INTEGRATED FISH FARMING IN CHINA

NACA Technical Manual 7

A WORLD FOOD DAY 1989 PUBLICATION

of the

NETWORK OF AQUACULTURE CENTRES IN ASIA AND THE PACIFIC

Bangkok, Thailand

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Prepared by the
Asian-Pacific Regional Research and Training Center
in Integrated Fish Farming, Wuxi, China

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FOREWORD

It is with a very great sense of satisfaction that I introduce this book on Integrated Fish Farming prepared at the Regional Lead Centre of NACA (Network of Aquaculture Centres in Asia) in Wuxi. During my first visit to China in 1978 as the Programme Leader of the UNDP/FAO Aquaculture Development Coordination Programme (ADCP), along with a group of Directors and senior officials of Fisheries Department of Asia and Africa, I recognized that integration of fish culture with crop and livestock farming was one of the main areas of aquaculture development that would be of direct interest to other developing countries, especially in relation to rural development. This conclusion guided the later establishment of the Wuxi Centre devoted to the collection, review and scientific understanding of the age-old Chinese practices of integrated fish farming, and the transfer of the technologies to other parts of the world. Linkage with other centres in the Network in Asia, and other centres of the global network developed by ADCP was intended to serve as the means of adapting the Chinese technologies to suit local conditions in other areas. Research, training and information programmes pursued at the Centre since its establishment in 1981, have made considerable progress and this book reflects the understanding and experience gained by the workers of the Centre, as a result of studies in China and technical cooperation with personnel from other countries. It is an example of the successful application of the original concepts of NACA and of the global network.

Fish-crop-livestock farming is obviously a complex system, integrating different technologies at different levels of intensity. However, the book largely focusses on systems where fish culture is the main constituent and crop and livestock farming are integrated with it to achieve high levels of production. So the text of the book starts with the Chinese systems of fish farming and follows on with methods of integrating it with crop and livestock farming and management of integrated farms.

I feel sure that this book will make a significant contribution to the practice of integrated fish farming in developing countries all over the world for many years to come. As aquaculture science progresses and capital intensive systems of production begin to be practised in developing countries as well, the technologies may change. Till then, this book will serve as a manual for the introduction of the Chinese system and a guide for adapting it to suit local conditions. The workers of the Wuxi Centre and the Government of the People's Republic of China deserve to be congratulated for this remarkable contribution.

T.V.R. Pillay

PREFACE

"Integrated fish farming is a diversified and coordinated way of farming or producing agricultural items in the fish farms with fish as the main product. The items produced are to be used either as source of feeds and fertilizer, source of additional income or both. The wise integration of these items in a fish farm promotes the full utilization of its land area and recycling of wastes and by-products, minimizes the operation expenses in feeds and fertilizer, improves the living conditions of the workers due to the increases of income and maintains a balanced ecosystem." This statement appears in the Back-to-Office Report of one of the trainees, Mr. Kapa La'a from Papua New Guinea, who participated in the second training course (1982) on integrated fish farming at the Asian-Pacific Regional Research and Training Centre for Integrated Fish Farming in Wuxi, Jiangsu Province, China. The Centre is one of the regional lead centres of the Network of Aquaculture Centres in Asia and the Pacific (NACA). Under the FAO/UNDP regional project for establishing the Network, the Centre has organized the four-month training course annually since 1981 and trained a total of 208 senior aquaculture technical personnel from 43 countries in the Asia-Pacific region, Africa, the Middle East, Latin America and Europe.

This book is meant to meet the need for an updated textbook on the Chinese systems of carp polyculture and integrated aquaculture-agriculture. It will be used for subsequent training courses on the subject and also as a reference for the past trainees and others interested in integrated fish farming as practiced in China.

China has a long history of integrated fish farming with its own set of technology. Since the 1950s, the government has placed much emphasis on the development of freshwater pond culture and its integration with agriculture and animal husbandry. Various integrated fish farming models have evolved according to different geographical and climatic conditions in the country and to local agricultural characteristics, socio-economic conditions and traditional practices. Hence, most fish farms have established complex integrated farming and management systems.

Materials included in this book have been class-tested, and updated and improved with new research findings over the past 9 years by the previous and present Directors and staff of the Centre. Because the Chinese systems of carp polyculture is the base level from which integration with other crops, plant and livestock has evolved, a good portion of the book begins with the biology of the major carp species and the introductory aspects of pond culture. A trainee from another country who is new to the Chinese practice of integrated farming needs to understand initially the basic biology, reproduction and culture of Chinese carps.

The release of this book is indeed timely since it signifies the completion of a decade of research and training by the NACA lead centre. It also marks the transformation of NACA from the status of an FAO/UNDP regional project to an autonomous, intergovernmental organization by the turn of the year, 1990, when the Centre celebrates the Tenth Anniversary of its establishment.

This publication is dedicated to World Food Day 1989 which has "Food and the Environment" as its theme. The integration of fish farming and agriculture, in which the recycling of organic wastes derived from both activities mutually enhances food production without adverse effect on the environment, aptly fits this theme to some extent.

"Integrated Fish Farming in China" is the first effort at compiling and collating the present information available on the Chinese systems of integrated fish farming. It provides an updated reference to both the past graduates who are involved in this area of work in their respective countries, as well as to research and development workers in this field. Although the language and some technical terms translated from Chinese to English could be further improved, the production of the manual as a whole is commendable. The dedicated effort of Mr. Guo Xianzhen, the present Director of the Centre, and the Centre staff as a whole, is very much appreciated and deserves high commendation.

CHEN Foo Yan
Project Coordinator
Network of Aquaculture Centres in Asia and the Pacific

ACKNOWLEDGEMENTS

This book represents the collaborative efforts of several individuals and institutions spanning a period of almost ten years. The initial compilation and writing of training materials which were used as lecture and laboratory notes for the first course was done by a team of scientists from Shanghai Fisheries University led by Professor Lu Gui who also served as the first Director of the Asian-Pacific Regional Research and Training Centre for Integrated Fish Farming, a regional lead centre of NACA in Wuxi, China. This body of organized lecture and laboratory notes became the foundation of the instructional materials which the researchers and training staff of the Centre used in subsequent training courses, updated and improved upon.

Updating and re-organizing the materials was gradual and continuous, but the formal and organized effort at developing the material into a training manual was done with the establishment of a technical editorial board headed by Mr. Shan Jian, then Director of the Centre, as editor-in-chief. The body of material was re-organized into specific chapters, with each chapter assigned to the expert or experts on the topic for contents editing. Chapter editors were Mr. Shen Peirong, Mr. Yu Shigang, Mr. Zhu Lingeng, Mr. Fei Yingwu, Ms. Li Shaoqi, Mr. Yang Hua-Zhu, Mr. Hu Bao-tong, Mr. Chen Yaowang, Mr. Tang Song-nan and Ms. Jiang Guizhen. A team of translators headed by Mr. Li Kangmin and including Messrs. Zhou Enhua, Min Kuan-hong, Yang Xianguang and Chen Baohua, worked on the manuscript and translated the Chinese text into English. The final phase of developing the training manual into its present form was done under the current leadership and staff of the Centre.

A special technical editorial assistance was provided by the International Development Research Centre (IDRC) of Canada through its expert, Mr. William M. Carman, who provided the initial editing on the English translation of the manuscript.

The final update and technical edit on the contents was made by the Centre, with the NACA Project Coordinating Unit providing the editorial guidance and assistance in the design and production of the book. Mr. Pedro B. Bueno, NACA Information Specialist and Mr. Zhou Xiaowei of the Centre worked in Wuxi and then in Bangkok to finalize the editing and preparation of the book in its present form. Ms. Rebecca Cajilig, NACA information officer, designed the book and prepared the manuscript for the press.

Through all the stages, Mr. Chen Foo Yan, NACA Coordinator, and Dr. F. Brian Davy, Associate Director (Fisheries) of IDRC provided the encouragement and guidance to the work.

Funds for the publication of this book were made available by the FAO/UNDP Regional Project (RAS/86/047) for the establishment of NACA.

On behalf of the Integrated Fish Farming Centre, I, as its present Director, acknowledge with gratitude the collective effort made by the above mentioned colleagues and institutions, as well as those who have contributed in one form or the other in the preparation and publication of this book. The continued interest and support of FAO, UNDP, IDRC and the Government of the People's Republic of China for the Centre's endeavour in technology transfer within the framework of Technical Cooperation among Developing Countries is also gratefully acknowledged.

Guo Xianzhen
Director
Asian-Pacific Regional Research and Training Centre
for Integrated Fish Farming
Network of Aquaculture Centres in Asia and the Pacific

Chapter 1

THE BIOLOGY OF MAJOR FRESHWATER-CULTIVATED FISHES IN CHINA

Shen Peirong

Biology of Major Cultivated Fishes

China has a vast freshwater system, with inland rivers, lakes, reservoirs, and ponds throughout the country. Because of this, China is rich in fishery resources. There is a wide variety of fishes, of which more than 50 per cent are carps. Until now, about 30 species have been cultured in the ponds of integrated fish farms. This introduction focuses on four well-known carps: silver carp, bighead, grass carp, and black carp. Other good stocks, i.e., common carp, crucian carp, Chinese bream (Wuchang fish), mud carp, tilapia, etc., are also discussed. Understanding the habits of fish, mastering the laws of their growth, development, propagation, and feeding, and satisfying their ecological requirements will be of great practical significance to fisheries production, the application of farming techniques, and the improvement of fish yields.

Morphology

Silver carp (Fig. 1.1)

Silver carp belongs to family ***Cyprinidae***, subfamily ***Hypophthalmichthyiane.*** Body: compressed. Scales: small. Mouth: in front, with lower jaw slightly slanting upward. Eyes: comparatively small, situated below horizontal axis of body. Gill membrane: not connected to isthmus. Gill rakers: dense, interlaced, connected, and covered with a spongelike sieve membrane. Abdominal keel: extending from the base of pectoral fins to the anus. Pectoral fin: terminal tip does not exceed the base of the ventral fin. Pharyngeal teeth: one row in 4/4, with fine lines and tiny grooves on surface. Intestinal length: 6-10 times body length. Colour of body (alive): silvery white; dorsal colour, very dark brown. The largest specimen found so far was 20 kg.

