	95	27
Potential (max) yield (mt/ha)	6.31	21.39	6.79	89.10	9.50	6.97
Average (actual) yield (mt/ha)	3.06	6.77	2.80	48.17	3.60	3.47
Yield gap (mt/ha)	3.46	14.62	3.99	44.30	5.90	3.50
Yield gap as % of max yield	54.88	68.36	58.76	49.72	62.11	50.19
Medium intensity						
No. of farms	146	155	232	71	105	56
Potential (max) yield (mt/ha)	6.69	28.95	14.62	96.10	10.60	10.11
Average (actual) yield (mt/ha)	3.23	11.69	3.20	57.40	3.70	3.53
Yield gap (mt/ha)	3.46	17.26	11.42	38.70	6.90	6.58
Yield gap as % of max yield	51.77	59.63	78.11	40.27	65.09	65.08
High intensity						
No. of farms	99	157	81	31	48	28
Potential (max) yield (mt/ha)	8.45	40.77	16.89	280.50	11.30	12.16
Average (actual) yield (mt/ha)	3.91	16.61	3.78	200.70	4.40	4.05
Yield gap (mt/ha)	4.54	24.16	13.11	79.80	6.00	8.11
Yield gap as % of max yield	53.76	59.26	77.62	28.45	53.09	66.69
Overall						
No. of farms	540	434	409		248	111
Potential (max) yield (mt/ha)	7.13	27.18	14.94		10.58	10.38
Average (actual) yield (mt/ha)	3.26	12.08	3.20		3.78	3.65
Yield gap (mt/ha)	3.87	15.10	11.74		6.80	6.73
Yield gap as % to max yield	54.30	55.56	78.58		64.27	64.84

[a] For Indonesia it is Running water, Floating cage and Double floating cage for low, medium and high intensity respectively.

Table 3.17. Yield loss (US$/year/ha) caused by various factors in five participating countries.

Factor	Bangladesh	China	India	Thailand	N.Vietnam	Average
Water quality	170.98	776.48	269.86	139.17	470.07	365.31
High turbidity	109.28	-	-	26.68	-	27.19
Plankton bloom	21.17	77.48	5.50	21.11	-	25.05
Fila. Algae/weed	4.52	-	-	68.53	-	14.61
Low Dissolved Oxygen	36.01	442.48	264.36	22.85	470.07	247.15
Pollution	-	256.52	-	-	-	51.30
Water quantity	55.74	-	211.51	341.81	378.35	197.48
Shortage of water	8.48	-	211.51	89.88	378.35	137.64
Flooding	47.26	-	-	251.93	-	59.84
Soil Problem	8.42	-	-	184.51	-	38.59
Acidity	-	-	-	108.54	-	21.71
Sedimentation	-	-	-	5.48	-	1.10
Seepage	8.42	-	-	70.49	-	15.78
Disease	8.11	625.06	247.71	128.71	354.15	272.75
Virus	2.58	253.09	-	61.91	-	63.52
Bacteria	5.53	258.58	247.71	66.80	-	115.72
Parasite	-	113.39	-	-	-	22.68
Temperature	-	84.90	-	123.85	15.29	44.81
High	-	47.21	-	28.72	-	15.19
Low	-	30.37	-	95.13	15.29	28.16
Abnormal fluctuation	-	7.32	-	-	-	1.46
Others	-	119.79	-	189.78	48.41	71.60
Reduced growth	-	61.33	-	-	-	12.27
Easily affected by disease	-	58.46	-	-	-	11.69
Others	-	-	-	-	-	-
Total loss (US$/ha)	243.24	1,691.13	729.08	1,231.68	1,281.56	1,035.34
Average gross output (US$/ha)	1,715.12	10,797.11	2,124.53	2,343.42	2,374.07	3,870.85
Loss % of the yield	14.18	15.66	34.32	52.56	53.98	34.14

Table 3.18. Percentage of each factor of total yield loss.

Factor	Bangladesh	China	India	Thailand	N.Vietnam	Average
Water quality	70.29	45.91	37.01	11.30	36.68	40.24
High turbidity	44.92	0.00	0.00	2.17	0.00	9.42
Plankton bloom	8.70	4.58	0.75	1.71	0.00	3.15
Fila. Algae/weed	1.86	0.00	0.00	5.56	0.00	1.48
Low Dissolved Oxygen	14.80	26.16	36.26	1.86	36.68	23.15
Pollution	0.00	15.17	0.00	0.00	0.00	3.03
Water quantity	22.91	0.00	29.01	27.75	29.52	21.84
Shortage of water	3.49	0.00	29.01	7.30	29.52	13.86
Flooding	19.43	0.00	0.00	20.45	0.00	7.98
Soil Problem	3.46	0.00	0.00	14.98	0.00	3.69
Acidity	0.00	0.00	0.00	8.81	0.00	1.76
Sedimentation	0.00	0.00	0.00	0.44	0.00	0.09
Seepage	3.46	0.00	0.00	5.72	0.00	1.84
Disease	3.33	36.96	33.98	10.45	27.63	22.47
Virus	1.06	14.97	0.00	5.03	0.00	4.21
Bacteria	2.27	15.29	33.98	5.42	0.00	11.39
Parasite	0.00	6.70	0.00	0.00	0.00	1.34
Temperature	0.00	5.02	0.00	10.06	1.19	3.25
High	0.00	2.79	0.00	2.33	0.00	1.02
Low	0.00	1.80	0.00	7.72	1.19	2.14
Abnormal fluctuation	0.00	0.43	0.00	0.00	0.00	0.09
Others	0.00	7.08	0.00	15.41	3.78	5.25
Reduced growth	0.00	3.63	0.00	0.00	0.00	0.73
Easily affected by disease	0.00	3.46	0.00	0.00	0.00	0.69
others	0.00	0.00	0.00	0.00	0.00	0.00
Total Loss	100.00	100.00	100.00	100.00	100.00	100.00

Table 3.19. Percentage of each factor of total yield loss classified by potential solutions.

Factor	Bangladesh	China	India	Thailand	N. Vietnam
Genetic research	**18.14**	**71.75**	**70.24**	**35.15**	**65.90**
Disease (total)	*3.33*	*38.91*	*33.98*	*11.62*	*27.80*
Virus	1.06	15.76	-	5.59	-
Bacteria	2.27	16.10	33.98	6.03	-
Parasite	-	7.06	-	-	-
Soil Problem	-	-	-	*10.29*	-
Acidity	-	-	-	9.80	-
Sedimentation	-	-	-	0.49	-
Water quality	*14.80*	*27.55*	*36.26*	*2.06*	*36.90*
Low Dissolved Oxygen	14.80	27.55	36.26	2.06	36.90
Temperature	-	*5.29*	-	*11.18*	*1.20*
High	-	2.94	-	2.59	-
Low	-	1.89	-	8.59	1.20
Abnormal fluctuation	-	0.46	-	-	-
Other form of research	**1.86**	-	-	**23.32**	-
Fila. Algae/weed	1.86	-	-	6.19	-
Others (predators)	-	-	-	17.13	-
Management	**80.00**	**20.79**	**29.76**	**41.53**	**33.50**
Water quality	*53.63*	*4.82*	*0.75*	*4.31*	-
High turbidity	44.92	-	-	2.41	-
Plankton bloom	8.70	4.82	0.75	1.91	-
Water quantity	*26.38*	*15.97*	*29.01*	*37.22*	*29.70*
Shortage of water	3.49	-	29.01	8.11	29.70
Flooding	19.43	-	-	22.74	-
Pollution	-	15.97	-	-	-
Seepage	3.46	-	-	6.36	-
Others	-	-	-	-	*3.80*

Technical efficiency of Asian fish farmers

Importance of technical efficiency study in aquaculture

The importance of aquaculture in Asia cannot be emphasized enough. Aquaculture production has struggled to keep pace with the growing demand for food, employment and foreign exchange. Aquaculture practices have changed over the last decade or so. Some countries are able to keep up with these changes, while others are lagging behind. Statistics on status of aquaculture practices, such as production per unit area, species composition, trends in production and inputs used are often available. However information on the status of achieving potential production levels is more limited, despite its significance in policy formulation. Here we investigate the technical efficiency levels of Asian fish farmers in Bangladesh, China, India, Indonesia, Thailand and North Vietnam.

Methods of analysing technical efficiency

An abundance of economic literature exists on whether farmers attempt to or are able to maximize their profits. The classical approach is to equate marginal costs with marginal revenues. A duality approach using profit or cost functions is another way of determining whether farmers maximize profits. These two frameworks have been of great use, but lack the ability to quantify the level of profit maximization. Another method of analysis, the frontier analysis, is used to estimate profit maximization.

Alternative approaches can be used to determine technical efficiencies. Frontier techniques have been used widely in determining production performance in agriculture, since Farrel's original article (Farrel 1957) which was followed by various approaches to estimate efficiency and production. However, recent reviews of the use of production frontier analyses in agriculture showed that no frontier studies had been applied to aquaculture (Battese 1992; Bravo-Ureta and Pinheiro 1993; Coelli 1995a and 1995b). Recently, a growing number of studies have been made on technical efficiency of Asian fish farmers. These include the studies of Dey et al. (2000a) on tilapia pond -grow-out farming in the Philippines, Sharma (1999) and Sharma and Leung (1998; 2000) on Indian, Pakistan and Nepalese aquaculture.

The production frontier function defines the technical efficiency in terms of a minimal set of inputs needed to produce a given output or as a maximal output obtainable from a given set of inputs. The production frontier provides a more appropriate framework than other economic models for determining the efficiency of resource allocation and for evaluating potential production achievable from an existing technology. This method provides two advantages over ordinary least squares (OLS) functions. The first is that while the estimation of an average function provides a snapshot of the state of technology for an average farm, the estimation of a frontier function identifies the best performing farms and hence reflects the best technology used to achieve this performance. Secondly, the frontier function identifies a best practice technology, against which the efficiency of farms within the industry can be measured. It is this second use of frontiers that has provided the impetus for using the frontier function in recent years (Coelli 1995a).

Stochastic production frontier and technical inefficiency model

Farrel's (1957) article on efficiency measurement led to the development of several approaches to efficiency and productivity analysis. Among these, the stochastic frontier production (Aigner et al. 1977; Meeusen and van den Broeck 1977) and data envelopment analysis (DEA) (Charnes et al. 1978) are two principal methods. Coelli (1995a) and Coelli et al. (1998) provided a detailed evaluation of measuring efficiency with the stochastic production frontier and DEA. As noted by Coelli et al. (1998), the stochastic frontier is more appropriate than DEA in agricultural applications, especially in developing countries, where the data are likely to be subject to large measurement errors and to variability from weather and disease. Frontier techniques are therefore ideal for aquaculture, including carp culture.

Thus, following Aigner et al. (1977) and Meeusen and van den Broeck (1977), the stochastic frontier production function with two error terms can be modelled as:

$$Y = f(X_i, \beta)\exp(V_i - U_i) \qquad (3)$$

where

Y_i is the production of the ith farm per unit area (i = 1, 2, 3……n),
X_i is a (1×k) vector of input variables applied by the i^{th} farm,
β is a (k×1) vector of unknown parameters to be estimated,
$V_i s$ are random variables assumed to be independently and identically distributed $N(0, \sigma^2_v)$ and independent of $U_i s$,
$U_i s$ are non-negative random variables, associated with technical inefficiency in production assumed to be independently and identically distributed (iid) and truncations (at zero) of the normal distribution with mean, μ_i and variance σ^2_u ($|N(\mu_i, \sigma^2_u)|$), where

$$\mu_i = Z_i\delta \qquad (4)$$

Z_i is a (1×m) vector of farm-specific variables associated with technical inefficiency,
δ is a (m×1) vector of unknown parameters to be estimated.

Model specification

The Cobb-Douglas (CD) specifications used to estimate the stochastic production frontier functions and inefficiency functions were used for all countries, except North Vietnam, where translog was used. Dey et al. (2000a) used CD in their study of technical efficiency (TE) of grow-out pond operations in the Philippines, as did Sharma (1999) and Sharma and Leung (1998; 2000) in their study of technical efficiency of carp production in Nepal, Pakistan and India. In Bangladesh, the generalized likelihood-ratio test was used to test the adequacy of CD over translog (Table 3.27). The result revealed that there was no gain in using the translog form over CD. Since the culture system and socio-economic structure differ between countries, several variables have been used to estimate the model in different countries. The culture system studied was grow-out in ponds, except for Indonesia, where fry and fingerling grow-out in cages was studied. Thailand estimated two models involving TE effects and error component models. China also estimated two TE effects models that included several variables. The variables used in the production frontier function and the technical inefficiency functions for participating countries appear in Tables 3.20 to 3.26.

Results and discussion

Estimates of parameters in the frontier production function and technical inefficiency functions appear in Tables 3.20 to 3.26. Parameter estimates of the production frontier, as well as the inefficiency functions, are reasonably accurate as several are statistically significant. However, statistical significance is of little relevance in technical efficiency studies. In general, stocking density, feeding rate and labour significantly affect fish production. The signs of the coefficients of these variables are positive, except for labour in Bangladesh, which is not significant. These results conform to the *a priori* assumption that the estimated production function is an increasing function. Fertilizers in the form of nitrogen, phosphorus or fertilizers in general were also significant in India, Indonesia (fingerling production) and Thailand. In addition, lime was a significant factor influencing fish production in Thailand.

Given the data and different model specifications for the various countries, the factor "years of experience" contributes significantly to the explanation of the technical inefficiencies among the sample of producers from different countries. The negative sign of the coefficient of years of experience (age of farmer in Bangladesh) indicates that more experienced farmers are more efficient. A regional effect on efficiency is also apparent within a country. Short distances to amenities (e.g., feed supply, river, road, nearest head quarter) positively influence efficiencies.

Several hypotheses were tested using the generalized likelihood-ratio test to assess the joint effects of the variables on the production frontier and inefficiency functions in Bangladesh. These results are presented in Table 3.27. Null hypotheses were rejected for pond age, feed and feed-fertilizer together, establishing that these variables significantly affect fish production. On the other hand, human labour use and use of fertilizers did not appear to influence production. Many farmers have not used fertilizers or have used amounts that were too small to show an effect.

The first null hypothesis under the inefficiency function that technical inefficiency effects are not present in carp production (Ho: $\gamma=\delta_0=\delta_1=\ldots=\delta_6=0$) is rejected. This result indicates that the traditional average production function (OLS) does not adequately represent the sample data. The second hypothesis (Ho: $\delta_0=\delta_1=\ldots=\delta_6=0$) which specifies that the intercept as well as all the coefficients associated with various farm specific variables involved (i.e., education, age, training and income of the operator, color of pond water, and regional differences) in the technical inefficiency model are zero (that the technical inefficiency effects have a half-normal distribution with zero mean) is rejected as well. The individual tests of the null hypotheses of age, training of the operator and colour of pond water were rejected ($p < 0.05$). Finally, a test for regional differences in technical inefficiencies in carp production was significant, indicating that high levels of development and technical efficiency lead to greater efficiency. Income and education were not statistically significant, although the negative coefficient of education indicates that higher levels of farmer education lead to greater efficiency.

Average technical efficiency for each country is presented in Table 3.28. The average technical efficiency was highest among Indonesian (FCS and DFCS) farmers with TE values of 84%, 78% and 74% for grow-out cage, fry and fingerling systems respectively. Average technical efficiency was lowest among Thai and Chinese farmers with an average of 47% efficiency. An error component model estimated an average of 51% technical efficiency, whereas data envelopment analysis (DEA) estimated an average of 57.8% in Thailand. Another TE-effects model in China estimated an average of 52% technical efficiency. Technical efficiencies of other countries were 70% for Bangladesh, 61% for India and 57% for North Vietnam. In India, inefficiency decreases as levels of intensity increase. This is consistent with the result reported by Sharma and Leung (2000) in a study on technical efficiency among Indian carp producers. In general, these findings suggest that inefficiency levels of Asian aquaculturists are quite high for some countries. About 16 to 53% of the full potential has yet to be achieved. Improvements in efficiency would be more cost effective through improved management practices than by generating new technologies (Dey et al. 2000; Belbase and Grabowski 1985; Shapiro 1983).

The distribution of technical efficiencies is presented in Table 3.29. For Bangladesh, more than 90% of the farms fall within the technical efficiency range of 51-90%. In the case of China, most farms are within the 21-60% efficiency level, while most farms in India fall within the 60 to 90% range. The majority of farms for each of the fry, fingerling and grow-out pond operators of Indonesia are in the 60-100% efficiency range. Thailand shows a different pattern of technical efficiency. Similar proportions of farms are observed within each of the classes between 21-80% efficiency levels. Efficiency levels of North Vietnamese farmers are scattered in all efficiency brackets with most at the 81-90% levels.

Table 3.20. Maximum Likelihood Estimate of Stochastic Cobb-Douglas Production Frontier and Technical Inefficiency Model in Bangladesh.

Variables of the stochastic frontier/Inefficiency function	Parameter	Coefficient estimates	St.d.
Stochastic Frontier Constant	β_0	3.2308*	0.2654
Ln Labour	β_1	-0.0157	0.0218
Ln Stocking	β_2	0.5884***	0.0287
Ln Water depth	β_3	-0.0439*	0.0258
Ln Pond age	β_4	-0.0108	0.0111
Feed user dummy	β_5	0.0808**	0.0376
Fertilizer user dummy	β_6	-0.0024	0.0310
Variance parameter:			
σ^2		0.1193***	0.0184
γ		0.6934***	0.0947
Inefficiency Function:			
Constant	δ_0	0.5957***	0.1299
Education	δ_1	-0.0027	0.0066
Age of operator	δ_2	-0.0034*	0.0019
Income of operator	δ_3	0.0001	0.0001
Training of operator	δ_4	0.1154**	0.0583
Water colour of pond	δ_5	-0.2013***	0.0634
Regional dummy	δ_6	-0.0902**	0.0465
Log-likelihood value		-110.78	
Mean technical efficiency index		70%	

* significant at $\alpha = 0.10$

** significant at $\alpha = 0.05$

*** significant at $\alpha = 0.01$

Table 3.21. Maximum Likelihood Estimate of Stochastic Cobb-Douglas Production Frontier and Technical Inefficiency Model for Grow-out pond operations in China.

Variables	Model 1			Model 2		
	Coefficient estimates		St. d.	Coefficient Estimates		St. d.
Frontier production function						
Constant	3.546	***	0.30	3.80	***	0.54
Ln Seed	0.602	***	0.06	0.58	***	0.08
Ln Labour	0.099	***	0.02	0.08	***	0.03
Ln Feed	0.086	**	0.04	0.06		0.05
Ln Fertilizer	-0.025		0.06	0.04		0.06
Ln Fuel	0.113	**	0.06	0.11	*	0.06
Ln Chemical				0.12		0.16
Ln Other cost				0.09		0.10
Fertilizer dummy	0.089		0.37	-0.38		0.38
Fuel dummy	-0.565	**	0.26	-0.61	**	0.28
Dummy for others				-0.58		0.43
Dummy for intensity				-0.11		0.19
Technical inefficiency function						
Constant	0.691	***	0.15	0.59	***	0.16
Distance from nearest headquarter				0.01		0.01
Distance from the main road				0.04		0.05
Distance from river	-0.023	***	0.01	-0.02	**	0.01
Distance from the market	-0.009		0.01	-0.02		0.02
Distance from seed supplier	0.014	*	0.01	0.01		0.01
Pond owner dummy	0.108		0.13	0.15		0.12
EAST dummy	0.621	***	0.13	0.65	***	0.13
WEST dummy	0.447	***	0.18	0.40	*	0.23
Experience	-0.004		0.0	-0.01		0.01
Total pond area	0.0		0.0	0.00		0.00
Dummy for hatchery owner				-0.08		0.14
Variance parameters						
σ^2	0.05	***	0.01	0.04	***	0.01
γ	1	***	0.03	1.00	***	0.06
Log-likelihood function	-7.89					
Average TE (%)	47.4			51.5		

* significant at = 0.10

** significant at = 0.05

*** significant at = 0.01

Table 3.22. Maximum Likelihood Estimate of Stochastic Cobb-Douglas Production Frontier and Technical Inefficiency Model in India.

Variables	Extensive		Semi-intensive		Intensive		All	
	Coefficient estimates	St.d	Coefficient estimates	St.d	Coefficient estimates	St.d	Coefficient estimates	St.d
Stochastic frontier production function								
Constant	3.514 ***	0.969	4.05 ***	0.53	7.513 ***	1.129	4.795 ***	0.279
Ln Stocking density	0.393 ***	0.124	0.36 ***	0.05	0.049	0.078	0.267 ***	0.032
Ln Cost of feed	0.226 ***	0.087	0.22 ***	0.04	0.493 ***	0.085	0.227 ***	0.024
Ln Nitrogen	0.228 **	0.111	0.07	0.06	-0.160 *	0.083	0.082 ***	0.030
Ln Phosphorus	-0.624 **	0.288	0.08	0.06	0.367 ***	0.139	0.059	0.041
Ln Preharvest labour	0.241 ***	0.085	0.19 ***	0.03	0.117	0.143	0.215 ***	0.019
Ln other cost	0.248 *	0.150	0.08 *	0.04	-0.082	0.116	0.045 *	0.026
Feed dummy	-1.683 **	0.792	-2.29 ***	0.34	-4.037 ***	0.778	-2.050 ***	0.236
Nitrogen dummy	-0.920 **	0.445	0.29	0.24	1.029 **	0.484	0.007	0.149
Phosphorus dummy	1.730 *	0.934	-0.29	0.25	-1.743 ***	0.513	-0.335 ***	0.140
Other cost dummy	-1.312 *	0.679	-0.57 **	0.29			-0.343 **	0.182
Technical inefficiency function								
Constant	3.513 **	1.379	1.07	0.91	0.303	1.241	2.457 ***	1.191
Total farm area	0.128 *	0.096	0.06	0.04	0.029 *	0.015	0.017 *	0.010
Education level	-0.003	0.042	-0.07 *	0.04	0.072	0.051	-0.018	0.022
Age	-0.048 *	0.025	0.01	0.02	0.020	0.023	0.006	0.008
Years of experience	-0.006	0.017	-0.07 ***	0.03	0.005	0.020	-0.017 *	0.010
Distance to nearest headquarter	0.013 **	0.006	0.00	0.01	-0.009	0.009	0.004	0.003
Distance to main road	-0.079	0.064	0.02	0.06	0.116 **	0.056	-0.018	0.022
Distance to nearest river	-0.009	0.030	0.02	0.02	-0.110 **	0.045	-0.008	0.011
Distance to feed supply	0.034 *	0.020	-0.01	0.01	-0.021 **	0.009	-0.003	0.005
Distance to feed home	-0.539 *	0.299	-0.17 **	0.11	0.004	0.145	-0.073 ***	0.017
Household size	0.073	0.077	-0.04	0.04	-0.005	0.017	-0.006	0.014
Flooding dummy	-0.201	0.848	0.45	0.45	-0.013	0.805	0.147	0.246
Minimum water retention Level during dry season	-0.264	0.197	-0.12	0.18	0.104	0.213	-0.230 ***	0.105
Andra Pradesh dummy	0.885	1.037	-0.82	1.02	-0.578	1.185	-2.225 ***	0.848
Haryana dummy		1.120	0.89	0.95	0.762	0.882	-0.225	0.764
Orissa dummy	0.241	0.981	1.03	0.76			-0.057	0.807
Karnataka dummy	-1.736 *	1.157	-4.82 ***	1.36	-1.170	1.224	-4.492 ***	1.344
Uttar Pradesh dummy	2.027 *	0.780	0.28	0.84	-2.175 *	1.264	-0.863	0.886
Single operation dummy	1.600 **	0.854	1.48 **	0.77	-1.120	1.028	0.364	0.555
Joint Operation dummy	0.570	0.559	0.39	0.80	-0.292	1.020	-0.162	0.585
Private own dummy	-3.271 ***	1.065	-1.66 ***	0.59	0.002	0.868	-1.856 ***	0.390
State own dummy	-3.584 ***	2.680	-2.09 ***	0.75	1.025	0.915	-1.476 ***	0.392
Perennial							0.223	0.261
Intensive							0.151	0.221
Extensive							-0.145	0.287
Variance parameters								
σ^2	0.338 ***	0.126	0.61 ***	0.12	0.326 ***	0.110	0.818 ***	0.159
γ	0.818 ***	0.069	0.84 ***	0.03	0.450 ***	0.167	0.897 ***	0.026
Log-likelihood function	-32.405		-122.08		-62.590		-305.87	
Mean TE (%)	54		68		71		61	

* significant at $\alpha = 0.10$ ** significant at $\alpha = 0.05$ *** significant at $\alpha = 0.01$

Table 3.24. Maximum Likelihood Estimate of Stochastic Cobb-Douglas Production Frontier and Technical Inefficiency Model for Grow-out pond operations in Indonesia.

Variables	Fry		Fingerling		Grow-out	
	Coefficient estimates	St. d.	Coefficient estimates	St. d.	Coefficient estimates	St. d.
Frontier production function						
Constant	10.148 ***	0.512	-0.033	0.490	0.229	0.802
Ln Male broodstock	0.185 ***	0.090				
Ln Female broodstock	0.069	0.093				
Ln Total broodstock			0.169 ***	0.030		
Ln Seeds					0.178 ***	0.029
Ln Feeds	0.280 **	0.127	0.493 ***	0.101	0.756 ***	0.047
Ln Labour	0.411 ***	0.114	0.248 ***	0.095	0.086 **	0.048
Ln Medicine	-0.026	0.085	0.273 ***	0.109	-0.007	0.037
Ln Fertilizer	0.042	0.073	0.129 ***	0.054		
Dummy for medicine	0.344	0.837	-2.247 *	1.155	0.058	0.494
Dummy for fertilizer	-0.612	0.789	-1.260 ***	0.510		
Technical inefficiency function						
Constant	-0.256	0.940	-0.826	1.670	0.082	0.422
Age	-0.003	0.007	-0.006	0.014	0.003	0.003
Education	0.013	0.019	-0.040	0.068	-0.003	0.010
Experience	0.008	0.007	-0.153 ***	0.049	-0.022	0.033
Farm area	-0.753 ***	0.204	-0.077	0.066	0.000	0.004
Culture frequency	-0.060 *	0.037	0.164 ***	0.064	-0.010	0.010
Water depth	0.011	0.012	0.033 *	0.018		
Dummy for fingerling			1.645 ***	0.537		
Dummy for running water					0.046	0.185
Dummy for floating cage					-0.060	0.151
Variance parameters						
σ^2	0.169 ***		0.387 ***		0.029 ***	0.008
γ	0.033		0.761 ***		0.985 ***	0.089
Log-likelihood function	-45.05		-22.60		-106.29	

* significant at $\alpha = 0.10$
** significant at $\alpha = 0.05$
*** significant at $\alpha = 0.01$

Table 3.25. Estimates of the production frontier and Technical inefficiency model, Thailand.

	TE effects model			Error component model		
	Coefficient estimates		St. d.	Coefficient estimates		St. d.
Frontier function						
Constant	7.338	***	0.769	5.83	***	0.87
Ln Stocking density	0.396	***	0.065	0.25	***	0.06
Ln Protein / fish	0.200	***	0.061	0.11	**	0.05
Ln Nitrogen / fish	0.267	***	0.099	0.16	***	0.05
Ln Lime	0.123	***	0.049	0.14	***	0.05
Ln Other feeds	0.187	***	0.060	0.21	***	0.06
Ln Labour	0.104		0.077	0.06		0.08
Protein dummy	-0.468	***	0.182	-0.74	**	0.32
Nitrogen dummy	0.181		0.128	-0.11		0.21
Lime dummy	-0.693	***	0.231	-0.80	***	0.23
Other feeds dummy	-1.824	***	0.534	-2.08	***	0.55
Technical inefficiency function						
Constant	1.526	***	0.656			
Age	-0.003		0.010			
Education	-0.019		0.045			
Experience	-0.129	**	0.064			
Distance from the headquarter	-0.015		0.017			
Distance from the main road	0.001		0.005			
Distance from the market	0.007		0.006			
Total farm size	-0.013		0.029			
Variance parameters						
σ^2	0.980	***	0.297	1.07	*	0.64
γ	0.817	***	0.113	0.74	***	0.14
log likelihood function	-278.19			-288.60		
Mean TE (%)	47.01			51.27		

* significant at $\alpha = 0.10$

** significant at $\alpha = 0.05$

*** significant at $\alpha = 0.01$

Table 3.26. Maximum Likelihood Estimate of Stochastic Cobb-Douglas Production Frontier and Technical Inefficiency Model for Grow-out pond operations in North Vietnam.

	Coefficient estimates		**St. d.**
Frontier production function			
Constant	6.698	***	0.951
Ln Stock	-0.252		0.334
Ln Feed	0.377		0.265
Ln Fertilizer	-0.271		0.368
Ln Lime	0.216		0.152
Ln Labour	-0.077	*	0.046
(Ln Stock)^2	0.174	***	0.053
(Ln Feed)^2	-0.053		0.040
(Ln Fertilizer)^2	0.092	*	0.054
Ln Stock * Ln Feed	-0.063		0.059
Ln Stock * Ln Fertilizer	-0.015		0.051
Ln Feed * Ln Fertilizer	0.008		0.029
Lime Dummy	-1.260		0.987
Fertilizer dummy	0.323		0.374
Feed dummy	-0.451		0.486
Technical inefficiency function			
Constant	1.648		0.932
Age	-0.009		0.013
Education	-0.069		0.058
Total farm area	0.000		0.000
Distance from the headquarter	0.002		0.060
Distance from the main road	-0.286	***	0.098
Distance from the river	0.013		0.046
Distance from the market	-0.264	**	0.130
Hanoi dummy	-0.869		0.554
Haidung dummy	1.121	**	0.484
Tnguyen dummy	2.065	***	0.514
Intensity dummy	-0.027		0.182
Variance parameters			
σ^2	0.633	****	0.128
γ	0.298	*	0.154
Log-likelihood function	-115.00		

* significant at $\alpha = 0.10$
** significant at $\alpha = 0.05$
*** significant at $\alpha = 0.01$

Table 3.27. Generalized likelihood ratio test of null hypotheses for parameters in the stochastic frontier production function and inefficiency function.

Test of null Hypotheses (H_0)	Log-likelihood value under H_0^a	Test Statistic (λ)	DF	Critical χ^2 value at 95%	Conclusion
Functional specification:					
Translog is not appropriate ($\beta_{11}= \beta_{22}=............=\beta_{34}= 0$)	-108.73	4.08	10	17.67	Accept H_0
Stochastic Frontier					
No labour use effect ($\beta_1 = 0$)	-111.06	0.56	1	2.71	Accept H_0
No water depth effect ($\beta_3= 0$)	-112.31	3.04**	1	2.71	Reject H_0
No pond age effect ($\beta_4= 0$)	-111.27	0.98	1	2.71	Accept H_0
No feed effect ($\beta_5= 0$)	-113.49	5.42***	1	2.71	Reject H_0
No fertilizer effect ($\beta_6= 0$)	-110.79	0.02	1	2.71	Accept H_0
No feed fertilizer effect ($\beta_5=\beta_6= 0$)	-113.76	5.96***	1	2.71	Reject H_0
Inefficiency function:					
No inefficiency effect ($\gamma=\delta_0=\delta_1 =........= \delta_6= 0$)	-133.44	45.30***	8	14.85	Reject H_0
No effect of inefficiency variables ($\delta_0 = \delta_1 =........= \delta_6= 0$)	-129.22	37.46***	7	13.40	Reject H_0
No effect of education ($\delta_1 =0$)	-110.87	0.18	1	2.71	Accept H_0
No effect of age ($\delta_2 =0$)	-112.71	3.88**	1	2.71	Reject H_0
No effect of income ($\delta_3 =0$)	-111.43	1.30	1	2.71	Accept H_0
No effect of training ($\delta_4 =0$)	-112.81	4.08**	1	2.71	Reject H_0
No effect of regional development ($\delta_5 =0$)	-119.58	17.60***	1	2.71	Reject H_0
No effect of water colour ($\delta_6 =0$)	-113.28	5.00**	1	2.71	Reject H_0

[a] The value of log likelihood function under the specification of the alternative hypothesis (i.e. under the unrestricted model) is –110.78

Table 3.28. Mean Technical Efficiency Levels of Asian Fish Farmers.

Countries	Mean TE
Bangladesh	70%
China	47 - 52
India	61%
Indonesia	
Fry producer	78%
Fingerling producer	74%
Grow-out pond operator	84%
Thailand	44-51
Vietnam: North	57%

Table 3.29. Distribution of Technical Efficiencies of Carp Producers of selected Asian Countries.

TE range (%)	Bangladesh	China[1]	India	Indonesia			Thailand[2]	North Vietnam
				Fry	Fingerling	Grow-out		
< 10			1.96		2.08		2.82	0.94
11-20		1.69	5.62		4.17		9.68	9.43
21-30	0.19	20.34	7.33		8.33		14.92	8.49
31-40	0.93	11.86	7.82				12.10	16.04
41-50	6.67	28.81	9.05	4.71	2.08	0.69	12.50	7.55
51-60	18.52	16.95	8.56	9.41	6.25	0.69	15.73	6.60
61-70	22.03	10.17	11.49	21.18	4.17	3.47	16.53	4.72
71-80	26.85		13.94	17.65	14.58	30.56	12.90	11.32
81-90	23.33	5.08	31.54	14.12	29.17	34.03	2.82	29.25
91-100	1.48	5.08	2.69	32.94	29.17	30.56		5.66

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[1] Based on Model 1

[2] Based on TE effects model

Patterns of fish consumption and traits preferred by consumers

Annual per capita fish consumption

Annual per capita fish consumption was estimated from consumer field surveys and household expenditure surveys (HES) in six countries from 1997-1998. A total of 5,931 consumers were interviewed. Tables 3.30 and 3.31 show annual trends and estimates of per capita fish consumption. Fish consumption differed between countries. It was highest in South Vietnam (37.8 kg) and lowest in North Vietnam (12.86 kg). Per capita fish consumption was 31.08 kg, 28.8 kg, 22.20 kg, 15.81 kg and 15.0 kg for China, Thailand, Bangladesh, Indonesia and India, respectively. These estimates of consumption are larger than estimates based on national food balance sheets. This difference can be attributed to the larger samples in the present study, from the areas where individuals consume large amounts of freshwater fish. For instance, surveys in China focused on areas of carp consumption, while surveys in Thailand did not focus on the southern area where consumption of marine fish is high. In the case of India, many vegetarian states were not included in the sample. In Bangladesh, surveys were conducted in areas rich in fish production. This bias has produced relatively higher estimates of fish consumption estimates than expected for individual countries.

Fish consumption by species

Table 3.31 shows the importance of each species to the total fish consumption in the participating countries. Consumers in China have the highest consumption of carps (92.7%), followed by North Vietnam (76.1%), Bangladesh (48.4%) and India (45.8%). In China, the most-consumed carp species included grass carp, crucian carp, silver carp and common carp. In North Vietnam, rohu, grass carp and silver carp were the dominant species consumed. In Bangladesh, silver carp was consumed most and this was due to its lower price relative to rohu, catla, mrigal and other species. Rohu and catla are commonly preferred in Bangladesh and India. In contrast, carp species are not prominent in the diets of Thais and South Vietnamese. Of the freshwater fish species, tilapia are consumed more by Thais, whilst the South Vietnamese prefer snakehead.

Expenditure on fish by income class

Levels of expenditure serve as rough indicators of the state of development in a country. The higher the level of expenditure and the greater the proportion spent on non-food items, the higher the level of development in a country. The total annual per capita expenditure is classified into quartile groups (Table 3.32). 'Rich' represents the consumers of the 4th group while 'medium', 'poor' and 'very poor' correspond to the 3rd, 2nd and 1st quartiles respectively. On average, total per capita expenditures by consumers is highest in Thailand (US$ 522.96), followed by India (US$ 339.84), Indonesia (US$ 188.76), North Vietnam (US$ 153.96), China (US$ 153.84) and South Vietnam (US$ 129.29). Of the total expenditure, food accounts for about 35-87%. Fish expenditure as a percentage of total food expenditure is highest in China (51.8%), followed by South Vietnam (29.8%), Thailand (15.6%), India (11.8%), North Vietnam (9.4%) and Indonesia (8.1%) (Table 3.32).

If expenditure is an indication of income, strong differences in income are apparent between quartiles for all countries, particularly between the rich and the other groups. The highest income group spent more than twice the amount spent by the medium group and 5-10 times that spent by the very poor group. In higher income groups, expenditure allocated to food items decreased for all countries. Consumers in South Vietnam spent the highest proportion of the budget on food (80-98%).

The proportion of expenditure on fish in the food budget by income class differed between countries. In China, India and Thailand, the proportion spent on fish increased as income increased. However, in Indonesia and North Vietnam proportionately less was spent on fish in higher income groups. In South Vietnam, the proportion of total food expenditure spent on fish was as high as 74% for the very poor income group, but between 25-27% for other income groups. Consumers in North and South Vietnam and Indonesia may shift their fish consumption to other kinds of meats as income increases. In Bangladesh, the percentage of fish expenditure across all income groups was more or less uniform.

Expenditure on fish by species

Fish expenditure by species and by quartile income groups for Bangladesh, China, India, Thailand, North Vietnam and South Vietnam is presented in Tables 3.33 and 3.34. Differences in the expenditure on fish across quartile groups were largest in China. Average fish prices paid by each group differed significantly across countries.

In Bangladesh and India, very poor consumers spent proportionately much more on fish than the other groups which had similar total expenditure on fish. The highest percentage of fish expenditure was for rohu in all income groups (34-41%) in India. Rivershad was the major item bought by all income groups in Bangladesh. The proportional expenditure on catla was highest in low-income groups.

In China, expenditure on crucian carp was highest for all income groups (22-24%), due to both a high rate of consumption and high prices. Expenditure on grass carp was the next highest for the first and second income groups. Common carp and silver carp appeared to be more affordable by low-income groups, because the share of expenditure allocated to these species varied inversely with income.

In Thailand, expenditure on fish by the very poor group was greatest for marine fishes. The expenditure of the other three groups was mainly on snakehead. Silver barb is popular for the lower income groups, as expenditures on this fish were inversely proportional to income level.

The pattern of fish expenditure in North Vietnam and South Vietnam was very different. The highest expenditure for all the income groups in South Vietnam was on snakehead, whereas expenditure on rohu predominated in North Vietnam. In North Vietnam, the percentage share of expenditure on silver carp and mrigal was inversely related to income, but in South Vietnam it was similar in all income groups. Consumers in North Vietnam spent more on common carp as income increased, which differs from consumer behaviour in South Vietnam, China and Thailand.

Consumption of fish by types of consumers

The annual per capita fish consumption classified by types of consumers for Bangladesh, India, Indonesia and Thailand appears in Table 3.35. Consumers in rural areas have higher per capita fish consumption than those in urban areas, except in Indonesia. Annual fish consumption in urban areas ranged from 11 to 20 kg per capita, while in rural areas, it ranged from 21 to 34 kg. This indicates the importance of fish farming in supplying the protein requirements of rural consumers. In rural areas in Bangladesh and Thailand, fish producers consume fish more than non-producers.

Price of fish by species and countries

Prices of fish in various countries are presented in Table 3.36. In Bangladesh, rohu, catla and mrigal fetched the highest prices, ranging between US$ 0.94 to US$ 1.44. In China, crucian carp and Chinese carp (US$ 1.30 each/kg) fetched the highest prices, followed by black carp (US$ 1.28/ kg) and common carp (US$ 1.07/kg), respectively. In India, rohu, catla and mrigal were priced at US$ 0.80 to US$ 0.86/kg. In Thailand, the prices per kg were US$ 0.90 for common carp, US$ 0.72 for silver barb and US$ 0.69 for tilapia. Black carp and common carp cost the most of species in North Vietnam (US$ 1.38 and US$ 0.82/kg, respectively), whereas in South Vietnam, catla, silver barb and common carp had the highest values.

Consumers' preference ranking by species

Table 3.37 presents consumers' preferences for freshwater species. The most preferred species in Bangladesh, as well as in India, was rohu, followed by catla and mrigal. Common carp was most preferred by consumers in Indonesia and South Vietnam. Snakehead and silver carp were the next most preferred species in South Vietnam. Consumers in North Vietnam ranked grass carp as the most preferred species, followed by mud carp and common carp. Chinese consumers ranked crucian carp, grass carp and common carp in that order. In Thailand, the freshwater fish most preferred was tilapia, followed by snakehead and catfish. Silver barb was ranked fifth.

Consumers' reasons for preference ranking of species

Reasons for consumer preferences of species (listed in Table 3.38) are mainly good taste, reasonable price and easy availability. Consumers in Bangladesh give high rankings to silver barb for its physical appearance.

Consumers' preference for various fish traits

Consumers in all countries ranked the traits they preferred for individual species. Table 3.39 presents four rankings by country and species. To simplify the table, only the first ranked trait preferences for each country are presented. Traits include high dress-out percentage, large size, colour, body shape, better flavour and high fat content. Respondents were asked to rank the traits they preferred for various species. Interestingly, trait preferences varied considerably among the three most preferred species in a country, except for rohu and catla in Bangladesh where colour and high dress-out percentage ranked first and second, respectively. Preferred traits for various species differed between countries, except for dress-out percentage of mrigal in Bangladesh and India. Another exception was for common carp, for which better flavour was the preferred trait of both Chinese and North Vietnamese. Similarly, large size was the preferred trait for consumers of grass carp in both countries. Unlike Bangladeshi consumers, Indian consumers preferred the body shape and flavour of rohu and the larger size and higher fat content of catla rather than the colour and higher dress-out percentage of these species. Like India, body shape, size and flavour were among the traits the Chinese considered in preferred species. Crucian carp was most preferred for its body shape and grass carp for its larger size.

High dress-out percentage, large size, better flavour and body shape are traits used by consumers in Thailand to select silver barb. Consumers in South Vietnam, however, preferred higher fat content in silver barband common carp.. While they most preferred the colour of silver carp, consumers in North Vietnam preferred its higher fat content.

Consumers' preference for size, shape, colour and other parts of fish

Table 3.40 displays consumers' preferences for size, shape, colour and other parts of fish. Larger individuals (up to three fish/kg) of carp species - other than silver barb, are preferred. Surprisingly, consumers in Bangladesh appeared to prefer larger fish (<1 to 1 fish/kg), compared to other countries. South Vietnam and Thailand, on the other hand, preferred smaller fish (<2 to 3 pcs/kg).

Shape preferences for some carp species, such as rohu, mrigal and grass carp, varied between countries. Consumers in Thailand and India preferred a long and thin shape for rohu and mrigal, but consumers in North and South Vietnam preferred short and thick fish. For grass carp, consumers in China and India preferred long and thin fish, whereas consumers in North and South Vietnam liked short and thick fish. For common carp, silver carp, silver barb, catla and crucian carp, consumers preferred fish that were short and thick, as well as short and deep.

Another interesting finding is that colour preferences for the same species varied considerably between countries. Silver-coloured rohu were preferred in Thailand, light rohu were preferred in North Vietnam and bright-coloured rohu were preferred in South Vietnam. Yellow and reddish coloured common carp are preferred by Chinese consumers. Silver mrigal were preferred in Thailand, black-blue mrigal in North Vietnam and bright mrigal in South Vietnam. Silver-coloured silver carp were most preferred in China and North Vietnam and brightly coloured silver carp in South Vietnam. Silver-coloured silver barb were preferred in Thailand, light-blue silver barb in North Vietnam and yellow finned silver barb in South Vietnam. Black, green or silver grass carp were preferred in China, but light grass carp in North Vietnam and bright grass carp in South Vietnam.

Like colour preferences, preferences for taste varied between countries and differed significantly for different parts of a fish. The three most-preferred body parts of the preferred species in each country also appears in Table 3.40. Consumers in Bangladesh mostly preferred the belly, tail and back of rohu and mrigal, while the head of catla was preferred most. Consumers in India, on the other hand, preferred the back portion over the belly of rohu, while mrigal eggs were preferred over the tail. In Thailand, the back portion was most preferred for all species. Interestingly, consumers in North and South Vietnam differed in their preferences not only for species, but also for their preferences in body parts of the same species. This indicates that the species and traits for genetic improvement should be different in these two regions.

In conclusion across all species, consumers in Bangladesh mostly prefer belly and head while those in India prefer belly. In Thailand, back is the most preferred part for all species. Head, back and belly are the most preferred parts in various carp species for the North Vietnamese. Head, back and tail are the parts mostly preferred by South Vietnamese in selected individual carp species.

Suggested traits for genetic improvement

Responses of consumers and producers in Asia for preferred traits are presented in table 3.41. Each country has a unique profile of preferences for traits, although some preferred traits are common between countries. For example, growth and disease resistance are invariably preferred by producers in all countries for all species. In Bangladesh, catla and silver barb appeared to be important candidates for genetic improvement. Rapid growth, high reproductive performance, bright appearance (for catla), and high dress-out percentage (for silver barb) might be traits for genetic improvement. Traits high on the list for genetic improvement of common carp in China are rapid growth, better meat quality, tolerance to low dissolved oxygen and disease resistance. Indians have identified rohu and catla, for which rapid growth, high dress-out percentage, disease resistance (rohu) and late maturity (for common carp) are high on the list of traits for genetic improvement. Indonesians prefer only common carp genetic improvement, for which they would like to select for more rapid growth, higher dress-out percentages and greater resistance to diseases. In Thailand, the choices for genetic improvement are silver barb and common carp, for which rapid growth, higher dress-out percentage and high survival are important. In Vietnam, silver barb and common carp are the preferred species for selection at RIA I and RIA II, respectively. Vietnamese prefer species with rapid growth, higher dress-out percentages and disease resistance.

Table 3.30. Trend in consumption of fish and fishery products* and contribution of fish to animal protein supply.

	Bangladesh[1]	China	India	Indonesia	Thailand	Vietnam
Animal protein (g/capita/day)						
1997	6.10	26.20	9.80	12.10	24.60	13.10
1990	4.90	13.60	8.50	12.90	17.70	9.60
1980	4.50	6.90	6.70	7.00	14.50	7.20
average (1961-97)	5.28	9.55	7.23	7.28	16.37	9.66
Growth rate (1961-97)	-0.09	4.77	1.52	2.95	1.84	0.44
z						
Fish protien (g/capita/day)						
1997	3.00	6.00	1.50	6.40	10.20	5.20
1990	2.10	2.70	1.10	5.10	5.90	3.20
1980	2.20	1.20	0.90	4.20	5.30	2.90
average (1961-97)	2.48	2.15	0.92	4.21	6.32	4.21
Growth rate (1961-97)	-0.44	3.10	2.17	2.50	1.94	-0.97
Share of fish of total animal protein (%)						
1997	49.20	22.90	15.30	52.90	41.50	39.70
1990	42.90	19.90	12.90	54.80	33.30	33.30
1980	48.90	17.40	13.40	60.00	36.60	40.30
average (1961-97)	46.85	24.19	12.61	58.78	38.11	43.66
Growth rate (1961-97)	-18.05	-43.43	7.38	-24.28	12.61	-60.35

Source: Laureti, E. (comp) 1961-1997 Fish and fishery products: world apparent consumption statistics based on food balance sheets. FAO Fisheries Circular. No. 821, Rev. 5. ROME, FAO. 1999. 424p.

*Wet weight

[1] For Bangladesh averages and growth rates are from 1972 to 1997.

Table 3.31. Proportion by fish species and per capita fish consumption in selected Asian countries.

Species composition													
Bangladesh		**China**		**India**		**Indonesia**		**Thailand**		**N. Vietnam**		**S. Vietnam**	
Rohu	9.33	Grass carp	20.9	Rohu	36.43	Marine fish	9.00	Tilapia	29.58	Rohu	27.5	Snakehead	27.50
Catla	6.79	Crucian carp	20.1	Catla	19.20	Common carp	4.80	Silver barb	16.25	Grass carp	20.9	Marine fish	15.90
Mrigal carp	5.72	Silver carp	15.6	Mrigal carp	4.42	Tilapia	2.40	Snakehead	15.42	Silver carp	15.3	Silver barb	6.60
Silver carp	14.13	Common carp	12.4	Common carp	2.04	Catfish	0.50	Walking catfish	10.42	Tilapia	10.5	Walking catfish	5.30
Silver barb	5.60	Bighead	9.8	Exotic carps	3.34	Others	83.30	Marine fish	8.33	Common	10.0	Dried fish	4.20
Other (exotic) carps	6.11	Black carp	7.3	Other freshwater	16.98			Driedfish	7.50	Dried fish	3.2	Rohu	2.70
Tilapia	2.47	Chinese bream	6.6	Other marine	16.94			Common carp	1.67	Bighead	1.5	Tilapia	2.10
River shad	9.66	Other fish	7.4					Other fresh water	10.83	Black carp	0.6	Common carp	1.90
Live fish	10.84									Mrigal carp	0.3	Silver carp	1.00
High-valued fish	5.74									Others	10.2	Mrigal carp	0.30
Assorted fish	23.61											Grass carp	0.10
												Others	32.40
Consumption (kg/capita/annum)	19.92		31.08		15.00		15.81		28.80		12.86		37.80

Table 3.32. Annual per capita expenditure by income class.

Income quartile	Country						
	Bangladesh	China	India	Indonesia	Thailand	N.Vietnam	S.Vietnam
	Total annual expenditure (US$) per capita						
I		60.00	90.84	63.72	219.48	40.68	27.29
II		97.20	158.04	106.44	343.08	85.32	88.83
III		144.00	234.48	175.32	496.32	135.96	131.71
IV		314.16	876.00	409.68	1,032.96	355.44	270.22
All		153.84	339.84	188.76	522.96	153.96	129.29
	Food expenditure as a percentage of total expenditure						
I		63.40	73.20	67.20	64.50	80.40	97.90
II		54.70	62.40	60.50	53.70	81.20	93.00
III		47.80	51.20	53..3	46.00	75.40	91.20
IV		33.20	22.20	38.20	28.00	45.70	81.90
All		43.10	35.20	47.30	40.30	59.50	87.10
	Total annual fish expenditure (US$) per capita						
I	15.97	11.88	9.12	3.96	20.04	4.08	19.79
II	23.51	22.92	10.20	5.52	27.48	7.32	20.99
III	28.06	36.12	12.00	7.68	36.24	9.72	32.66
IV	41.19	66.36	24.48	11.64	47.76	13.32	61.04
All	27.19	34.32	14.04	7.20	32.88	8.64	33.57
	Fish expenditure as a percentage of total expenditure						
I		19.80	10.10	6.20	9.10	10.00	72.40
II		23.60	6.40	5.20	8.00	8.60	23.60
III		25.10	5.10	4.30	7.30	7.20	24.80
IV		21.10	2.80	2.80	4.60	3.70	22.60
All		22.30	4.10	1.50	6.30	5.60	25.90
	Fish expenditure as a percentage of food expenditure						
I	26.10	31.20	13.70	9.20	14.10	12.50	74.00
II	26.80	43.10	10.30	8.60	14.90	10.60	25.40
III	25.40	52.40	10.00	8.20	15.90	9.50	27.20
IV	23.90	63.40	12.60	7.40	16.50	8.20	27.60
All	25.20	51.80	11.80	8.10	15.60	9.40	29.80
	Fish expenditure as a percentage of animal protein expenditure						
I	77.77	58.80	63.00			17.20	92.00
II	73.91	70.80	35.50			16.90	55.40
III	71.92	77.70	29.50			15.80	53.50
IV	68.94	85.00	30.70			15.50	51.10

Table 3.33. Annual fish consumption and expenditure by income classes

Income	Country						
quartile	Bangladesh	China	India	Indonesia	Thailand	N.Vietnam	S.Vietnam
		Annual per capita fish consumption (kg)					
I		13.08	10.08		22.08	6.86	23.88
II		23.40	11.52		27.96	11.71	25.56
III		33.72	13.80		32.40	13.68	39.24
IV		54.12	24.48		32.52	19.32	62.52
Average	19.92	31.08	15.00		28.80	12.86	37.80
		Annual per capita fish expenditure (US$)					
I	15.97	11.88	9.12		20.04	4.08	19.80
II	23.51	22.92	10.20		27.48	7.32	21.00
III	28.06	36.12	12.00		36.24	9.72	32.64
IV	41.19	66.36	24.48		47.76	13.32	61.08
Average	27.19	34.32	14.04		32.88	8.64	33.48
		Average price of fish (US$/kg.)					
I		0.91	0.90		0.91	0.59	0.83
II		0.98	0.89		0.98	0.62	0.82
III		1.07	0.87		1.12	0.71	0.83
IV		1.22	1.00		1.47	0.69	0.98
Average	1.22	1.10	0.94		1.14	0.67	0.89

Table 3.34. Percentage of each species of total fish expenditure by income class.

	Income quartile				
Species	Average	I	II	III	IV
Bangladesh					
Rohu	11.8	11.2	12.5	12.1	11.4
Catla	7.7	7.0	6.9	7.9	8.3
Mrigal	4.6	4.4	4.7	4.5	4.7
Silver carp	9.3	11.5	10.3	9.7	7.7
Silver barb	3.8	3.0	3.6	4.1	4.0
Other (exotic) carp	5.8	4.7	5.6	5.5	6.5
Tilapia	1.9	2.7	2.4	1.9	1.4
River shad	12.9	14.1	14.6	12.0	12.2
Live species	16.0	14.0	13.4	15.3	18.5
High valued species	9.5	9.1	9.4	10.5	9.2
Assorted small fish	16.7	18.2	16.6	16.5	16.1
China					
Crucian carp	23.6	24.4	22.6	23.4	23.9
Grass carp	20.0	14.7	14.7	18.7	23.5
Common carp	12.0	17.3	15.3	12.1	9.9
Silver carp	9.2	16.3	12.4	9.2	6.9
Black carp	8.4	5.5	7.2	10.4	8.3
Bighead carp	7.6	6.9	9.6	8.2	6.8
Others	11.3	7.9	9.5	8.3	14.3
India					
Rohu	36.3	35.1	35.2	41.4	34.7
Catla	19.4	20.7	24.9	23.7	14.3
Mrigal	4.4	8.3	6.2	3.8	1.9
Common carp	1.6	0.2	2.3	3.8	0.7
Other (exotic) carp	3.5	9.9	4.3	2.9	1.4
Other freshwater fish	8.6	9.2	11.4	10.1	6.6
Other marine fish	26.2	16.7	15.8	14.0	40.4
Thailand					
Tilapia	17.8	24.7	19.8	18.9	12.7
Snakehead	22.8	24.9	25.5	25.5	18.3
Silver barb	10.2	20.7	12.8	10.5	4.2
Walking catfish	6.8	6.9	7.1	7.0	6.4
Common carp	1.2	2.0	1.6	1.5	0.5
Other Freshwater fish	10.1	9.5	10.2	7.8	12.1
Marine fish	15.3	3.1	10.8	14.2	23.8
Dried fish	15.8	8.2	12.2	14.6	22.0

Table 3.34. Continued...

Species	Average	Income quartile I	II	III	IV
North Vietnam					
Rohu	25.1	23.6	26.5	21.4	27.6
Common	12.2	5.6	7.9	18.6	12.1
Tilapia	10.3	9.9	7.9	10.9	11.4
Silver carp	9.4	12.3	12.1	8.5	7.7
Mrigal	5.7	16.6	7.8	2.2	3.8
Bighead	1.2	0	2.4	0.3	1.7
Black	1.1	1.4	2.5	0	0.9
Dried fish	3.9	4.2	2.9	3.3	4.9
Others	9.9	7.3	11.9	12.9	7.4
South Vietnam					
Snakehead	37.4	34.5	34.1	36.6	39.9
Walking catfish	6.0	7.6	5.0	6.2	5.8
Silver barb	5.8	4.3	5.3	5.8	6.5
Rohu	2.3	0.1	2.4	2.3	3.0
Common carp	1.7	5.2	1.1	1.6	0.8
Tilapia	1.6	1.9	0.8	2.7	1.1
Silver carp	0.7	0.1	1.6	0.9	0.5
Mrigal	0.3	0.0	0.5	0.5	0.1
Marine fish	11.0	11.1	13.6	11.6	9.8
Dried fish	5.5	0.1	4.1	6.4	7.2
Others	27.7	35.1	31.5	25.4	25.3

Table 3.35. Fish consumption (kg.) by individual species and by consumer types.

	Bangladesh			India		Thailand		
	Urban	Rural		Urban	Rural	Urban	Rural	
		Producer	Non-producer				Producer	Non-producer
Total annual per capita consumption (kg)	19.92	21.36	18.36	11.13	23.16	19.92	34.92	28.68
Species (%):								
Rohu	10.05	8.95	8.98	29.40	44.94			
Catla	7.27	7.12	5.97	17.71	22.56	3.01	22.68	14.64
Mrigal	6.68	5.62	4.88	3.12	5.98			
Silver carp	13.92	14.35	14.11			z		
Silver barb	6.11	5.32	5.37					
Tilapia	2.63	2.22	2.57			23.49	31.62	30.54
River shad	9.54	10.03	9.41					
Assorted small fish	21.16	24.15	25.53					
Live fish	10.37	10.72	11.42					
High value fish	5.86	5.90	5.44					
Common carp				1.79	2.33	0.60	2.41	1.26
Other carps	6.39	5.62	6.31	1.64	5.40			
Milkfish								
Walking catfish						9.04	8.59	13.39
Snakehead						14.47	12.71	18.83
Other freshwater fish				24.72	7.44	10.24	12.37	9.62
Other marine fish				21.62	11.34	24.09	3.78	5.86
Dried fish						15.06	5.84	5.86
Others	31.10	35.80	34.20					

Table 3.36. Consumer prices (US$) of different fish species in selected Asian countries.

	Bangladesh	China	India	Thailand	N. Vietnam	S. Vietnam
Rohu	1.44		0.85		0.61	
Catla	1.20		0.86			1.47
Mrigal	0.94		0.80		0.72	0.64
Silver carp	0.81	0.65				0.62
Common carp		1.07	0.65	0.90	0.82	0.77
Bighead		0.86			0.56	
Black carp		1.28			1.38	
Chinese bream		1.30				
Crucian carp		1.30				
Grass carp		1.06			0.67	0.50
Silver barb	0.77			0.72	0.41	0.84
Other (exotic) carps	0.93		0.89			
Tilapia	0.84			0.69	0.66	0.65
River shad	1.42					
Assorted small fish	0.82					
Livefish	1.61					
High-valued fish	1.74					
Milkfish						
Bisugo						
Bonito						
Hybrid catfish						
Dried fish				2.40	0.84	1.17
Snake head				1.70		1.21
Catfish				0.74		
Puntius alstus						1.07
Kissing gourami						0.62
Climbing perch						0.71
Sand goby						0.73
Pangasius bocourti						1.23
Pangasius siamensis						1.22
Clarias catfish						1.01
Rasbosa						0.43
Mystus						0.61
Other freshwater fish			0.35			
Other marine fish		1.27	1.17	2.15	0.72	0.61
Other fish		1.70		1.05	1.28	

Table 3.37. Consumers' preferences for freshwater species in Asia.

Rank	Bangladesh	China	India	Thailand	N. Vietnam	S. Vietnam
1	Rohu	Crucian carp	Rohu	Tilapia	Grass carp	Common carp
2	Catla	Grass carp	Catla	Snakehead	Mud carp	Snakehead
3	Mrigal	Common carp	Mrigal	Catfish	Common carp	Silver carp
4	Silver barb	Bighead	Common carp	Indo-pacific mackerel	Silver carp	Climbing perch
5	Common carp	Chinese bream	Grass	Silver barb		Walking catfish
6	Mirror	Silver carp	Silver carp			Giant gourami
7	Silver carp	Black carp				*Pangasius bocourti*
8	Grass carp					*Puntius attus*
9	Kalibasu					Silver barb

Table 3.38 Consumers' reasons for preference of selected carp species

Country/Species	Rohu	Common carp	Mrigal	Silver carp	Silver barb	Catla	Grass carp	Crucian carp
Bangladesh	Good taste Easily available Look good	Good taste Look good Reasonable price	Easily available Look good Good taste	Reasonable price Easily available Look good	Look good Reasonable price Good taste	Easily available Look good Good taste	Good taste Look good Reasonable price	
China		Good taste Reasonable price Easily available		Good taste Reasonable price Easily available			Good taste Reasonable price Easily available	Good taste Reasonable price Easily available
India	Good taste Easily available	Good taste Reasonable price	Good taste	Good taste		Good taste Easily available	Good taste	
Thailand	Good taste Easily available Reasonable price	Good taste	Good taste		Good taste Easily available			
North Vietnam	Reasonable price	Good taste		Reasonable price Good taste			Good taste	

Table 3.39. Consumers' preferences for traits of preferred carp species in Asia.

Bangladesh	China	India	Thailand	North Vietnam	South Vietnam
Rohu	Crucian carp	Rohu	Silver barb	Grass carp	Common carp
Colour	Body shape	Body shape	Higher dress-out %	Bigger size	Higher fat
Higher dress-out %	Bigger size	Better flavour	Bigger size	Higher dress-out %	Bigger size
Bigger size	Colour	Colour	Better flavour	Body shape	Colour
	Better flavour		Body shape	Better flavour	Body shape
Catla				Common carp	
Colour	Grass carp	Catla		Better flavour	Silver carp
Higher dress-out %	Bigger size	Bigger size		Colour	Colour
	Better flavour	Higher fat		Body shape	Bigger size
	Higher dress-out %	Better flavour		Bigger size	Body shape
	Higher fat	Higher dress-out %			Higher fat
Mrigal					
Higher dress-out %	Common carp	Mrigal		Silver carp	
Colour	Better flavour	Higher dress-out %		Higher fat	Silver barb
	Higher dress-out %	Body shape		Higher dress-out %	Higher fat
	Body shape	Colour		Bigger size	Better flavour
	Colour	Better flavour		Colour	Body shape
					Higher dress-out %

Table 3.40. Consumer's preference for size, shape, colour and other parts of selected carp species

	Rohu	Common	Mrigal	Silver carp	Silver barb	Catla	Grass carp	Crucian carp
Size(pcs./kg.)								
Bangladesh	<1	<1 to 1	<1 to 1	<1	2 to 3	<1	<1	
China		1 to 2		1 to 2		1 to 3	1	
India	1 to 2	1 to 2	1 to 2			1 to2	1	
Thailand	<2-3	<2-3	<2-3		<2-5			
North Vietnam				2			2	
South Vietnam	<2	<2-3	<2-3	<2-3	2 to 5		<2-3	
Shape								
Bangladesh								
China		Short & thick		Short & thick			Long & thin	Short & thick
India	Long & thin	Short-thick-deep	Long & thin			Short-thick-deep	Long & thin	
Thailand	Big,long& thin	Big,short & thick	Big,long & thin		Big,short-thick-deep			
North Vietnam	Short & thick	Short-thick-deep	Short & thick	Short-thick-deep	Short & thick		Short/long & thick	
South Vietnam	Short-thick-deep	Short & thick	Short/long & thick	Short & thick	Short -thick-deep		Short/long & thick	
Colour								
Bangladesh								
China		Reddish & yellow		Silver			Black-green-silver	Black and silver
India								
Thailand	Silver	Yellow/Silver	Silver		Silver			
North Vietnam	Light	yellow	Black-blue	Silver	Light-blue		Light,light-blue	
South Vietnam	Bright	Yellow	Bright	Bright	Yellow fin		Bright	

Table 3.40. continued

Body Parts							
Bangladesh	Belly, tail, back		Belly, tail, back	Belly, back, head		Head, belly, back	
China							
India	Back, belly, tail	Belly, back, tail	Belly, back, egg			Belly, back, tail	Belly, back,tail
Thailand	Back, belly, egg	Back, belly, egg	Back, egg, belly		Back, belly, egg		
North Vietnam	Head, back, belly	Back, egg, belly	Back, tail, head	Belly, head, back			Back, belly, tail
South Vietnam	Head, belly, egg	Head, belly, egg	Tail, back, head	Back, belly, head	Back, belly, egg		Tail, belly, back

Table 3.41. Traits for genetic improvement of preferred species suggested by carp producers and consumers in Asia.

Bangladesh	China	India	Indonesia	Thailand	Vietnam
Catla • Growth • Reproduction • Brightness (colour)	Common carp ▪ Growth ▪ Meat quality ▪ Tolerance to low dissolved oxygen ▪ Resistance to disease	Rohu ▪ Growth ▪ Resistance to disease ▪ Dress-out %	Common carp ▪ Growth ▪ Edible portion ▪ Resistance to disease	Silver barb ▪ Growth ▪ Dress-out % ▪ Survival rate (disease, temp. tolerance)	Silver barb (RIA 1) ▪ Growth ▪ Dress-out % ▪ Resistance to disease
Silver barb ▪ Growth ▪ Reproduction/ dress-out % ▪ Resistance to disease		Common carp ▪ Growth ▪ Dress-out % ▪ Late maturity		Common carp ▪ Growth ▪ Dress-out % ▪ Survival rate	Common carp (RIA 1) ▪ Growth ▪ Dress-out % ▪ Resistance to disease

4. CARP GENETICS RESEARCH

Although carps have been an essential part of the economies of countries in South and Southeast Asia, until recently only a limited amount of research had been undertaken to characterize these species and to improve them through selective breeding and gene manipulation. One of the goals of the current project was to stimulate research into the use of selective breeding to improve cultured stocks of carps. Selective breeding has been successfully used with tilapias and salmonids to achieve impressive gains in growth and other traits.

The objective of the present project was to transfer the selective breeding methodologies that were successful in developing a fast growing strain of Nile tilapia (the GIFT fish) to major species of carp in Asian countries. This technology consists of several steps. The first is use of genetically divergent strains within a species to form a base population with a broad genetic diversity. The amount of gain that can be achieved through selection will depend to some degree on how much genetic diversity exists in this base population. The second step is the production of separate family units so that an accurate pedigree can be maintained. The tagging of individual fish is an important aid in record keeping and allows the testing of fish from different families in various production environments. Another important benefit of tracking families through tagging is the ability to select brood fish on the basis of traits that can be measured in relatives. Not all traits can be measured on live fish.

This section gives a brief overview of previous work on genetic enhancement, and then presents the results of collaborations with six countries. Most of the projects used some form of selective breeding to improve a species of interest. The results of these projects are presented by species and illustrate the problems and effectiveness of various breeding designs.

Overview of genetic enhancement research in Asia

Bangladesh

Several agencies, including ICLARM (Malaysia), ACIAR/CSIRO (Australia) and IOA, University of Stirling (Scotland) have greatly stimulated genetic research through the provision of technical and financial assistance. The ADB funded the "DEGITA" project, which focused on the genetic evaluation of the GIFT strain from 1994-96. A collaborative research program with the Institute of Aquaculture, University of Stirling, Scotland produced an all female population of silver barb using gynogenesis and sex-reversal. The population genetic structure of hilsa shad in Bangladesh was investigated using allozyme analysis in the "Hilsa Research Project" of BFRI, Bangladesh and CSIRO/ACIAR, Australia. Other programs, including selective breeding of rohu, further genetic selection and development of an all male GIFT strain population, genetic manipulation of shingi and genetic conservation of threatened fish species, such as gonia, reba and *Channa striata,* are being implemented under BFRI core and contract research funding.

The Freshwater Station, BFRI Mymensingh with an area of 40 ha has 118 drainable ponds ranging in size from 0.04 to 2.5 ha, a well-equipped carp hatchery with various incubating systems and numerous tanks for breeding fish and conducting genetics research. The station has six laboratories, which are well equipped with microscopes, marking and tagging equipment and other standard laboratory devices needed for research in breeding, genetics and histology.

China

Although China has a long history of aquaculture of at least 2500 years, genetic studies of fish and selective breeding have only taken place over the last 30 years. Hence, the application of genetic principles to aquaculture is far behind the use of genetics in agriculture or animal husbandry, and the contribution of genetics to aquaculture is weak. Scientific research in genetics has only contributed about 10% to aquaculture growth. Major achievements include: (1) breeding of common carp, including red common carp, Jian common carp, Songpu common carp and others, and crucian carp (such as allogynogenetic silver crucian carp) in the early 1980s; (2) gene engineering in the late 1980s and (3) creation of triploid crucian carp in the 1990s. Although these activities have played an increasingly important role in the development of aquaculture in China, most cultured fish are derived from wild stock that have not been genetically improved. The breeding and genetic improvement of carps to increase the production and economic benefit is a priority in China.

Monoculture trials of common carp were conducted at the experimental fish farm of the Freshwater Fisheries Research Centre (FFRC), which was also used as a hatchery. Polyculture trials of common carp were conducted at the fish farm of the Agriculture Development Company of Mashan District, Wuxi. 18 monoculture ponds and 18 polyculture ponds were used for common carp growth trials in 1998. In 1999, six additional ponds were used for growth trials of silver carp and one additional pond was used for culture trials of triploid common carp. Trial ponds were 1 mu each (1 hectare = 15 mu, 1 mu $\approx$ 667m^2). The range in water depth of the ponds was 1.5-2m. Other facilities, such as spawning ponds, nests (palm fibre), nets and cages, were also prepared for culture trials. Natural spawning, hatching, rearing and growth trials were conducted at the fish farm, whereas artificial insemination and growth measurements were conducted in the laboratory. Facilities in the laboratory included 20 0.3 m^3 tanks, a microscope, other equipment and access to chemicals (HCG and LRH-A) to induce spawning.

Two facilities, the Nanhui Aquatic Genetic Resources Experimental Station (NAGRES) and Shangahi Fisheries University, were used for the selective breeding project of blunt snout bream. NAGRES has four earthen ponds each 1400 m^2, one 6000 m^2 earth pond and 24 concrete ponds each 28 m^2. The laboratory at the Shanghai Fisheries University houses nine aquaria each 4 m^2 for fish culture, as well as equipment for analysing morphology, karyotype and molecular genetic variability. Two field stations, Wangxin Aquatic Good Breed Farm in Shanghai and Gehu Lake Blunt Snout Bream Breed Farm in Jiangsu Province, were used for strain testing and seed production.