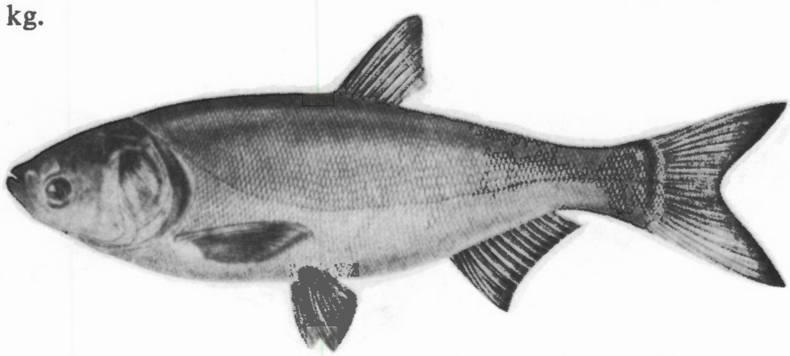


Fig. 1.1. Silver carp *(Hypophthalmichthys molitrix).*

Bighead carp (Fig. 1.2)

Bighead is similar to silver carp in shape, and belongs to the same subfamily, ***Hypophthalmichthys.*** Head: bigger than silver carp. Snout: short and blunt. Eyes: small, situated below horizontal axis of body. Gill membrane: not connected to isthmus. Gill rakes: dense and separated; without spongelike sieve membrane. Abdominal keel: between the bases of ventral fins and the anus. Pectoral fin: terminal tip reaches one-third to two-fifths of the base of the ventral fin. Pharyngeal teeth: one row in 4/4, surface flat. Intestinal length: about 5 times body length. Colour of body (alive): dorsal and upper sides, light black, scattered with irregular yellowish black spots; ventral surface, silvery white. The largest specimen found so far was 40 kg.

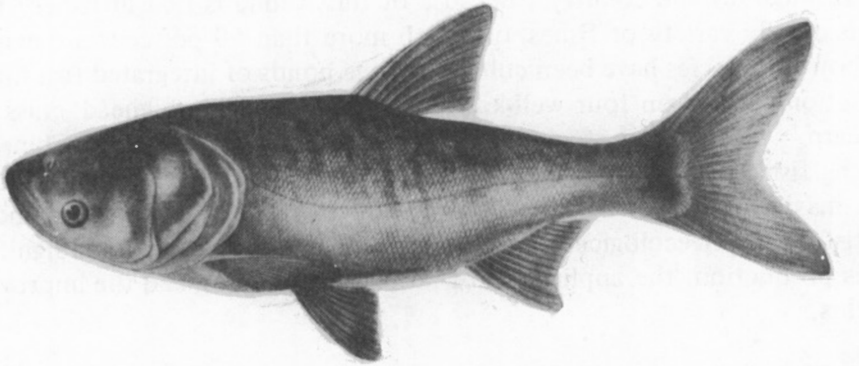


Fig. 1.2. Bighead *(Aristichthys nobilis)*

Grass Carp (Fig. 1.3)

Grass carp is a large fish, belonging to subfamily ***Leuciscinae***, family ***Cyprinidae***. Body shape: almost cylindrical, with flat head and round abdomen. Scales: big. Mouth: in front; lower jaw, shorter. Gill membrane: connected to isthmus. Gill rakes: small and short, in scattered arrangement. Pharyngeal teeth: two rows in 2,5/4,2, compressed like combs. Intestinal length: 2.3-3.3 times body length. Colour of body (alive): dorsal, grey; abdomen, yellowish white; sides, greenish yellow; fins, a lighter colour. The largest specimen found so far was 35 kg.

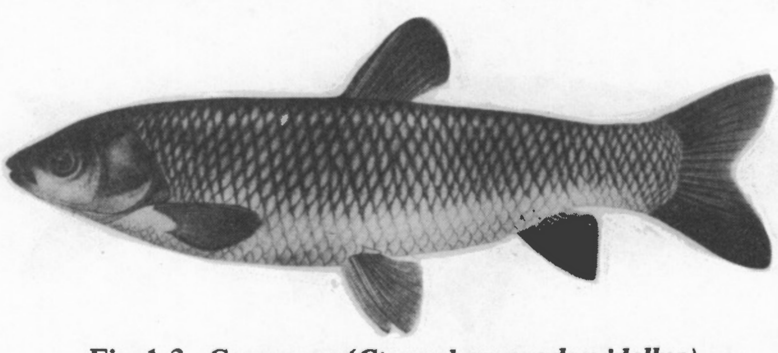


Fig. 1.3. Grass carp *(Ctenopharyngodon idellus)*

Black carp (Fig. 1.4)

Among ***Cyprinidae,*** black carp is similar to grass carp. Body shape: like grass carp, but with a pointed head. Scales: big and circular. Mouth: arc-shaped in front. Eyes: medium size, situated in the middle part of head sides. Gill rakes: short. Gill membrane: connected to the isthmus. Pharyngeal teeth: one row in 5/4; big, short, and molarlike; surface smooth. Intestinal length: 1.2-2 times body length. Colour of body (alive): dark grey dorsal, darker; abdomen, light grey; fin, black. The largest specimen found so far was 70 kg.

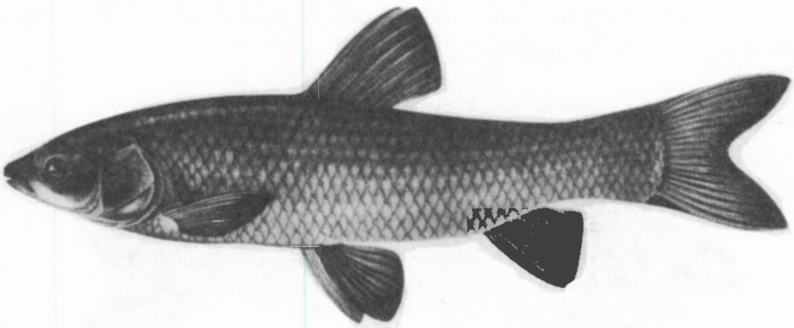


Fig. 1.4. Black carp *(Mylopharyngodon piceus)*

Common carp (Fig. 1.5)

China has a long history of culturing common carp, which have a wide distribution and strong adaptability. There have been a lot of morphological variations through the artificial breeding and natural selection of this species: e.g., scale carp, mirror carp, Wu Yuan red purse carp, Xing Guo red carp, etc. Body: compressed. Dorsal: projected in an arc shape. Abdomen: round. Mouth: slightly downward with a long blunt snout and with two pairs of barbels on upper jaw; lower pair a little longer. Dorsal fin: long. Scales: big and thick. Pharyngeal teeth: three rows in 1,1,3/3,1,1; molarlike teeth on inner sides. Intestinal length: 1.5-2 times body length. Colour of body (alive): varying with different living conditions, usually dark grey or yellowish brown on dorsal; sides, golden yellow; lower part of caudal fin, red. The largest specimen found so far was 40 kg.

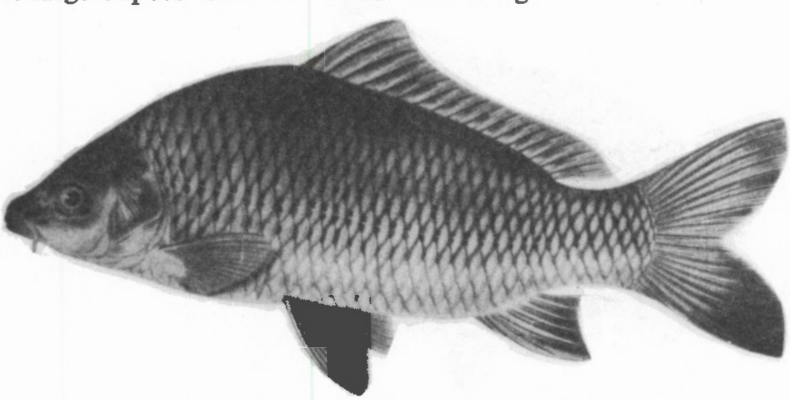


Fig. 1.5. Common carp *(Cyprinus carpio)*

Crucian carp (Fig. 1.6)

Crucian carp is close to common carp among ***Cyprinidae***. Body: compressed and relatively thick. Abdomen: round. Head: small and short. Snout: blunt. Mouth; arc-shaped in front. Lip: thick without barbels. Pharyngeal teeth: compressed, one row in 4/4. Intestinal length; 2.7/3.2 times of body length, some even reaching 5 times. Colour of body: silvery grey (alive); darker on dorsal and lighter on abdomen. The largest specimen found was 1.5 kg.

Crucian carp has a wide distribution and a strong adaptability. It can live in different water bodies such as rivers, lakes, ponds and ditches with some variations and differentiations in characteristics.

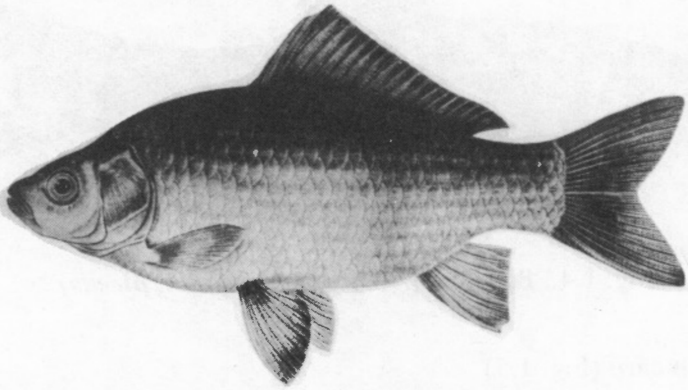


Fig. 1.6. Crucian carp *(Carassius auratus)*

Chinese bream (Wuchang fish) (Fig. 1.7)

Chinese bream belongs to subfamily ***Abramidinae***. Body: high, compressed and lozenge-shaped. Head: small and short. Mouth: slanting. Abdominal keel: extending from the base of pelvic in to the anus, Pharyngeal teeth: 3 rows in 2,4,5/4,4,2. Intestinal length: 2.7 times of body length. Colour of body: dark grey (alive), darker on dorsal; scale, dark gı y in the middle and lighter on its edge. The largest body found was 3 kg.

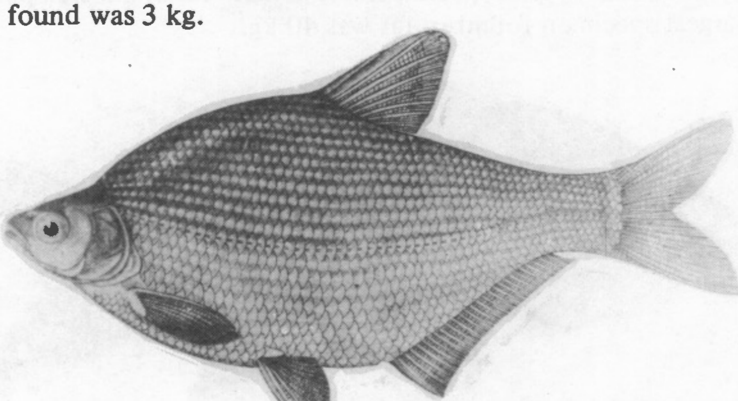


Fig. 1.7. Chinese bream or Wuchang fish *(Megalobrama amblycephala)*

Mud carp (Fig. 1.8)

Mud carp belongs to family ***Cyprinidae,*** subfamily ***Barbinae.*** Body: long and compressed. Abdomen: round and slightly flat. Snout: short, round, and blunt. Mouth: inferior and transverse, with two pairs of barbels; snout barbels, strong and thick; jaw barbels, small and short. Caudal fin: deeply separated with upper part a little longer than the lower part. From the upper part of the pectoral fin around the lateral line, there are 8-12 scales with dark dots at their bases that form lozenge-shaped spots. Fins: dark grey. Pharyngeal teeth: three rows in 2,4,5/5,4,2. Intestinal length: about 14 times body length. The largest specimen found so far was 4 kg.

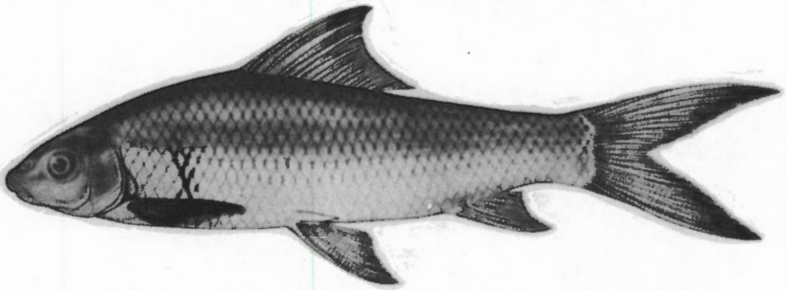


Fig. 1.8. Mud carp *(Cirrhina molitorella)*

Tilapia (Figs. 1.9 and 1.10)

Tilapia belongs to order ***Perciformes,*** family ***Cichlidae.*** This genus consists of more than 100 species and subspecies. At present, 15 species of *Tilapia* are being cultured around the world. In China, mainly *Oreochromis mossambica* and *O. nilotica* are reared.

Oreochromis mossambica (Fig. 1.9) – Body: short and compressed. Dorsal: a little higher. Shape: similar to crucian carp. Mouth: bigger. Lip: thick, with lower jaw a little longer than upper jaw. Scales: circular. Lateral line: disjointed. Intestinal length: about 7 times body length. Colour of body (alive): dark grey; during spawning stage, male fish is dark green; edges of dorsal, anal and caudal fins, obvious red; female, grayish yellow. The largest specimen found so far was 0.5 kg.

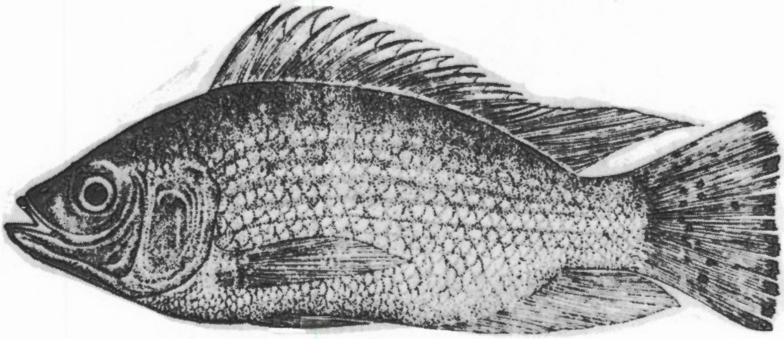


Fig. 1.9. *Oreochromis mossambica*

Oreochromis nilotica (Fig. 1.10) – Colour: changing with external conditions, light black; abdomen, white, with nine longitudinal black stripes on body surface, of which seven are below dorsal fin and two are on the peduncle; caudal fin with 10 clear vertical black stripes for life. Scales: ctenoid. The largest specimen found so far was 2.5 kg.

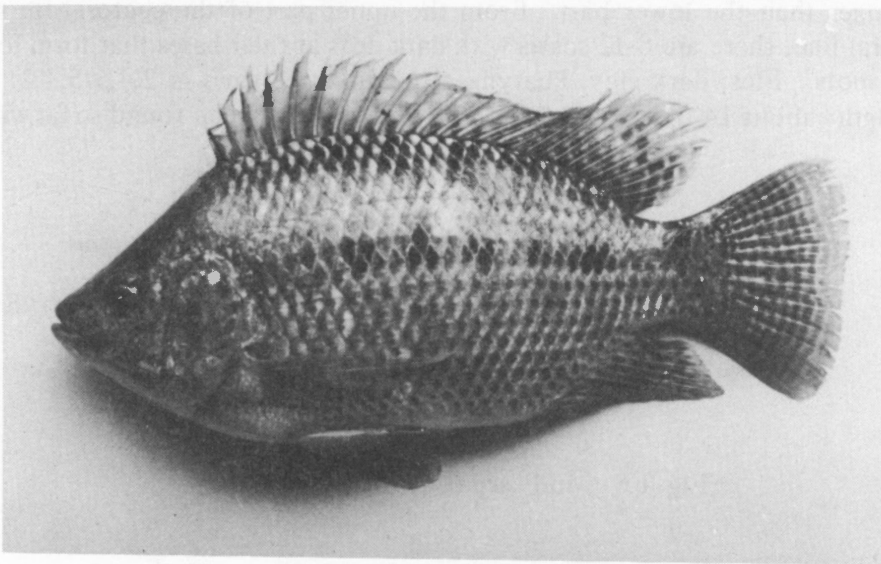


Fig. 1.10. *Oreochromis nilotica*

Nuptial colour can be found on male and female tilapia during the reproductive period. External genital organs of the male and female are different in appearance. The male has two pores: anus in front and urinogenital pore in the rear (Fig. 1.11 A). The female has three pores: anus in front, oviduct opening in the middle, and urinary pore in the rear (Fig. 1.11 B).

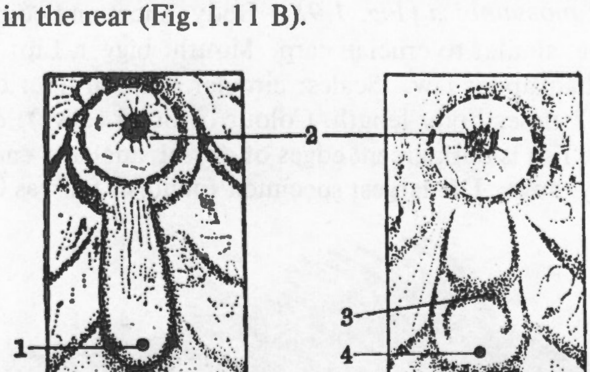


Fig. 1.11. A: male, B: female.

1. urinogenital pore
2. anus
3. oviduct pore
4. urinary pore

Feeding Habits

Although silver carp, bighead, grass carp, black carp, common carp, and mud carp all belong to **Cyprinidae**, they have their own methods of food intake and food chain positions at different stages of development. This is due to their long-term adaptation to ecological conditions. The method of food intake and the structure and function of the digestive organs improve as the fish grows.

Silver carp and bighead carp

At the larval stage, silver carp mainly feed on zooplankton. As they mature, their feeding turns to phytoplankton. Bighead, throughout their life, feed mainly on zooplankton. This difference in feeding is due to the differences in structure and density of gill rakers (the filtering organ) between the two species.

The gill rakers of silver carp and bighead are situated in the operculum with four pairs on either side; the fifth pair is on the gill arch, which is specialized into the inferior pharyngoskeleton. The gill rakers and gill filaments are attached to the gill arch bone. The gill rakers of bighead are delicate and sabre-shaped, each consisting of a neck, a stem, and a base. The neck is narrow and short. The stem is the principal part of the gill raker, the dorsal side being thicker than the ventral side. On each side, there is a row of "wartlike", lateral protuberances (Fig. 1.12). Each

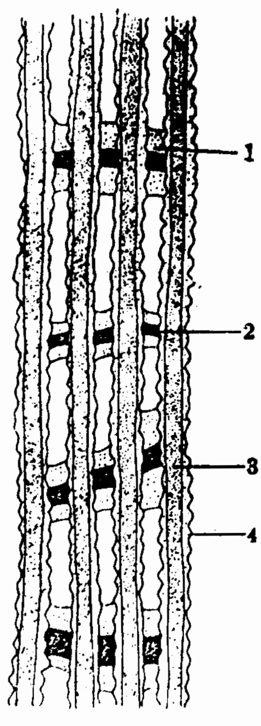


Fig. 1.12. Structure of the gill raker of silver carp.

1. inner gill raker 3. gill raker
2. bony bridge 4. lateral protuberanc-

lateral protuberance of a gill raker is interwoven with the next. Occasionally, there are opposite protuberances; their triangular bases cling to the gill arch bones. The gill rakers of silver carp, unlike those of bighead, are interconnected by minute bony bridges that are covered with spongy sieve membranes (Fig. 1.12). Gill raker density is higher in silver carp than in bighead.

There are broad and narrow gill rakers (Fig. 1.13); one broad gill raker occurs for every three to six narrow gill rakers.