India

No unified breeding programme exists in India, even though many species are cultured throughout the country. Fish genetics research is in its infancy and is based on need. Several institutions conduct research in genetic enhancement and genetic resource conservation. NBFGR, CIFA, the University of Agricultural Sciences, Bangalore and other institutions are pursuing studies to characterize and conserve genetic resources and to enhance the performance of fish. In collaboration with AKVAFORSK, Norway, CIFA has had a selective breeding programme on the Indian major carp rohu for the last eight years, and the University of Agricultural Sciences, Bangalore has conducted genetics research at its Fisheries Research Station for the last six years. This University, in collaboration with the University of Wales, Swansea and The Institute of Aquaculture, Stirling, UK and with support from the DFID Fish Genetics Programme has conducted research on genetic improvement of carps for the last five years. Other Institutes, such as CCMB and traditional Universities, pursue research on karyotyping and biochemical genetics.

Scientists at the Central Institute of Freshwater Aquaculture (CIFA) have investigated fish hybridization and chromosomal manipulations. They have developed standard protocols to induce both meiotic and mitotic gynogenesis, as well as polyploidy (triploidy and tetraploidy) in Indian major carps. Since 1992, the Institute of Aquaculture Research (AKVAFORSK) in Norway has collaborated with CIFA (Bhubaneswar) on the selective breeding of rohu. After three generations the selection response was estimated to be about 22% per generation. The staff at CIFA has developed an annual training program on aquaculture genetics for personnel at universities and state fishery departments to enhance awareness of the importance of applying genetic principles in aquaculture.

A separate division in the institute on Fish Genetics and Biotechnology is staffed by geneticists and biotechnicians, who work in a well-equipped laboratory to carry out research related to genome manipulations, cytogenetics, biochemical and molecular genetics. Under the current ICLARM-ADB project, molecular genetic markers are being developed to distinguish selected from unselected strains. The institute has 141 hectares of farmland with hundreds of ponds, 200 m^2 to 4000 m^2 in size, and two reservoirs of about 1.5 ha each. The Fish Genetics and Biotechnology Division also has a wet laboratory and hatchery facilities. The institute has a separate hatchery for commercial production of fish seed.

Indonesia

Researchers in Indonesia have had limited experience in quantitative genetics, particularly in genetically based selective breeding. The main problem in conducting this research was the development of suitable and inexpensive tags for marking fish. This was overcome by the development of a cheap, but high-quality tag.

Facilities for genetics research on genetic improvement of common carp at RIFF Sukamandi West-Java Indonesia, include earthen ponds and hatcheries. The hatchery facilities include:

- 1 unit for egg incubation and hatching (20 hatching funnels, 50 aquaria of 40 x 60 x 80 cm, 20 fibreglass containers and 500 aquaria of 20 x 20 x 20 cm)
- 1 unit for larval rearing (1 re-circulation system consisting of 20 fibreglass tanks of 50 l, 100 aquaria of 40 x 60 x 80 cm and 40 fibreglass containers of 1 m in diameter and 1.5 m in height)
- 2 units for fingerling management (1 re-circulation system consisting of 16 concrete tanks of 8 x 1.5 x 2 m, 1 re-circulation system for fry rearing consisting of 24 concrete tanks of 3 x 1.5 x 0.75 m
- 500 fine mesh hapas and coarse net hapas of 2 x 2 x1.2 m).

Thailand

Kamonrat (1996) studied the spatial genetic structure of silver barb populations in Thailand. In this study, microsatellite DNA markers were developed from a Thai silver barb genomic library. These markers were used to study various aspects of populations in Thailand to provide a means of evaluating management policies for conservation and genetic improvement of the species. The potential use of microsatellites for brood stock improvement in aquaculture was also studied (Kamonrut 1996). Pedigrees of individuals were successfully established in a large communal rearing by using one to five microsatellites. The ability to identify individuals allowed a complicated genetic experiment and selective breeding to be conducted where facilities were limited. Gynogenetic diploid silver barb were successfully induced by UV irradiation of sperm and cold shocking of fertilized eggs (Pongthana et al. 1995). Na-Nakorn and Legrand (1992) reported the chromosome number of silver barb as 2n = 50.

Facilities, including laboratories, hatcheries, concrete tanks, floating cages and earthen ponds at the National Aquaculture Genetics Research Institute, Pitsanulok Regional Genetic Centre, and

Khonkaen Regional Genetic Centre were allocated for genetics research on silver barb in the present project.

Vietnam

The size of the country's breeding program, especially in southern Vietnam, is limited because most breeding programs were initiated only a few years ago. These programs have received support from international and national agencies. Examples are the silver barb breeding program under ADB-ICLARM sponsorship and two programs on shrimp and river catfish, supported by the Ministry of Fisheries (MOFI). In the next five years the SPS program of DANIDA aims to support various fishery activities. One component, SUFA (Support Unit of Freshwater Aquaculture), plans to upgrade three National Freshwater Seed Centres in three geographical areas from northern, through central and southern Vietnam. This investment represents a good opportunity for Vietnam to improve and develop breeding programs that will effectively serve the national aquaculture programs until 2010.

Vietnam has only a few projects on fish genetic research. During the 1960's one PhD dissertation was published on the genetic variation of the different strains of Vietnamese common carp in Northern Vietnam (Trong 1967). In the 1970s, some projects on the intraspecific crossbreeding of common carp strains were completed. In the 1980s, breeding programs of common carp were designed and conducted at RIA-1. In the 1990s, numerous genetic research projects were initiated in Vietnam with support from ABD, DEGITA, ICLARM, DFID and NORAD. National funding has supported research to domesticate some high value species, such as black tiger shrimp and river catfish, and to establish *in situ* populations for conservation and gene banks through sperm cryopreservation. Various methods of genetic manipulation, such as polyploidy, gynogenesis and sex reversal, have also been employed in research projects. New high technologies will also be developed, including molecular genetic analysis and genetic engineering.

Two national breeding centres focusing on freshwater and marine aquaculture under RIA 2 will be upgraded in 2001 and 2002. These facilities have a large number of earthen ponds, concrete and composite tanks and are suitable for genetic research on domestication, selective breeding and live gene pool conservation. Three laboratories, under the Division of Experimental Biology (RIA2), focus on fish reproduction physiology, cryopreservation and genetic manipulation, especially for reduced polyploidy, and are well equipped to support several kinds of research projects.

During the 1970s-1990s, numerous genetic studies on fish have been conducted by various institutions in Vietnam. Efforts focused chiefly on characterizing various species and strains of carp with morphological, biochemical and genetic analyses as well as on using hybridisation and inter-strain crossing to improve production. In the current decade, aquaculture production in Vietnam increased from 360,750 tonnes in 1990 to 650,000 tonnes in 1999 (Ministry of Fishery 1999). It was estimated that fresh water aquaculture has contributed up to 70-80 % of total aquaculture production. Among fresh water species, carp play the most important role in aquaculture, particularly in northern regions. However, the genetic quality of several cultured strains has deteriorated. As a result, the effects of domestication and improvement through genetic enhancement have become the focus of several research institutions, including the Research Institutes for Aquaculture (RIAs) and the University of Fisheries and National Institute of Biotechnology. During 1997-2000, several studies on fish genetics and breeding were conducted in Vietnam. The results of these studies show the feasibility of applying selection methods, chromosomal and molecular methods for improving strains of fish for aquaculture.

Field facilities used in the breeding program of common carp included four brood stock ponds (800 m^2 each), 10 nursing/rearing ponds (600 m^2 each) and four grow-out ponds (600 m^2 each).

A total of 300 nylon net hapas, with sizes ranging from 1 to 4 m^3, were used to rear fry and fingerlings. Hapas (100, 30m^3 each) were used for growing fingerlings to marketable size. Mature fish were induced to spawn in an indoor hatchery. Facilities in the hatchery included 8 composite tanks (500 l each), 2 breeding tanks (4 m^3 each), egg incubators (60 jars of 10 l each, 3 jars of 200 l each), 40 indoor cement tanks (5 m^3 each) and 20 outdoor tanks (25 m^3 each).

Genetic improvement of common carp

Common carp is a native species of the temperate regions of Asia. However, it has been transplanted into scores of countries, so that it now enjoys the status of being a global fish and its culture is widespread

China

The distinctive fish farming technology and advanced fish breeding technology in China provide a sound basis for the carp genetic improvement project. Common carp grows rapidly and is suitable for many farming systems. The protein content of common carp is high and the production costs are relatively low. Common carp currently ranks fourth in the production of cultured carps in China and plays an important role in the carp culture industry.

Objective—The culture of common carp presently faces various problems such as reduced growth rate, increased disease susceptibility and declining economic return. Genetic improvement of common carp and other carp species can effectively tackle such problems and improve the production and economic benefit of the fish in culture. Therefore, common carp were selected as the major target for genetic improvement in this study. The key objective was to improve growth performance and other attributes that are related to economic value.

Research methods—Brood fish of three varieties of common carp: Jian carp, Hebao red carp and Huanghe carp, were collected in 1997. Jian carp has been bred at the Freshwater Fisheries Research Centre, Chinese Academy of Fishery Sciences (CAFS). The parental strains of Jian carp are Hebao red carp and Yuanjiang carp. Jian carp was the first Chinese carp to be bred artificially and was developed by a combined breeding technique using family selection, inter-line crossing and gynogenesis. Jian carp has been widely distributed to thirty provinces, municipalities and autonomous regions in China, and is cultured in more than 660,000 ha of culture ponds in China. Production is more than 1,000,000 t annually. Huanghe carp is a well-known local variety of common carp that originated from natural populations. Broodstock was collected from the Superior Breed Farm of Huanghe carp, Zhenzhou, Henan province. Hebao red carp was collected from the breeding agency of Hebao red carp—the broodstock farm of Hebao red carp, Wuyuan county, Jiangxi province. This variety has been cultured in Wuyuan for over 300 years. After six generations of selection, the inheritance of the red colour tends to be stable, in that 89.5% of the offspring are red. Total production is about 5000 t annually.

Six trial groups: Jianhuang (Jian carpE × Huanghe carpΓ), Jianhe (Jian carpE × Hebao red carpΓ), Hebao, Huanghe and two groups of Jian carp (selected and unselected) were designed and produced for growth trials. Brood fish were stocked at a density of 100 kg/mu and were fed on sunny and warm winter days with commercial feed and soybean cakes. Each brooder required a daily feeding rate of 1-2% body weight. In February, mature females and males of three varieties (Jian, Hebao and Huanghe) were reared separately until they reached sexual maturity. From February to April, parental fish were fed twice daily with commercial feed and soybean cakes at a daily feeding rate of 3-5% body weight. The weight of a mature fish was more than 1kg. Rearing ponds were 1 mu each with a depth of 2 m and were cleaned and sterilized two weeks before use. In anticipation of artificial spawning, spawning ponds, nests and spawn-inducing chemicals (HCG and LRH-A) were prepared. In April 1998, as the water temperature reached 18°C, fish were artificially induced to spawn. The average number of eggs from a female was 50,000-100,000. The fertilizing-rate of natural and artificial insemination was 82% and 95% respectively.

Artificial insemination was used for matings between varieties. After the mature fish were injected with hormone, males and females were reared separately in cages in different ponds. When the brood fish were in oestrus and began to spawn, they were immediately captured and gametes were used to make crossbreeds. Fertilized eggs were allowed to adhere to palm-fibre nests (10 eggs/cm^2), which were then moved to hatching ponds. Each group contained five pairs of brood fish.

The brood fish of Jian carp were placed in spawning ponds with nests. After spawning and fertilization, eggs were moved to hatching ponds. A total of 50 females and 50 males were selected from more than 1,000 brood fish to continue a selection line. Another 50 randomly chosen pairs were used as parents for an unselected group. The selection criteria included: 1) an average weight of 1-2kg each; 2) a long body shape, greyish in colour, 3) a female of age 3-4 years and a male of 2-4 years.

Fertilized eggs of six trial groups were hatched in six separate ponds with densities of 200,000 eggs/mu. Fry hatched after 4 days with a hatching rate of 65% at water temperatures of 18-20°C. Fry were reared at densities of about 130,000 fish/mu at 20-22°C. They were fed with natural and artificial food, including soybean milk, which was given twice a day at 4kg/mu. After 40 days, fry reached 3-5 cm and were ready for stocking as fingerlings.

Three replicates of the different groups of fish were tested for growthin 18 monoculture ponds and 18 polyculture ponds in 1998. The monoculture growth trial was carried out in 1999. Experimental fish were stocked in monoculture ponds at densities of 10,000 fry/mu or 1,000 fingerlings/mu. In polyculture, 100 fry were reared with grass carp, silver carp, bighead carp, Chinese bream and crucian carp. In the first month, fingerlings were fed soybean dregs and soybean cakes (3-4 kg/10,000 fish), then commercial feed (3-5% of body weight) twice a day. Larger fish were also fed commercial feed twice a day at a daily rate of 3-5% of body weight. In monoculture, growth was measured monthly from stocking through to harvesting as body weight and length . In polyculture, growth was measured only once at harvest. Average weight was estimated from 300 randomly sampled fish in groups of 10 fish from each of the groups. Thirty fish were sampled to measure body length.

Results—After 587 days in monoculture, the mean body weight of the hybrid Jianhuang was 12% heavier than that of its female parent, Jian carp, and 32% heavier than the male parent, Huanghe carp (Figure 4.1). Under the same rearing conditions, the body weight of the hybrid Jianhe was 8% lower than that of its female parent, Jian carp, and 21% higher than that of the male parent, Hebao red carp. The differences between these groups were highly significant ($P<0.01$).

After 222 days in polyculture, the mean body weight of Jianhuang was 19% and 6% higher than that of the parental strains, Huanghe carp and Jian carp, respectively. The body weight of Jianhe was 63% higher and 18% lower than its parent fish, Hebao red and Jian carp, respectively (Figure 4.1). These differences were highly significant ($P<0.01$). Rapid growth and good body shape and colour in Jianhuang carps indicate that this fish has potential for aquaculture.

After 587 days of monoculture, the body weight of the selected group of Jian carp was 6% higher than that of the unselected group(Figure 4.2). In polyculture, body weights in the selected Jian carp were 9% higher than weights of the unselected group 222 days after stocking. The difference between the two groups was highly significant ($P<0.01$). The selective breeding of Jian carp was effective in improving growth performance.

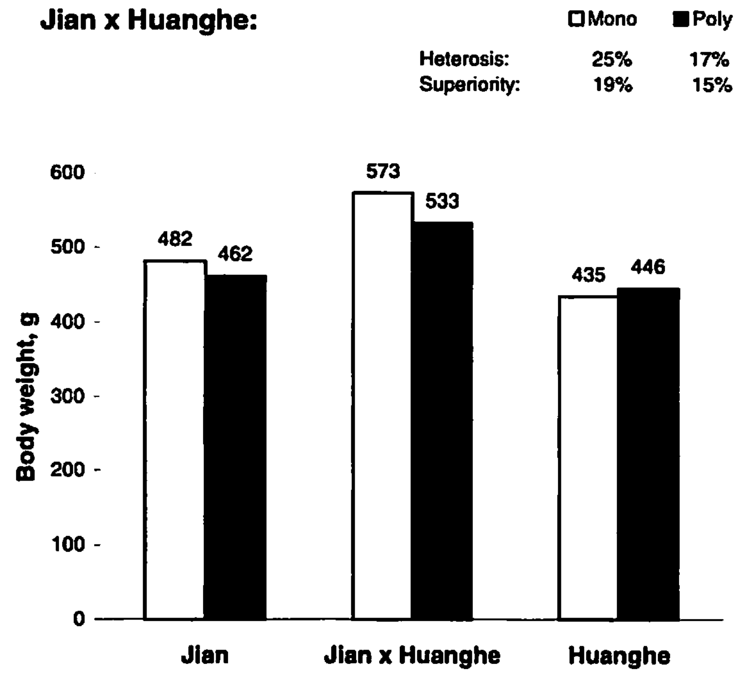


Figure 4.1. Growth performance of the crossbreeds Jianhe (Jian x Hebao) and Jianhuang (Jian x Huanghe), and their parental strains Jian, Hebao and Huanghe.

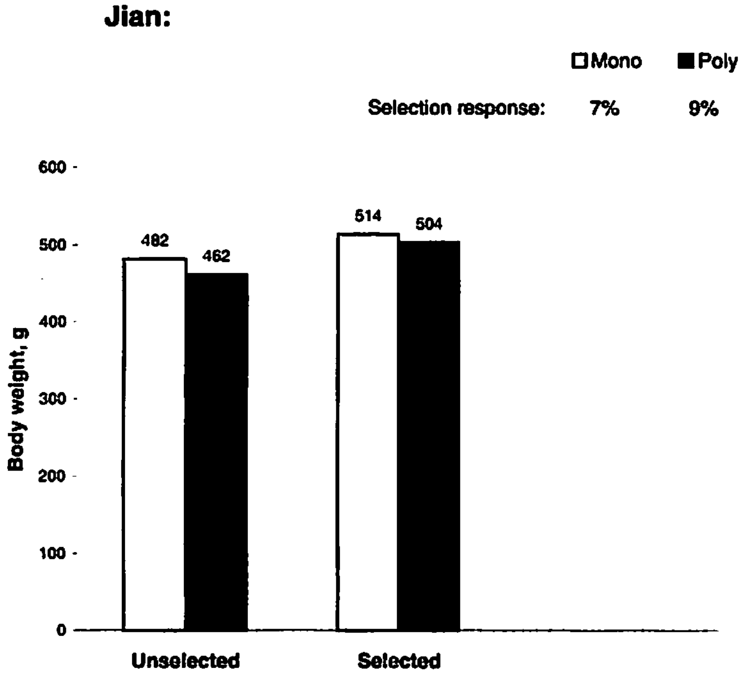


Figure 4.2. Growth performance of selected and unselected Jian carp in mono- and polyculture pond farming.

India

Common carp is becoming an increasingly important species for aquaculture throughout the Bangalore region.

Objective—Common carp is well adapted to static waters and can reproduce in grow-out systems. This can become a significant disadvantage as the fish can become sexually mature before reaching a marketable size (around 7 months post hatch, Basavaraju et al. 1996). This may result in over population through new recruits and adversely influence the growth of common carp and other species in a polyculture system. Hence, as an approach to control early sexual maturation and unwanted reproduction, sterility was induced through triploidy, and the triploid fish were evaluated for their use in aquaculture and enhanced fisheries.

Alternative options to control unwanted reproduction is the production of all phenotypically male populations through sex reversal. Earlier studies indicated that rates of sex reversal are higher in small fish and that doses of 50 & 100 mg methyl di-hydroxy testosterone/kg of feed did not influence sex reversal rates. Therefore, a study of the effect of age and size on sex reversal at a fixed dose (50-mg/kg feed) was designed.

Research methods—Triploidy was induced by subjecting the fertilized eggs to heat shock following previously developed protocols (Basavaraju et al. 1998). Triploidy was assessed by measuring the major axes of red blood cells. Triploid and control fish were tagged either with PIT tags or by fin cauterisation. The triploidy rate in the batch of fish used for the growth trails was about 90%. Growth trials in polyculture were initiated in November - December 1999 at five locations. However, a complete set of data could only be collected from two locations because of technical problems. At the end of the experiment, surviving fish were sacrificed to measure somatic and gonad weights to calculate GSI and dress-out percentages. Differences between groups were detected with ANOVA.

The production of monosex populations was conducted in fibreglass tanks. The treatment duration was for 40, 50 or 60 days for different sized groups of common carp at a dosage of 50 mg/kg with two replicates per treatment. Fish were given feed treated with methyl di-hydroxy testosterone (groundnut cake and rice bran in equal proportion) *ad libitum* four times a day at four-hour intervals. Tanks were cleaned daily to remove excess feed and water was replaced partially to maintain the water quality. The duration of the treatment was 40 days. After hormone treatment, fry were shifted to 4m^2 tanks for post treatment rearing on hormone-free diet until they reached a size at which they could be sexed. When the fish attained a size of around 12g, they were cut open and sex was determined with aceto carmine squashes of chromosomes. For each treatment, 25 fish were sacrificed to assess the sex ratio. The null hypothesis of no difference between control and treated groups and among the treated groups was tested with a contingency-table analysis and the chi-square statistic. Earlier studies indicated that 50-mg/kg gave higher percentages of males (76 - 100%). To see whether we could get similar results at lower doses, another experiment was designed. The treatment dosages were 25 mg/kg and 50 mg/kg for different sized and aged groups of common carp with durations of 50 days and two replicates per treatment.

Results—Table 4.1 summarizes the data from two growth trials designed to evaluate performance of triploid (3n) common carp relative to diploids (2n). In both trials, the weights of fish at initial stocking were not significantly different from each other. Survival rates were significantly higher in triploid groups compared to diploid groups. At the end of the experiment, weights of triploid and diploid common carp (pooled sex) were not significantly different at BRP and FRS. Triploids were slightly heavier than diploid fish at FRS, whereas diploids were slightly larger than triploids at BRP. When sexes were segregated, females were significantly larger (BRP) or not significantly different (FRS) from males in the same ploidy group in the same trial. Similar trends were also seen for weight gain. Dress-out value showed a significant difference between ploidy groups with 3n being higher than 2n in both the trials.

GSI values were significantly higher for diploids than for triploids in both the trials. Triploid males had higher GSI values in both the trials.

Fish that had been fed methyl di-hydroxy testosterone were examined for gonad development at about 10 g. Twenty-five fish for each treatment were sacrificed and the sex determined. Since no significant differences in sex were found between the replicates, replicates were pooled for statistical analysis. Significant differences were found between the seven groups (6-MDHT treated groups and one control group), but no differences were found among the 6 treatments (Table 4.2). When individual treatments were tested against the control group, 3 treatments (40 day large, 50 day small, 50 day large) had significantly greater numbers of males. The results indicate that the greatest number of males can be obtained by treating 50-day-old fish with MDHT. A second experiment was designed to determine if similar results could be obtained with smaller doses of MDHT. No significant differences were found between the replicates of each treatment, so they were pooled. No significant differences were found between the eight groups (Table 4.3). However, as in the previous experiment, maximal male percentages were obtained with a dosage of 50mg/kg with 50-day-old fish. It is interesting to note that for small size fry a dosage of 50 mg/kg for 50 days yielded a significant change in sex ratio (more males) in all the experiments.

Table 4.1. Growth performance, gonad somatic index (GSI) and dress-out percentage of diploid (2n) and triploid (3n) common carp*.

Location	Fish group	Weight gain, g	Survival, %	GSI, %	Dress-out, %
BRP	2n	313 ± 9^{b}	88^{b}	12.3 ± 1.0^{a}	81 ± 1.4^{b}
	2n + treatment	375 ± 10^{a}		15.5 ± 0.7^{a}	79 ± 0.7^{b}
	3n	310 ± 9^{b}	96^{a}	7.3 ± 1.3^{b}	87 ± 1.3^{a}
	3n + treatment	351 ± 34^{ab}		5.0 ± 1.3^{b}	89 ± 1.4^{a}
FRS	2n	124 ± 4^{A}	56^{b}	14.7 ± 0.7^{A}	78 ± 0.5^{B}
	2n + treatment	99 ± 16^{A}		15.9 ± 2.6^{A}	72 ± 2.1^{C}
	3n	111 ± 6^{A}	100^{a}	6.5 ± 2.2^{B}	86 ± 1.5^{A}
	3n + treatment	127 ± 10^{A}		4.9 ± 1.1^{B}	89 ± 2.1^{A}

* Different superscript letters indicate significant ($P<0.05$) differences between fish groups within locations.

Table 4.2. Percentage of males, females and intersex in different sized common carps treated with 50 mg MDHT/kg feed at different ages.

Age, days	Size	Males, %	Females, %	Intersex, %
40*	Mixed	54	46	0
40	Small	62	0	38
40	Large	76	0	24
50	Small	77	0	23
50	Large	76	0	24
60	Small	58	8	34
60	Large	57	14	29

* Control without any treatment

Table 4.3. Percentage of males, females and intersex in different sized common carps treated with 25 or 50 mg MDHT/kg feed at different ages.

Age, days	Dosage, mg	Size	Males, %	Females, %	Intersex, %
40	-	Mixed	54	46	0
40	25	Small	72	16	12
40	25	Large	68	10	22
40	50	Small	72	0	28
40	50	Large	70	8	22
50	25	Small	62	8	30
50	25	Large	58	20	22
50	50	Small	74	6	20
50	50	Large	64	12	24

Indonesia

The common carp is believed to have been imported from China during the period of Dutch colonization, about 200 years ago (in the 1800s) and later from the continent of Europe, specifically the Netherlands, as the Galician strain in 1927 and the frankisia strain in 1930. It was also imported later from Taiwan, Japan, and Germany (Schuster 1950). The common carp subpopulations of Europe and Asia spread throughout Indonesia during the development of aquaculture. Today, common carp is the main freshwater fish species produced by farmers in all provinces in Indonesia and it has contributed considerably to the local economies. In 1997, production of common carp was 146,672 tons, the highest production of all cultured fish, contributing 51% of the total freshwater production in Indonesia (DGF 1999).

Objective—The development of common carp culture has apparently led to inbreeding, which is capable of lowering the genetic quality. This occurred because most farmers have insufficient numbers of fish stocks with a large effective breeding size, N_e. Many farmers use less than 10 individuals (Dharma *et al.* 1986; Matricia 1990; Gustiano 1994; Maskur et al. 1996; Gustiano et al. 1998). Inbreeding depression in the course of fish culture development tends to continuously lower the genetic quality. This is characterized by slow growth of the fish, early-age gonadal maturation and high mortality due to decreasing resistance to diseases (Sumawijaya et al. 1980). Poor genetic quality may affect a range of people involved directly or indirectly with common carp culture. It is important to attempt to improve the genetic quality of the common carp. One approach to improving the genetic quality of the common carp is through selective breeding. The ultimate goal of this program will be to produce superior-quality broodstock fish that will transmit superior traits to their offspring (Tave 1993). The objective of the present project was to establish a base population of common carp by conducting a diallele cross with six Indonesian strains and to estimate heterosis effects for maternal and production traits.

Research methods—The research was conducted at the Cijeruk Research Station of the Research Institute for Freshwater Fisheries. Estimation of heterosis was carried out through repeated spawning of 16 diallele crosses of the test fish (synthetic population) of the common carp strains rajadanu, wildan cianjur, sutisna kuningan, and majalaya from the Institute's collection. The synthetic population was used for testing. For each strain, five pairs of brood stock were used, ranging in body weight from two to six kg. The broodstock care management was based on observations of the degree of egg maturation of each female in each strain, by taking egg samples using a catheter. Sixteen crosses of the four strains of common carp rajadanu (RR), wildan cianjur (NW), majalaya (MM) and sutisna kuningan (SS) were carried out. Breeding was induced by injection. The number of broodstock injected for each strain group (4 strains) consisted of seven females and five males. From the injected female brood stock, at least five females were expected to undergo ovulation. Injections were made using ovaprim hormone to induce ovulation and shedding of sperm, at a dosage of 0.8 cc ovaprim/kg of broodstock. For the female broodstock, two dosages were given (a total of 1.6 cc ovaprim/kg of broodstock), in two separate injections at a time interval of six hours. For the male broodstock, one dose was given (0.8 cc ovaprim/kg) at the same time as that of the second injection of the female broodstock. Ovulation was expected to take place 6 to 8 hours after the second injection. Eggs of females in each strain group (4 groups in all) were shed by stripping. All the eggs shed from each female were weighed for each strain group. To obtain data prior to fertilization, one gram of the eggs was sampled, counted and their diameters measured. Then all the ovulated eggs were divided into equal quantities in 20 containers. From the sperm of each male (five individuals in all) in each strain group, a sample of five cc of sperm was diluted by a factor of 200 in physiological solution consisting of 7.98 g NaCl + 0.002 g Na2HCO3 + 1,000 ml distilled water. Thus, each male of each strain group had 200 cc diluted sperm. The sperm was then divided equally into four containers (about 50 cc sperm container^{-1}). The sperm in container 1 (50 cc sperm) of the first male of each strain group was used to fertilize the eggs in containers 1, 2, 3, 4 and 5 (each being fertilized with about 10 cc sperm). The sperm in container 2 (50 cc sperm) was used to fertilize eggs in containers 1, 2, 3, 4 and 5 of a different strain group. Similarly, the sperm of the containers 3 (50 cc) and 4 (50 cc) was used to fertilize the eggs of the different strain groups. Eggs in each of five containers from each female (five fish in all) of each strain group, which had been each fertilized with each one of the different male individuals, were combined into one group. In this way, the total number of two-way crossings was still 16 crossings, namely 4 groups of male strains were crossed with 4 groups of female strains (4x4).

Calculation of fish fecundity or number of eggs was carried out by sampling and counting the number in 1g of eggs from each strain with three replicates. Ovulated eggs were weighed with an electronic balance. To prevent the presence of debris at the time of ovulation, the broodstock were fasted one day before spawning. 3 g of fertilized eggs were sampled from each cross. Every 1 g of eggs was sprayed on two square glass plates (10 x 10 cm) and placed in an aquarium (20 x 20 x 20 cm, with a water depth of 15 cm). Using this design, in which each strain was represented by three replicates, a total of 48 aquaria and 96 glass plates were used. Samples of 100 eggs from the first glass plate were used to estimate fertilization rate and 100 eggs from the second glass plate were used to estimate hatching rate. The percentage of fertilized eggs was estimated 4-6 hours following fertilization. The hatching rate was calculated as the percentage of fertilized eggs producing larvae. Aeration was continuously supplied during the hatching process in aquaria. Eggs were also placed in kakabans, which were placed in hapas set in a pond. This produced larvae from all crosses for further study. In this process, 480 kakabans, and 160 hapas of 2 x 2 x 1 m (10 hapas for each cross) were used. Aeration was continuously supplied and the hapas were covered with plastic to protect the eggs from rainfall.

Observations of survival rate of larvae (during the period of unabsorbed yolk sac) and post-larvae (eight days after yolk sac was absorbed) were carried out in aquaria of 20 x 20 x 20 cm with a water depth of 15 cm. A total of 50 larvae from each cross were stocked with three replicates. The surviving larvae were reused for age observations of post-larvae. Each cross was represented by 25 post-larvae with three replicates. During rearing, larvae were fed artemia. Larval rearing in fine mesh hapas and fingerling rearing in coarse net hapas were designed to produce fishes of appropriate size for tagging. Larval and fingerling rearing of the crosses were carried out in Sukamandi. The larvae were obtained from previous work carried out at the Research Station for Freshwater Fisheries, Cijeruk. Larvae and fingerlings from each cross were reared separately. Subsequent rearing was conducted in the same pond. Rearing of the 8-day old larvae 0.3-1 g (fingerling I) was conducted in a pond of 4000 m^2 at the Research Institute for Freshwater Fisheries Sukamandi. 80 hapas of 2 x 1 x 1.2 m were placed in the pond using bamboo frames. The larvae from each cross were stocked in five hapas (five replicates). The stocking density of each cross was of 1000 larvae/hapa. The larvae were reared in hapas for 1-1.5 months to obtain an individual weight of 0.3-1 g (2-3 cm, fingerling I) and were fed *Moina sp.* and *Daphnia sp.*, which were grown in ponds fertilized with chicken manure (250 g m^2), urea (2.5 g/m^2), and TSP (1.25 g/m^2). In addition to the natural food, commercial meal (PSP brand) containing 40% protein was also given at the rate of 10% fish weight daily. Fry obtained as fingerling I from previous rearing were reared to obtained fingerling II with individual sizes of 0.3-1.0 g. Fry were reared in the same pond (4000 m^2) following larval rearing in hapas in 80 coarse net hapas 2 x 2 x 1.2 m (mesh size of 3 mm). Each cross was represented by five coarse net hapas (replications) with a stocking density of 300 fry/hapa. Fry were reared in net cages for about two months to obtained fish of 5-g at harvest (fingerling II). The fry were fed floating commercial feed at a daily feeding rate of 10% of total fish weight.

Heterosis for growth was estimated at two locations: Research Institution for Freshwater Fisheries in two earthen ponds of 2000 m^2, and Cirata reservoir in two floating net cages 7 x 7 x 2 m each. Fish for these experiments came from 16 diallele crosses of the four common carp strains with a weight range of 30 to 66 g. Individually tagged fish were reared communally both in pond and floating net cages. Communal rearing was as follows: 1) earthen pond of 2000 m^2 at RIFF Sukamandi using 100 fish with a weight range of 38-42 g for each cross, 2) floating net cage (7 x 7 x 2 m) at Cirata reservoir using 100 fish with a weight range of 37-41 g for each cross, 3) earthen pond 2 (2000 m^2) at RIFF Sukamandi using 75 fish with a weight range of 30-34 g for each cross, 4) floating net cage (7 x 7 x 2 m) at Cirata reservoir using 75 fish with weight range of 60-66 g for each cross. Fish were reared for 3 months to obtain an expected individual weight at harvest (consumption size) of 250-300 g. Growth was measured monthly by sampling 30% of total fish stocked for each cross. Heterosis (H) was estimated by H = (average of reciprocal F1 hybrid - average of parent/ average of parent) x 100% (Tave 1993).

Results—Ovisomatic index (OSI) and fecundity data of the common carp strains rajadanu, wildan cianjur, sutisna kuningan and majalaya are presented in Table 4.4. The OSI means range from 14% to 17%. There is a tendency for OSI to increase with increase in body weight of broodstock, except in the majalaya strain. Average fecundity ranged from 74,300 to 99,800 eggs/kg of broodstock. Rates of fertilization and egg hatching are presented in Table 4.5 and Table 4.6. As for the fertilization rate, maternal effects are larger than paternal effects on fertilization success. Maternal effects were also more important than paternal effects on egg hatching rate.

Table 4.7 and Table 4.8 show mean larval survival rates and post-larval survival rates, respectively, of 16 crossings of the common carp strains rajadanu, wildan cianjur, sutisna kuningan and majalaya. The contributions of the rajadanu female and male dominate both the larval and post-larval survival rates. The dominant contribution to variation is by genetic factors. Data after one month of larval rearing in hapas are presented in Table 4.9 and Table 4.10. The fry were then reared further in fine-meshed floating net cages. Before stocking in the coarse net hapas, the fry were grouped based on relative size uniformity for all crossings. Data from fingerling rearing are presented in Table 4.11 and Table 4.12.

For the communal stocking in pond I and floating net cage I, stocking was done on June 21, 2000 and first sampling was done on July 21, 2000. First sampling included all fish in each cross. This was done to alter the tagging type in each individual. The last sampling was done on November 12, 2000. For communal stocking in pond II and floating net cage II, the last sampling was done at the same time (November 12, 2000).

Tags are a major cost in communal stocking experiments, so tags were developed in Indonesia. Replacement of the tag type in the first sampling of communally stocked fish in Pond I and floating net Cage I was intended to facilitate selection of individuals in each cross. The old tags were not used in numerical order for each cross, so that there was difficulty in separating individuals from different matings. The new tags were numbered consecutively and were distinguishable by the colour. Weight data from the communal stocking of Pond I and Cage I appear in Table 4.13. Estimates of heterosis for growth 1 in communally stocked Pond I ranged from –2.1% to 2.5%, and for survival ranged from -0.6% to 7.3%. In communally stocked floating net Cage I, heterosis for growth and survival, ranged from -1.3% to 1.6%. Data from communal stocking Pond II and floating net Cage II appear in Table 4.13. Overall heterosis (growth and survival) of fish from communal stocking of Pond II ranged from -0.3% to 4.8%. The heterosis for growth ranged from –0.3% to 3.8% and survival from 0.0% to 4.8%. From communal stocking of floating net Cage II, overall heterosis ranged from -4.7% to 4.9%. Heterosis for growth ranged from 0.2% to 4.9% and for survival ranged from -4.7% to 1.6%.