Newly hatched silver carp and bighead fry nourish themselves with egg yolk for the first 3 or 4 days. After this, when they are 7-9 mm long, they begin to take in plankton. Until body length reaches 15 mm, the food-filtering organs are imperfect, with short and sparse gill rakers. During this time, silver carp and bighead eat the same food. The major groups of zooplankton that silver carp and bighead eat are rotifers, nauplius of copepods, and tiny cladocerans.

The shape and structure of the filtering organs of fry about 20-30 mm long are generally the same as that of an adult fish. Because silver carp fry have nearly 200 gill rakers – 1 mm in length each, with minute bony bridges between them and

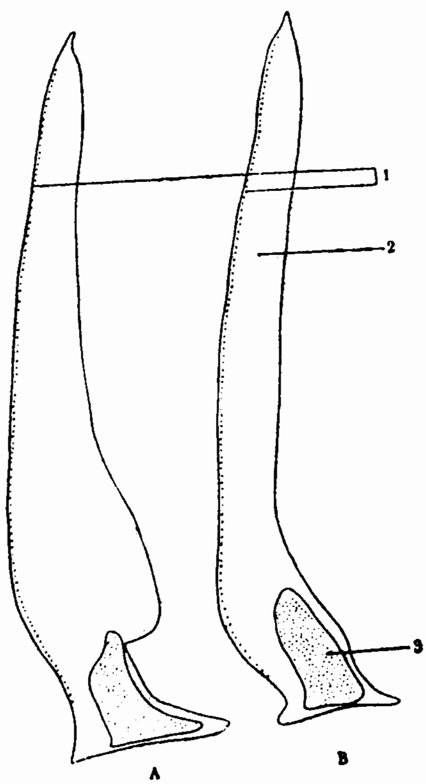


Fig. 1.13. (A) Broad gill raker. (B) Narrow gill raker.

1. Lateral protruberance
2. stalk
3. base

sieve membranes covering the bridges to form a fine net – their main food is phytoplankton. The short and sparse gill rakers of bighead fry are separated by larger spaces and, therefore, the tiny phytoplankton are more difficult to detain. As a result, their main food changes from tiny zooplankton to all sorts of zooplankton as they mature.

In addition to the filtering organs (gill rakers), silver carp and bighead have accessory organs: palatine folds. Palatine folds, located at the apex of the mouth cavity, consist of nine vertical ridges of mucous membrane, four on either side and one in between. The middle ridge is short and resembles an inverted "Y". Palatine folds act in coordination with gill rakers in filtering the food.

Under culture conditions, silver carp and bighead can also eat commercial feeds such as cakes, brans, and dregs.

Grass carp and black carp

The fry of both grass carp and black carp under 15 mm in length feed mainly on zooplankton. However, the feeding habits of fry larger than 20-30 mm are different. At this time, the fry of grass carp begin to consume tender aquatic plants and the fry of black carp start to feed on benthos such as snails and *Corbicula* spp.

Grass carp is a typical herbivorous species, consuming all sorts of aquatic and terrestrial grasses; hence, the pharyngeal teeth are well developed, tough, and strong (tooth formula: 2,5/4,2). The teeth are shaped like choppers with saw-toothed edges. Pharyngeal teeth at both sides are interlaced and are against the callous pad of the basioccipital, grinding food into pieces for digestion in intestines. Grass carp are voracious eaters, but cannot digest plant cellulose.

Black carp is a carnivorous species and usually feeds on molluscs such as snails, clams, and *Corbicula* spp. By using its pharyngeal teeth and callous pad, they crush the hard shells, spit them out, and swallow the meat. Their pharyngeal teeth are strong, tough, and molar-shaped (tooth formula: 4/5).

Under culture conditions, both species are omnivorous, feeding on oil cakes, brans, dregs, and animal feeds such as silkworm pupae, earthworm, and animal entrails.

Common carp and crucian carp

At the larval stage, the feeding habits of common carp and crucian carp are basically similar. They chiefly feed on rotifers, cladocerans, copepods, chironomid larvae, and other insect larvae. Common carp and crucian carp about 50 mm in length are omnivorous. Common carp are inclined to be more carnivorous, whereas crucian carp are more herbivorous. Both species have feeding habits of phagotrophy.

Common carp has relatively well-developed, molar-shaped pharyngeal teeth in three rows, with transverse grooves on the rest of the inner row except the first tooth, which is smooth. This species feeds on a wide range of foods. Their common natural foods are benthos such as snails, young clams, *Corbicula* spp., cladocerans, copepods, chironomid larvae, shrimps, and insect larvae. They can also consume the detritus of higher aquatic plants and plant seeds. The nasal bone of common carp is well developed, enabling them to project their premaxilla and mandible like a tube and dig in the mud for organic detritus.

Crucian carp chiefly feeds on large amounts of detritus, diatoms, filamentous algae, aquatic grasses, and plant seeds. Other foods include cladocerans, copepods, chironomid larvae, and water earthworms.

Under culture conditions, common carp and crucian carp also consume commercial feeds such as oil cakes, brans, crops, and silkworm pupae.

Chinese bream (Wuchang fish)

At the larval stage, Chinese bream feeds mainly on zooplankton such as cladocerans and copepods. At the adult stage, it feeds mainly on aquatic grasses such as *Vallisneria spiralis, Hydrilla verticillata,* and *Potamogeton malainus.* Secondary food include *Potamogeton crispus, Myriophyllum spicatum, Spirogyra,* and plant detritus. With a small mouth and small and weak pharyngeal teeth and callous pad, their ability to search for food and the intensity of food intake are much less than those of grass carp.

Mud carp

With a small mouth, transverse in inferior position, under natural conditions, mud carp uses the bony edges of its upper and lower jaws to scrape diatoms, green algae *(Chlamydomonas),* and filamentous algae off stones. Mud carp also commonly feeds on the detritus of higher plants, bottom humus, and zooplankton.

Under culture conditions, mud carp consumes commercial feeds such as oilcakes, dregs, brans, and animal manure.

Tilapia

Tilapia is omnivorous with a tendency to be herbivorous. At larvae stage, it feeds mainly on zooplankton. The scope of food widens as the fish grows. Common foods include all kinds of planktonic, benthic, and epiphytic algae, tender higher aquatic plants, all organic detritus, and some animal material (earthworms, small shrimps, and aquatic insects).

Oreochromis, possessing denser gill rakers (24-31), is more likely to feed on phytoplankton and could utilize some of green algae, *Chlorophyta,* and bluegreen algae, *Cyanophyta,* which can hardly be digested by other fishes. However, because *O. mossambica* has only 14-19 gill rakers, it consumes mainly detritus. Under culture conditions, both species can feed on all kinds of vegetable leaves, tender grass, animal manure, bran, oil cake, and pelleted feeds. Their ability to search for and consume food is dependent on temperature.

Growth

Growth rate is an important criterion in the evaluation of production efficiency. Silver carp, bighead, grass carp, black carp, and common carp, with their larger size and speedy growth, are the dominant cultured species for polyculture in integrated fish farms. Crucian carp, wuchang fish, and mud carp, however, owing to their smaller size and slower growth, are usually regarded as secondary species for polyculture. Nevertheless, these secondary species are also important in the improvement of fish yield.

Growth rates are genetically controlled, as well as being closely related to water quality, water temperature, nourishment, stocking density, and management. As a rule, growth rates (length and weight) are faster before the first sexual maturity (Table 1.1); after this, growth slows or even stops.

Table 1.1 Ages (years) at which the primary cultured fish in China experience maximum growth.

	Silver carp	*Bighead carp*	*Grass carp*	*Black carp*	*Common carp*	*Crucian carp*	*Wuchang fish*	*Mud carp*
Maximum length increase	2	2-3	1-2	1-2	1-2	1	1-2	1-2
Maximum weight gain	3-6	3	2-3	3-4	4-5	4-5	2	5-6

Natural Reproduction

Silver carp, bighead, grass carp, black carp and mud carp

The natural spawning grounds of silver carp, grass carp, and black carp are vastly distributed in Pearl River, Qiantangjiang River, Changjiang River, Huaihe River, and northwards up to the Heilongjiang River systems. Those of bighead are mainly in Changjiang River, Huaihe River, and Pearl River. Mud carp, as a subtropical species, has its spawning grounds in the southern part of China: Hainan Island, Guangdong, Guangxi, Fijian, and Yunnan. Among all these river systems, the spawning grounds of Changjiang River and Pearl River are the biggest. Fry of silver carp, bighead, grass carp, and black carp proliferate in the Changjiang River and Pearl River systems. For feeding, Chinese carp usually prefer the lower reaches of rivers, river branches, or lakes, where the water flows slowly and is abundant with food. When the spawning season draws near, spawning schools begin to gather and migrate toward the middle and upper course spawning grounds. At this time, the gonads of the brood fish have, in most cases, reached stage IV and the gonads of the male fish have reached stage V. If the ecological conditions in the spawning grounds are suitable for reproduction, the fish will spawn.

Spawning occurs in the summer and varies with climatic condition. In the Changjiang River drainage, silver carp and grass carp generally start spawning in late

April or early May; bighead begins to spawn in middle or late May. In the Pearl River drainage, spawning season begins in middle or late April; bighead spawns a little later. As a rule, the spawning season in the north is later than that in the south by 1 or 2 months.

During the spawning season, the mature brood fish is ready to spawn when the water level rises and the temperature is between 18 and 30°C. The optimum temperature for spawning is 22-28°C. As a subtropical species, mud carp needs a little higher temperature for spawning; its optimum spawning temperature ranged from 26 to 30°C. There are two common patterns of spawning. Spawning on the surface is termed "floating spawning" and underwater spawning is called "muffled spawning". In floating spawning, the male chases the female excitedly, often bumping against the abdomen of the female with its head, jumping out of the water, and then splashing into the waves. Sometimes, both the male and the female would float on their backs with their pectoral fins vibrating violently. When the climax of estrus is achieved, the female and male discharge their eggs and milt, respectively. The eggs are fertilized in the water. In muffled spawning, all the chasing occurs underwater. There is usually an overwhelming majority of male fish on the spawning ground (Table 1.2). The age and weight distribution of spawning schools varies with the region. In the Pearl River drainage, fish are generally smaller and mature earlier than in the Changjiang River drainage (by 1 year). The fish in the Heilongjiang River drainage mature 1 or 2 years later than in the Changjiang River drainage.