Table 4.4. Body weight (kg), ovisomatic index (OSI, %) and fecundity (egg number per kg body weight) of four strains of common carp: rajadanu (R), wildan cianjur (W), majalaya (M) and sutisna kuningan (S), mean ±standard deviation (n=5 females).

Parameter	Strain			
	M	R	S	W
Body weight, kg	4.8±1.0	4.0±0.8	6.2±0.4	4.9±0.3
OSI, %	16.3±2.0	14.4±1.2	17.4±4.7	14.9±1.9
Fecundity, eggs kg^{-1}	85,500±16,500	80,800±6,300	99,800±30,600	74,300±13,000

Table 4.5. Fertilization rate (%)*, mean±standard deviation.

Female	Male			
	M	R	S	W
M	74±13	89±5 (23%)	73±5 (9%)	72±4 (4%)
R	66±29 (-9%)	71±13	89±5 (36%)	46±20 (-31%)
S	65±29 (-3%)	72±10 (9%)	60±30	49±9 (-21%)
W	81±21 (17%)	70±10 (4%)	86±7 (40%)	63±19

* Heterosis effects are given in parentheses.

Table 4.6. Hatchability rate (%)*, mean±standard deviation.

Female	Male			
	M	R	S	W
M	58±22	61±38 (-3%)	71±4 (56%)	50±31 (-1%)
R	34±20 (-46%)	68±19	61±37 (22%)	71±20 (28%)
S	42±15 (-8%)	66±16 (32%)	33±17	71±20 (88%)
W	61±21 (20%)	52±28 (-7%)	61±21 (60%)	43±4

* Heterosis effects are given in parentheses.

Table 4.7. Larval survival (%)* to yolk sac absorption, mean±standard deviation.

Female	Male			
	M	R	S	W
M	84±18	97±5 (11%)	89±11 (15%)	89±11 (10%)
R	89±14 (2%)	91±14	97±3 (21%)	89±17 (5%)
S	86±11 (12%)	95±3 (18%)	70±18	89±18 (20%)
W	86±13 (6%)	95±3 (13%)	85±13 (15%)	78±15

* Heterosis effects are given in parentheses.

Table 4.8. Post-larval survival (%)* during the first eight days after absorbing the yolk sac, mean±standard deviation.

Female	Male			
	M	R	S	W
M	74±23	92±12 (10%)	85±15 (18%)	75±25 (7%)
R	78±25 (-7%)	92±8	90±11 (12%)	84±8 (8%)
S	81±8 (13%)	86±10 (6%)	70±25	84±8 (25%)
W	78±23 (11%)	86±9 (10%)	81±7 (20%)	65±26

* Heterosis effects are given in parentheses.

Table 4.9. Body weight (g)* of larvae after 30 days in hapas, mean±standard deviation.

Female	Male			
	M	R	S	W
M	0.99	0.94 (-6%)	0.80 (-28%)	0.82 (-27%)
R	0.68 (-32%)	1.01	1.18 (6%)	0.67 (-41%)
S	1.02 (-8%)	0.77 (-31%)	1.22	1.06 (-14%)
W	0.69 (-38%)	0.89 (-21%)	1.12 (-9%)	1.25

* Heterosis effects are given in parentheses.

Table 4.10. Survival rate (%)* of larvae after 30 days in nursery hapas, mean±standard deviation.

Female	Male			
	M	R	S	W
M	47	36 (-15%)	56 (2%)	34 (-33%)
R	40 (-8%)	39	50 (-2%)	32 (-33%)
S	47 (-14%)	47 (-8%)	63	50 (-15%)
W	33 (-36%)	39 (-18%)	62 (5%)	56

* Heterosis effects are given in parentheses.

Table 4.11. Body weight (g)* of fingerlings after 90 days in hapas, mean±standard deviation.

Female	Male			
	M	R	S	W
M	8.3	5.6 (-41%)	13.2 (16%)	6.5 (-40%)
R	7.1 (-25%)	10.6	12.6 (0%)	6.0 (-50%)
S	9.1 (-20%)	6.6 (-47%)	14.5	10.4 (-25%)
W	5.6 (-48%)	9.1 (-24%)	9.1 (-34%)	13.2

* Heterosis effects are given in parentheses.

Table 4.12. Survival rate (%)* of fingerlings after 90 days in hapas, mean±standard deviation.

Female	Male			
	M	R	S	W
M	31	41 (-4%)	41 (87%)	43 (21%)
R	62 (44%)	55	24 (-29%)	51 (7%)
S	62 (184%)	39 (16%)	12	46 (71%)
W	41 (15%)	42 (-12%)	55 (109%)	41

* Heterosis effects are given in parentheses.

Table 4.13. Initial and final body weights (g) of different purebred strains and their crosses in ponds and cages, mean±standard deviation.

Group	Pond I		Pond II		Cage I		Cage II	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
M	39	254±21	30	163±13	39	261±11	65	284±31
MxR	39	261±12	30	172±12	41	264±13	61	286±17
MxS	39	252±12	32	169±12	38	269±25	64	298±20
MxW	39	256±14	30	168±10	40	271±25	65	289±27
R	40	258±27	32	168±24	39	270±25	60	297±22
RxM	39	263±17	30	171±16	40	275±18	64	295±18
RxS	40	256±24	31	170±21	39	267±22	61	294±23
RxW	40	260±24	33	177±20	37	271±32	66	311±10
S	40	256±12	34	173±24	39	271±21	62	291±27
SxM	38	263±17	30	168±24	38	270±16	61	285±24
SxR	39	258±24	32	171±17	38	268±16	64	298±15
SxW	41	262±12	31	176±19	38	271±24	62	288±38
W	40	258±17	30	170±14	39	270±18	62	296±21
WxM	39	251±28	31	167±21	39	265±24	60	289±24
WxR	40	269±24	32	178±10	39	278±20	63	305±22
WxS	42	253±12	32	172±16	41	271±34	66	298±25

Thailand

The fishing industry has been important in Thailand. Fish make up most of the animal protein in the diets of Thais. Most of this fish produce has come from the capture fishery, but an increasing amount originates from aquaculture, which has been largely influenced by Chinese traditions in the choice of fish and culture techniques. However, scientific assessments of growth potential and the potential for genetic enhancement have only been made recently.

Objective—This project was focused on the evaluation of growth performances of three purebred strains of common carp and their crossbreeds.

Research methods—Three strains of common carp were used in the strain evaluation trial. 1) A local strain cultured in the northern part of Thailand. Fish were collected from the Nan River in Pitsanulok. 2) A Vietnamese strain originating from a fifth generation of mass selection. This strain was introduced to Thailand in April 1997 from the Research Institute for Aquaculture No.1 (RIA#1), Vietnam. 3) An Indonesian strain from the Rajadanu strain was introduced to Thailand in September 1998 from the Research Institute for Freshwater Fisheries (RIFF), Indonesia. All strains are maintained in the living gene bank at Pitsanulok Regional Genetic Centre, Pitsanulok.

Comparative performances of the Vietnamese (selected 5th generation) and local (Pitsanulok) strains were evaluated at Pitsanulok Regional Genetic Centre for a period of 12 months starting from May 1997 to May 1998. 2000 fingerlings of the Vietnamese strain were marked by right pectoral fin clip, and 2000 fingerlings of the Local strain were marked by left pectoral fin clip. Fingerlings from both strains were communally reared in three 600 m^2 earthen ponds at a stocking density of one fish/m^2. Fish were fed commercial pellets at 3% body weight three times daily. Monthly growth performances were measured from a random sampling of 30 fish/pond/strain and measured in terms of total length, body weight, body width and depth. After 12 months, growth performances of both strains were recorded from surviving fish.

Comparative performances of the Indonesian (Rajadanu) and Local (Pitsanulok) strains were evaluated at Pitsanulok Regional Genetic Centre for a period of six months starting from October 1998 to April 1999. Fingerlings from the Indonesian and Local strains were separately reared in 70 m^2 concrete tanks at a stocking density of one fish/m^2, with three tanks per strain. Survival rate and growth performances were measured from monthly counts of surviving fish and from measurements of total length, body weight, body depth and body width. After 6 months, survival rate and growth performances of both strains were recorded.

A complete diallele crossing of all nine hybrid and pure strain combinations of the three strains of common carp was used to estimate the magnitude of non-additive genetic effect (heterosis) and to determine whether selection or crossbreeding could be used as a breeding strategy. Comparative performances have been evaluated at the National Aquaculture Genetics Research Institute since June 2000, and will be completed in February 2001. Fingerlings were separately nursed for two months in 20 m^2 concrete tanks at a stocking density of 1,000 fish/tank, with three tanks per strain or cross. Survival rates were recorded at the end of the nursery period and fish were measured for total length and body weight. Fish in each strain or cross were randomly selected and reared separately in 1 x 1 x 1m^3 floating cages at a stocking density of 50 fish/cage, with six cages per strain or cross. Survival rates, total length and body weight were recorded bimonthly. At the end of six months, survival, length and weight will be recorded. The percent heterosis was calculated as the deviations of crosses from the average of their parental strains (Tave 1993).

Results—Performances of the Vietnamese and Local strains of common carp over 11 months are shown in Figure 4.3. The initial average total length and body weight of the Local strain were 4.2±0.1 cm and 1.3±0.1 g, respectively. The average survival rate was 78%. The sex ratio was 42% males and 58%females. The average total length and body weight of the Local strain at the final harvest were 22.6±2.9 cm and 211.3±62.5 g, respectively. The average total length and body weight of males of the Local strain at the final harvest were 23.4±2.9 cm and 200±56.6 g, respectively. The average total length and body weight of females of the Local strain at the final harvest were 21.8±3.0 cm and 222.6±64.9 g, respectively.

The initial average total length and body weight of Vietnam strain were 5.1±0.1 cm and 2.0±0.2 g, respectively. The average survival rate was 85%. The sex ratio was 49% males and 51% females. The overall average total length and body weight of Vietnamese strain at the final harvest were 23±2.9 cm and 193±57 g, respectively. The average total length and body weight of males of the Vietnamese strain at the final harvest were 24±2.8 cm and 180±52 g, respectively. The average total length and body weight of females of Vietnamese strain at the final harvest were 22±3 cm and 206±62 g, respectively. The Local strain grew significantly faster than the Vietnamese strain, but showed significantly lower survival. Males and females of the Local strain had significantly larger body weights than males and females of Vietnamese strain.

Performances of the Indonesian and Local strains of common carp evaluated for a period of six months are shown in Figure 4.4. The average initial total length and body weight of the Local strain were 4.2±0.1 cm and 1.5±0.1 g, respectively. The average survival rate was 91±5 %. Sex differentiation was observed after three months' grow-out in concrete tanks. The sex ratio was 44% males and 56% females. The overall average total length and body weight of the Local strain at the final harvest were 18.3±1.4 cm and 135±28.8 g, respectively. The average total length and body weight of males of the Local strain at the final harvest were 17.1±1.1 cm and 107.4±17.4 g, respectively. The average total length and body weight of females of the Local strain at the final harvest were 19.7±1.8 cm and 163.7±41.7 g, respectively. The average initial total length and body weight of the Indonesian strain were 3.7±0.3 cm and 1.1±0.3 g, respectively. The average survival rate was 49±6%. Sex differentiation was observed after three months grow-out in concrete tanks. The sex ratio was 40% males and 60% females. The overall average total length and body weight of the Indonesian strain at the final harvest were 23.6±1.5 cm and 303.9±54.4 g, respectively.

The average total length and body weight of males of the Indonesian strain at the final harvest were 20.9±2 cm and 221.7±64.5 g, respectively. The average total length and body weight of Indonesian strain females at the final harvest were 25.3±1.8 cm and 355.8±73.3 g, respectively. The Indonesian strain grew significantly faster than the Local strain, but survival was significantly lower. Males and females of the Indonesian strain had significantly larger total length, body width, body depth and body weight than males and females of the Local strain.

Performances of fingerlings after a nursery period of two months are shown in Table 4.14. Survival rates of the Vietnamese (V), Indonesian (I) and Local (L) strains were 43%, 33% and 63%, respectively. The averages of total length and body weight for the Vietnam, Indonesian and Local strains were 5.2±0.3 cm and 2.2±0.3 g, 5.9±0.3 cm and 3.5±0.5 g, 4.4±0.2 cm and 1.5±0.2 g, respectively. Survival rates of crosses VxI, IxV, VxL, LxV, IxL, LxI were 67%, 50%, 43%, 60%, 78% and 37%, respectively. The averages of total length and body weight of crosses VxI, IxV, VxL, LxV, IxL, LxI were 4.9±0.3 cm and 1.9±0.2 g, 5.2±0.3 cm and 2.2±0.3 g, 4.7±0.3 cm and 1.9±0.2 g, 4.8±0.3 cm and 1.8±0.2 g, 4.8±0.3 cm and 1.8±0.3 g, 4.7±0.3 cm and 1.9±0.2 g, respectively. The Indonesian strain grew significantly faster than the other two purebred strains, while the Local strain had significantly slower growth. The Vietnamese strain showed highest survival among the three purebred strains, while the Indonesian strain had the lowest survival.

Both VxI and IxV crosses grew significantly slower than their parental strains, but survived significantly better. The VxL and LxV crosses grew significantly faster than the Local strain, but slower than the Vietnamese strain. The cross LxV survived significantly better than the

Vietnamese strain and the cross VxL. The IxL and LxI crosses grew significantly faster than the Local strain, but were slower than the Indonesian strain. The cross IxL survived significantly better than their parental strains and the cross LxI. However, no crosses grew faster than the best pure strain.

Performances after a grow-out period of two months in floating cages are shown in Table 4.15. Survival rates of the Vietnam, Indonesian and Local strains were 80%, 51% and 59%, respectively. The averagetotal lengths and body weights of the Vietnamese, Indonesian and Local strains were 7.6±1.2 cm and 9.5±4.1 g, 8.3±2 cm and 14.2±6.5 g, 6.0±0.8 cm and 4.8±2.3 g, respectively. Survival rates of crosses VxI, IxV, VxL, LxV, IxL, LxI were 45%, 54%, 62%, 73%, 55% and 54%, respectively. The average total lengths and body weights of crosses VxI, IxV, VxL, LxV, IxL, LxI were 7.6±1.2 cm and 10.1±4.7 g, 7.7±1.1 cm and 10±4.7 g, 7.5±1.3 cm and 10.7±6.1 g, 6.9±1.4 cm and 7.7±5.4 g, 8.4±1.5 cm and 14.2±9.4 g, 6.5±0.9 cm and 5.9±2.2 g, respectively. The Indonesian strain grew significantly faster among the three strains, while the Local strain grew significantly slower. The Vietnamese strain survived significantly better than the Local and Indonesian strains.

The VxI and IxV crosses grew significantly slower than the Indonesian strain, but grew similarly to the Vietnamese strain. Positive heterosis responses of 15% and 29% were observed for total length and body weight in the crosses VxL and LxV relative to the averages of their parental strains. However, only the cross VxL grew significantly faster than the Local strain and grew similarly to the Vietnamese strain. Survival of both crosses was significantly lower than the that of the Vietnamese strain, but significantly higher than for the Local strain. The positive heterosis responses of 12% and 6% were observed for total length and body weight in the crosses IxL and LxI relative to the averages of their parental strains. Only the cross IxL grew significantly faster than the Local strain, but grew similarly to the Indonesian strain. Survival of both crosses was similar to their parental strains.

In conclusion, the Local strain of common carp grew significantly faster than the Vietnamese strain, but survival was significantly lower after a grow-out period of 11 months in communal earthen ponds. The Indonesian strain of common carp grew significantly faster than the Local strain, but survival was significantly lower after a grow-out period of six months in separate concrete tanks. After a nursery period of two months in separate concrete tanks and a grow-out period of two months in separate floating cages, the Indonesian strain was significantly the fastest growing strain among the nine hybrid and pure strain combinations resulting from a complete 3x3 diallele crossing.. No crosses performed better than the best pure strain for growth. Specific strain crossing schemes will only result in marginal improvements in growth performance. Therefore, a combined family and mass selection for growth will be adopted as a breeding strategy for genetic improvement of common carp in Thailand.

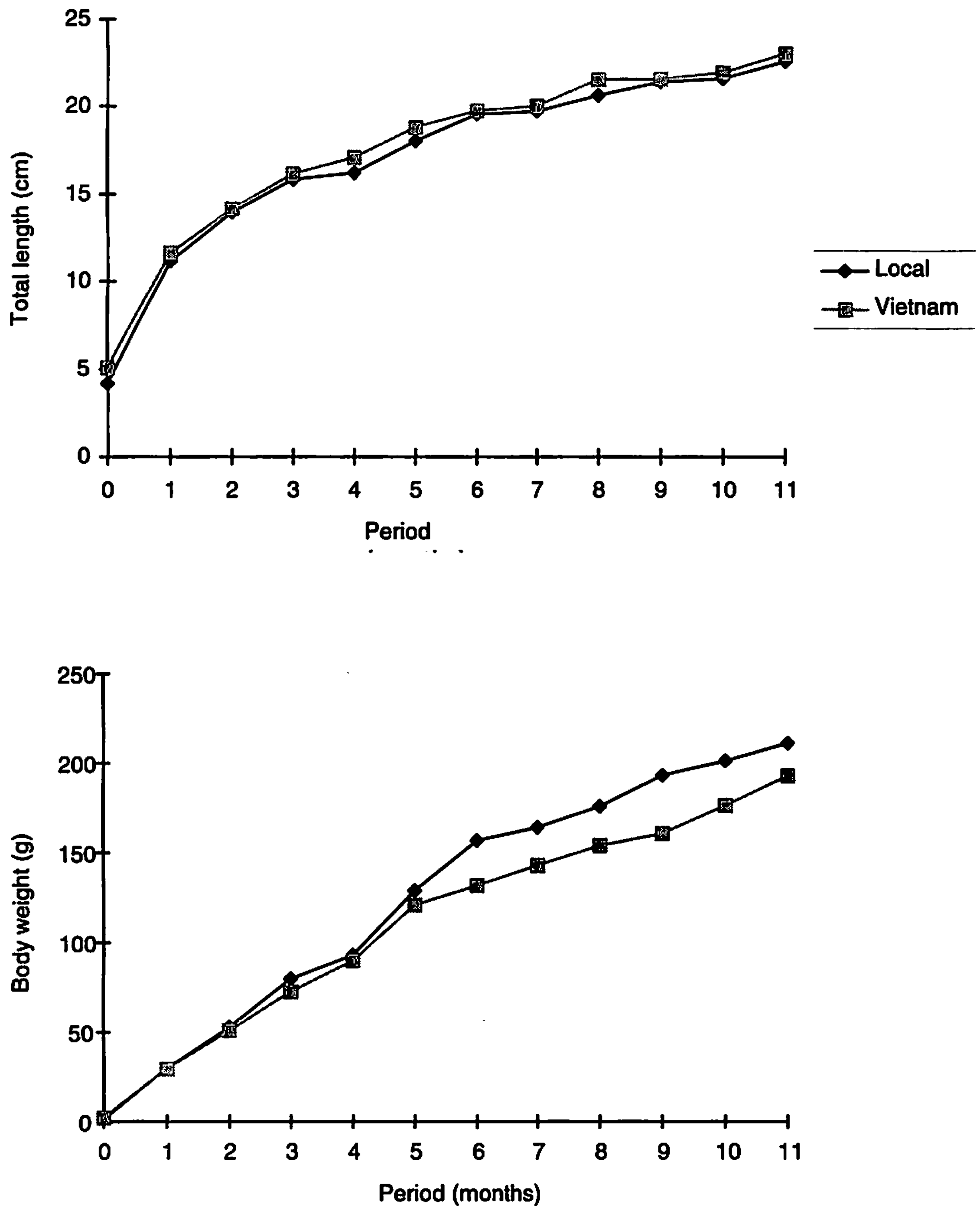


Figure 4.3. Growth performances of the Vietnamese and Local strains of common carp.

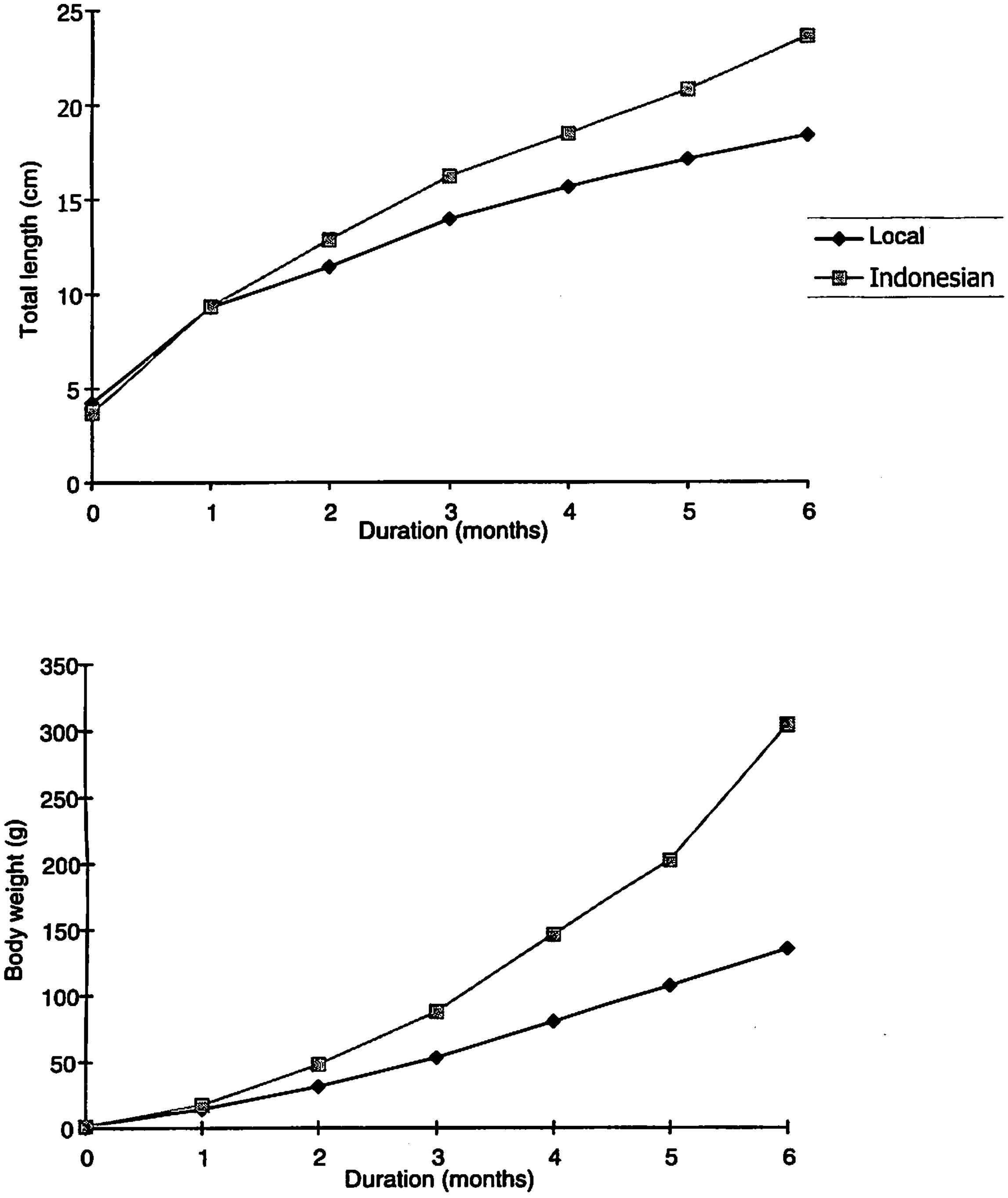


Figure 4.4. Growth performances of the Indonesian and Local strains of common carp.

Table 4.14. Performance of the purebreds: Local (L), Indonesian (I) and Vietnamese (V), and their crosses during the nursery period.

Group	Total length		Body weight		Survival rate	
	cm	Heterosis,%	g	Heterosis, %	%	Heterosis, %
L	4.4	-	1.5	-	63	-
LxI	4.7	-9	1.9	-24	37	-23
IxL	4.8	-7	1.8	-28	78	63
I	5.9	-	3.5	-	33	-
IxV	5.2	-6	2.2	-23	50	32
VxI	4.9	-12	1.9	-33	67	76
V	5.2	-	2.2	-	43	-
VxL	4.1	-15	1.9	3	43	-19
LxV	4.8	0	1.8	-3	60	13

Table 4.15. Performance of the purebreds: Local (L), Indonesian (I) and Vietnamese (V), and their crosses during the grow-out period.

Group	Total length		Body weight		Survival rate	
	cm	Heterosis,%	g	Heterosis, %	%	Heterosis, %
L	5.0	-	4.7	-	59	-
LxI	6.5	-2	5.9	-38	54	-2
IxL	8.4	26	14.2	50	55	0
I	8.3	-	14.2	-	51	-
IxV	7.7	-3	10.0	-16	54	-18
VxI	7.6	-4	10.1	-15	45	-31
V	7.6	-	9.5	-	80	-
VxL	7.5	19	10.7	51	62	-11
LxV	6.9	10	7.7	8	73	5

Vietnam

Objective—The primary objective of the breeding program was to produce a strain of common carp with faster growth, higher survival and more stable genetic quality relative to a base population using selective breeding. The base population used for selection consisted of individuals from the sixth generation of a strain of common carp derived from mass selection for growth.

Research methods—Mass selection of common carp was conducted at the Research Institute for Aquaculture No.1 (RIA-1) from 1985 - 1995. The fish used for selection were derived from three hybrid stocks arising from crosses between Vietnamese white, Hungarian scale and Indonesian yellow carps. After five generations of mass selection, the growth rate of selected fish increased by 33 % compared to the base population (Thien, 1996). However, the realized heritability (h^2) of body weight gradually declined to nearly zero by the 6th generation. This program was implemented through the following steps: 1) production of full-sib families through artificial propagation, 2) rearing of fry and fingerlings of each family in separate hapas or in ponds to evaluate the growth and survival of early life stages, 3) marking of fingerlings, then communal stocking in grow-out ponds until marketable size, 4) computing genetic parameters such as heritability and breeding value based on information on individual weight, survival rate and sex ratio, and 5) selection of "best" families and individuals within families for the next generation.

The base population for family selection consisted of 100 families (100 males and 100 females), which were randomly chosen from the sixth generation of the mass-selected fish. Fish in the base population were three years old with mean body weights of 1.9±0.2 kg (male) and 2.4±0.2 kg (female). All the individuals appeared healthy and free of disease and morphological deformity.

All fish in the 100 families were uniquely marked with PIT tags (AVID Microchip). Males and females were stocked (1 fish/4 m^2) separately during sexual maturation to avoid natural breeding in ponds. Fish were conditioned from September to February by feeding twice daily at a rate of 5 % body weight (BW) with food containing 25 % crude protein (CP). Ponds were well managed and the maturation condition of the fish was checked monthly. In early March, fully mature fish were chosen for artificial spawning. A mature fish was injected twice with the hormone, LRH-a, after a five hour interval. About 8-10 hrs after the second injection, eggs were stripped and fertilized using the dry method. After washing, fertilized eggs were incubated separately for each family in jars. Larvae hatched from the eggs after 48-50 hours at a water temperature of 22°C.

After hatching, larvae were gathered in the fine-meshed hapas for nursing. Yolk absorption was complete within three days and swim-up fry were fed with artificial food for two days, before being transferred to the rearing facility. Swim-up fry were reared in hapas to 0.5-1.0 g. The swim-up fry of each family were divided and stocked into three 1 m^3 hapas with a stocking density of 1,000 fry/hapa. Fry were fed 10% of their body weight daily with pellets containing 40 % crude protein. Rearing lasted about two months over March-May. Fingerlings of each family were reared in triplicate in separate 3 m^3 hapas with 100 fry stocked in each hapa. Fry were fed 7% of their body weight daily with pellets containing 30 % crude protein. Rearing of this stage lasted from May to July.

Fingerlings were marked by fin clipping and stocked communally in earthen ponds at a density of 1 fish/3 m^2. 50 fingerlings of each family were stocked in grow-out ponds. In addition, fingerlings of each family were stocked in three 30 m^3 hapas with a stocking density of 100 fish $hapa^{-1}$. Fish in both ponds and hapas were fed 5% of their body weight daily with the feed containing 25 % crude protein. Growth was measured monthly by weighing 30 fish in each family and each experimental unit. Feeding was adjusted monthly based on the fish biomass. Fish were harvested after 5-6 months in both systems, and survival rate and individual weights were measured for each family. The best families were selected based on the spawning performance, viability of juvenilse and growth rate of adult fish. Within these families, 20% of the largest individuals were selected, but with a sex ratio (male: female) of 1:1.

Results—In early March, most of the brood fish reached sexual maturation. However, not all individuals from some families could be induced to breed at the same time, because the timing of maturity varied among families. Therefore, only 27 families (27 males and 27 females) of the 45 families in the experimental ponds could be used for induced spawning. Fish from 27 families were induced to spawn, but the best spawning performance was obtained from only 14 families. The remaining 13 families showed low fertilization (< 50 %) and hatching (< 40 %) rates, as well as poor viability of larvae. Mean weight by family ranged from 1.4-2.4 kg for males and from 1.6 to 2.9 kg for females. Mean family fecundities ranged from 63,900 to 77,800 eggs/kg body weight. Mean fertilization rates ranged from 70 to 87%. Mean hatching rates ranged from 72 to 90% and mean larval survival among families ranged from 66 to 86%.

All fry were harvested to estimate growth and survival. Results for the 14 "best" families of fry reared in hapas appear in Table 4.16. Mean weights ranged from 0.6 to 2.1 g, and survival ranged from 10 to 67%. Survival was negatively correlated with growth ($R^2 = 0.87$). Fingerlings were reared in larger hapas with stocking densities of one tenth of the stocking densities of fry (100 fry/3 m^3 hapa). Except for family 10, the survival of fingerlings exceeded 80 % and survival between families was not significantly different ($P > 0.05$). Rapid growth at the fingerling stage is an important criterion for family selection. These results also indicate that hapas can be used for rearing common carp fingerlings. Growth performance of fish in 14 families in earthen ponds was estimated from mean body weights measured from September to December. Survival rates were high (> 90 %) in all families and were not significantly different ($P > 0.05$) among families. The mean weight of fish in some families was significantly larger ($P < 0.05$) than mean weights in other families.

Growth performances of fish reared in hapas were also measured monthly for evaluation and selection of families. As with fish reared in earthen ponds, all families showed high survival rates (> 95 %), which were not significantly different ($P > 0.05$) beteen families. However, the mean weight of fish in some families was significantly larger ($P < 0.05$) than mean weights in other families (Table 4.17). With the same feeding regime, the final mean weight of fish in earthen ponds ranged from 263-364 g, while the final mean weight of fish in hapas ranged from only 65-96 g. The final weight of individual fish was positively correlated with the initial weight of fish in both ponds and hapas ($R^2 > 0.9$). Larger fingerlings grew to a larger final size than did smaller fingerlings, under the same culture condition. Larger fingerling weight might therefore be used in formulating a selection criterion, because larger fingerlings yield a larger biomass at the end of a grow-out period.

According to the selection criteria, families 2, 3, 4, 8 and 15 were considered to be the best families for selection in terms of high survival of juveniles and fast growth during the grow-out stage (Table 4.18). Twenty percent of the largest individuals in these families were selected as parents of the next generation. The progeny of these five families selected for growth and survival in 1998 were grown to maturity using intensive culture methods. Fish from both the base population (P_o) and the first generation of selection (F_1) were induced to spawn; fry and fingerlings (F_2) from these matings were grown in hapas and juveniles were placed in ponds for grow-out.

Fingerlings of five families selected in 1998 were reared to market size in hapas and ponds from the end of December 1998 to early April 1999. The growth of fish reared in ponds was significantly ($P < 0.05$) greater than the growth of fish reared in hapas. In April 1999, 55 fish from each family reared in hapas and 30 fish from each family reared in ponds (ratio of male: female was 1:1) were selected for further grow-out in ponds. A total of 275 fish taken from hapas were stocked in a 1,900 m^2 pond (1 fish/7 m^2) and 150 fish taken from ponds stocked in a 500 m^2 pond (1fish/3.6 m^2). A total of 1,400 unselected fish were transferred to the RIA-1 Fish Farm for seed production. The selected fish were fed daily at a rate of 7 % BW with the feed containing 25 % CP from April to November 1999. In November 1999, the selected fish were conditioned for spawning to produce the second generation (in March 2000). The same procedure used for the first generation was also used to produce the second generation. About 3,000 swim-up fry from each family were divided and reared separately in three 1 m^3 hapas. A total of 120 hapas were used to rear fry and fingerlings of 40 families. A subset of other fingerlings were marked and stocked communally in hapas. About 9,000 fry from different families of the selected generation, as well as 9,000 fry from the base population were reared in five hapas to fingerling size from March to August 2000. The mean weights of fry in the selected and base populations were not significantly different ($P > 0.05$) and weights of fingerlings in the two groups were also not significantly different (Table 4.19). In mid-August 2000, a total of 300 fingerlings from the base population and 300 fingerlings from the selected parents were stocked communally in the ponds and reared to marketable size. Fingerlings from selected parents were marked by fin clipping and stocked communally with the unmarked fingerlings from the base population. Body weights were estimated from a sample of 30% of the population initially, then in September and October. At stocking, the mean weight of fingerlings from selected parents was 18 g and was significantly greater ($P < 0.05$) than the mean weight of fingerlings from the base population (14 g). However, the mean weights of fish in these two groups in September and October were not significantly different from each other ($P > 0.05$).

Table 4.16. Performances of families during the larval, fry and fingerling stages, mean value ± standard deviation (n=3 replicates).

Family	Larvae	Fry		Fingerlings	
	Survival, %	Weight, g	Survival, %	Weight, g	Survival, %
1	76	0.58±0.01	55	3.9±0.5	91
2	80	0.94±0.10	37	5.4±0.9	92
3	81	0.52±0.07	67	3.7±0.7	95
4	81	0.48±0.10	60	4.6±0.8	92
5	78	0.80±0.10	34	4.7±0.9	82
6	66	0.88±0.09	34	5.0±0.6	96
7	72	0.67±0.07	45	3.7±0.6	92
8	86	0.42±0.05	64	7.2±0.7	91
9	68	0.92±0.09	26	4.5±0.5	93
10	73	0.56±0.05	40	3.8±0.5	64
11	75	0.66±0.07	37	5.7±1.0	81
12	83	2.11±0.18	10	5.7±0.8	90
13	81	1.99±0.16	13	4.0±0.5	88
14	83	0.72±0.16	44	5.0±0.6	90

Table 4.17. Performances of families during the grow-out stage in ponds and hapas, mean values ± standard deviation (n=3 replicates).

Family	Grow-out hapas		Grow-out ponds	
	Initial weight, g	Final weight, g	Initial weight, g	Final weight, g
1	25±3.1	85±13	74±3.5	291±15
2	29±2.4	84±7.3	90±6.7	364±29
3	28±4.3	80±5.7	72±3.7	296±14
4	25±3.5	79±5.8	78±5.0	309±26
5	26±4.6	73±8.9	82±6.1	308±34
6	31±4.7	85±7.2	81±6.3	305±23
7	25±3.7	72±8.6	85±5.8	320±16
8	29±4.4	91±12	76±4.0	342±19
9	28±4.1	87±9.7	66±4.7	263±30
10	30±5.2	96±10	71±4.6	306±20
11	28±3.7	76±8.8	79±5.0	318±17
12	31±5.3	84±7.9	77±4.2	303±19
13	33±5.8	86±8.6	75±5.2	293±22
14	32±6.2	94±9.6	82±5.6	339±21

Table 4.18. Performance ranking of families.

Family	Larval survival	Fry survival	Fingerling growth	Growth in hapas	Growth in ponds	Score
1		X			X	2
2	X		X	X	X	4*
3	X	X	X			3*
4	X	X	X	X		4*
5						0
6			X		X	2
7		X	X	X		3
8	X	X	X	X	X	5*
9			X		X	2
10					X	1
11				X		1
12	X				X	2
13	X				X	2
14	X	X	X	X	X	5*

* Selected families.

Table 4.19. Growth performance of the base and selected population, mean values ± standard deviation (n=5 replicates).

Population	Fry		Fingerlings		Grow-out
	Weight, g	Survival, %	Weight, g	Survival, %	Weight, g
Base	0.67±0.10	57	8.9±0.8	54	192±11
Selected	0.66±0.03	64	10.1±0.7	54	199±11

Genetic improvement of silver barb

Silver barb are naturally distributed in the Mekong, Chao Phraya and Xe Bangfai basins, Malay Peninsula, Sumatra and Java. They are large migratory fish often used as a pituitary donor for artificial propagation in aquaculture.

Bangladesh

Production of the endemic carp fry through artificial breeding has become common since 1967 (Ali 1967). Most hatcheries rear their own broodstock and usually do not add broodstock from natural populations or exchange breeders between farms. Each hatchery, therefore, is a self-sustaining and genetically closed unit (Eknath and Doyle 1990). In genetically closed hatchery populations, random drift and inbreeding in small culture populations and inadvertent selection by various farm management practices can result in the genetic deterioration of a stock (Doyle 1983). Data collected from silver barb hatcheries in Jessore, Bogra, Commilla and Mymensingh revealed that most hatchery operators have little knowledge of the principles of broodstock management and do not follow any guidelines in selecting adequately sized breeders, injecting hypophysation and mating (Hussain and Mazid 1997). Ignorance of appropriate hatchery procedures can lead to negative selection.

Objective--Stock deterioration in hatchery populations due to poor broodstock management and inbreeding depression have been observed. In recent years, retarded growth, reduction in reproductive performance, morphological deformities and an increased incidence of disease and mortality of hatchery produced seeds of various major carps and silver barb have been reported. Interspecific hybridization between some carp species has also been reported. These hybrids are produced intentionally or unintentionally by the private hatchery operators for sale to farmers and nursery operators.

Large quantities of degraded and introgressed hybrid fish are used in aquaculture and sometimes stocked in floodplains and open water bodies. This stocking in the floodplains and open water bodies might lead to gene introgression in wild stocks, and may adversely affect aquaculture and inland open water fish production. To avoid loss of genetic diversity and inbreeding depression in hatchery populations, the development of improved broodstocks through breeding plans has been identified as an important area of research in Bangladesh.

Under this project, genetic stock improvement has been initiated on silver barb with the following objectives:

- Genetic stock improvement through selective breeding techniques.
- Evaluation of the growth performance of improved stock.
- Dissemination of the culture technology for genetically improved stock.

Research Methods—The breeding program was initiated with two wild strains from Thailand and Indonesia and an existing local stock from Bangladesh. These unrelated stocks were maintained separately in earthen ponds. Sexually mature fish were mated within strains under a normal induced breeding program until the selection protocol began. Intra-strain crosses consisted of Thai x Thai (TxT), Indo x Indo (IxI) and Bangla x Bangla (BxB). In 1996, a parental base population was made through a complete 3x3 diallele cross to produce nine outbred groups (Table 4.20). Three purebred (control) strains and six crossbred groups derived from diallele crosses were stocked communally with equal numbers of fish from each group. PIT tags were used to mark advanced fingerlings in the same pond. Six ponds were selected on the basis of productivity, depth and other physical features. These ponds were categorized into "Good", "Medium" and "Poor". Each of the test environments had two replicated ponds with the same stocking density. Fish were fed twice daily with a standard feed at 2–4% of their biomass daily. Fish were sampled monthly to adjust their feed and monitor growth until maturity and harvest eight months after stocking.

In 1997, the F_1 crossbred progeny were produced from mature fish in the base population. For each of the reciprocal crosses, five to eight pairs were mated separately and the best three progeny groups were selected to make 18 full-sib progeny families. A mixed population was created by mixing 125 larvae from each family; these were then grown in nursery, rearing and grow-out ponds. During the breeding season of 1998, when F_1 crossbred progeny had matured at the age of 10 months, 20% of the largest and heaviest females and males were mass selected and held separately in earthen ponds until they were used for breeding. Breeders were selected on the basis of large size, good health, shape and shiny colour. F_2 silver barb were produced by mating at least 150 ready-to-spawn males and females in common and by separately mating 50 pairs of stock (BxB) in a circular spawning system. Mating of 40-60 pairs per batch was completed separately within 2 - 3 days. Additional mass selection was conducted with matured F_2 selected fish using 15% of the best females and males during the breeding season of 1999. About 182 pairs of mass selected breeders and 50 pairs of existing stock (BxB) were separately pool mated to produce F_3 progeny.

An 8-month experiment was conducted from September 1997-May 1998. Ponds were stocked with F_1 crossbred fish and existing stock (BxB) at the rate of 3 fish/m^3 in four chambers of a pond partitioned with bamboo screening, each with two replicates. Fish were regularly fed with a mixture of rice bran (30%), wheat bran (30%), mustard oil cake (25%), fishmeal (15%) and vitamin premix (1%) at the daily rate of 3% of body weight. The chambers were regularly fertilized with cattle manure (1000 kg/ha). Fish were sampled at monthly intervals to measure growth and adjust feed ration.

A comparison of growth between the F_2 selected group and existing stock (BxB) was conducted in earthen ponds for five months. Stocking density was 1.5 fish m^{-3}. Fish were fed daily with a mixture of rice bran (30%), wheat bran (30%), mustard oil cake (25%), fish meal (15%) and vitamin premix (1%) at the rate of 3-5% body weight. The quantity of feed was adjusted from monthly estimates of growth.

Growth of the F_3 selected group and existing stock (BxB) were evaluated for six months. Three ponds, each about 360 m^2, were partitioned into a total of six chambers with bamboo screens covered with fine meshed nylon cloth. The ponds were drained and limed at the rate of 250 kg CaO ha^{-1}.and refilled with ground water three days later. They were then fertilized with cattle manure at the rate of 1000 kg ha^{-1}. About three to four days after fertilization, the ponds were stocked with three replicates of F_3 crossbred and existing stock at the rate of two fish/m^3 in six chambers of the three partitioned ponds. The stocked fish were regularly fed with a mixture of rice bran (30%), wheat bran (30%), wheat flour (5%), soybean meal (4%), mustard oil cake (10%), fish meal (20%) and vitamin premix (1%) at the rate of 3-5% of body weight. All the chambers were regularly fertilized with cattle manure (500 kg ha^{-1}). Fish were sampled at fortnightly intervals to assess growth and adjust the feed ration.

Results—Table 4.21 shows the mean growth performance data of the nine genetic groups derived from the 3x3 diallele crosses. The highest growth in weight was attained by the TxI (Thai x Indo) crossbred group, followed by the BxI (Bangla x Indo) group. The growth rates of these two groups were not significantly different ($P>0.05$) from growth in the other genetic groups, except the IxB (Indo x Bangla) group. Advanced fingerlings from all nine genetic groups were stocked in replicated communal ponds using PIT tags for identification. However, initial weights were significantly different among the groups, because similar stocking sizes were difficult to maintain. Correlations of mean initial weight with final weight in each pond did not show any significant differences among the communal groups by ponds. Final weights were independent of initial weights. Pooled mean final weights of fish from two environments (Good and Medium ponds) were not significantly different, and were significantly greater than the weights from Poor ponds. Fish in Poor (P) ponds grew less, probably because of shallow depth, less productivity and other inferior physical features. The sex ratio of all the genetic groups was assessed at harvest and did not differ significantly from 1:1.

The initial approach of this project was to bring wild strains from Thailand and Indonesia to Bangladesh to provide a broad genetic base for selective breeding. A sequential breeding design was followed. First diallele crossing was initiated to increase heterosis. Then, individual (mass) selection of brood stock was used to increase the chances of achieving genetic gains through the accumulation of favourable traits (Schom and Bailey, 1986). Eknath et al. (1993) collected eight different strains of Nile tilapia from Africa and Asia and evaluated the growth for generations and found significant differences in growth among strains. Nine genetic groups, in the present study, that were derived from diallelic crosses showed a weak, but insignificant correlation between mean initial and final weight in all experimental ponds.

The 8-month growth data of the F_1 crossbred and pure stock (BxB) appear in Table 4.22. The crossbred group grew faster over most of the period of observation, but no significant differences ($P > 0.05$) appeared between the crossbred and control groups. Table 4.23 presents the growth data of F_2 selected and control (BxB) groups. At five months the crossbred group weighed marginally more than the control stock, but the difference was not significant ($P > 0.05$). At harvest, sex ratios of both groups did not deviate from a 1:1 ratio.

Table 4.24 shows the fortnightly mean weights of F_3 selected and control (BxB) groups. During the initial 3 months (samplings 2-6), the selected group weighed more than the control stock, but this difference was not significant ($P > 0.05$). During the latter 3 months (samplings 7-12), the selected group weighed significantly ($P < 0.05$ and $P < 0.01$) more than the control group. At harvest, the mean weights of the selected and control (BXB) groups were 72 g and 59 g, respectively. The average sex ratios in the replicated chambers in both the selected and control groups were not significantly different from a 1:1 ratio.

The F_1 crossbred group weighed 8% more than the control stock; the F_2 selected group weighed 2% more than the F_1 crossbred group; and the F_3 selected group weighed 12% more than the F_2 generation. The average weight gain per generation after two generations of selection was 7%. However, growth of the 3rd generation of selected fish grew 22% more than the local control group (BXB). The present genetic improvement of silver barb through crossbreeding and selection can serve as a model for improving other carp species in Bangladesh.

Table 4.20. Mating design for production of the base population of silver barb (*B. gonionotus*) through a 3 X 3 diallele crossing pattern.

Males	Females		
	Thai	Indonesian	Bangladesh
Thai	-	X	X
Indonesian	X	-	X
Bangladesh	X	X	-

Table 4.21. Body weight (g) of the nine genetic groups of silver barb derived from a complete diallele cross, mean ± standard deviation.

Group*	Month				
	1	2	3	4	5
IxI	$36^a \pm 2.9$	$82^a \pm 15$	$105^a \pm 14$	$135^b \pm 16$	$167^{ab} \pm 15$
BxT	$32^b \pm 2.7$	$82^a \pm 15$	$115^a \pm 19$	$143^{ab} \pm 31$	$169^{ab} \pm 39$
BxI	$30^b \pm 0.8$	$79^{ab} \pm 13$	$112^a \pm 15$	$146^{ab} \pm 32$	$195^a \pm 55$
BxB	$30^b \pm 6.3$	$77^{ab} \pm 12$	$113^a \pm 18$	$145^{ab} \pm 20$	$187^{ab} \pm 44$
IxB	$28^c \pm 2.6$	$74^{bc} \pm 11$	$104^a \pm 16$	$131^b \pm 30$	$157^b \pm 39$
TxT	$27^c \pm 1.6$	$73^{bc} \pm 13$	$111^a \pm 11$	$147^{ab} \pm 20$	$181^{ab} \pm 36$
TxI	$24^d \pm 3.6$	$75^{abc} \pm 13$	$113^a \pm 12$	$161^a \pm 28$	$197^a \pm 37$
IxT	$23^d \pm 2.3$	$69^c \pm 14$	$103^a \pm 15$	$135^b \pm 16$	$169^{ab} \pm 24$
TxB	$17^c \pm 2.6$	$60^d \pm 11$	$91^b \pm 12$	$137^b \pm 25$	$180^{ab} \pm 44$

*Different superscript letters indicate significant ($P<0.05$) differences between genetic groups.

Table 4.22. Body weight (g) of crossbred group (F_1) and existing group (BxB) at bimonthly intervals, mean ± standard deviation*.

Group	Month				
	0	2	4	6	8
BxB	3.5 ± 1.0	21 ± 5.1^a	35 ± 9.2	41 ± 12	59 ± 14
F_1	3.9 ± 1.2	23 ± 5.7^b	36 ± 10	43 ± 14	63 ± 27

* different superscript letters indicate significant ($P<0.05$) differences between genetic groups.

Table 4.23. Body weight (g) of crossbred group (F_2) and existing group (BxB) at monthly intervals, mean ± standard deviation.

Group	Month				
	1	2	3	4	5
BxB	15 ±8.6	21±9.5	32±14	58±23	71±20
F_2	17 ±11	22±12	39±15	61±27	77±28

Table 4.24. Body weight (g) and body length (cm) of F_3 selected group (Selected) and existing stock (BxB) at fortnightly intervals, mean ± standard deviation*.

Sample	BxB		Selected	
	Body weight	Body length	Body weight	Body length
Initial	0.2±0.1	2.7±0.6	0.2±0.1	2.5±0.5
1	3.4±1.6	6.2±0.8	4.0±2.1	6.4±1.0
2	9.1±3.0	8.7±0.9	9.4±2.3	8.7±0.8
3	13±3.6	10±0.9	15±5.1	10±1.0
4	17±3.5	11±0.8	20±3.9	11±0.7
5	26±5.2	12±0.8	29±5.0	13±0.7
6	32±8.3^b	13±1.1	37±10^a	13±1.2
7	33±7.7^b	14±1.0	39±8.2^a	14±0.9
8	37±9.0^b	14±0.9	46±9.8^a	15±0.9
9	44±11^b	15±0.9	52±12^a	16±1.1
10	52±13^b	16±1.2	67±14^a	17±1.1
11	59±17^b	17±1.5	72±18^a	18±1.4

*Different superscript letters indicate significant ($P<0.05$) differences between genetic groups.

Thailand

Thailand has a long history of aquaculture, but selective breeding has only been used in recent years.

Objective—Breeding programs for genetic improvement of cultured aquatic species such as tilapia and silver barb were initiated in the early 1990s. Genetic manipulation and sex control have been applied to produce monosex fry. The National Aquaculture Genetics Research Institute (NAGRI) and their four Regional Genetic Centres located at Pitsanulok, Khonkaen, Suratthani and Petchaburi are responsible for undertaking the long-term genetic improvement of aquatic species in Thailand. The Institute and their Regional Genetic Centres serve as the Primary Multiplier Stations or the National Broodstock Centres for multiplication or production of genetically improved breeders for the Secondary Multiplier Station, as well as for evaluation and certification of multipliers. The provincial fisheries stations under the Department of Fisheries serve as the Secondary Multiplier Stations for mass production of genetically improved fingerlings for grow-out. The objective of the present project was to genetically improve silver barb.

Research Methods—Two distinct base populations were used as founder stocks for the genetic improvement programs in silver barb. The founder stock of the Chao Phraya River population was collected from the Chao Phraya River in Nakhonsawan and transferred to the Pitsanulok Regional Genetic Centre, Pitsanulok, in June 1998 to be maintained as a live gene bank. The founder stock of the Mekong River population was collected from the Mekong River in Nongkai in March 1999 and maintained live at the Konkaen Regional Genetic Centre, Khonkaen.

The first generation of silver barb was produced from the Chao Phraya River population in July 1998 at Pitsanulok Regional Genetic Centre. Mating of 50 pairs of breeders produced fifty families. Female breeders were induced to spawn by injection of the dompamine antagonist (domperidone) in the commercial form of Motilium at a dosage of 10 mg/kg and the gonadotropin releasing hormone in the form of LHRHa at a dosage of 10 mg kg^{-1}. Breeding of each pair was in a 2000-l FRP tank. Breeders were removed after spawning. Two-day old randomly selected fry from each mating were transferred to hapas (1 x 1 x 1 m^3) hanging in a 70 m^2 concrete tank with a water depth of 70 cm at a density of 10,000 fry/hapa, 1 hapa family^{-1}. Fry were fed with rotifers and *Moina sp. ad libitum*. After nursing for one week, 240 randomly selected fry from each of 50 families were transferred together to one 600 m^2 earthen pond at a stocking density of 20 fish/m^2 or 12,000 fish/pond. Fry were fed with commercial powder feeds *ad libitum*. After nursing for one month, randomly selected fingerlings were transferred to a 600 m^2 earthen pond at a density of 2 fish/m^2 or 1,200 fish/pond. Fish were fed three times daily with commercial pellets at 3% body weight/day. Growth (total length and body weight) was measured in a random sample of 100 fish after eight months grow-out in the earthen pond. Males and females of the first generation with the 10% highest body weights were selected as breeders for the next generation.

The second generation of Chao Phraya silver barb was produced in July 1999 at Pitsanulok Regional Genetic Centre. After nursing for one week, 480 randomly selected fry from each of 50 families were transferred to two 600 m^2 earthen ponds at a density of 20 fish/m^2 or 12,000 fish/pond. Fry were fed with commercial powder feeds *ad libitum*. After one month, 1,200 randomly selected fingerlings from the first pond were transferred to rear as broodstock of the second generation in one 600 m^2 earthen pond at a stocking density of 2 fish/m^2. In the second pond, 1,200 fingerlings were randomly selected for genetic gain trials. After eight months grow-out in earthen ponds, brood stock for the selected strain were selected from males and females of the second generation with the 10% highest body weights. The third generation of Chao Phraya silver barb was produced in July 2000 at the Pitsanulok Regional Genetic Centre. Genetic gain has been evaluated since July 2000 following the previously described procedures, and will be completed in January 2001.

Genetic gain was determined from performance evaluations of the selected strain and control population of the first generation from July 1999 to January 2000. Offspring of the control population were produced by mating 30 randomly selected pairs of control breeders with average body weights at Pitsanulok Regional Genetic Centre following procedures used to produce the first generation. Two hundred randomly selected fry, each from 30 families in the control population, were transferred to one 600 m^2 earthen pond at a density of 20 fish/m^2 or 12,000 fish pond^{-1}. Fry were fed with commercial powder feeds *ad libitum*. After one month, 1,200 randomly selected fingerlings were transferred to three 200 m^2 earthen ponds with 2 fish/m^2 or 400 fish/pond. Fingerlings of the selected strain were transferred to three 200 m^2 earthen ponds with 2 fish/m^2 or 400 fish/pond. Fish in both groups were fed three times daily with commercial pellets at 3% body weight/day. Monthly growth was estimated from a random sample of 50 fish/pond using total length, body weight, body width and body depth. After six months, growth of all fish was recorded.

The first generation of silver barb from Mekong River fish was produced in April 1999 at Khonkaen Regional Genetic Centre. Fifty families were produced by mating 50 pairs of breeders as described for the Chao Phraya population. Growth was recorded after 9 months grow-out in earthen ponds. Broodstock of the selected strain were selected from males and females of the first generation with the 10% highest body weights.

The second generation of Mekong silver barb was produced in September 2000 at the Khonkaen Regional Genetic Centre. After one month, 1,200 randomly selected fingerlings were transferred to one 800 m^2 earthen pond at a density of 2 fish/m^2 to rear as broodstock for the second generation. In the second pond, 1,200 fingerlings were randomly selected for genetic gain which will be assessed in May 2001.

Results—Growth of the first generation Chao phraya strain is shown in Figure 4.5. The average initial total length and body weight of the 1st generation were 4.7±0.4 cm and 1.4±0.3 g, respectively. The survival rate was 93%. Sex differentiation was observed after five months in an earthen pond giving a sex ratio of 54% males and 46% females. The overall average total length and body weight were 17.7±4.3 cm, and 92.1±32.4 g, respectively. The average total length and body weight of males at the final harvest were 16.6±1.5 cm and 67.7±18.2 g, respectively. The average total length and body weight of females at the final harvest were 18.8±6 cm and 107.3±32.4 g, respectively.

Growth of the second generation of the Chao Phraya strain is shown in Figure 4.6. The average initial total length and body weight were 2.3±0.6 cm and 0.2±0.1 g, respectively. The survival rate was 65%. Sex differentiation was observed after 4 months in the earthen pond, and the sex ratio was 48% males and 52% females. The overall average total length and body weight of the second generation at the final harvest were 19±1.8 cm and 101.7±27.6 g, respectively. The average total length and body weight of males at the final harvest were 18.2±1.1 cm and 85.5±17.5 g, respectively. The average total length and body weight of females at the final harvest were 19.9±1.9 cm and 116.8±52.6 g, respectively.

Genetic gain in the Chao Phraya strain was estimated for the selected strain and control populations (Figure 4.7). The average initial total length and body weight of selected strain were 2.3±0.6 cm and 0.2±0.1 g, respectively. The survival rate was 82%. Sex differentiation was observed after four months in earthen ponds, and the sex ratio was 45% males and 55% females. The overall average total length and body weight of the selected strain at the final harvest were 19.9±7.2 cm and 111.2±28.2 g, respectively. The average total length and body weight of males of the selected strain at the final harvest were 19.3±7.8 cm and 97.3±20.4 g, respectively. The average total length and body weight of females of the selected strain at the final harvest were 20.4±6.6 cm and 122.5±28.5 g, respectively. The average initial total length and body weight of the control population were 2.1±0.5 cm and 0.2±0.1 g, respectively. The survival rate was 77%. Sex differentiation was observed after four months in earthen ponds, and the sex ratio was 43% males and 57% females. The overall average total length and body weight of the control population at the final harvest were 17.6±4.3 cm and 83.2±22.5 g, respectively. The average total length and body weight of males of the control population at the final harvest were 17.9±1.9 cm and 86.2±14.8 g, respectively. The average total length and body weight of females of the control population at the final harvest were 18.9±1.7 cm and 90±22.9 g, respectively.

The selected Chao Phraya strain grew significantly faster and survived significantly better than the control population. Males and females of the selected strain had significantly larger sizes than males and females of the control population. Genetic gain after one generation of mass selection for body weight in the Chao Phraya River population of silver barb was 30%. The estimated realized heritability for body weight at seven months was 0.40.

The first generation of the Mekong River population of silver barb was produced from 50 male breeders with an average size of 18±1 cm and 70±7 g, and 50 female breeders with an average size of 20±1 cm and 125±9 g in total length and body weight, respectively. Growth of the first generation fish is shown in Figure 4.8. The average initial total length and body weight of the first generation were 3.6±0.3 cm and 0.6±0.2 g, respectively. The survival rate was 91%. Sex differentiation was observed after six months in the earthen pond, and the sex ratio was 47% males and 53% females. The overall average total length and body weight at the final harvest were 20.2±2.4 cm and 127.4±54.3 g, respectively. The average total length and body weight of males at the final harvest were 19.3±1.8 cm and 112.8±30 g, respectively. The average total length and body weight of females at the final harvest were 20.9±2.6 cm and 147.1±62.9 g, respectively. The second generation was produced from 50 male breeders with an average size of 25±1 cm and 218±26 g, and 50 female breeders with an average size of 29±2 cm and 406±50 g in total length and body weight, respectively. Observations of growth began in November 2000 and will continue until May 2001, when genetic gain will be calculated.

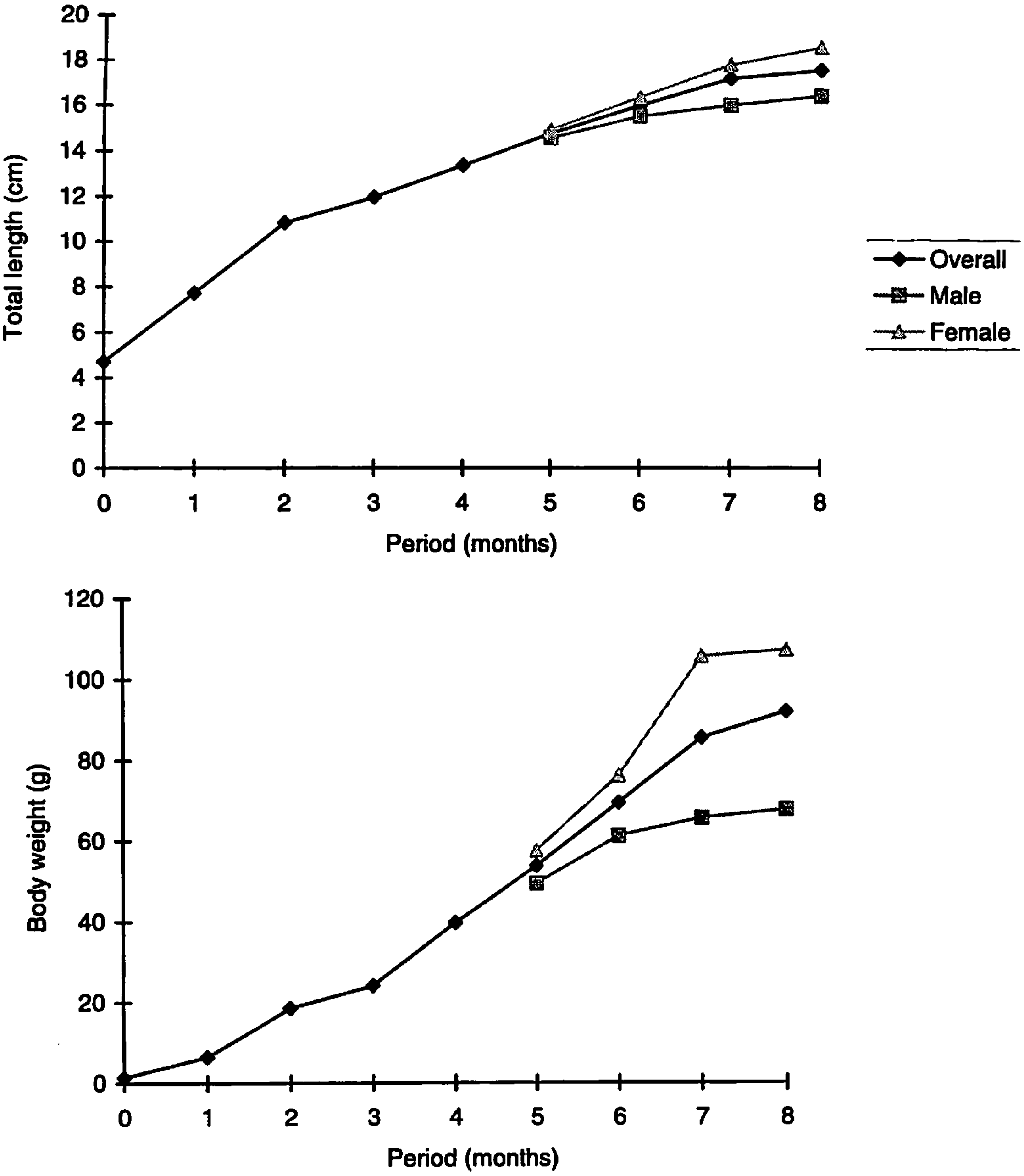


Figure 4.5. Growth of 1st generation silver barb from the Chao Phraya River.

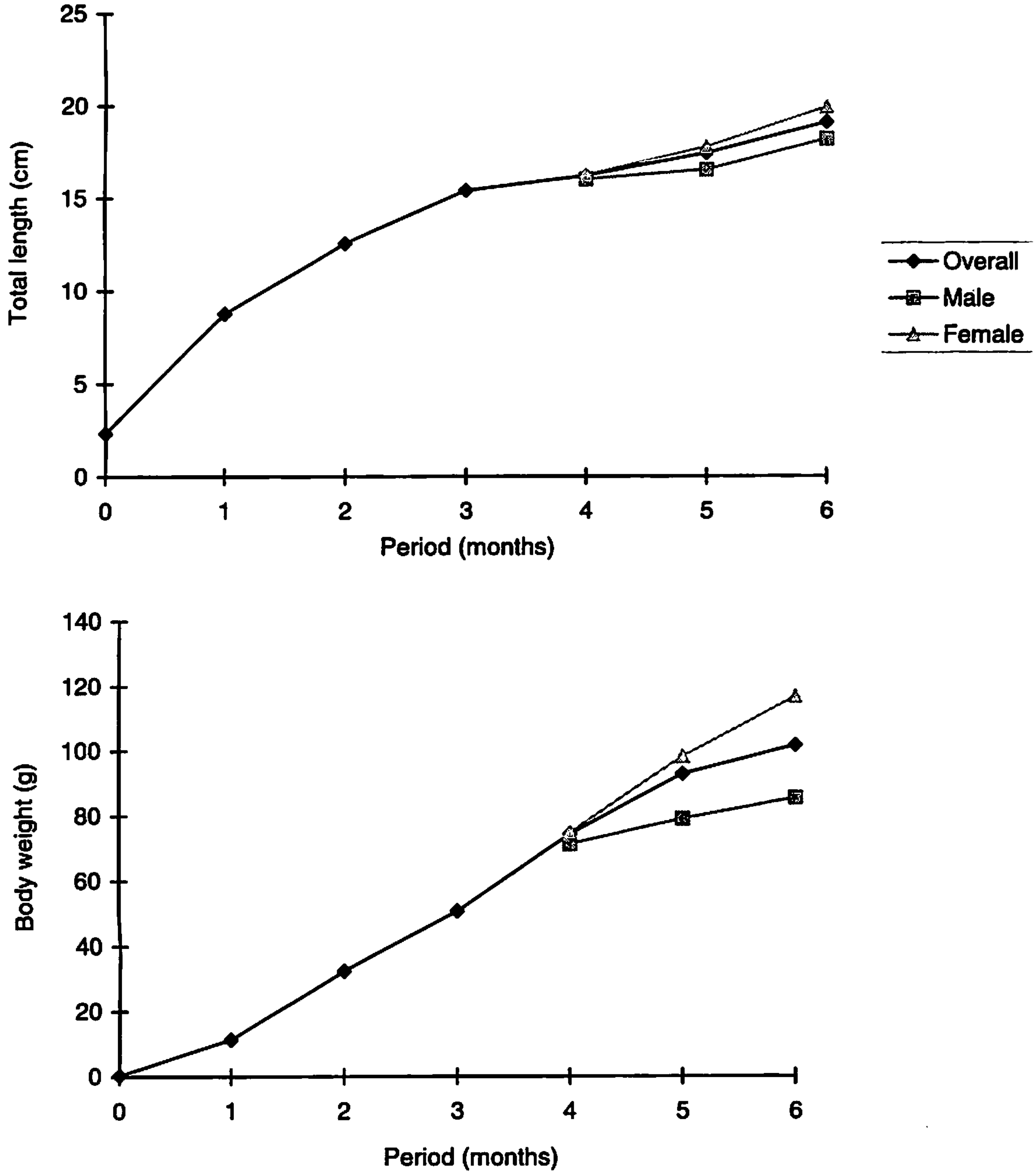


Figure 4.6. Growth of 2nd generation silver barb from Chao Phraya River.

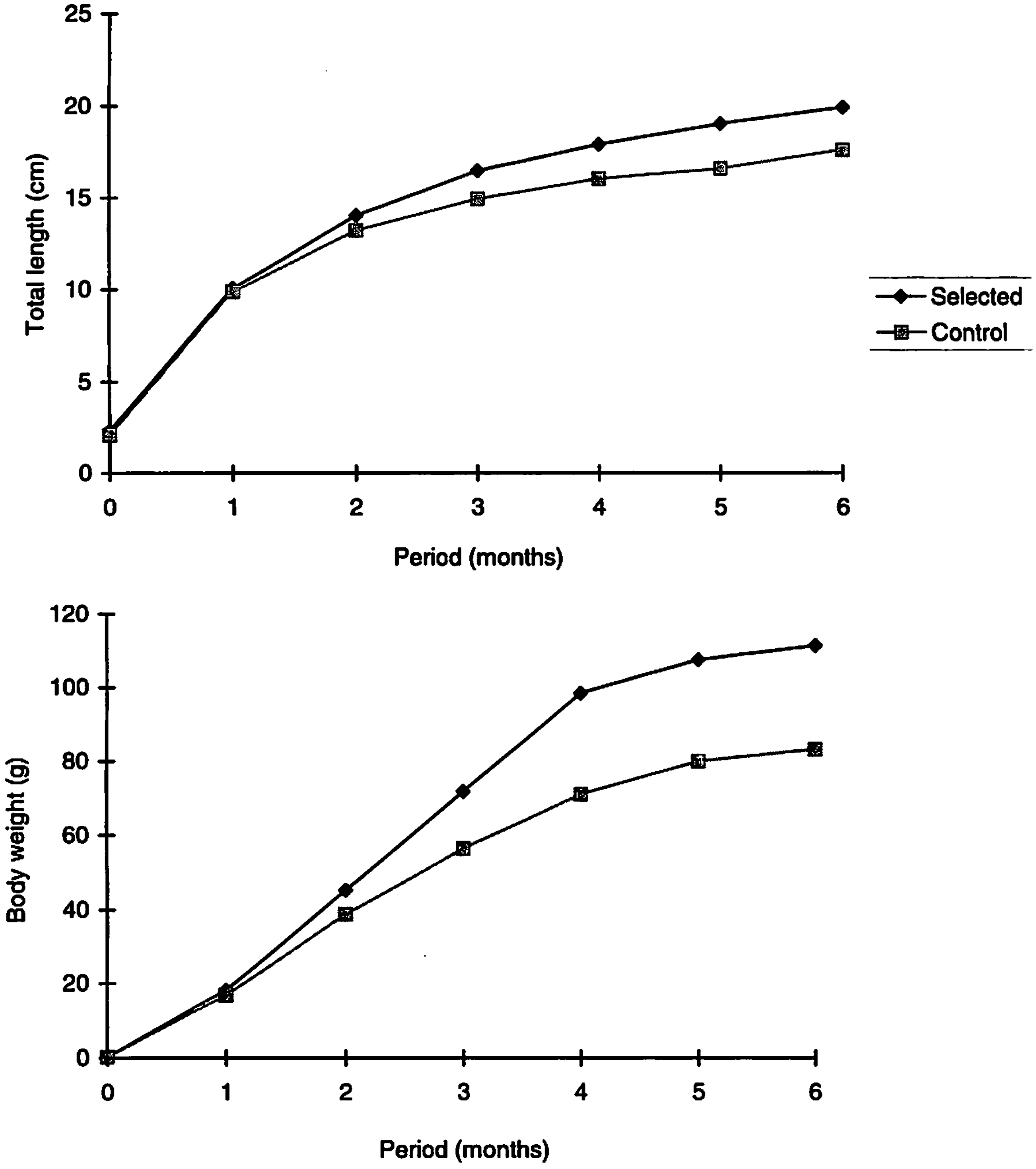
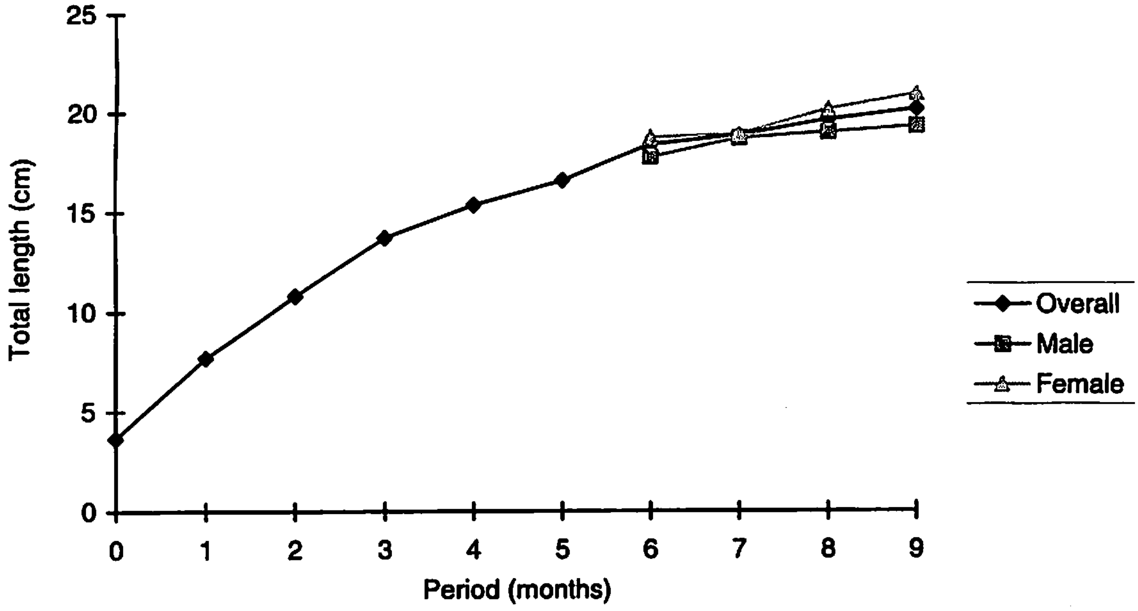


Figure 4.7. Growth of the selected strain and control populations of Chao Phraya River of silver barb.