The fecundity of silver carp, bighead, grass carp, and black carp is measured by sampling. Both the absolute and the relative fecundities can be determined. The former refers to the total number of young born to one fish in one spawning season; the latter refers to the number of young born per gram of female body weight in one spawning season. There is no relationship between the number of eggs per gram of ovary and the size of the fish.

The eggs of silver carp, bighead, grass carp, black carp, and mud carp are separated and nonadhesive. The discharged eggs expand by absorbing water through the egg membrane and become plump, transparent, and elastic. Having a greater specific gravity than water, they sink to the bottom in still water; yet, they are semi-

Table 1.2. Sex composition of silver carp and grass carp spawning schools in three spawning grounds.

Item	*Changjiang River*			*Xijiang River*			*Songhua jiang River*			*Average (%)*	
Species	*No.*	*M*	*F*	*No.*	*M*	*F*	*No.*	*M*	*F*	*M*	*F*
Silver carp	149	145	4	33	29	4	172	165	7	93.7	6.3
Grass carp	112	87	25	40	30	10	100	80	20	77.5	22.5

M = male, F = female

Table 1.3. Absolute and relative fecundity and maturity rate of silver carp, bighead, grass carp, and black carp in the Changjiang River.

Species	*Average body weight (g)*	*Average ovary weight (g)*	*Average absolute fecundity (pieces)*	*Average relative fecundity (pieces)*	*Egg (g) ovary*	*Average maturity rate* (%)*
Silver carp	7,900	1,190	1,035,000	131.0	869.7	15.1
Bighead	19,900	2,710	1,925,000	96.7	710.3	13.6
Grass carp	9,200	1,310	830,000	90.2	633.4	14.2
Black carp	22,900	2,520	2,131,000	93.1	845.1	11.0

* Maturity rate (gonad or ovary weight/body weight) x 100

buoyant in a current, floating until the fry hatch. The eggs must be incubated in the same temperature range as that required by brooders to spawn: 18-30°C; the optimum incubation temperature is between 22 and 28°C. The speed of embryonic development is directly related to water temperature.

Common carp and crucian carp

With their wide distribution, common carp and crucian carp do not require exact environmental conditions for gonad development and reproduction; therefore, they naturally reproduce in the still or running waters of Southern and Northern China.

Common carp and crucian carp spawn from the end of March to early April in central and central eastern part of China, from April to May in northern China, and in June in northeastern China; however, spawning begins as early as late December in the Pearl River basin. Although the spawning season begins at different times, water temperature requirements are identical, at least 18°C for common carp and at least 20°C for crucian carp. Because the eggs of common carp and crucian carp are adhesive, the fundamental requirement for spawning is the presence of substrata (e.g., aquatic plants) that the eggs can adhere to.

Spawning activity proceeds from midnight to dawn. If environmental conditions are favourable, however, these fish can spawn the whole day. In estrus, two or three males chase one female; the male repeatedly hits its head against the female's abdomen until the female is lying on its side adjacent to some aquatic plants. The female then spawns while the male discharges milt. This action occurs repeatedly so that the mature eggs stick to the aquatic plants. Age and body size at sexual maturity vary with environment and climate. In the Changjiang River and Yellow River basins, common carp and crucian carp generally reach maturity in 2 years. In northeastern China sexual maturity arrives later when the fish is larger. The fecundity is related to fish size. The average fecundity of a 3-year-old, 44-48 cm, 1-9-2.75 kg common carp is around 244,000 pieces. For a 5-year-old, 54 cm, 3.5 kg common carp, the fecundity is around 447,000 pieces. A 0.5-1 kg crucian carp has an average fecundity of 200,000-300,000 pieces. At 20°C, the fertilized eggs of common carp take 101-104 h to incubate; at 25°C, 49-53 h; at 30°C, 47- 50 h.

Habitat

Water layer

Silver carp, bighead, grass carp, black carp, common carp, crucian carp, and mud carp live in different water layers because of their different feeding habits. Silver carp and bighead chiefly feed on plankton and dwell mostly in the upper water layer where plankton is abundant. Grass carp and wuchang fish prefer to search for food in the upper and middle water layers or near the river bank, side lake, or pond dike. Black carp, common carp, crucian carp, and mud carp prefer the bottom layer because they are benthos feeders.

Water temperature

Fish are poikilothermic (cold-blooded); their metabolism is dependent on temperature. Feeding diminishes when the temperature drops below 15°C and stops below 5-7°C. As a whole, carp are very temperature resistant. They can live between 0.5 and 38°C, with an optimum range of 25-32°C; yet, the optimum temperature range for food intake and growth is 25-32°C (30-32°C for mud carp). Silver carp, bighead, grass carp, black carp, and wuchang fish begin to die when the temperature falls below 0.5°C or rises above 40°C. Mud carp, *O. niloticus,* and *O. mossambicus,* however, often freeze to death below 7.8 and 12°C, respectively.

Water quality

Silver carp, bighead, mud carp, and tilapia feed on plankton and, therefore, habituate themselves in fertile water. Grass carp and wuchang fish feed on grasses. Black carp feed on molluscs and, therefore, prefer sheer water. Common carp and crucian carp, with their strong adaptability, can live in water bodies with different fertilities.

Dissolved oxygen and pH

Silver carp, bighead, grass carp, and black carp prefer a slightly alkaline environment (pH 7.5-8.5). Environments outside this pH range will retard growth.

A fish must be able to carry out normal gas exchange and demands a certain amount of dissolved oxygen. The higher the dissolved oxygen content (DOC), the greater the feeding intensity. With the DOC above 4 or 5 mg/L, feeding is intense, growth is fast, and the food-conversion factor is low. With the DOC below 2 mg/L, fish lose their appetite; below 1 mg/L, fish stop feeding and gasp for air; below 0.5 mg/L, suffocation and death normally result.

Biology of Artificial Propagation

In artificial propagation, sexual maturity, ovulation, spawning, and fry incubation are all artificially controlled. The gonad of the female is the ovary; that of the male is the testis. At sexual maturity, eggs and sperm develop in the ovary and testis, respectively. The gonads exhibit a cyclical variance in its development, which is controlled by various external, ecological factors and the endocrine and nervous systems. These external and internal factors are associated and the former may restrict the latter.

Structure of the Ovary and the Ovum

Ovary

Fish have one pair ovaries which are saclike and located in the body cavity symmetrically. Their walls are formed by connective tissues and smooth muscle. The inner wall of the ovary protrudes and forms the septum (ovum-producing plate) which is responsible for producing the ova. Following sexual maturity, the follicular membranes break and the ova drop into the ovarian cavity. At the end of the ovarian cavity there is a short oviduct that opens to the exterior of body. There are blood vessels and nerve branches on the ovarian tissue.

Ovum

Fish ova possess all the constituents common to cells: cytoplasm, nucleus, cell membrane, etc. At the initial stage of development, the sphere-shaped egg cells only have a nucleus and cytoplasm. As they develop, the eggs accumulate yolk material. The egg yolk contains the nutritional materials essential for embryonic development (protein, fat, glycogen, vitamins, etc.). Eventually, there is much more egg yolk than egg cytoplasm. The distribution of yolk and cytoplasm in the egg is polarized. Except for the yolk, most of the egg constituents (cytoplasm, nucleus, etc.) are concentrated around the "animal pole". Opposite the animal pole is the "vegetal pole." It is here that the yolk, with its greater specific gravity, is concentrated. After fertilization, the first mitotic division occurs and embryonic development begins. The egg yolk neither takes part in nor hinders mitosis. The nucleus consists of a nuclear membrane, nucleoli, nuclear fluid, and chromosomes. The nucleus is sphere-shaped or leaf-shaped. Its function is to maintain the genetic material (deoxyribonucleic acid, DNA), which controls cellular metabolism and is passed from one generation to the next.

The cell membrane covers the exterior of the egg cell and can be divided into three distinct membrane systems, depending on the origin of their material. The primary cell membrane, or yolk membrane, is made of the cell's own plasm, with many radiant, ductlike pores ("radiant belt"), which are involved in the absorption of nutrients and the discharge of metabolic wastes. The secondary cell membrane, or chorion, is secreted by follicle cells in the ovary. This membrane is normally adhesive. It is common in the adhesive eggs of common carp, crucian carp, and wuchang fish. The tertiary cell membrane is composed of a secretion from glands in the oviduct. It is prevalent in the gummy cell membranes of frog and cuttlefish. Most fish do not have all three membrane systems. Silver carp, bighead, grass carp, and black carp only have the primary cell membrane and common carp, crucian carp, and wuchang fish have primary and secondary membranes.

Development of the Ovary

The stages of ovary development can be examined by visual observation or histological survey. Fish gonad development may be divided into six stages according to appearance, colour, size, weight, blood vessel distribution, and ova maturity. However, the classification of ovary developmental stages varies from country to country. Five stages are recognized in India, Japan, and the United States of America; several countries recognize seven stages; and, in China, six stages are defined. Silver carp is used as an example to describe these six stages.

Stage I ovary

By visual observation, the gonads are located at the lower part of the air bladder, closely attached to the coelomic membrane, and are lineal in shape, transparent, and flesh white in colour. It is impossible to distinguish the sexes with the naked eye.

Tissue section – Cells are tiny; diameter, 12-22 μm. The nucleus is rather large, occupying more than half of oocyte's diameter. There are few nucleoli in the centre of the nucleus (Fig. 1.14).

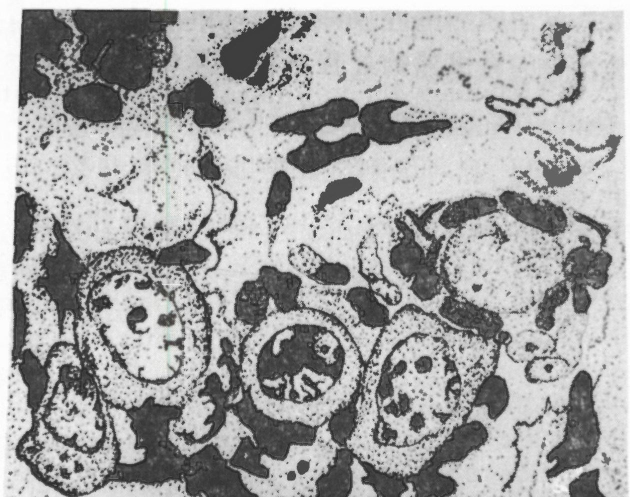


Fig. 1.14. Tissue section of stage I ovary of silver carp.

Stage II ovary

Ribbon-shaped, flesh white, semitransparent gonads are observed. With the naked eye, it is impossible to distinguish one ova from another; however, small eggs are visible when the tissue is examined under a magnifying glass; when fixed, the eggs are petal shaped. At this stage, it is possible to distinguish visually the sexes. The gonad index (percentage of gonad weight to body weight) is 1-2 per cent.

Tissue section – Cells are multiangular or sphere-shaped; diameter 90-300 μm. A thin layer of flat follicle cells surrounds the oocyte. The nucleoli are closely attached to the nuclear membrane (Fig. 1.15).

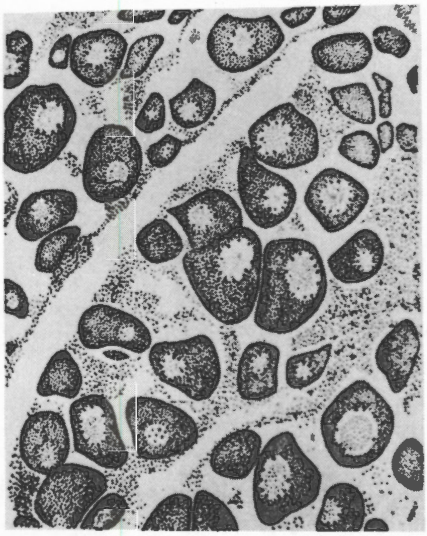


Fig. 1.15. Tissue section of stage II ovary of silver carp.

Stage III ovary

By visual observation, the capacity of the ovary has become conspicuously enlarged. Due to the appearance of melanotic pigment, the colour of the ovary changes to greenish grey. Eggs are visible with the naked eye but not easily separable. The distribution of blood vessels is clear. The gonad index is 3-6 per cent in this stage.

Tissue section – The follicular membrane surrounding the oocyte is a bilayer. The egg yolk begins to form. One or two layers of vacuoles appear on the edge of the cell. The cell is 250-500 μm in diameter. The nucleus in the centre is irregular or oval-shaped (Fig. 1.16.). Most of the nucleoli are distributed along the edge of the nuclear membrane; a small number is scattered in the centre of the nucleus.

The gonads of mature brooders are generally at stage III in the winter.

Stage IV ovary

The ovary is now long and saclike, occupying one-third to one-half of the coelomic cavity. Eggs are plump, greenish grey or light yellow, and can be easily separated. The ovary is fully distributed with blood vessels, and the gonad index is 12-22 per cent.

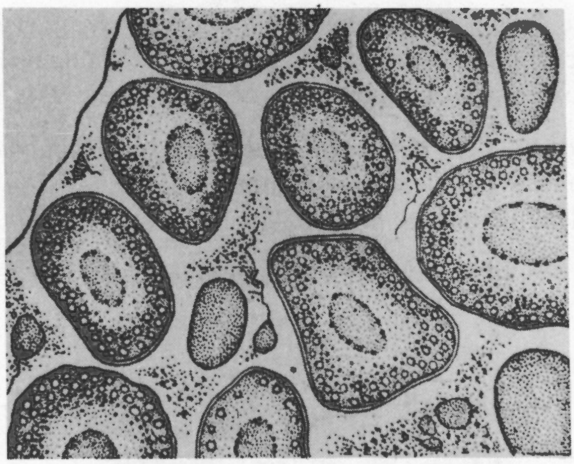


Fig. 1.16. Tissue section of stage III ovary of silver carp.

Tissue section – Egg yolk granules fill almost all the space outside the nucleus, with only a little cytoplasm spreading around the nucleus and near egg membrane (Fig. 1.17); diameter 800-1580 μm. The nucleus edge is wavy, with a few nucleoli inserted in the troughs; most of the nucleoli are moving toward the centre of the nucleus.

This stage can be further divided into three substages based on oocyte diameter and nucleus location. Early stage IV: egg diameter, 800 μm; nucleus in the centre. Middle stage IV: egg diameter, 1000 μm; nucleus in the centre or slightly toward the animal pole. Late stage IV: egg diameter, 1580 μm; nucleus at the animal pole (polarization).

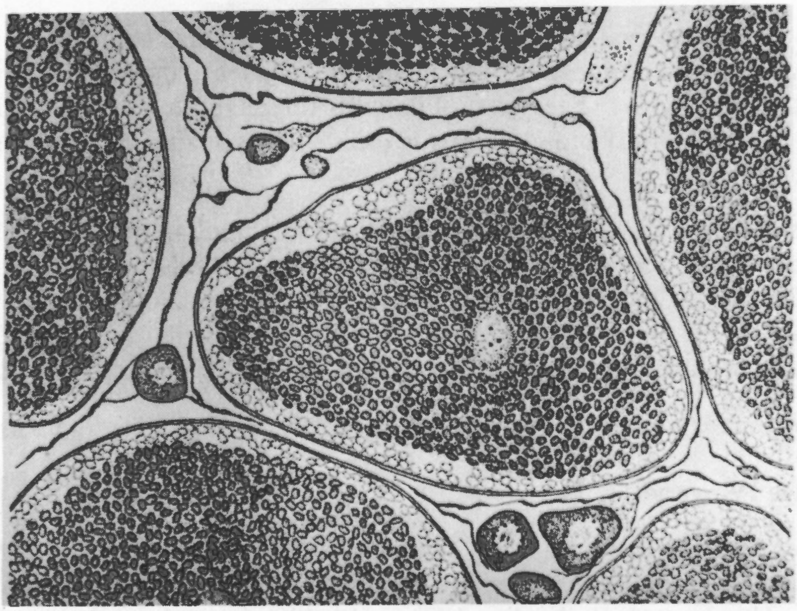


Fig. 1.17. Tissue section of stage IV ovary of silver carp.

Experimental data and practical application have shown that mature eggs cannot be obtained by inducement of early stage IV oocytes from silver carp, bighead, grass carp, or black carp. Only in middle and late stage IV, when the nucleus is eccentric or polarized, can mature eggs be acquired; artificial induction of estrus will then succeed. These stages could last as long as 1, 2, or even 3 months, providing that the proper ecological conditions for spawning are not available and that no artificial propagation is performed.

Stage V ovary

In this stage, oocytes enter the ovarian cavity as follicular membranes break, and the eggs are flowing freely. The ovary and the belly of the fish are very soft. A slight pressure on the belly would cause the eggs to flow through the cloacal opening.

Tissue section – Yolk granules begin to fuse. The cytoplasm and the nucleus have moved to the animal pole. The nucleoli concentrate in the centre of the nucleus and the nuclear membrane dissolves. The nucleus looks transparent.

As the oocytes proceed to maturity, the follicle epithelial cells secrete a substance that dissolves and absorbs tissues between the follicular and egg membranes; thus, the eggs can easily be released from the follicles and flow freely in the ovary (ovulation). During spawning, the eggs are released from the body through the cloacal opening.

The oocytes proceed quickly from stage IV to maturity (stage V). In nature, the process may be complete 20-40 h after the rising of the river's water level. When estrus is artificially induced, maturity may be reached in 10-20 h or less. If the

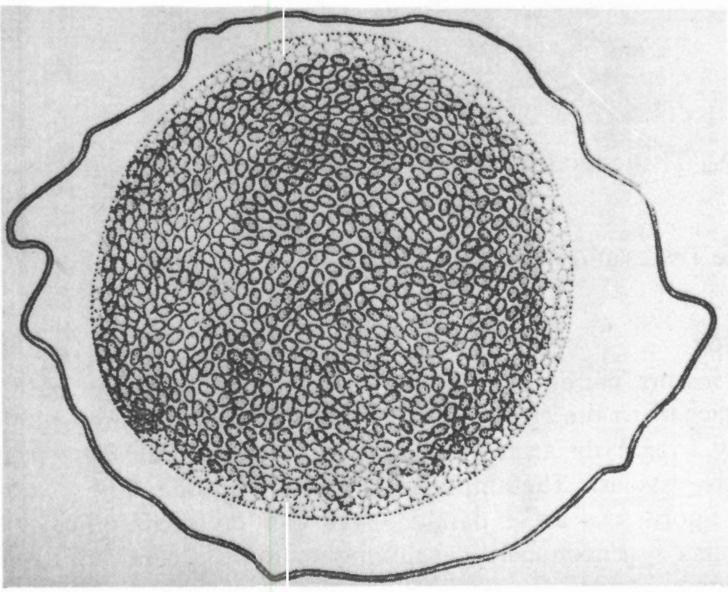


Fig. 1.18. Tissue section of stage V egg of silver carp.

follicles discharged immature eggs, the rate of fertilization would be adversely affected. If the follicles did not release the mature eggs, the eggs would become overripe, and the rate of fertilization would certainly be adversely affected. Even if some of these eggs were fertilized, the embryos would not develop normally. In other words, the success of either natural spawning or artificial insemination depends upon knowing exactly the maturity stage and spawning time of the fish. If the mature eggs are not released, the oocytes would degenerate and be absorbed.

Stage VI ovary

At this stage, most of the eggs has been laid. There are still some stage IV oocytes in the ovary. The ovary is slack and noticeably smaller, and blood vessels have become enlarged with lump-shaped extravasated blood.

Tissue section – After ovulation, there are abundant follicular membranes and some undischarged mature eggs in ovary. The undischarged eggs will soon degenerate and be absorbed, forming a semi-transparent, irregular, orange-yellow structure. Many interim oocytes can still be seen (Fig. 1.19).