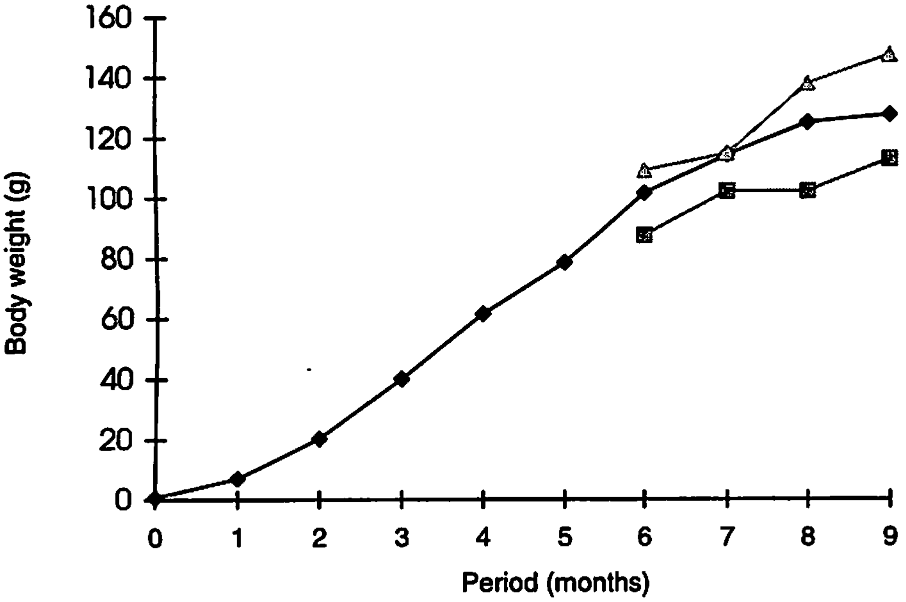


Figure 4.8. Growth of 1st generation silver barb from the Mekong River.

South Vietnam

Vietnam has a long history of small-scale aquaculture. Fish products have provided a large proportion of the animal protein in the diets of the Vietnamese people. To meet the demand for fish, several species of carps have been introduced or domesticated, including big head, silver carp and major Indian carps such as rohu, mrigal, and catla. Common carp, grass carp, bighead, silver carp and mud carp are the most important species in northern areas of Vietnam. Silver barb is most important in central and southern areas.

Objective—The objective of this project was to evaluate the growth performance in various groups and combinations of silver barb and to establish a suitable base population for a selective breeding program through individual and family selection of growth and other important traits.

Research methods—Silver barb, originating from various locations in the Mekong Delta, are presently being propagated in captivity for aquaculture. Broodstock were collected from two domesticated populations at the Cai Be fish farm (An Thai Trung village, Cai Be district, Tien Giang province) and at the Can Tho fish farm (Cai Khe village, Can Tho city, Can Tho province). These two provinces are the main freshwater fish centres of the Mekong Delta. However, to increase genetic variability in the initial base population to be used for selective breeding and to eliminate possible inbreeding, wild silver barb broodstock was also collected at three locations in the Mekong River Delta. These areas are the Bassac River in the Tan Hoa village, Phu Tan district, An Giang province, Mekong River in the Long Khanh village, Hong Ngu district, Dong Thap province and saline intrusion areas in Mo Cai town, Mo Cai district, Ben Tre province. Broodstock were also collected from the Tri An reservoir in La Nga village, Dinh Quan district, Dong Nai province. These fish were kept at the Cai Be freshwater fish centre of RIA-2 for experimental breeding.

The chief purpose of the first experiment (Experiment 1) was to determine the relative performances of the six strains collected from various farm environments. A secondary purpose of these experiments, was to develop specific technical procedures for seed production at the various life stages. Suitable tagging methods were also developed. Fish were stocked in earthen ponds (600 m^2) 70-100 cm in depth, with 1 pond/group at a density of 0.2 fish/m^2. Fish were fed 5% of their body weight daily with a mix of rice bran (65%) and fish meal (35%). Fish were induced to spawn with LRH-a + DOM at a dose of 150 µg/kg for males and 30 µg/kg for females. Larvae were incubated in aerated conical plankton nets. Larvae were then transferred to concrete tanks and fed egg yolk at the rate of 10g/3000 fish/day, for three days, then soybean meal at the rate of 15g/3000 fish/day. After the fifteenth day, rations were gradually increased to 20 g soybean meal, 10 g fishmeal and Moina, turbifex five times daily. Water in the tanks was exchanged every three days. Larger fish were placed in earthen ponds and fed a ration of rice bran (62.5%), fish meal (27.5%) and dry Acetes (10.0%) twice daily with a total amount of 10% of their body weight/day. On-station growth trials were made in monoculture ponds 1800 m^2 and 3600 m^2 at a stocking density of 2 fish m^{-1}. Fish were fed rice bran (50%) and fish meal (50%) twice daily at a total rate of 5% of their body weight. On-farm trials were made in rice ponds and polyculture ponds (7000 m^2) (with snake-skin gourami, common carp and tilapia) at a total stocking density of 0.66 fish/ m^2. Silver barb were stocked in these polyculture ponds at a density of 0.26 fish/m^2. These fish were not fed. Purebred crosses of several strains were made and included Dong Nai, Ben Tre, Bassac, Mekong, Can Tho and Tien Giang. Reciprocal crosses were made between the following strains: Mekong x Dong Nai, Bassac x Ben Tre, Tien Giang x Can Tho.

Based on the results in 1998, an experiment (Experiment 2) was designed to evaluate the growth of the four best groups for short-term use. The following crosses were made: Can Tho x Can Tho; female Can Tho x male Tien Giang; male Can Tho x female Tien Giang; Tien Giang x Tien Giang; Dong Nai x Dong Nai. In another experiment (Experiment 3), we evaluated the growth of two combinations established in 1998. This included the following crosses: communal brooder x communal brooder (9 groups); selected communal brooder x selected communal brooder (4 groups); Can Tho selected x Can Tho selected; Can Tho control x Can Tho control (parental brooder); and Mekong control x Mekong control (parental brooder).

Several marking techniques were used to identify individuals. One was the clipping of the dorsal, pectoral, ventral and anal fins. Another was the use of red, yellow, green, and orange fluorescent dyes applied 3-5 cm from the fish with a compressed nitrogen nozzle to various parts of the body at a pressure of 11 kg cm^2. A third method was the injection of alcian blue into various sites on the body. And the final technique used combinations of either fin clipping and fluorescent dye or fin clipping and alcian blue.

Results—Fish collected for the experiments were about one year old with average body weights of 175-370 g. After one year of growth, the average body weights of broodstock fish were at least 70 g for males and 50 g for females (Khanh 1996). One-year old broodstock matured two months after stocking in earthen ponds. Feeding appeared to be a key factor in broodstock management. Regular feeding can produce sexual maturation in silver barb throughout the year.

Broodfish can be selected for induced spawning after two months of intensive culture. Ovulation occurred five to six hours after hormone injections. The mean fertilization rate was about 75%. The hatching rate reached an average of 83% after 14 hours of incubation. The traditional Chinese style of incubation could not be used because fertilized eggs from different crosses had to be kept separately. Instead of using a Hungarian weiss jar system, a system of conical hapas was developed. The regular exchange of water in the incubation container and careful cleaning of the conical hapa were the key factors in the success of this system.

Two nursing stages were developed, because silver barb fry are small and weak. In the first stage, fry were grown in plankton-net hapas placed in concrete tanks (1 x 2 m^2) for one month with an aerator. The average survival rate was about 18%. In a second stage, fingerlings were reared in plastic hapas placed in earthen ponds. The key technique in this stage was to reduce the variation in body weights through monitoring and managing densities and the feeding regime. The culture of similarly sized fingerlings from groups before marking and stocking in a communal grow-out pond was an important factor. The mean survival rate of the second stage was 83%.

Different parts of the fingerling were marked with fluorescent dyes. Various distances of the dye nozzle to the body and various pressures were used to find the best marking. Two sites were most suited: the upper portion of the pelvic fins (lower head) and the corner of the pectoral fins. The optimal distance of the nozzle to the fish was about 3 cm with a pressure of 11 kg cm^2 after anaesthetization in MS 222 50-70 mg l^{-1}. Fluorescent dye marking could be combined with fin clipping. After four months, 50% of the dye marks remained, and 71% of the fin clips were recognizable. The optimal size of fish for marking with alcian blue was about 4-8g. The most suitable parts of the body for both fluorescent dye and alcian blue marking were the lower head and corners of pectoral fins. More places could be used for alcian blue marking (1 to 3) on the lower head than for fluorescent dyes, which could be effectively applied only in one area on the lower head. Dorsal and pectoral fins are the best fins for clipping. After four months of culture, 49% of the alcian blue marks and 71% of fin clips could still be recognized.

In the on-station trials of fish grown in earthen ponds, the growth performance of reciprocal crosses between the Mekong x Dong Nai strains had an average final body weight of about 57g. Among nine crosses, the reciprocal cross, Can Tho x Tien Giang, and two purebred crosses, Dong Nai x Dong Nai and Tien Giang x Tien Giang, grew the most ($p<0.0001$) (Table 4.25). In the on-farm growth trials, the final mean size of the reciprocal cross Mekong x Dong Nai was still placed in the middle position among the nine crosses. In the rice fields, the two pure breeds, Can Tho x Can Tho and Dong Nai x Dong Nai, and one reciprocal cross, Can Tho x Tien Giang, grew most ($P<0.05$) (Table 4.25). However, the two domesticated groups showed varied results. The pure breed, Tien Giang, performed well in earthen ponds, whereas the pure breed, Can Tho, showed excellent growth in rice fields. Growth rates of the nine groups of crosses can be divided into 3 groups. The first group consisted of Can Tho x Can Tho, Can Tho x Tien Giang and Tien Giang x Tien Giang in earthen ponds and Can Tho x Can Tho, Can Tho x Tien Giang and Dong Nai x Dong Nai in rice fields. The rest of the trial crosses were in the second and the third groups.

Evidence for genotype-environment interactions was examined in the various crosses. Only the pure bred cross Can Tho grew differently ($p < 0.05$) between the two environments. This strain did not grow as well in the station trial. Based on the results presented in Table 4.25, and on the short-term and long-term goals of our breeding program, two communal broodstock populations were created. Group 4N (4 best brooders group) involved the four fastest growing crosses in two different environments. These included Can Tho x Can Tho, Tien Giang x Tien Giang, Dong Nai x Dong Nai and Can Tho x Tien Giang. These groups can be used for a short-term strategy to supply good seed to farmers and private hatcheries. Group 9N (communal brooder group) involved all nine crosses. This group can be used for long-term selective breeding because of its high level of genetic variation. Broodstock were created with a selection intensity of about 10 % for the fastest growing fish and with randomly selected individuals from the upper 20 % of the remaining fish in each group. This principal was applied to both the selected communal brooders (group 4N) and the communal brooders (group 9N).

Growth performances of the four best groups and the maternal effects of one of the reciprocal crosses (Can Tho x Tien Giang) appear in Table 4.26. Growth in two reciprocal crosses, Can Tho x Tien Giang and Tien Giang x Can Tho, were not significantly different ($p > 0.05$) and hence did not show any maternal effects. Growth in two groups, Dong Nai and Tien Giang, were not significantly different. This result is similar to the previous experiment in 1998. The Can Tho group grew the most of the five groups ($p < 0.01$). These results confirm initial gains made through domestication in the beginning stages of this breeding program.

The performance of the communal brooder group was intermediate amongst the groups tested in experiment three (Table 4.27). The selected communal brooder had the best performance ($p<0.05$). This demonstrates the advantages of using the 4N group for short-term gains. The performance of the communal brooder group was relatively good for a long-term selection program. In 2000 a breeding program of silver barb started by using the population base of communal brooders. Mass selection was used to improve growth.

Table 4.25. The growth* of silver barb in Experiment 1. Mean ± standard deviation.

Group	Body weight, g		
	At stocking	On-station trial	On-farm trial
Can Tho x Can Tho	7.9	60 ± 1.6^{b}	73 ± 4.3^{a}
Tien Giang x Tien Giang	6.9	63 ± 1.4^{a}	58 ± 3.5^{b}
Tien Giang x Can Tho	7.2	66 ± 1.5^{a}	68 ± 3.5^{a}
Bassac x Bassac	6.5	55 ± 1.4^{cd}	50 ± 3.8^{b}
Ben Tre x Ben Tre	7.3	57 ± 1.4^{bc}	57 ± 3.7^{b}
Ben Tre x Bassac	8.2	55 ± 1.6^{cd}	54 ± 3.7^{b}
Mekong x Mekong	7.0	53 ± 1.6^{d}	51 ± 3.9^{b}
Dong Nai x Dong Nai	6.5	64 ± 1.6^{a}	66 ± 4.2^{a}
Mekong x Dong Nai	7.6	57 ± 1.0^{bc}	56 ± 2.7^{b}

*Different superscripts indicate significant ($P<0.01$) differences between genetic groups.

Table 4.26. The growth* of silver barb in Experiment 2. Mean ± standard deviation

Group	Body weight, g	
	At stocking	At harvest
Dong Nai x Dong Nai	7.7	58 ± 1.5^{b}
Can Tho x Can Tho	7.1	62 ± 1.0^{a}
Tien Giang x Tien Giang	6.6	56 ± 1.5^{b}
Tien Giang x Can Tho	6.7	51 ± 1.8^{c}
Can Tho x Tien Giang	6.1	53 ± 1.5^{c}

*Different superscripts indicate significant ($P<0.01$) differences between genetic groups.

Table 4.27. The growth* of silver barb in Experiment 3. Mean ± standard deviation.

Group	Body weight, g	
	At stocking	At harvest
Selected x Selected	6.2	53 ± 1.0^{a}
Communal x Communal	5.7	50 ± 0.6^{b}
Mekong x Mekong	4.3	49 ± 0.9^{bc}
Can Tho x Can Tho (Control)	5.6	46 ± 1.1^{c}
Can Tho x Can Tho (Selected)	4.9	46 ± 1.0^{c}

*Different superscripts indicate significant ($P<0.01$) differences between genetic groups.

Genetic improvement of blunt snout bream

Blunt snout bream are naturally distributed in only a few lakes in the middle reaches of the Yangtze River, China. This species exhibits several desirable qualities for aquaculture, including good performance in culture, a grass diet, resistance to disease, easy fishing, good reproduction and a high survival rate.

China

China undoubtedly has the longest history of fish culture of Asian countries. It also has a long tradition of the use of selection to produce fish of desirable body shape and colour. The production of fish through aquaculture far exceeds the production in other countries in the world.

Objective—Since 1964, blunt snout bream has been domesticated and has become important to aquaculture in the whole of China (Ke 1965). In 1999, the overall production of all bream species was 480,000 tons, ranking sixth among freshwater fishes cultured in China. After domestication, the aquaculture performance of many broodstocks of this species deteriorated with slower growth, earlier maturity, smaller size at maturity and thinner and longer bodies. Poor management of breeders and inbreeding is the major reason for this deterioration in performance.

Systematic selection for desirable traits in blunt snout bream was started in 1986. The founding population for selection originated from the Yuni Lake (2000 ha) in Hubei province in 1985 and 1986. This initial population was used to establish two parallel groups for selection (line 1 and line 2) and one control group. Another reference control group was based on the original brood fish introduced from Liangzi Lake (26700 ha) in Hubei province in early 1998. The objective of the present project was to continue selection for increased growth rate, so that fish can reach an ideal market size of 500-600 g in their second year under normal culture conditions.

Research methods—Experimental founding populations were created with fish collected in Lake Yuni in 1985 and 1986. Two selected lines (to allow for replication and unforeseen catastrophes), a control group and an inbred line were developed from this base population. Another reference group, based on the original brood fish introduced from Lake Liangzi, was created in early 1998. 15 male and 15 female brood fish were introduced from Lake Yuni at the end of 1985; 46 females and 112 males were introduced from the Lake in late 1986. A control group was created from these fish. Later in 1992, 2000 juveniles were collected at Lake Yuni and mixed with the control group. A reference control, based on eight females and 12 males, was established with fish from Lake Liangzi in early 1998. Offspring of both control groups were kept without selection.

It would take 18 years to produce six generations of selected fish, because this fish takes three years to mature under natural conditions. However, we found that this fish matures and reproduces normally in 2+ year-old fish with intensive cultivation. Earlier maturing fish are smaller, weigh less and have lower fecundities (average 11,900 eggs) than 3+ year-old fish, but have the same sized eggs (diameter = 1.05mm) (Li, 1998). To accelerate selection, both 2+ year-old brood fish and 3+ year old brood fish were used for selection experiments after 1992. Selection strains I and II reached the sixth generation (F6) in 1998 and 1999, respectively.

Full-sib mating experiments, designed to study the effect of inbreeding, have also been carried out since 1989. A pair from the original stock was used to breed and the offspring were cultured without selection. Full-sib matings were made when these fish matured. Aquaculture performance and isoenzyme variability were monitored in successive generations, which were kept for grow-out and reproduction but without selection.

Fishes of four groups, including selective strains I and II, the inbreeding group and control group, were tagged by fin clipping and raised communally in tanks (28 m^2) and ponds (1400 m^2). Fish were reared using a complete randomised block design to compare aquaculture performance of the various groups. Four replicates were generally used to eliminate the influence of environmental variability. Absolute body weight gain per day, coefficients of variation (CV), frequency of deformity, over-winter survival rate, selective response and realized heritability were calculated.

Results—Comparisons of total length and body weight between four groups of 5th generation (F_5) blunt snout bream at one, two and three years of age are shown in Table 4.28. Total lengths of the two selected lines were significantly greater ($P = 0.0001$) than lengths of the control and inbred groups in all three years. Fish in line I of the selected group were significantly longer than those in line II in all three years. The control group was significantly longer than the inbred group in years one and two, but not in year three. A similar result appeared for body weights, except that in the third year the two selected lines were not significantly different from each other. These two lines were significantly heavier than the control group and the inbred group ($P = 0.001$), which were not significantly different from each other.

Table 4.29 shows the relative daily weight gain of one-year old fish in selected line I (F_6) and F_4 inbreeds, as well as for two-year old fish of selected line II (F_5) and F_3 inbreeds. Growth in the selected group was significantly greater than growth in the control group. Fingerling testing was conducted in eight tanks using communal stocking. At the end of the year, fish from eight tanks were pooled into a 1,400 m^2 earthen pond for grow out. The average absolute weight gain of the two-year old selected line II fish improved 29% more than the control group did; each generation improved by 5.8%. Whereas, growth of the F_3 inbred group was 17% less (5.5% less per month) than that of the control group.

The over-winter survival rate of fingerlings differed significantly among the selected line, control group and inbred group. Compared with the control group, the selected line had 38% greater survival, but the inbred group had 28% less survival. In 1998, 2.8% of the fingerlings of the fourth generation (IB_4) of the inbred group were deformed. After discarding abnormal fingerlings, 1.8% of the fish in this group were deformed after 290 days of growth. However, no deformed fingerlings were found in the selected or control groups.

The estimated realized heritability of body weight gain in one-year old fish is 0.07. The effects of selection and inbreeding on levels of genetic variability were examined by Li and Yang (1996) with biochemical genetics markers. The proportion of polymorphic loci (P) was the same (5.26%) in the selected line F_4 and inbred group second generation, but was 20% higher in the control group. Average heterozygosity (H) was highest in the selected line F_4 (0.02) and lowest in the inbred group F_2 (0.017). These results indicated that heterozygosity increased by 4% after four generations of selection, which tends to reduce genetic variability but decreased 15% after two generations of strong inbreeding (-7.5% per generation). As expected, strong inbreeding leads quickly to the loss of genetic variability.

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Table 4.28. Standard length (cm) and body weight (g) of genetic groups of F_5 blunt snout bream at different ages*, mean ± standard deviation.

Group	Year	Standard length	Body weight
Selected, line I	1	12.8 ± 1.4^a	49 ± 19^a
Selected, line II	1	12.5 ± 1.1^b	46 ± 13^b
Control	1	11.0 ± 1.7^c	33 ± 16^c
Inbred	1	10.6 ± 1.2^d	26 ± 11^d
Selected, line I	2	23.9 ± 1.9^a	415 ± 97^a
Selected, line II	2	23.4 ± 1.5^b	359 ± 68^b
Control	2	21.8 ± 2.2^c	328 ± 85^c
Inbred	2	21.2 ± 1.7^d	272 ± 74^d
Selected, line I	3	33.8 ± 1.4^a	1043 ± 394^a
Selected, line II	3	33.1 ± 1.1^b	941 ± 667^a
Control	3	31.8 ± 1.5^c	817 ± 120^b
Inbred	3	32.1 ± 2.0^c	786 ± 93^b

* Different superscripts indicate significant ($P<0.01$) differences between genetic groups.

Table 4.29. Relative daily weight gain (g/day) of selected and inbred groups compared with control groups at one and two years of age.

Age	Control	Selected Line I	Selected Line II	Inbred IB4	Inbred IB3	Selected / Control, %	Inbred / Control, %
1	0.25	0.55	-	0.18	-	117	-27
2	0.76	-	0.98	-	0.63	29	-17

Genetic improvement of rohu

Rohu is a natural inhabitant of the rivers of north India, Pakistan, Bangladesh, Burma and Nepal, but has been exported for culture in several other countries.

India

Rohu is one of the most common aquaculture species in India. The Ganga River network in the northern part of the country is their natural habitat, where they breed naturally. However, they do not breed in confined waters, even when mature. In 1957, pond reared and matured carps were successfully bred by the administration of pituitary hormones. Since then, the technique has been used widely, even among fish farmers. Over the last two decades, the production of larvae has become a routine practice in research and among fish farmers. This practice, however, has lead to problems, because there has been no systematic approach to the domestication of these carps. The production of seed does not follow any genetic procedures, particularly in the management of brood fish, the maintenance of effective breeding number or the replenishment of brood stock (Eknath and Doyle 1990). Consequently, the quality of hatchery-produced larvae appears to have declined, as indicated by poor survival and growth.

Objective—Previous studies conducted by Basavaraju et al. (1998) indicated that the existing major carp populations in the hatcheries of Karnataka are likely to be inbred. The two major hatchery stocks were considered as reproductively and genetically isolated inbred populations. The first objective was to produce crossbreeds of these two populations and to evaluate their performance in different aquaculture systems.

Genetic management and improvement of rohu stocks is urgently needed to boost production. This is being attempted through selective breeding. Moreover, selective breeding requires knowledge of the pedigree of selected populations. The rearing of offspring from different families before they can be physical tagged requires separate nursery ponds or cages, which is space and labour intensive. These limitations can potentially be overcome with family specific DNA fingerprinting profiles. The major objectives in a second part of this project were 1) to produce DNA fingerprints of controls, unselected and selected stocks, and to attempt to correlate DNA markers with performance traits for use in marker-assisted selection, 2) to search for unique molecular markers for use in breeding programs, 3) to evaluate suspected inbreeding in farm-stocks, and 4) to make genetic linkage maps in Indian major carps. This will support the conventional selective breeding via marker-assisted selection.

Research methods—Crosses, reciprocal crosses and pure lines of rohu were produced by transporting the milt on ice between two hatcheries following hypophysation and dry stripping (Basavaraju *et al.* 1998). Crosses were made by fertilizing eggs pooled from four to five females with milt from five males. The eggs fertilized by individual males (crosses and pure lines) were incubated separately in jars, and the spawn was pooled for each breed by taking about the same number of eggs. Fry were reared separately until they were large enough to tag for growth trials. Fish weighing about 6 g were tagged with PIT tags for easy identification of individual breeds. Growth performances of crosses and pure lines were evaluated at two locations, the Fisheries Research Station, Hesaraghatta (mono and polyculture) and the Government fish farm, B.R. Project (polyculture).

Researchers at CIFA and NBFGR collected blood samples in September 1999 from the second generation of rohu in the selection programme at CIFA, Bhubaneshwar, India. Samples were fixed in 95% alcohol in a 1:5 ratio and stored at 4°C until analysis. Blood was collected from four groups: a) families in the selection programme, b) unselected families, c) control – CIFA farm stock, and d) rohu from an unrelated seed producing hatchery, Neelamber Fish Farm, Nanoki- Sakrali, Punjab, India.

Samples for RAPD analysis at CIFA included: "CIFA-selected" (CIFA-s, N = 53); "CIFA-unselected" (CIFA-u, N = 51); "CIFA-control" (CIFA-c, N = 19) and Parents of families (N = 12). Samples used for RAPD and microsatellite analysis at NBFGR included: "CIFA-Selected" (CIFA-s, N = 58); "CIFA-Unselected" (CIFA-u, N = 52); "CIFA-Control" (CIFA-c, N = 20) and Neelanbar fish farm (HATCH, N = 70). Total DNA from alcohol preserved blood was extracted with Proteinase K digestions followed by a standard phenol: chloroform protocol and dissolved in TE buffer (pH 8.0). The concentration of genomic DNA was adjusted to 25 ng/ml TE for use as a template for PCR.

DNAs from selected and unselected fish were examined for polymorphisms with RAPDs using 40 random 10-mer primers from Operon Tech. Inc. (Operon A kit), USA. The PCR reaction conditions were as follows: denaturation for 4 min at 94°C, 45 cycles of denaturation for 1 min at 94°C, annealing for 1 min at 36°C and polymerization for 2 min at 72°C; and a final extension of 7 min at 72°C. The PCR products were fractionated by electrophoresis through 1.8% agarose gels and denaturing gradient gel electrophoresis (DGGE) for polymorphism and marker studies. Probe based DNA fingerprints were created with different combinations of 4 oligonucleotide probes, (GATA)4, (GACA)4, (GGAT)4 and (CAC)5, and five restriction enzymes, Hinf 1, Taq 1, Msp 1, Alu 1 and Hind III, with southern blotting and hybridization techniques.

A single microsatellite locus, G1, was examined for variability with primer sequences developed for *Catla catla* (Naish and Skibinski 1998). The forward primer was 5'-AGCAGGTTGATCATTTCTCC-3' and the reverse primer was 5'-TGCTGTGTTTCAAATGTTCC-3'. The PCR reaction mix contained 50 ng of template DNA, 5 p moles of each primer, 0.2 mM each dNTP, 1X Taq buffer, 2.0 mM $MgCl_2$ and 1.5 U Taq polymerase. PCR amplification conditions were: 5 min at 94°C, 30 sec at 94°C, 30 sec at 55°C, 1 min at 72°C for 25 cycles, 4 min at 72°C and 40°C in a Perkin-Elmer thermal cycler 480. DNA fragments were separated by electrophoresis in 10 % PAGE (19:1) gels and stained with silver.

Results—The final mean weights of crossbreeds in polyculture at both locations were slightly higher than final mean weights of the pure breeds (Table 4.30). However the difference in weight gain was not statistically significant. The final mean weights at BRP were higher than those in polyculture at FRSH. The possible reason for this could be the size of the pond, water source and the survival rates, which were comparatively low at BRP. In polyculture, the contribution of the crossbreeds to the total biomass (yield) was significantly higher than the contributions of pure breeds at both locations (47% and 10% at BRP and FRSH, respectively). This indicates that although the crosses did not attain significantly higher weights, on average, their contribution to total yield was significantly greater. A similar trend was seen in earlier studies on catla in which crossbreeds also yielded more than pure lines (Basavaraju et al. 1997). In monoculture, however, pure lines attained higher mean weights compared to crossbreeds (Table 4.31). The final biomass of crossbreeds was 15.90% less than the biomass of pure breeds. Unlike, catla, the results of the growth trials of inbred lines does not give a clear indication of genetic deterioration in rohu. Genetic deterioration can be reduced by improving broodstock management and breeding practices. As a short-term approach it is beneficial to produce crossbreeds, as their overall performance is superior to that of pure lines.

The primers that amplified clear and reproducible bands in unrelated individuals of rohu were used for RAPD analysis to search for differences between selected and unselected fish (second generation). Forty primers were tested (OPC & OPY series), of which 30 generated banding profiles. Among the forty primers, 11 primers from OPC and 12 primers from OPY produced polymorphic bands, both in selected and unselected stocks of rohu. The thirty primers giving results produced different RAPD banding patterns. The total of 537 bands were scored, of which 275 occurred in selected and 262 in unselected fish. Each random primer amplified 9.16 polymorphic bands, on average, in selected and 8.73 polymorphic bands in unselected fish.

About 26.2% and 22.5% of the amplified bands in selected and unselected fish, respectively, were polymorphic. However, no RAPD marker(s) unique to each group were detected. To verify the above results, PCR products using OPC 01, OPC 02, OPC 03, OPC 04, OPC 07, OPC 08, OPC 09 and OPY 14 were resolved through Denaturing Gradient Gel Electrophoresis (DGGE). So far, only two primers, OPC 08 and OPC 12, showed a single band that was present in selected stocks, but absent in unselected stocks. Mendelian inheritance for these banding polymorphisms should be established through analysis of family data. Attempts to find family-specific markers with RAPDs were made with eight random primers (OPY 02, OPY 03, OPY 04, OPY 05, OPY 07, OPY 14, OPY 15 and OPY 17) to establish genetic tags for the ongoing breeding programme. Among these, only OPY 15 showed parent-specific bands.

Probe-based DNA fingerprinting was tested with combinations of four oligonucleotide probes, (GATA)4, (GACA)4, (GGAT)4 and (CAC)5, and five restriction enzymes, Hinf 1, Taq 1 Msp 1, Alu 1 and Hind III. The combinations Hinf 1 / (GACA)4 and Taq 1 / (GATA)4 generated polymorphic fingerprints in samples from unrelated fish. Subsequent experiments with these combinations in selectedversus unselected fish and a search for family-specific markers were unsuccessful, most likely because of the degradation of the DNA probes during a power failure.

A total of 20 random-sequence PCR primers were tested and nine of these yielded clear banding patterns showing some polymorphisms among individuals. Banding patterns were estimated to represent 54 loci. The samples of different groups were analysed with nine primers. Percentage polymorphism, heterozygosity and mean number of alleles per locus were marginally different among the four groups (Table 4.32). Analyses of 43 possible tests at 54 loci detected significant frequency heterogeneity of RAPD alleles for all the groups of rohu samples ($p < 0.0001$). The results of 29 tests were significant ($p < 0.05$) after Bonferroni's adjustment for simultaneous comparisons. The data were further tested for allelic heterogeneity between six possible pairs of groups and these results indicated that a major contribution to heterogeneity was due to differences between hatchery samples and other samples. The selected, unselected and control groups differed at 8 RAPD loci (Table 4.33). Allele frequencies and heterozygosities in Table 4.34 indicate that selective breeding led to significant increases or decreases in allelic frequencies and levels of heterozygosity. However, no locus provided genetic tags for individual identification. Nevertheless, frequencies of a dominant allele increased to 1.0 at loci A01-2 and A17-4. A significant difference in allelic frequencies also occurred at loci A04-4 and A14-3. The loci, A04-3, A 15-3, A15-5 and A20-3, also showed a significant decrease in allelic frequencies, compared to other groups.

At the G1 locus, only four alleles were observed, with sizes of about 121, 135, 171 and 187 bp. The samples from the selected and unselected groups lacked the 121 bp allele. The control group had only two alleles, 171 and 135 bp, and the hatchery sample lacked allele 171 bp (Table 4.34). The largest observed and expected heterozygosities occurred in CIFA-s and the smallest in CIFA-c. The G1 locus showed significant heterogeneity in allelic and genotypic frequencies when tested over all groups of samples ($p < 0.0001$). However, pairwise comparisons of allelic frequencies failed to detect significant differences between selected, unselected and control CIFA samples. All three groups were significantly different from the hatchery population. The Weir and Cockerham (1984) estimator (F) was calculated for four samples. An excess of heterozygotes was observed at the G1 microsatellite locus and was significantly different from zero (Table 4.35). F_{is} values based on RAPD markers did not differ significantly from zero.

Table 4.30. Performance of hatchery stocks of rohu and their crosses in polyculture systems at two locations*.

Location	Group	Initial weight, g	Final weight, g	Weight gain, g	Survival rate, %
BRP	BRPxBRP	5.4±0.1^{c}	144±11	139±11	44^{a}
	BRPxTB	7.8±0.2^{a}	179±9	171±9	44^{a}
	TBxBRP	5.6±0.1^{c}	160±4	154±4	41^{b}
	TBxTB	6.0±0.1^{b}	154±17	148±17	22^{c}
FRSH	BRPxBRP	6.3±0.1^{C}	94±6	88±6	90^{B}
	BRPxTB	7.9±0.1^{A}	100±10	92±10	100^{A}
	TBxBRP	6.6±0.1^{B}	110±9	104±9	90^{B}
	TBxTB	6.4±0.1^{BC}	105±6	99±6	90^{B}

* Different subscript letters indicate significant ($P<0.05$) differences between fish groups within locations.

Table 4.31. Performance of hatchery stocks of rohu and their crosses in a monoculture system at FRSH*.

Location	Group	Initial weight, g	Final weight, g	Weight gain, g	Survival rate, %
FRSH	BRPxBRP	5.1±0.1^{c}	73±3^{b}	68±3^{b}	88^{c}
	BRPxTB	6.6±0.1^{a}	64±3^{c}	58±3^{cb}	92^{b}
	TBxBRP	5.5±0.1^{b}	78±3^{b}	73±3^{b}	92^{b}
	TBxTB	5.2±0.1^{c}	96±6^{a}	91±6^{a}	96^{a}

* Different subscript letters indicate significant ($P<0.05$) differences between fish groups.