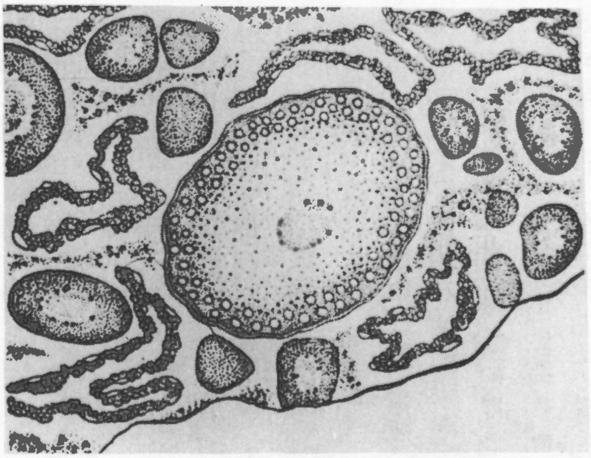


Fig. 1.19. Tissue section of stage VI ovary of silver carp after spawning

Structure of the Testes and the Sperm

Testis

The testes are paired and tubular. They are situated on both sides of the air bladder, attached to the coelomic wall. The mature testes are white, and, inside, there are many irregularly arranged ampullae. The spaces between ampullae are full of connective tissues. The ampullae are composed of many spores or (seminal vesicle sacs). Spore sacs are separated by a thin layer of follicular cells. Each spore sac contains synchronously developing germ cells, and germ cells in various stages of development can be seen in different spore sacs. At the centre of the ampullae, there is a hollow cavity. After the formation of sperm cells, the spore sacs dissolve and the sperms enter this cavity. The terminal end of the testis is connected to a short seminal duct with and opening to the exterior of the body.

Sperm

Chinese carp sperm cells consist of a head, a neck, and a tail (Fig. 1.20). The sperm head of silver carp is almost spherical, 2.2-2.5 μm in diameter, consisting of an apex and a nucleus. The apex is situated at the front part of the head. It is also called the "penetrator" because of its function, which is to penetrate the egg membrane. The neck is very short and situated between the head and the tail. The sperm neck of silver carp is about 1.1 μm long. The tail, narrow and long, is many times longer than the head: about 35 μm. The tail is the metabolic centre and motor organ of the sperm.

Mature sperms congregate in ampullae cavities after the disintegration of the spore sacs. Sperms mix with the fluid secreted by the interstitial cells in the testis, forming milt. This milt is exuded or pressed out of body at the climax of brooders' estrus; 1 mL of silver carp milt holds approximately 48 million sperms. The total amount of milt exuded from one male spawner could reach 30-40 mL.

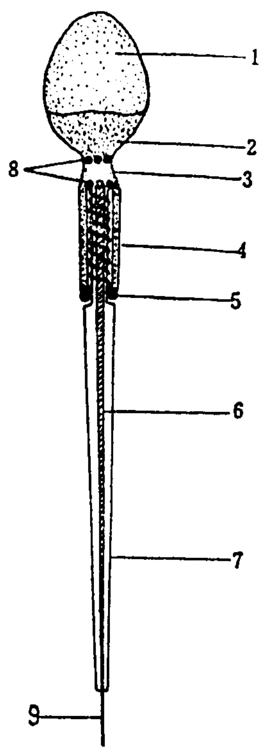


Fig. 1.20. Structure of a sperm:

1. apex
2. nucleus
3. neck
4. middle part
5. end ring
6. spindle filament
7. plasm sheath
8. knots (front and rear)
9. flagellum

Development of the Testis

Like the ovary, the development of the testis may be divided into six stages.

Stage I testis

Testis are lineal in shape, transparent, and closely attached to the coelomic wall. At this stage, it is impossible to distinguish between the sexes. On the tissue slice, scattered spermatogonia, 16 μm in diameter, may be observed. The nucleus is big and round, 9 μm in diameter. Ampulli and seminal vesicles are still forming; therefore, there is no clear, fixed arrangement of sperm cells.

Stage II testis

Testis are lacelike and either translucent or opaque. Blood vessels are not clearly visible. Characteristic of this stage are the multiplication of spermatogonia and the formation of seminal vesicles, which are arrayed in bundles. At this stage, ampulli are solid and separated by connective tissue.

Stage III testis

Testis are rod-shaped, pink or yellowish, and elastic on the surface, with a clear distribution of blood vessels. On the tissue slice, a hollow cavity may appear in the middle of the solid ampullae, with one or several layers of seminal vesicles on the ampullar walls.

Stage IV testis

Testis are milky white with a clear distribution of blood vessels on the surface. It is impossible to squeeze out milt early in this stage, but becomes possible later in stage IV. On the tissue slice, some large primary spermatocytes, smaller secondary spermatocytes, and smallest spermatids can be observed; all of these cells congregate on the walls of the seminal vesicles with a small number of sperms.

Stage V testis

Testes are white and full of milt. The milt will flow out through the cloacal opening if the male's head is taken up and its belly is slightly pressed. A large number of sperms, both mature and in various stages of development, can be seen inside the ampulli on the tissue slice.

Stage VI testis

The volume of the testes has greatly decreased after milt exudation, and the testes are now yellowish white or pink. Only spermatogonia, some primary spermatocytes, and connective tissue remain in the seminal vesicles. After milt exudation, the testes revert to stage III and redevelop from there.

Sexual Cycle and Maturity Age

There is a certain sexual cycle in the development and maturity of fish gonads. When a fish reaches sexual maturity and spawns or discharges milt for the first time, its gonads begin to develop cyclically with the seasons. This is termed the sexual cycle. In pond fish culture, the sexual cycles of silver carp, bighead, grass carp, black carp, and mud carp are essentially the same. In nature, these fish spawn once a year. In southern China, the climate is warmer. Through intensive culture, pond-reared spawners, after spawning in the spring, can reach maturity in the same year and be induced to spawn two or three times a year.

Both sexual maturity and gonad development are tightly associated with environmental conditions (i.e., water temperature, food availability, DOC, etc.). Accordingly, the sexual cycle varies from region to region. Even in the same region, gonad development may vary because of environmental conditions.

Cyclic variance of ovary development

Over the winter (November-January), the ovary of silver carp in Zhejiang Province develops from stage I to stage III with a gonad index of 5-6 per cent. Lipid accounts for about 3.5 per cent of the fish's body weight. At this time, old-generation eggs are degenerating and being absorbed. The new oocytes begin to accumulate egg yolk.

In the spring (February-April), the ovary develops from stage III to stage IV, with a gonad index of 5-10 per cent. The lipid content decreases gradually as the new oocytes accumulate egg yolk. Beginning in early April, the egg cells begin to grow quickly and the fish belly becomes expanded gradually. The ovary enters stage IV.

In the summer (May-July), the ovary grows quickly with obvious increases in weight, developing from stage IV to maturity with a gonad index of 17-20 per cent. The lipid content decreases sharply and the belly is soft and expanded. If the water temperature is favourable, the fish may be induced.

In the autumn (August-October), after ovulation, the ovary is in atrophy, with a gonad index around 10 per cent. The majority of those ovaries that have not ovulated show apparent degeneration, returning quickly from stage IV to stage II. In the winter, the ovary develops again from stage II or stage III. The nutritive materials such as lipid will gradually accumulate for the next sexual cycle. Because mud carp is a subtropical fish, their gonad development requires a higher temperature. The gonad develops slowly in the winter when the ovary is at stage II. Up to next April (26°C water temperature in southern China), the gonad develops quickly to stage IV (Fig. 1.21).

Cyclic variance of testes development

Testes develop earlier than ovaries. In the winter (November-January), testes are in stage III and the maturing rate is 0.2-0.4 per cent. By the time spring

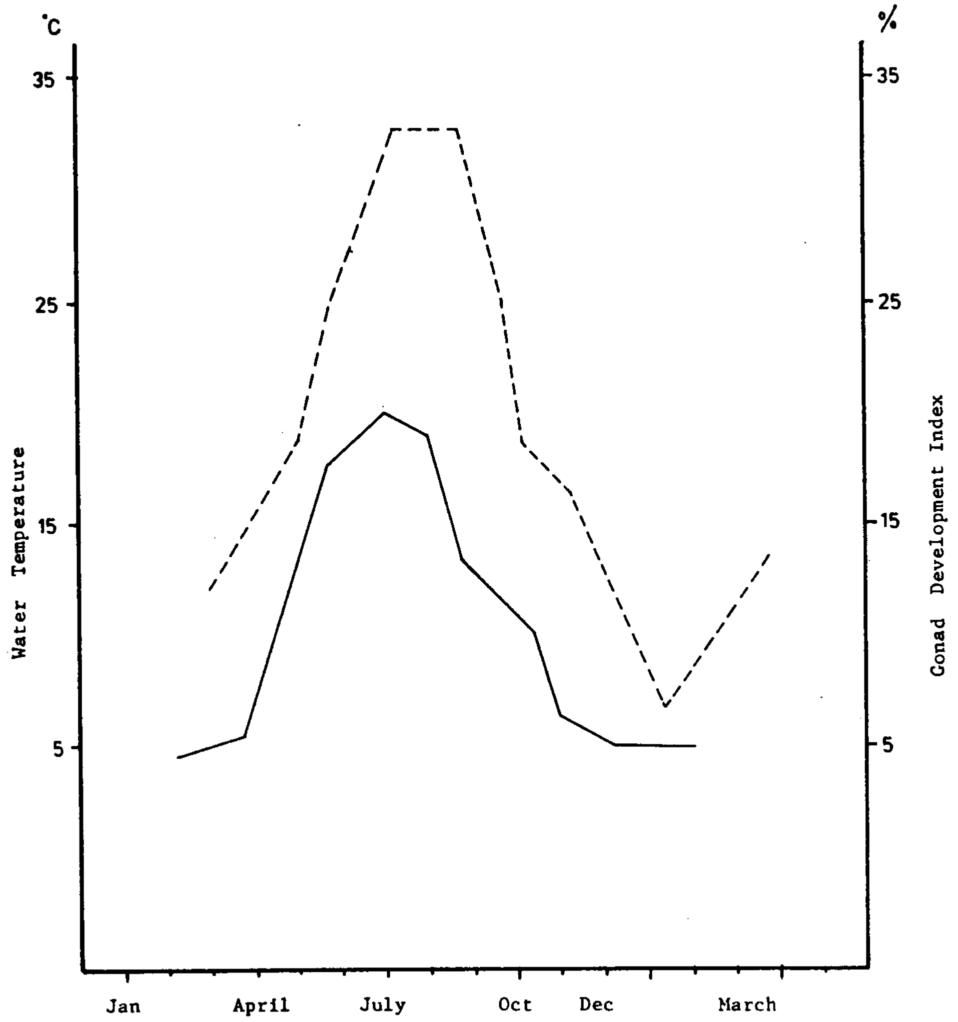


Fig. 1.21. Annual variation of gonad development index of silver carp cultured in pond.