Table 4.32. NBFGR: Estimates of heterozygosity, polymorphism (%) and mean number of alleles for RAPD loci in selected (CIFA-s), unselected (CIFA-u) and control groups of rohu from CIFA (CIFA-c) and from an unrelated hatchery (Hatch).

Group	Heterozygosity		Polymorphic loci	Mean no. of
	H_{exp}	H_{obs}	%	alleles/loci
CIFA-s	0.24	0.24	58.5	1.6
CIFA-u	0.24	0.25	58.5	1.6
CIFA-c	0.22	0.23	52.8	1.5
Hatch	0.22	0.22	61.1	1.7

Table 4.33. Frequency of dominant alleles and heterozygosities (in parentheses) at eight RAPD loci in selected (CIFA-s), unselected (CIFA-u) and control groups of rohu from CIFA (CIFA-c) and from an unrelated hatchery (Hatch).

Group	Locus							
	A04-3	A04-4	A01-2	A15-3	A15-5	A14-3	A20-3	A17-4
CIFA-s	0.550 (0.500)	0.840 (0.280)	1.000 (0.000)	0.375 (0.477)	0.193 (0.295)	0.833 (0.285)	0.477 (0.500)	1.000 (0.000)
CIFA-u	0.663 (0.456)	1.000 (0.000)	0.825 (0.300)	0.586 (0.482)	0.446 (0.464)	1.000 (0.000)	0.693 (0.431)	0.771 (0.375)
CIFA-c	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.375 (0.500)	0.313 (0.375)	1.000 (0.000)	0.500 (0.500)	0.625 (0.500)
Hatch	0.500 (0.500)	1.000 (0.000)	1.000 (0.000)	0.285 (0.415)	0.531 (0.500)	1.000 (0.000)	0.866 (0.238)	0.007 (0.014)

Table 4.34. NBFGR: Allele frequencies and heterozygosity values (observed and expected) in rohu belonging to selected (CIFA-s), unselected (CIFA-u) and control groups from CIFA (CIFA-c) and an unrelated hatchery (Hatch).

Group	Number	Heterozygosity		Alleles			
		H_{exp}	H_{obs}	187	171	135	121
CIFA-s	58	0.416	0.552	0.035	0.241	0.724	0.000
CIFA-u	49	0.400	0.531	0.020	0.245	0.735	0.000
CIFA-c	19	0.301	0.368	0.000	0.184	0.816	0.000
Hatch	51	0.372	0.471	0.206	0.000	0.765	0.029

Table 4.35. Inbreeding Coefficient (F_{is}) calculated following Weir and Cockerham's (1984) estimator for microsatellite (G1) and RAPD markers in four samples of rohu.

Group	F_{is}	
	G1	RAPD
CIFA-s	-0.31792*	0.00080
CIFA-u	-0.31785*	-0.00629
CIFA-c	-0.20000*	0.03134
Hatch	-0.25589*	-0.00155

*Values deviating significantly from zero. Negative values indicate excess of heterozygotes.

Summary and Discussion

The objective of the genetic enhancement research was to transfer the selective breeding (GIFT) technology to major species of carps in Asian countries. This technology includes forming a base population with a broad genetic diversity, producing separate families, tagging of individuals to track pedigrees, testing of fish from all families in different production environments, and selecting brood fish for several traits based on their own performance and the performance of their relatives.

In the present project, brood fish from domesticated and/or wild populations of common carp and silver barb were used in crossbreeding experiments to form base populations with a broad genetic diversity. These experiments were also used to estimate hybrid vigour (heterosis). In general, hybrid vigour was only observed for fitness traits (i.e. fertilization, hatchability and survival) and not for production traits (i.e. growth).

The major challenges for transferring the GIFT technology to carp species were limitations in producing a large number of families in separate units and problems tagging individual fish with external tags. Carps are generally less tolerant than tilapias to rearing in hapas (small net cages) and are therefore reared in concrete tanks and ponds. As a result, carp breeding programs require larger physical facilities than do tilapia breeding programs. Furthermore, it seems that external tags, such as Floy tags, are not ideal for carps and that more expensive internal tags (e.g. PIT tags) are required. However, experiences in Indonesia and Vietnam suggest that it is possible to produce families of common carp in hapas when reared at low densities, and that it is also possible to use external Floy tags if the inserting needles are sterilized before use.

Due to problems with producing individually tagged family groups of carp, individual selection (i.e. mass-selection) was chosen as the strategy to genetically enhance fish in projects. Fish from the base population were stocked in the same pond and allowed to breed with each other. Fry were collected and stocked in another pond; selection of brood fish to produce the next generation was based on the performance of the breeding candidates themselves. This mass-selection strategy can only be used to improve traits that can be measured on the breeding candidates while they are alive. As a result, selection criteria are restricted to growth (measured as body weight at harvest), body shape and colour. A major concern with the use of a mass selection is the problem with uncontrolled mating of relatives that leads to inbreeding and to inbreeding depression. Experiences in China and Vietnam suggest that the mass-selection strategy might give acceptable genetic gain in the first 5-6 generations of selection, but selection responses in later generations are restricted due to loss of genetic diversity in the breeding population.

Training and workshops

There were three major workshops and two training sessions conducted during Phase I of the project.

The first workshop was a Planning Workshop for the Genetic Improvement of Carps Species in Asia Project held from 26-29 July 1997 at the Central Institute of Freshwater Aquaculture, Bhubaneswar, Orissa, India. ICLARM organized the planning workshop to spin-off the activities of the project. The objectives of the planning workshop were:

1) to review existing information on carp species;
2) to discuss and unify research methodologies and development of a work plan and
3) to finalize work plans and their implementation schedules for the six participating countries.

Thirty-one collaborators from the six participating countries, one from Malaysia and five ICLARM staff participated in the planning workshop.

A Review Workshop on the Carp Genetics Project together with the INGA Steering Committee meeting was held from 1-5 March 1999, Kuala Lumpur, Malaysia. Eighteen collaborators of the Carps Project attended the review workshop. Other INGA member countries and representatives from associate member-institutions were also present during the meeting.

The Final Workshop was conducted at the Freshwater Fisheries Research Centre, Chinese Academy of Fishery Sciences, Wuxi, China on 14-17 November, 2000. The objectives of the final workshop were: to present results of data analysis of the surveys and experiments and to finalize plans for the next phase of the project. The final workshop in Wuxi was extended from 18 November to 2 December held in Penang, Malaysia to finalize the reports for both the socioeconomics and genetics components of the project.

The Training Workshop on Socioeconomic Analysis of Carp Farming and Genetic Research Prioritization in Asia was held from 26 January-11 February 1999 at ICLARM Headquarters in Makati, the Philippines. Ten socioeconomists from the six participating countries were trained for data analysis and use of statistical softwares. Four ICLARM staff were involved in the training. Another training session was conducted entitled "Training Workshop on Analysis of Socioeconomic and Genetic Data" at the Equatorial Hotel, Penang, Malaysia from the 21 March to 7 April 2000. The objectives of this training program were: to help national scientists analyse the data of the surveys and experiments so far completed and to strengthen their capabilities in data handling.

Review of project implementation

ADB Review Mission

There were two major review missions and an inception review conducted by the Bank represented by Mr Weidong Zhou.

The Inception Mission was conducted from 10-12 November, 1997 in Makati, the Philippines. The mission was conducted to assess the initial preparations and plans of the project. The initial preparation and progress of the project was concluded to be satisfactory. Research methodologies and activities had been finalized and participating institutes had been established.

The first review mission was conducted from 9-12 February 1999. The Mission was concluded to be satisfactory. The overall activities and accomplishments of the project were reviewed. Mr Weidong met with scientists from the six participating countries who had attended the Training Workshop on Socioeconomic Analysis of Carp Farming and Genetic Research Prioritization in Asia from 26 January to 11 February 1999. Socioeconomics surveys were being carried out extensively in each of the six participating countries and some preliminary analysis of data were summarized. The impressive approach to the methodology for the socioeconomics component led to an additional grant from FAO to study the production, consumption and accessibility of freshwater aquaculture products in five countries (Bangladesh, China, India, the Philippines and Thailand). For the carp genetic research component, several visits were facilitated and detailed research plans identified.

The second review mission was during the period 27-30 March, 2000, in Penang, Malaysia. Mr Weidong Zhou, ADB's Project Specialist visited ICLARM Headquarters and attended the latter part of the workshop held during that period. The progress of the project was considered to be satisfactory. Discussion with some biologists and economists were facilitated. There were no major issues that hindered the smooth implementation of the project, although there were some delays due to ICLARM Headquarters' move to Penang, Malaysia and some minor reasons from the collaborators.

In-house review at ICLARM-The World Fish Center

Two In-house reviews were conducted at ICLARM in 1999 and 2001 at ICLARM Headquarters in the Philippines and Malaysia, respectively.

One review meeting was conducted among collaborators of the participating countries from 6-7 April 2000. These were the last two days of the training workshop held from 21 March to 7 April, 2000 in Penang, Malaysia. This meeting basically facilitated the interaction and sharing of ideas and experiences between the Socioeconomics and Genetics groups.

General observations on the performance of various participating institutes

Members of the six participating DMCs have carried out the survey process, analysis and presentation of the results excellently. They were very willing to learn different methods of analysis, both in economics and statistics, using computer software. Most of them have learned to use various Econometrics and Statistical software, and some have used their advanced skills in analysis of the other projects in their institutes. Members from the Genetics component group, have shown initiative in other research methodologies and found ways to maximize use of resources such as making their own floy tags instead of buying them from commercial companies. Generally, all the collaborators have expressed enthusiasm and cooperation. Although there were some minor problems, such as delays in the submission of progress reports, these did not cause major issues in the overall implementation of the project.

5. IMPACTS OF CARPS PROJECT

Aquaculture is a rapidly growing industry in numerous Asian countries. The major potential impact of the present project is the transfer of breeding technologies and methods that will enable participating countries to carry out their own breeding programs. These technologies will lead to the improvement of fish strains that can increase production by enhancing growth and survival and ensure a more efficient use of materials available to poor farmers.

Bangladesh

Silver barb has gained popularity among farmers who depend on private and public hatcheries for fingerlings. However, poor broodstock management has led the deterioration of hatchery populations through inbreeding, which has increased susceptibility to diseases, such as epizootic ulcerative syndrome. Therefore, a major influence of the present project includes not only the development of improved strains, but also a better awareness of broodstock management practices to avoid inbreeding and the loss of genetic diversity in hatchery populations.

Genetic improvement, together with better management, will lead to increased fish production by shortening the production cycle. In the present project, strains from Thailand and Indonesia were mixed with local stocks and used for two generations of selective breeding. The additive genetic gain in F_1 crossbred groups was 8%, in F_2 selected fish, gain was 2% over crossbred fish and in F_3 selected fish, gain was 12% over F_2 generation fish. These additive genetic gains in two generations of selection are encouraging for breeding and stock improvement of silver barb.

Another outcome has been the adoption of selective breeding methods that were successful in the GIFT project. The results of selection in the present project confirm this breeding model. BFRI plans to formulate a national breeding plan for silver barb and other carp species. The largest NGO in Bangladesh, BRAC, will also adopt this breeding program. The general dissemination of improved silver barb, produced in this project, is in its early stages. During the last breeding season of 1999, fingerlings were distributed to several fish farmers (nursery and pond grow-out operators) in Fulpur Upazilla of Mymensingh District of Bangladesh. Preliminary evaluations demonstrated that the selected strain grew more rapidly and survived better than local strains. Improved strains of silver barb will not require any additional inputs to the culture system and will therefore lead to greater fish production.

A training program on "Culture of Genetically Improved Silver Barb" was organized for 24 fish farmers at the Freshwater Station, BFRI, Mymensingh 21-23 October, 2000. Similar training programs for farmers, hatchery and nursery operators will continue. Under this program two senior level scientists were trained in the analysis of genetic and socioeconomic data.

China

The activities in this project led to several positive influences on research capacity and fish production. First of all, significant progress was made during the project to improve the growth of Jian carp. This strain is characterized by rapid growth with an average of 30% higher body weight over other local and introduced common carp varieties. The selective breeding during this project has further improved its growth performance by 6-12%. Huanghe carp were crossed with Jian carp to further improve growth and other commercial traits. Body weights of the hybrid Jianhuang (jian carp ♀ × huanghe ♂) were 6-12% higher than for the female parent Jian carp and 19-33% higher than for male parent Huanghe carp. Experiments and farm trials showed that the hybrid Jianhuang has improved growth performance compared with parental varieties. Hybrid Jianhuang, as well as Jian carp, have large potential for use in aquaculture.

The use of these improved strains and hybrids can lead to better food security. Improved Jian carp easily adapts to various culture environments and can achieve increased production in low input culture systems. The market value of improved Jian carp is high. Culture techniques for improved carp species are less complicated than those for other species, so that small farmers can easily master culture methods and achieve greater profits. The successful culture of Jian carps in many impoverished rural areas on a small-scale has improved the well being of farmers and women. Widespread use of improved Jian carp has the potential of helping on a broader scale. The FFRC organized training courses on fish farming techniques and management, these were attended by more than 300 low-income farmers.

Researchers at FFRC have greatly benefited from the exchange of information on the analysis of socioeconomic and genetic data, research methods and breeding technology for improved performance. Under this project, ICLARM introduced to China for the first time the conceptual framework and methodology of socioeconomic research in aquaculture. An important result of this project has been that the Chinese government has paid more attention to carp genetics and breeding. Common carp and other important carp culture species, (crucian carp, blunt-snout bream and silver carp), are now the focus of research projects in China. In view of the successful improvement of Jian carp, the Chinese Ministry of Agriculture has funded a project at the FFRC on the genetic conservation of Jian carp.

Jian carp has been distributed to thirty provinces, municipalities and autonomous regions. Four billion Jian carp seed have been produced and supplied to farmers. The culture area devoted to Jian carp now exceeds more than 660,000 ha and production is over 1,000,000 mt annually, which represents 50% of the total annual production of common carp in China. In some areas, Jian carp production accounts for 70% of the total fish production. 600,000 Jianhuang seed were provided to farmers and 50 ha ponds were involved in growth trials in 2000.

India

The focus of this project in India was to use molecular genetic methods to characterize genetic variation in and among varieties of carp, including crossbreeds of rohu, triploids and monosex populations of common carp. The results of the project have positively influenced production of rohu. One important result was the finding that inbreeding in experimental populations of rohu was not occurring at the same rate as inbreeding in catla. Project activities made gains toward evaluating the usefulness of triploid common carp as a way of controlling reproduction. Triploid fish had low gonadal somatic indices (GSI, 4.99-9.87) and high dress-out percentages and are promising for commercial use. The development of monosex populations will also lead to greater production. Protocols to produce all male populations were optimized and sex-reversed males were crossed with normal females to produce 100% male populations. Although the selective breeding program is not complete, small farmers will most likely adopt the improved strains to increase their production. Improved strains will also be stocked in reservoirs to boost the catch of fisher folk who depend on fish for their livelihoods.

The project has also led to international cooperation. Improved common carp germplasm has been sent from Indonesia and Vietnam to Thailand. Vietnam has also sent some of these strains to India, Bangladesh and Lao PDR, and to Thailand for a second time. Improved rohu has been sent from India to Thailand. India has imported common carp from Hungary (2 stocks) and Vietnam (1 stock). India is also likely to import another stock from Indonesia with the assistance of INGA for the on-going project on Genetic Improvement of Common carp funded by the Department for International Development of UK (DFID) FGP.

This ADB funded project has led to additional funding from other donors and has influenced policies in India. As a result of this project, the state Department of Fisheries has agreed to produce crossbreeds of catla and rohu to increase the fish production. The Department has also agreed to keep separate breeding centres for Indian major carps and common carp to implement genetic improvement programs. DIFD is also providing complementary funds to India for genetic improvement of catla and common carp. This project has also contributed to increased research capacity in India. We conducted one training program on broodstock management and genetic techniques for aquaculture officers and hatchery managers in the Department of Fisheries in collaboration with DFID, FGP.

Plans have been made for the dissemination of improved strains of fish. In the state of Karnataka, the Department of Fisheries plays a major role in disseminating improved fish. The fish developed at the University will be supplied to state hatcheries; in turn, these hatcheries will produce and distribute seed to farmers, either directly or through their Fish Farmers Development Agencies (FFDA). This scheme is the general practice in most Indian states.

Indonesia

The activities of this project have benefited the research activities in Indonesian institutes and farmers in several ways. This project stimulated the development of a network to exchange information at annual meetings to evaluate the research progress and to confer on research problems. Annual meetings were held on 8 February 1999 in Jakarta and 3-4 November 2000 in Bogor. The participating institute is a member of the Indonesian Network on Fish Genetics Research and Development (INFIGRAD) and the Breeding Science Society of Indonesia (BSSI). This project also stimulated the development of inexpensive, but reliable tags for use in the breeding program. Other countries can also benefit from the development of these tags.

Genetically selected broodstock (G1) have been distributed to the small farmers/private hatchery in three steps: 1) from the Research Institute for Freshwater Fisheries (RIFF) – Central Research Institute for Fisheries Indonesia (CRIFI) to the Freshwater Aquaculture Development Centre FADC- Director General of Fisheries (DGF); 2) from FADC-DGF to Centre of Seed Production (CSP-DGF); and 3) from CSP to farmers. In the last step, both seed and broodstock may be distributed. Germplasm and breeding technology have also been disseminated to participating countries and have supported research activities on the genetic improvement of carps in other areas of Asia.

Thailand

Participation in the present project has led to a greater awareness of the importance of aquaculture. The Thai Government has increased its contribution to research in the fields of biotechnology for developing genetically improved breeds of aquatic species, gene banking for conservation of aquatic genetic resources, and dissemination of genetically improved aquatic breeds to public and private sectors. The Government has also increased budgets for production and dissemination of genetically improved breeds to grow-out operations. The National Aquaculture Genetics Research Institute (NAGRI) and their Regional Genetic Centres serve as Primary Multiplier Stations or National Broodstock Centres for production of genetically improved breeders for the Secondary Multiplier Stations as well as for evaluation and certification of multipliers. The Provincial Fisheries Stations under the Department of Fisheries serve as Secondary Multiplier Stations for mass production of genetically improved fingerlings for grow-out operations.

Several areas of research have benefited from this project and will in turn benefit farmers through increased production. One area has been a better understanding of selection methods to improve fish breeds, including not only the development of breeding schemes, but also improved methods of broodstock management. The selected third generation of the Chao

Phraya River population of silver barb was developed by mass selection for body weight. The additive genetic gain by one generation of mass selection for body weight was 30%. To sustain genetic gain in silver barb, a combined family and mass selection for growth and other traits will be adopted as a breeding strategy for genetic improvement of silver barb in Thailand. Gains from these experiments will produce fish that will increase the production of silver barb in Thailand.

Vietnam

This project funded two sub-projects in Vietnam which stimulated progress in several important areas of research and production. In North Vietnam at RIA-1, the project provided an opportunity to learn many technical aspects of fish culture and, in particular, how to design and conduct breeding experiments. Two of the staff at RIA-1 also received training in the use of the SAS computer program for analysing data from the project. One outcome of the project that will be important for the production of common carp, was the demonstration that fry and fingerlings could be reared successfully in hapas. This development provides a means of rearing common carp at rearing facilities lacking suitable earthen ponds. Numerous farmers, especially in the northern highland region, have adopted this method of rearing common carp fry using hapas suspended in lakes or reservoirs.

Several research successes were achieved in the three years of the project. Following a scheme of family selection provided by ICLARM, two generations of selected fish have been raised and are expected to produce a gain in growth of about 5% per generation. The present project introduced family selection to improve traits in carp for the first time in Vietnam. The successes of this project will undoubtedly influence how research is conducted at RIA-1 and elsewhere in Vietnam. Some of the improved common carp fry and fingerlings were distributed to farmers for food production. These fish showed higher levels of survival and growth than did local strains of common carp. The higher level of productivity has reduced required investments by farmers and increased profitability. The present project also stimulated the development of dissemination procedures. Improved strains are deposited in three National Brood Stock Centres, in northern, central and southern Vietnam. These centres will maintain the genetic quality of the brood stock and will distribute fish to provincial and private hatcheries to produce fry for farmers.

In Southern Vietnam at RIA-2, researchers focused on the improvement of silver barb. The Carps Project stimulated the development of breeding methods for research. These methods include the use of hormone injections to induce and synchronize spawning, the development of conical plankton nets for incubation of fry and the use of alcian blue injections and fin clipping to mark fingerlings in breeding experiments. The project also stimulated the improvement of broodstock management. The implementation of these procedures will help to farmers to improve production and will enhance profitability of raising silver barb. In the coming year, about two million silver barb fry will be distributed to private hatcheries and farmers.

6. PROPOSED OUTLINE FOR PHASE II

Summary

Following the promising start in phase I to genetically improving important carp species in Asia, we note progress is still in the early phases. Some countries are close to the start of what selection schemes may be able to provide in growth enhancement and improved efficiency of production. The longer generation time of carps with respect to tilapia means that carp breeding is a longer process and more needs to be done to realize the achievable impacts. However, the immense importance of carps, representing over 50% of the total fresh water aquaculture catch globally, and their central role in Asian aquaculture and food security provide the impetus for further research and development.

ICLARM and our DMC partners propose to increase food fish production and to improve the nutrition and income of small scale fish farmers and poorer fish consumers by developing superior carp (high yielding, disease resistant, improved meat quality, better survival) for aquaculture and by disseminating improved strains to resource poor fish farmers. We believe that this is entirely feasible based on ICLARM's own experience with tilapia and the demonstrated success of the Norwegian salmon industry, employing similar techniques. Previous research projects, the Genetic Improvement of Farmed Tilapia (GIFT) project (partially funded by the Asian Development Bank (ADB) under RETA No. 5279) and the Dissemination and Evaluation of Genetically Improved Tilapia in Asia (DEGITA) project (funded by ADB under RETA No. 5558) applied genetic improvement methods to tilapias and examined the effectiveness of improved strains in enhancing the efficiency of tilapia production among farmers. The use of genetic selection in the GIFT project was impressive. A gain of over 80% in growth was achieved after five generations of selection on families in a base populations consisting of eight genetically diverse strains of Nile tilapia.

The next stage of the project for carp improvement has been developed in a fully participatory mode with all our DMC partners. The prioritization of preferred species and traits for improvement have resulted from documenting knowledge of the genetic resources and farming systems in each of the DMCs, and confirming both producer and consumer preferences through surveys. Evaluation of biotic and abiotic risks has provided input into the ranking of traits of common importance to the six countries, such as disease resistance.

Specifically, the proposed second-phase research project will follow up on promising results of the first phase by (i) continuing the development of improved breeds based on priorities set during the Phase I of the project, (ii) testing improved carp species under on-farm conditions in diverse environments, (iii) assessing economic, social and environmental impacts of the improved strains, (iv) developing national strategies for dissemination of improved strains, and (v) establishing national carp breeding programs. The project framework given in Table 1 details the relevant inputs and outputs in attaining these objectives.

For the people of Asia fish contributes as much 40-80% of the animal protein intake. While capture fish production is showing hardly any growth, aquaculture production has more than doubled between 1990 and 1999 (from 16.8 million mt in 1990 to 42.8 million mt in 1999; FAO 1999). Aquaculture has become the world's fastest growing food-producing sector, with a growth rate of 10% annually since 1984. Asia produces about 91% of the world's total aquaculture production, with China, India, Japan, Republic of Korea, the Philippines, Indonesia, Thailand, Bangladesh and Vietnam as top producers.

Increases in aquaculture production can be achieved through the development and adoption of new technologies (e.g., improved management, better nutrition and genetic improvement of the strains used for culture) and improvements in the economic efficiency of fish farming operations. Given the relatively high technical efficiency of fish farmers in Asia and the evidence of genetic deterioration (including inbreeding depression) of cultured stocks, genetic improvement can play a key role in increasing fish production in Asia.

Introduction

Fish is an important source of animal protein to people in developing countries and contributes as much 40-80% of the animal protein intake in most countries of Asia. World fish production from all sources in 1999 was estimated at 137 million mt, including 43 million mt from aquaculture and 94 million mt from capture fisheries. While capture fish production is showing hardly any growth, aquaculture production has more than doubled between 1990 and 1999 (from 16.8 million mt in 1990 to 42.8 million mt in 1999; FAO 1999). Aquaculture has become the world's fastest growing food-producing sector, with a growth rate of 10% annually since 1984. Asia produces about 91% of the world's total aquaculture production, with China, India, Japan, Republic of Korea, the Philippines, Indonesia, Thailand, Bangladesh and Vietnam as top producers.

Most of the fisheries globally have been either over-exploited or reached maximum sustainable yields and would not be able to contribute to increased production. The world is looking to increased production from aquaculture to meet the increasing demand for aquatic products from growing population.

Increases in aquaculture production can be achieved through the development and adoption of new technologies (e.g., improved management, better nutrition and genetic improvement of the strains used for culture) and improvements in the economic efficiency of fish farming operations. If farmers are reasonably efficient, then increases in productivity would require new inputs and the development and adoption of new technologies (e.g. genetically improved strains of cultured fish, with better performance in terms of growth and survival and better fish farming technology) to increase the fish production further. Given the relatively high technical efficiency of fish farmers in Asia and the evidence of genetic deterioration (including inbreeding depression) of cultured stocks, genetic improvement can play a key role in increasing fish production in Asia.

Previously, the Genetic Improvement of Farmed Tilapia (GIFT) project (partially funded by the Asian Development Bank (ADB) under RETA No. 5279) and the Dissemination and Evaluation of Genetically Improved Tilapia in Asia (DEGITA) project (funded by ADB under RETA No. 5558) applied genetic improvement methods to tilapias and examined the effectiveness of improved strains in enhancing the efficiency of tilapia production among farmers. The use of genetic selection in the GIFT project was impressive. A gain of over 80% in growth was achieved after five generations of selection on families in a base populations consisting of eight genetically diverse strains of Nile tilapia.

Encouraged by the impressive results of the GIFT and DEGITA projects, several carp producing developing member countries (DMCs) of the Asian Development Bank approached ICLARM to initiate a 'GIFT-type' strategic research and training initiative on Asian carps which contribute about 51% to total aquaculture production in Asia. However, the target for genetic improvement of carps is complex because of the diversity of species, farming systems and socioeconomic scenarios prevailing in the various Asian carp producing nations. Also, the generation intervals of most carp species are longer than those for tilapia--about two to three years in tropical environments. Finally, a fish breeder must choose among numerous commercially important traits that might be improved.

Given the complexity and time requirement of the carp genetic research, ICLARM developed a proposal for the consideration of ADB to implementation a collaborative project on the genetic improvement of carps in Asia in two phases; phase I focusing on determining research priorities and initiating research leading to the development of high yielding breeds and strains, and phase II concentrating on (i) the continued development of improved breeds, (ii) dissemination and evaluation of improved carp species, and (iii) establishment of national carp breeding programs. The ADB approved a collaborative project on the genetic improvement of carps in Asia for implementation in two phases, and provided a Technical Assistance Grant (RETA No. 5711) of US$ 1.3 million to ICLARM for implementing the first phase of the Project from 1 June 1997 to 31 December 2000 in six DMCs of the Bank (Bangladesh, People's Republic of China, India, Indonesia, Thailand and Vietnam).

The results of the first phase of the project have been impressive. During the first phase of the project, research priorities (species for genetic improvement, farming environment, and traits) have been identified, genetic resource-bases have been evaluated, and growth rate for some of the priority species have been improved. The project has developed improved silver barb (*Barbodes gonionotus*) in Bangladesh with 22% higher growth performance in 3 generations of selection, improved Jian Carp (common carp, *Cyprinus carpio)*) in China with further growth improvement of 6 to 12%, and improved blunt snout bream (*Megalobrama amblyocephala*) in China with 29% higher growth. Other participating countries have successfully initiated the genetic improvement experiments for growth improvement of priority species. The initial results show that the growth performance of carps can be improved by 10% per generation of selection.

In order to sustain the gain achieved during the first phase of the project, genetic improvement of priority species of carps will have to be continued with the incorporation in the breeding goal of other important priority traits identified. Senior scientists and planners from all the participating member countries of the first phase of carp genetic improvement project and ICLARM scientists met during the Sixth Steering Committee meeting of the International Network of Genetics in Aquaculture (INGA) held in Hanoi, Vietnam, during 8 to 10 May 2001. Progress to date in carp genetic improvement research in different countries was reviewed and all the participants strongly felt the need to continue the research initiated during the first phase of the project and requested ICLARM to approach the Asian Development Bank to finance the next phase of the project under its CGIAR RETA program. This present proposal is based on the analysis of the results of the first phase of the project and discussions and interactions between ICLARM staff and concerned ADB personnel.

Background and Rationale

Carp are the most important cultured fish species in Asia. About 20 carp species are extensively cultured under diverse farming systems; all of these species are natural inhabitants of Asian waters. They are favored by low-income Asian consumers because of taste and relatively low prices; in many areas, carps are the only source of animal protein affordable by the poor. Carp culture in Asia typically involves simple, low external-input pond culture, operated by small farmers in predominantly rice-based farming systems. Much of the production by low-income carp farmers is consumed at home, but extended marketing networks are emerging in some countries. Carp aquaculture generally does not compete with other enterprises for natural resources (land, water), and external inputs (manure, fertilizer, feed) into carp farming are currently low.

Carp breeding is a long process. The important sequential steps to be followed in developing a practical and sustainable carp-breeding program are: 1) identification and prioritization of species, target environments and traits, 2) systematic documentation and evaluation of available genetic resources and choice of genetic base, 3) development of a breeding strategy, 4) development of selection criteria and evaluation (including tagging), 5) development of improved strains through successive generations of selection, 6) impact assessment, and 7) dissemination of improved strains. During the first phase of the project, research priorities (species, farming environments, and traits) have been identified based on survey of fish producers and fish consumers, genetic resource-bases have been evaluated, and growth rate for some of the priority species have been improved. The second phase of the Project will be built on the successes that were achieved by the participating countries and ICLARM during the first phase of the project.

The table below summarizes the carp genetic research priorities with regard to species, farming environments, and traits in six DMCs identified during the first phase of the project.

Country	Species	Trait	Farm Environment
Bangladesh	Silver barb	Growth, higher reproductive performance, dress-out ,and disease resistance	Pond polyculture, seasonal ponds
	Catla	Growth, higher reproductive performance, and color	Pond polyculture
China	Common carp	Growth, meat quality, tolerance to low dissolved oxygen and disease resistance	Pond polyculture
	Blunt snout bream	Growth and infertility	Pond polyculture
India	Rohu	Growth, disease resistance, and dress-out	Pond polyculture
	Common carp	Growth, late maturity, and dress-out	Pond polyculture
Indonesia	Common carp	Growth, disease resistance, dress-out and color	Cage monoculture
Thailand	Silver barb	Growth, survival rate (disease resistance and cold tolerance), and dress-out	Pond polyculture
	Common carp	Growth, survival rate (disease resistance and cold tolerance), and dress-out	Pond polyculture
Vietnam			
North	Common carp	Growth, disease resistance, and dress-out	Pond polyculture
South	Silver barb	Growth, disease resistance, and dress-out	Pond polyculture

The above results indicate the lack of a universal set of priority species or traits that might be used for genetic improvement. Each country has a unique situation, although some traits are common among countries. For example, increases in growth and disease resistance have been identified as priority traits by most of the countries for most of the species. In Bangladesh, catla and silver barb are the important candidates for genetic improvement. Rapid growth, high reproductive performance, bright appearance (for catla), disease resistance (for silver barb) and high dress-out percentage (for silver barb) are the traits identified for genetic improvement. Traits high on the list for genetic improvement in common carp in China are rapid growth, better meat quality, tolerance to low dissolved oxygen and disease resistance. It has been identified that rohu and common carp are the priority species in India, for which rapid growth, high dress-out percentage, disease resistance (rohu) and late maturity (for common carp) are high on the list of traits for genetic improvement. In Indonesian, only common carp is a priority carp species and the priority traits for genetic improvement are rapid growth, higher dress-out percentages, greater resistance to diseases and color. In Thailand, the choice for genetic improvement is silver barb and common carp, for which rapid growth, high dress-out percentage and high survivability (disease resistance and cold tolerance) are important. In Vietnam, silver barb and common carp are the priority species, and the priority traits for genetic improvement would be rapid growth, high dress-out percentages and disease resistance.

Base populations with large genetic diversity have been established in most countries by using fish from different sources in diallel cross experiments. Results of studies undertaken in Phase I of the project have demonstrated that fish in these base populations often perform better than local existing strains (e.g., results in Bangladesh). The improved growth performance is most likely due to the introduction of new and better alleles and/or hybrid vigor. In addition to these results, information on the carp genetic resources of the region has been documented and made available to all. This information will be helpful in developing a base population with high genetic diversity.

Selection for growth has been initiated in some countries, and it has been demonstrated that growth performance of carps can be further improved by selection. The early gains made during the first phase of the project must be consolidated both through the formal installation of national breeding strategies, dissemination pathways and enhanced national capacity. Continued development of the improved carp strains with incorporation of other priority traits (e.g., resistance to diseases and stress, product quality, etc.) will give higher economic gain and will eventually lead to the establishment of a viable carp industry in all the participating countries. A multi-country approach based on the newly established principles of selective breeding (see Annex II to this proposal) can augment work in all DMCs in line with national requirements.

The Proposed Study

Objectives

The general objective of the proposed study is to assist the six participating DMCs (Bangladesh, China, India, Indonesia, Thailand, and Vietnam) to increase food fish production and to improve the nutrition and income of small scale fish farmers and poorer fish consumers by developing superior carp (high yielding, disease resistant, improved meat quality, better survival) for aquaculture and by disseminating improved strains to resource poor fish farmers.

Specifically, the proposed second-phase research project will follow up on promising results of the first phase by I) continuing the development of improved breeds based on priorities set during the Phase I of the project, (ii) testing improved carp species under on-farm conditions in diverse environments, (iii) assessing economic, social and environmental impacts of the improved strains, (iv) developing national strategies for dissemination of improved strains, and (v) establishing national carp breeding programs. The project framework given in table 1 details the relevant inputs and outputs in attaining these objectives.

Scope

The approach to the genetic enhancement of carp species in Asia is composed of two phases. Phase I, which officially ended in December 2000, focused on determining the research priorities and initiating research leading to the development of high yielding breeds and strains. The identification of the key carp species, farming systems, and traits important to collaborating DMCs provides the framework for the research under Phase II in priority areas.

In the proposed second phase, the experimental gains achieved during Phase 1 will be consolidated and the genetic research on enhancement of growth performance would be extended to other important production and marketing traits (e.g. resistance to disease and various biotic stress, improved meat quality, color etc.). The research strategy to be followed for genetic improvement is to improve several traits simultaneously by selecting fish based on selection indices where each trait is weighed according to its economic and/or social importance. This will (selection based on indices) require well-designed breeding programs and advanced statistical analysis of the breeding data. Results of the surveys and experiments conducted during Phase I will be used to inform and guide activities proposed during Phase II. Specifically, the proposed Phase II will comprise of the following activities:

(i.) Economic valuation of priority traits and estimation of breeding value in multi-trait selection

Economic valuation of genetic traits, which was initiated in Phase I through the analysis of producers and consumers survey data, will be extended through the development of new methodologies, using the results of some of the experiments conducted in the six DMCs. Methodology will be developed for estimation of the aggregated breeding value of the individual fish in multi-trait selection. Furthermore, genetic diversity of important traits will be evaluated.

(ii.) Continued development of improved carp strains

The relationship and continuity between the phase I outputs and the research and activities proposed for phase II are given in Annex I to this proposal. Genetic enhancement research will be continued for common carp in China, India, Thailand and Vietnam, for silver barb in Bangladesh, Thailand and Vietnam, for rohu in India, for catla in Bangladesh, and for blunt snout bream in China. Activities will focus on further selection of the best carp species considering other traits (other than growth) like disease resistance and qualitative traits. The potential for improving additional traits other than growth in carps will depend on the development of new methodologies to record these traits, either directly or indirectly. Selective breeding research in Norway has resulted in methodologies for recording disease resistance (using challenge tests) and quality traits (i.e. meat color and texture, fat content and fat distribution) in Atlantic salmon. However, these methodologies need to be tested out on carps before they can be applied in breeding programs.

Since all the participating countries have prioritized more than one trait for genetic improvement, existing methodologies on multi-trait selection will be evaluated with consideration of weights or economic values of traits. It is anticipated that through continued work on estimating the breeding values, all the traits that the countries prioritized as important will be evaluated. In so doing, traits that are positively correlated could be combined resulting in simplified selection procedure.

Although limited research facilities can be considered as one of the constraints to achieving long-term genetic gains, the project will seek to maximize the use of the available resources and to innovate methods appropriate to the DMCs to avoid economic and genetic losses.

Rigorous analysis and complex statistical modeling will be used in the analysis for multi-trait selection. ICLARM will provide guidance in data analysis and modeling exercise.

(iii.) On -farm testing of the improved stains

On-farm trials of the improved carps will be conducted in various agro-ecological zones, production environments (ponds, cages) and production systems (monoculture, polyculture) in the participating DMCs. Improved carps which are tested (on-farm and on-station) will be disseminated to farmers towards the end of the project.

(iv.) Development of strategies for dissemination of improved carp breeds

Detailed survey of carp hatchery operations, brood stock management, and fish seed distribution systems will be conducted in each participating DMCs. Analysis of existing institutional structure for aquaculture research and extension, including the role of private sector, will also be made. Based on the in-depth analysis of carp hatchery and grow-out systems, national strategies for dissemination of genetically improved carps to farmers will be developed.

(v.) Conducting training and workshops to strengthen the capacity of national partners (DMCs)

Training of the national scientists on statistical analysis (e.g. calculate heritabilities and genetic correlations and use these when making selection indices, economic valuation of traits), experimental methodologies (multi trait section) and molecular techniques will be given importance so that they will be able to share the knowledge they have learned amongst and within their respective institutes. To achieve this, extensive workshops and trainings will be conducted. It is highly probable that selected partners will be sent to advanced research institutes to gain knowledge on complex experimental methodologies and statistical modeling. One workshop will be organized to introduce members of the project teams to the techniques of molecular science appropriate to marker assisted selection. This will allow more authoritative interaction between national breeding schemes and upstream providers of molecular markers for the future development of breeding schemes for aquaculture development (see Annex II).

(vi.) Assessment of potential economic, social and environmental impacts of the improved breeds

Impact of the adoption of improved carp strains on the socioeconomic condition of different stakeholders (fish producers, fish consumers, traders, land less laborers, etc.) and on environment (including fish bio diversity) will be assessed. The analysis will include the assessment of impact on poverty alleviation, food security, equity, and sustainability. Strategies and options will be identified to assist the poor fish farmers of DMCs to adopt the improved carp strains.

(vii.) Designing of national carp breeding programs

National carp breeding programs will be designed and established. National breeding programs of the collaborating institutes that have established national breeding programs will be further strengthened through coordination with the International Network on Genetics in Aquaculture (INGA).

Implementation Arrangements

ICLARM will be the Executing Agency (EA) for the study, with national agricultural research system (NARS) in DMCs as partners in implementation. A study team leader will be appointed by ICLARM and each collaborating agency will also appoint a national team leader for its work. ICLARM will submit to the Bank semiannual progress reports, semiannual financial statements accounting for the use of funds, and an audited annual financial statement. Funds will be drawn in semi-annual installments based on the EA's estimate of forthcoming expenditures and subject to satisfactory substantiation of expenditures at the end of the corresponding period. The study will be implemented over a period of three years. A comprehensive completion report will be submitted to the Bank within four months of the completion of the study

Procurement of goods and services and recruitment of expert consultants will be undertaken by ICLARM in accordance with the Bank's *Guidelines of Procurement* and *Guidelines on the Use of Consultants*, respectively, or through other arrangements acceptable to the Bank.

The project will have its main office at ICLARM headquarters in Penang, Malaysia. The collaborating institutions include: Bangladesh Fisheries Research Institute (Bangladesh); Bureau of Socioeconomic Research and Training (Bangladesh); Shanghai Fisheries University (China); Freshwater Fisheries Research Centre (China); Central Institute for Freshwater Aquaculture (India); National Bureau of Fish Genetic Resources (India), University of Agricultural Sciences, Bangalore (India); Central Research Institute of Aquaculture (Indonesia); Research Center for Marine and Fisheries Product Processing and Socioeconomics (Indonesia); National Aquatic Genetics Research Institute (Thailand), Fisheries Economics Division of the Department of Fisheries (Thailand); Research Institute for Aquaculture No. 1 and No.2 (Viet Nam).

Two internationally recruited experts (a Geneticist/Project Coordinator and an Aquaculture Economist), one regionally recruited expert (data analyst), and several visiting scientists[1] from participating DMCs will provide a total of 106 person-months of services in genetics, aquaculture economics, aquaculture, and social and environmental science. National teams will be responsible for specific research and field activities and consist of scientists in the field represented by the corresponding international experts (i.e., geneticist, social scientist and ecologist).

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[1] Visiting scientists in the field of fish genetics and social science to be selected by ICLARM from six participating DMCs as key researchers responsible for analyzing and reporting the results of location-specific research in these countries.

Table 1. Technical Assistance Project Framework

Design Summary	Performance Targets	Monitoring Mechanisms	Assumptions and Risks
A. Goal			
▪ Increase food fish production and improve the nutrition and income of small scale fish farmers and poorer fish consumers by developing improved carp strains (high-yielding, disease resistant, improved quality, better survival) for aquaculture	▪ Increase carp production by 20 to 40% per hectare ▪ Increase income of small scale fish farmers by 15 to 35% Increase per capita animal protein intake of low income consumers by 20 to 30 %	▪ Government statistics ▪ Project termination report ▪ Socioeconomic survey	▪ Commitment of national governments (DMCs) ▪ Adoption of the improved carps by farmers
B. Objectives			
▪ Assist six major carp producing countries (DMCs) in developing improved carp breeds (high yielding, better survival, disease resistant, improved quality) ▪ Assist six participating DMCs in identifying the strategy for dissemination of improved strains for the benefit of poor producers and consumers	▪ Improved carp stains with higher yield (at 20 to 40 % higher yield), better meat quality, more resistance to disease, and higher survival ▪ National carp breeding programs in six participating countries ▪ National strategy for dissemination of improved carp strains in the six participating countries	▪ Semiannual reports, technical documents and final report	▪ Commitment of national government and collaboration of participating agencies in DMCs

C. Outputs

▪ Estimated economic value of priority genetic traits for use in the multi-trait selection procedure in six participating countries	▪ Appropriate methodologies for economic valuation of various traits and for estimation of breeding value of individual fish in multi trait section procedure ▪ Information on economic values of important production and marketing traits in the 6 participating countries	▪ Manual on economic valuation of genetic traits ▪ Progress report and technical papers	▪ Adequate national staff to handle data and statistical analyses ▪ Availability and suitability of data from experiments and surveys in all participating DMCs for use in extracting economic weights for breeding values estimation
▪ Improved methodology on multi-trait selection	▪ Methodology to test carps for disease resistance and quality traits ▪ Estimates of heritabilities and genetic variances and correlations for design of appropriate selection programs for carp ▪ Increased genetic diversity in breeding populations ▪ Improved techniques for rearing and tagging of fish ▪ Development and evaluation of marker-assisted selection programs for rohu in India	▪ Use or application of biological, marker-assisted and statistical methodologies learned in trainings and workshops ▪ Progress reports, review missions and final report	▪ Active participation of DMCs ▪ Sufficient data from DMCs for estimation procedures

▪ Improved carp strains in the participating countries	▪ Faster growing carp strains (common carp in China, India, and Vietnam, silver barb in Bangladesh and Thailand and rohu in India, and bream in China) for adoption by fish farmers in the six participating DMCs. These faster growing strains would be subjected to adequate on-station and on-farm trails before releasing these to fish farmers ▪ Improved strain (increased disease resistance and/or improved quality traits in addition to increased growth performance in several production environments) of common carp in China, India, Thailand and Vietnam, silver barb in Bangladesh, Thailand and Vietnam, rohu in India, and bream in China for on-farm testing	▪ Progress report and final report	▪ Adequate research facilities ▪ Adequate number of qualified researchers ▪ Active participation of NARS institutes and national scientists ▪ Adequate support of DMCs ▪ Active participation of local farmers ▪ Adequate coordination of ICLARM and NARS

▪ Strategies and options to assist DMCs' resource poor fish farmers to adopt improved carp strains	▪ Analysis of carp hatchery and grow out operation systems based on surveys and appraisals ▪ Analysis of existing structure for aquaculture research and extension, and brood stock management (including the role of private sector) ▪ Analysis of the potential impact of the improved carp stains on different stake holder groups and on environment in the six participating countries ▪ Established national strategies for dissemination of improved carp in the six participating countries for the benefit of poor households	▪ Progress reports, review missions and final report	▪ Active participation of national governments ▪ Active participation of local farmers and consumers
▪ Strengthened capabilities of participating DMCs in multi-trait selection methodologies, molecular techniques, and statistical analyses	▪ About 40 national scientists are trained on multi trait section methodologies, molecular techniques and statistical analyses ▪ Information, training manuals developed for use of the national scientists of DMCs	▪ Progress reports	▪ Active participation of national governments

▪ Strengthened national breeding programs	▪ Established national carp breeding programs in the six participating countries ▪ Strategies for continued genetic enhancement of carp in the participating DMCs.	▪ Progress reports and final report	▪ Active participation of NARS ▪ Adequate support of national governments

Annex I to the phase II proposal: *The relationship between outputs from the phase I project and activities proposed in phase II*

Country	Achievements during Phase I	Issues to be addressed in Phase II
Bangladesh	▪ Three generations of selection for growth of silver barb were done. The cumulative genetic gain is about 22%. ▪ Catla and silver barb were identified as priority species for genetic improvement. ▪ Rapid growth, high reproductive performance, bright appearance (for catla), disease resistance (for silver barb) and high dress-out percentage (for silver barb) were identified as the priority traits for genetic improvement. ▪ Genetic resource-base of carps have been evaluated and documented. ▪ Catla broodstock were collected from three river systems. These genetic stocks will be used to derive the initial base population for future selection. ▪ Surveys of 540 fish producing households and 360 fish consuming households were conducted to identify priorities for carp genetic research. ▪ Research priorities (species for genetic improvement, farming environments, and traits) have been identified. ▪ Fingerlings of improved silver barb were disseminated to fish farmers (nursery and and grow-out operators in Mymensingh District) for on-farm testing. Results show that selected (improved) fish grew	▪ Improvement for growth of silver barb will be continued. ▪ Addition of other traits for selection (higher reproductive performance, higher dress-out percentage, and disease resistance) of silver barb will be considered for further selection. ▪ Selection of catla for growth, higher reproductive performance and color traits will be initiated. ▪ Improved silver barb will be tested in different farming systems under on-farm conditions. ▪ Strategies for dissemination of improved carp breeds will be developed. ▪ Potential economic, social and environmental impacts of the improved carp breeds will be assessed. ▪ National carp breeding program will be designed.

	more rapidly and survived better than local strains. ▪ Twenty-four fish farmers were trained on "Culture of Genetically Improved Silver Barb".	
China	▪ Growth of Jian carp (an improved strain of common carp) was improved further by 6 to 9% through selection. ▪ Crossbreeding of Jian carp and Huanghe strain was done which resulted to about 6-12% improvement in growth performance. ▪ Continued the genetic improvement of blunt snout bream project at Shanghai Fisheries University, and made further growth improvement of 29%. ▪ Four billion Jian carp seed have been produced and distributed to thirty provinces, municipalities and autonomous regions. ▪ Jianhuang (Jian x Hunaghe) seed were produced and distributed to farmers for evaluation experiment. ▪ The genetic resource-base of carps has been evaluated and documented. About 22 carp species have the potential for use in aquaculture. ▪ Activities of the project have led the government of China paying more attention to carp genetics and breeding. The government has funded a project at the Freshwater Fisheries Research Centre on genetic conservation of Jian carp. ▪ Surveys of 383 fish producing households and 480 fish consuming	▪ Genetic improvement for growth of common carp will be continued. ▪ Other traits like meat quality, tolerance to low dissolved oxygen and disease resistance will also be considered for selection of common carp. ▪ Selection of blunt snout bream will be continued with addition of fertility trait. ▪ Improved fish (common carp and blunt snout bream) will be tested in different ▪ agroecological zones and environments under farm conditions. ▪ Potential economic, social and environmental impacts of the improved carp breeds will be assessed.

	households were conducted to identify priorities for carp genetic research. ▪ Common carp and blunt snout bream were identified as priority species for genetic improvement. ▪ Rapid growth, better meat quality, tolerance to low dissolved oxygen and disease resistance have been identified as priority traits for genetic improvement in common carp in China. ▪ Three hundred low-income farmers were trained in fish farming techniques and management.	
India	▪ Growth trials of rohu were conducted in 2 aquaculture systems (polyculture and monoculture). In polyculture, no significant difference in weight was found between crossbreeds and pure breeds. In monoculture, pure lines attained higher weights than cross breeds. ▪ Molecular genetic methods were used to characterize genetic variation in and among carp breeds, including crossbreeds of rohu, triploids and monosex populations of common carp. ▪ The usefulness of triploid common carp to control reproduction was demonstrated. ▪ Experiments on triploids showed that triploid fish have low gonadal somatic indices and high dress-out percentages which are very promising for	▪ Genetic improvement of rohu will be continued. Disease resistance and high dress-out percentage will be incorporated in the breeding goal. ▪ Common carp will also be improved for other priority traits (late maturity and high dress-out percentage) ▪ Improved breeds of common carp and rohu will be evaluated in different farming conditions under on-farm trials. ▪ National carp breeding programmes will further be strengthened. ▪ Potential economic, social and environmental impacts of the improved carp breeds will be assessed. ▪ Strategies for dissemination of improved carp breeds will be developed ▪ Improved fish (common carp and rohu) will be disseminated to farmers.

	commercial use. ▪ International cooperation has widened and improved common carp from Indonesia, Vietnam and Thailand was sent to India. ▪ The project has led to additional donors contributing to selection and improvement work and has affected policies in India. The Department of Fisheries has agreed to produce crossbreeds of catla and rohu to increase production and to keep separate breeding centers for Indian major carps and common carp to implement genetic improvement programs. ▪ The genetic resource-base of carps has been evaluated and documented. ▪ Surveys of 409 fish producing households and 682 fish consuming households were conducted to identify priorities for carp genetic research. ▪ Rohu and common carp were identified as priority species for genetic improvement. ▪ Rapid growth, high dress-out percentage, disease resistance (rohu) and late maturity (for common carp) have been identified as the priority traits for genetic improvement of common carp and rohu.	
Thailand	▪ The third generation of selection for body weight of the Chao Phraya River population of silver barb was done by mass selection. The additive genetic gain is estimated to be about 30%.	▪ Genetic improvement of silver barb will be continued using combined (family and mass) selection procedure for improvement of growth and other traits such as survival rate (disease resistance and cold tolerance) and high dress-out percentage. ▪ Selection of common carp will also be continued with addition of other traits such as survival rate

	▪ The method of broodstock management was improved. ▪ Encouraged by the positive outcome of the project, the government of Thailand has increased budgets for production and dissemination of genetically improved breeds to grow-out operations. ▪ The genetic resource-base of carps has been evaluated and documented. ▪ Surveys of 284 fish producing households and 456 fish consuming households were conducted to identify priorities for carp genetic research. ▪ Silver barb and common carp were identified as priority species for genetic improvement. ▪ Rapid growth, high dress-out percentage and high survivability (disease resistance and cold tolerance) have been identified as the priority traits for genetic improvements of silver barb and common carp.	(disease resistance and cold tolerance) and high dress-out percentage. ▪ Strategies for dissemination of improved carp breeds will be developed. ▪ Potential economic, social and environmental impacts of the improved carp breeds will be assessed.
North Vietnam	▪ Two generations of selection for growth of common carp was done using family selection. About 5% genetic gain per generation was achieved. ▪ A methodology for rearing carp fry and fingerling in hapas was improved. This has provided advantages in using limited numbers of earthen ponds in the experiment. Farmers in the northern highland region have adopted this technology. ▪ Improved common carp	▪ Genetic improvement of common carp will be continued with the incorporation of 2 other identified priority traits (i.e., disease resistance and high dress-out percentage). ▪ Strategies for dissemination of improved carp breeds will be developed. ▪ Potential economic, social and environmental impacts of the improved carp breeds will be assessed.

of conical plankton nets for incubation of fry and use of alcian blue injections and fin clipping to mark fingerlings in breeding experiments.

- The genetic resource-base of carps has been evaluated and documented.
- Surveys of 240 fish producing households and 318 fish consuming households were conducted to identify priorities for carp genetic research.
- Silver barb was identified as the priority species for genetic improvement and the priority traits identified are rapid growth, high dress-out percentages and disease resistance.

	fry and fingerlings were distributed to farmers for food production. ▪ The genetic quality of broodstock has been maintained and deposited at three national brood stock centers in Northern, Central and Southern Vietnam. ▪ Genetic resource-base of carps have been evaluated and documented. ▪ Surveys of 158 fish producing households and 514 fish consuming households were conducted to identify priorities for carp genetic research. ▪ Common carp was identified as the priority species for genetic improvement, and the identified priority traits are rapid growth, high dress-out percentages and disease resistance.	
South Vietnam	▪ Analysis of genotype by environment interaction was done for crosses of two domestic strains and three wild strains of silver barb from Mekong River. Pure breed, Tien Giang had a good performance in earthen ponds while pure breed Can Tho was excellent in rice fields. ▪ A breeding programme for silver barb using a population base of communal brooders was initiated. ▪ Silver barb from various locations of the Mekong Delta were collected. ▪ Breeding methods for research were developed. These are use of hormone injections to induce and synchronize spawning of silver barb, development	▪ Selection for growth of silver barb will be continued with addition of other traits like disease resistance and high dress out percentage. ▪ Potential economic, social and environmental impacts of the improved carp breeds will be assessed.

Environmental considerations: Strains improved by the recommended selective breeding method will be assessed for their impacts (as it is hypothesized that faster growing fisher could be more competitive in the wild if accidentally released). Strategies for dissemination of improved strains will take into account possible interactions with wild populations, the need to conserve centers of diversity of natural populations (based on specific river basins etc.) and best hatchery practices to maintain genetic diversity in cultured populations.

Appropriate biotechnological approaches in fish improvement: Not all new biotechnologies are focused on transgenesis, and most do not have the same inherent or ethical drawbacks. New genetic technologies provide several potential tools which could be applied appropriately and safely in developing countries in further enhancing breed improvement schemes. These largely focus on the use of different types of genetic markers to a) evaluate the extent of heterogeneity in wild populations of fish for the selection of populations for breeding and to identify outlier populations for conservation, b) identify family relationships in fish to determine parentage and pedigree information and, in the future, c) identify regions of the fish chromosomes correlated (or linked) with the expression of particular traits (e.g. growth, but also in the future perhaps late maturation, or disease resistance). By this latter means of marking traits can be easily followed in different generations of fish to assist in selection schemes without the substantial phenotypic (functional) measurement and testing that currently is required. The advantage may manifest itself in being able to breed for two or more traits simultaneously. Advances in all these techniques are being made and pursued in upstream laboratories, particularly concerned with the improvement of salmon. ICLARM believes that the group of selective breeders and colleagues in the national programs of the collaborating DMCs should receive exposure to, and training in, the new technologies for their application in breeding schemes in the future. Countries advanced in the application of such techniques (e.g. India applied to rohu), as well as scientists from advanced institutes in other countries, could be used as examples to provide south-south training and awareness within the training events planned for the phase II project. The opportunity within and beyond the project is to foster the appropriate application of genetic technologies to the improvement of carps and other fish for aquaculture in Asia (such as the AMBIONET project, also ADB supported does for maize improvement).

Annex II to the Phase II Proposal

Selective breeding and the appropriate use of biotechnology in aquaculture

Family based selection for fish improvement: The proposal describes the family based selection method that ICLARM has used, firstly to develop an improved strain (the GIFT strain) of Nile tilapia. The method has then subsequently been shown to be applicable to Asian carps through the recently completed ADB RETA phase I project. This quantitative genetic approach has been used for the long-term development of Atlantic salmon also. The method rests in developing a base population containing as much genetic diversity as possible, within a single species, by crossing together fish from geographically separated populations. Selection for a trait (in this case growth) then begins on the basis of the superior expression of the character when large numbers of fish are grown in similar pond environments. Whilst presumably selecting the best genes governing growth, the overall admixture of genes (or the genetic heterogeneity) in the offspring is kept as large as possible through family selection. The alternative (called mass selection) would simply be to take the best individuals from each generation and crossing those. The latter approach can give good results for a few generations but can equally quickly lead to inbreeding (and perhaps loss of the gains in growth) and deterioration in the resulting strain.

The basis for improvement through breeding: In each case (salmon, tilapia and now in Asian carps) substantial gain (often in the order of 7-10%, and sometimes as much as 22%) in the growth of fish has been shown per generation over several generations. Although the breeding techniques are similar to those used in traditional livestock and plant breeding the generational gain observed is larger in fish. This is because the method is being applied to populations of fish which are actually wild or are very close to the wild state. The genetic diversity of the base populations and the consequent ability to reorganize genes into productive combinations is still very high in fish. In contrast, some livestock breeds have been in existence for tens if not hundreds of years. The genetic diversity between high performing individuals is small and the breeder has smaller genetic differences on which to make further improvement through breeding. However, in all cases of traditional selective breeding, selection is based on the observed performance of animals, and breed or strain improvement results from chance genetic reorganization. These are NOT considered to be genetically modified organisms (GMOs).

What are genetically modified fish?: Genetically modified organisms, in contrast, arise from the introduction of exogenous genes (genetic material introduced from other organisms or species) in random or ostensibly targeted ways into the genome of the target species. Most usually this involves the introduction (through injection into cells of early embryos) of specific genes thought to govern traits (as growth hormone is assumed to be key to growth responses). Transgenesis, as this artificial transfer of gene and function into new individuals has been called, has been successfully carried out in fish with experimental genetic constructs. The genetically modified fish which result (albeit at very low frequencies) have shown dramatic increases in growth. However, this is not uniformly successful and the genetic makeup of the recipient fish heavily influences the success or failure of such procedures. Fish populations derived from low frequency transgenic events are likely to be based on very few individuals and, without extensive outbreeding again, would have disadvantages akin to inbred lines. Because of the unpredictability in the results of this procedure, the fact that long term gains are unlikely to be made from the transfer of single genes (most production traits are quantitative i.e. depend the action of several genes for effective function) and because of the reliable long term gains still to be had from family based selection in fish, ICLARM is not espousing the development of GMOs in the second phase proposal for the improvement of carps in Asia. These arguments are made on straightforward genetic grounds, but there are appropriate concerns about the use and deployment of GMOs of which ICLARM is also well aware.

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Outline of the Book
on

"CARP GENETICS RESOURCES FOR AQUACULTURE IN ASIA"

(Editors: D. Penman, M.V. Gupta and M M Dey)

1. **Preface**

2. **Introduction** (D. Penman, M.V. Gupta, M. Dey)
   (Need for increase in aquaculture production in Asia; importance of cyprinids in aquaculture globally; in Asia and in project countries; their value for low income consumers/farmers; role of genetics in aquaculture development of GIFT project, DEGITA, INGA and the present project)

3. **Carp production in Asia** (M. Dey)
   (Past, Current and Future projections; to include capture and culture)

4. **Carp Genetic Resources** (by project partners)
   (organised for each country, covering: introduction; species of importance (endemic and introduced), biology; documentation of genetic resources (molecular and cytogenetic data on natural populations and/or cultured strains; quantitative and qualitative genetic information); status of genetic evaluation and improvement of different species (completed and ongoing where possible); utilisation of genetic resources in aquaculture)

   **List of Individual Countries
   4.1 Bangladesh
   4.2 China
   4.3 India
   4.4 Indonesia
   4.5 Thailand
   4.6 Vietnam

5. **Genetics research and results** (D. Penman, M.V.Gupta)
   - 5.1 Progress in genetics research
   - 5.2 Impact of research to date (to include dissemination, constraints in dissemination)
   - 5.3 Current project

6. **Research needs and constraints** (M. Dey)
   (in documentation of resources, research, institutional weaknesses, human resources)

7. **Carp species introductions in Asia** (B. Acosta)
   (summary of introduced cyprinid species of aquaculture importance in Asia and origin of these stocks, arranged by country) (link to Appendix II)

8. **Threatened carp species** (B. Acosta)

References

Appendices

I. Descriptions of cyprinid species of importance to aquaculture in Asia, split into two groups: (a) those currently being cultured on a commercial scale; (b) those identified as being of potential interest by member countries, through consumption data, etc. (taxonomic hierarchy including species names then individual description alphabetically by Latin name; distribution map/info, picture/line drawing for each species). For other cyprinids, list of references to key publications on taxonomy, distribution, biology, etc.

II. Information relevant to transfers/introductions of genetic material between countries (watersheds), including FAO code of conduct, INGA codes, MTA, etc.

APPENDIX 1
Other reports

A. Books

1.) Carp Genetic Resources for aquaculture in Asia (Editors: D. Penman, M. V. Gupta and M. M. Dey). Outline is attached.

2.) Production, Consumption and Accessibility of Aquaculture Products in Asia (Editor. M. M. Dey; to be published jointly with FAO). Outline is attached.

3.) The Genetic Resource Studies of Silver carp, Bighead, and Grass Carp in the Yangtze River, Zhu River, and Heilong River (Editors: Li Sifa, Wu Lizhao, Wang Qiang, Chou Qianru, Chen Yongle and translated by Zhanjiang (John) Liu)

B. Journal articles

The following eight journal articles are being finalized by ICLARM scientists (Madan M Dey and Jorn Thodeson) in collaboration with the partners from the participating countries, for submission to various peer reviewed international journals.

1.) Economics of fresh water aquaculture in Asia: past trend, present status and future prospects;
2.) Technical efficiency of fresh water aquaculture in Asia: a cross-country analysis;
3.) Pattern of fish consumption and consumers' preference for various types of fish in Asia;
4.). Demand for freshwater fish species in Asia: an analysis by fish type
5.) Analysis of the gap between potential and actual farm yield of carp polyculture in Asia: implication for future research.
6.) Genetic enhancement of common carp, *Cyprinus carpio*, in China.
7) Genetic enhancement of common carp, *Cyprinus carpio*, in Indonesia: results from a complete diallele cross experiment with four strain".
8.) Stock improvement of silver barb (*Barbodes gonionotus* B) in Bangladesh through several generations of genetic selection.

In addition, several other journal articles are being prepared by the scientists from the participating countries.

Outline of the Book
on
"PRODUCTION, CONSUMPTION AND ACCESSIBILITY OF AQUACULTURE PRODUCTS IN ASIA"

(Editor: Madan Mohan Dey)

Chapter 1. Introduction (Madan Mohan Dey)
Chapter 2. Production, Consumption and Marketing of Aquaculture Products in Asia: Synthesis (M. M. Dey, M. F. Alam, and F. Paraguas)
Chapter 3. Production, accessibility and consumption of aquaculture products in Bangladesh (S. Alam)
Chapter 4. Production, accessibility and consumption of aquaculture products in China (J. Huang, J. Xu, and .F Qiao)
Chapter 5. Production, accessibility and consumption of aquaculture products in India (R. Bhatta)
Chapter 6. Production, accessibility and consumption of aquaculture products in the Philippines (C. Olallo)
Chapter 7. Production, accessibility and consumption of aquaculture products in Thailand (S. Piumsombun)

Each of the country chapters and the synthesis chapter deals with the following topics.

1. **Sector overview** - production & production trends. Contribution of aquaculture to national fish and protein production and supplies. Trends. Prevalent farm size; farm ownership/tenure (family-based; private-commercial; state-owned; collective; etc.) and estimated contribution to national aquaculture production. Prevalent production systems and main cultured species. Mode of operation (stand-alone; part of farming system). Objective (subsistence; market-oriented).

2. **Development Policies** - macro-economic policies as they may influence markets and access. Export earnings vs. products for local consumption. Land ownership/tenure security. Incentives & disincentives.

3. **Demand Characteristics** - protein consumption: fish vs. other protein sources. Freshwater fish vs. marine fish. Consumption/demand by income group, changes in consumption by income group over last 20 years; aquaculture producers vs. non-producers. Cultural preferences and geographic differences. Trends. Elasticities of demand: price and income elasticities, cross price elasticities.

4. **Marketing** - (a) **overview:** of marketing practices. Market structure and channels (rural, urban). Marketing margins. Credit. (Insurance schemes in aquaculture. Ownership structure (private, co-operative, municipal, state, etc.). Short section on retail developments.

(b) **Obstacles to access:** deficiencies in market access which may be due to low volume, lack of buyers, inadequate infrastructure and marketing facilities; economic factors such as weakness of competitive position and lack of bargaining power in price formation, financial constraints, consumer attitudes(c) **Impact of changes in production centres and methods of production** - shift of production to peri-urban areas near major consumption centres (to reduce marketing costs ?). Effects of growing intensification of production on fish prices. Impact of increased industrialization on production (i.e. shift to large-scale industrial producers).

5. **Socio-economics** - purchasing power: rural vs. urban consumers. Trends. Price levels of different species (cultured & captured, high valued and low valued) vs. other protein sources. Role of women in fish production and fish trade (where applicable).

6. **Conclusions and recommendations** - consumption and access implications (for aquaculture products) of noted trends, policy measures, production, disposable income, marketing, etc. Analysis of future domestic market potential in view of existing and evolving consumption patterns and marketing development, and measures required to realize the potential. Specific actions by specific actors/sectors. Possible role of Government.

APPENDIX 2
Participating Teams

INTERNATIONAL TEAM

NAME	EXPERTISE	INSTITUTION
1. Dr Madan Mohan Dey (Project Leader)	Resource Economist	ICLARM -The World Fish Center
2. Dr M V Gupta (Project Coordinator)	Aquaculturist	ICLARM -The World Fish Center
3. Dr Rex A Dunham (Program Leader, November 1997-July 1999)	Geneticist	ICLARM -The World Fish Center
4. Dr Stewart Grant (Program Leader, January 2000 - May 2001)	Geneticist	ICLARM -The World Fish Center
5. Dr Jorn Thodesen	Geneticist	ICLARM -The World Fish Center
6. David Penman (Consultant)	Geneticist	ICLARM -The World Fish Center
7. Ms Florabelle Gagalac-Llanto	Statistician	ICLARM -The World Fish Center
8. Mr Ferdinand Paraguas	Statistician	ICLARM -The World Fish Center
9. Mr Gaspar B Bimbao (Research Associate, 1997-1999)	Aquaculturist	ICLARM -The World Fish Center

BANGLADESH

NAME	EXPERTISE	INSTITUTION
1. Dr Gulam Hussain	Geneticist	Bangladesh Fisheries Research Institute
2. Dr Md Ferdous Alam	Economist	Bangladesh Agricultural University
3. Mr Md Kamruzzaman	Economist	Bangladesh Agricultural University

CHINA

NAME	EXPERTISE	INSTITUTION
1. Prof Li Sifa	Geneticist	Shanghai Fisheries University
2. Mr Zou Shuming	Geneticist	Shanghai Fisheries University
3. Dr Chen Jiaxin	Aquaculturist	Freshwater Fisheries Research Centre
4. Dr Miao Weimin	Aquaculturist	Freshwater Fisheries Research Centre
5. Mr Yuan Xinhua	Aquaculturist	Freshwater Fisheries Research Centre
6. Mr Zhu Jian	Geneticist	Freshwater Fisheries Research Centre
7. Mr Qian Jiren	Aquaculturist	Freshwater Fisheries Research Centre

INDIA

NAME	EXPERTISE	INSTITUTION
1. Dr P V J K Reddy	Geneticist	Central Institute for Freshwater Aquaculture
2. Dr S Ayyappan	Aquaculturist	Central Institute for Freshwater Aquaculture
3. Dr R S Shrivastava	Economist	Central Institute for Freshwater Aquaculture
4. Dr H K Barman	Geneticist	Central Institute for Freshwater Aquaculture
5. Dr A G Ponniah	Geneticist	National Bureau of Fish Genetic Resources
6. Dr Vindhya Mohindra	Geneticist	National Bureau of Fish Genetic Resources
7. Dr Ramachandra Bhatta	Economist	University of Agricultural Sciences
8. Dr Y Basavaraju	Geneticist	University of Agricultural Sciences

INDONESIA

NAME	EXPERTISE	INSTITUTION
1. Dr Sonny Koeshendrajana	Economist	Research Institute for Freshwater Fisheries
2. Mr Rudhy Gustiano	Geneticist	Research Institute for Freshwater Fisheries
3. Mr Subagyo	Geneticist	Research Institute for Freshwater Fisheries
4. Dr Ir Rahim Darma	Economist	Hasanuddin University

THAILAND

NAME	EXPERTISE	INSTITUTION
1. Dr Nuanmanee Pongthana	Geneticist	National Aquaculture Genetics Research Institute (NAGRI)
2. Dr Somying Piumsombun	Economist	Department of Fisheries
3. Ms Nartaya Srichantuk	Economist	Fisheries Economics Division, Department of Fisheries
4. Ms Wacherapranee Claithong	Economist	Fisheries Economics Division, Department of Fisheries
5. Ms Molrudee Nipanpong	Statistician	Fisheries Economics Division, Department of Fisheries

VIETNAM

NAME	EXPERTISE	INSTITUTION
1. Dr Tran Mai Thien	Geneticist	Research Institute for Aquaculture No. 1
2. Dr Nguyen Cong Dan	Geneticist	Research Institute for Aquaculture No. 1
3. Ms Dinh Kim Nhung	Economist	Research Institute for Aquaculture No. 1
4. Dr Nguyen Van Hao	Geneticist	Research Institute for Aquaculture No. 2
5. Mr Nguyen Van Sang	Aquaculturist	Research Institute for Aquaculture No. 1
6. Ms Le Thi Chau Dung	Statistician	Vietnam Agricultural Science Institute