-------- Water Temperature

———— Gonad Development Index (%)

(February-April) arrives, testes have developed to stage IV and the gonad index is 0.2-1.5 per cent. The testes reach maturity (stage V) in the summer (May-July), and the gonad index is 1.6 per cent. In the autumn (August-October), after milt has been released, the testes are in stage VI, the gonad index is 0.6 per cent, and the remaining sperms are absorbed. The spermatocytes of a new generation begin to grow and the testes begin a new sexual cycle (Fig. 1.22).

Maturity age

Under different geographical and ecological conditions, the maturity age of the same species is widely different. The maturity age of male and female silver

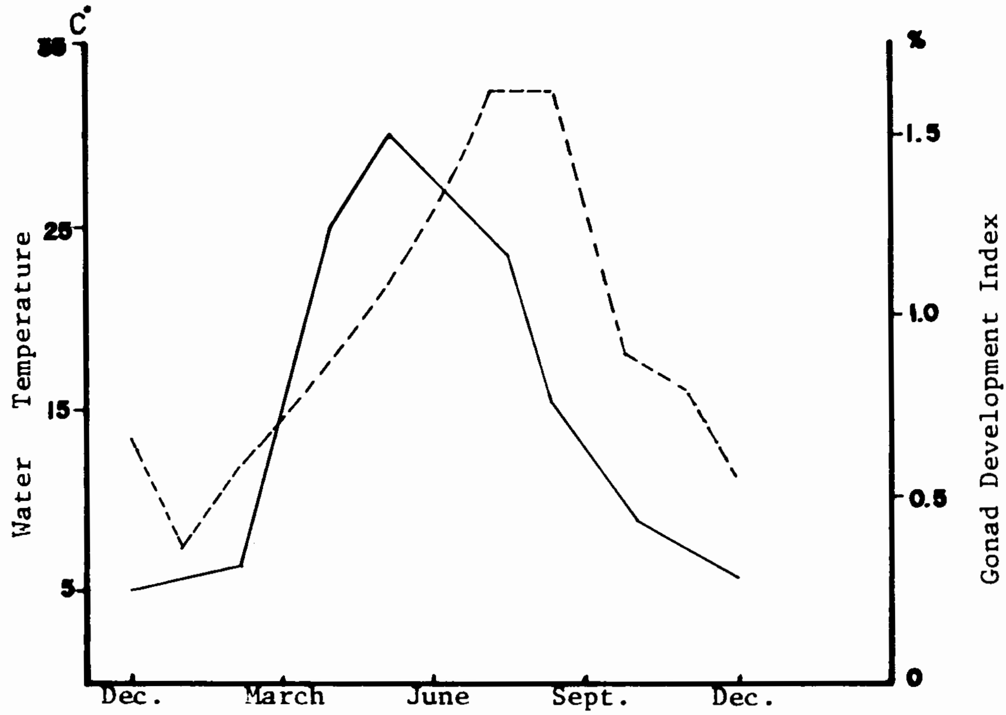


Fig. 1.22. Annual variation of gonad development index of male silver carp cultured in pond.

\- - - - - - - - - - - Water temperature (°C)

———————— Gonad development index (%)

carp, bighead, and grass carp in southern China is 1-2 years earlier than that in northern China (Table 1.4). However, even in the same region, maturity age varies with ecological conditions. For example, in Jiangsu and Zhejiang provinces, the maturity age for female silver carp is 4 years; for grass carp and bighead, 5 years; and for black carp, 7 years. If ecological conditions are optimum, maturity could occur 1 year earlier. Males generally mature 1 year earlier than females.

Table 1.4. Maturity age (years) of silver carp, bighead, grass carp, and black carp reared in ponds.

Species	*Southern China*	*Central China and Eastern China*	*Northern China*	*Northeastern China*
Silver carp	2-3	3-4	3-4	5-6
Bighead	3-4	5	5-6	6-7
Grass carp	3-4	4-5	5-6	6-7
Black carp	–	5-7	7-8	8

Reproductive capacity

Reproductive capacity refers to the ability of fish producing their offspring. The assessment of reproduction capacity is based on maturity age, sexual cycle, fecundity or amount of the mature germ cells, effective egg production, fry survival rate, etc. Emphasis here is placed on the fecundity and spawning amount of pond-reared silver carp, bighead, grass carp, and mud carp.

Chinese carp have many similar features in terms of reproduction (Table 1.5). For example, the gonad index of fully mature female spawners is between 15 and 20 per cent. The fecundity of spawners is generally high. The relative fecundity is 110-140 pieces. Fecundity does not apparently relate to region, but to culture management (mainly nutrients).

Table 1.5. Absolute and relative fecundity and maturity rate of silver carp, bighead, grass carp, black carp and mud carp.

Species	*Average body weight (g)*	*Average ovary weight (g)*	*Average absolute fecundity (pieces)*	*Average ralative fecundity (pieces)*	*Average maturity rate (%)*
Silver carp	4,461	897	627,620	141	20.1
Bighead	8,640	1,540	1,078,000	124	17.8
Grass carp	6,310	1,079	755,300	120	17.1
Black carp	21,950	3,446	2,412,500	114	15.6
Mud carp	850	136	204,000	240	16.0

Under artificial propagation, the average egg production of silver carp, bighead, grass carp, and black carp is 52 pieces/g body weight; the average maximum egg production is 95 pieces/g body weight. Mud carp shows higher egg production because its eggs are much smaller (Table 1.6).

Table 1.6. Egg production of carps under artificial propagation.

Species	*Maximum egg production (piece/g body weight)*	*Average egg production (piece/g gody weight)*
Silver carp	75.4	51.8
Bighead	77.6	58.8
Grass carp	103.0	47.7
Black carp	125.0	49.3
Mud carp	211.0	77.9

Relationship between the Endocrine System and Gonad Development

Just like other vertebrates, all the physiological activities of carp are regulated and controlled principally by the nervous system and the endocrine system, of which the pituitary, or hypophysis, gonad, and thyroid glands are closely associated with gonad development.

Hypophysis

The hypophysis of fish is located below and on the ventral side of the thalamencephalon and is attached to the hypothalamus. It is divided into two parts: neurohypophysis and adenohypophysis. The neurohypophysis is directly connected to the hypothalamus, with its nervous fibres and blood vessels planted deep into the adenohypophysis. The adenohypophysis could be divided into anterior (proadenohypophysis), transitional (mesoadenohypophysis), and posterior (motaadenohypophysis) lobes. The anterior lobe is situated nearest to the thalamencephalon where there is a little distribution of nervous branches and blood vessels. The transitional lobe is situated at the lower front of the anterior lobe and the posterior lobe is situated at the lower front of the transitional lobe (Fig. 1.23).

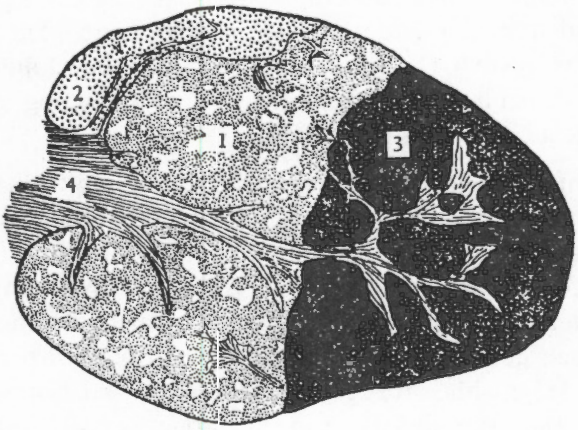


Fig. 1.23. Vertical section of a grass carp hypophysis:
1. mesoadenohypophysis 3. motaadenohypophysis
2. proadenohypophysis 4. neurohypophysis

The mesoadenohypophysis contains basophils that secrete a sexual hormone: follicle-stimulating hormone (FSH). This hormone stimulates growth, development, maturity, and ovulation of eggs. It promotes the synthesis and secretion of estrogen in the female or the formation of sperm and the secretion of androgen in the male.

The sex-stimulating hormone of the hypophysis varies with age and season. As a rule, the amount of this hormone secreted by mature fish is greater than that secreted by immature fish and is higher before than after spawning. Hypophyseal hormones are used to artificially induce estrus and are effective within species, within genus, and, usually, within family. For example, common carp and silver carp belong to different genera; but the hypophysis of common carp is effective in inducing silver carp and vice versa.

Gonads

The gonads of fish produce germ cells (sperm cells and eggs) and secrete sexual hormones. The male sex hormone secreted by the testes is called androgen. The female sex hormone secreted by the ovary is called estrogen. The hormones initiate the development of subsidiary sexual organs and secondary sexual character, and are responsible for the sexual behaviour of the fish. Other endocrine glands directly or indirectly affect gonad development. For example, thyroxine, which is secreted by the thyroid gland, stimulates spawning at low temperatures. The adrenal cortex (internal tissue) secretes adrenal cortex hormone. This hormone regulates carbohydrate metabolism and is involved in controlling the salt and water balance.

Function of the Nervous System in Propagation

Successful propagation of a species depends upon the maintenance of a balance between physiological processes and ecological conditions. The realization of this balance relies upon the coordination of the nervous system and the body fluid regulatory system. Gonad development is, to a great extent, controlled by the hypophysis, and hypophysis activity is, in turn, controlled by external factors through the nervous system (Fig. 1.24). The gonad development of silver carp, bighead, grass carp, and black carp from stage IV to spawning stage V is controlled by external, ecological conditions (Fig. 1.24).

When certain ecological conditions stimulate the external sense organs, the nerves of these organs transmit impulses to the central nervous system, which induces the hypothalamus into releasing luteinizing hormone releasing hormone (LRH). This hormone, through the portal vein of the hypophysis, stimulates the basophilous cells in the hypophysis to release luteinizing hormone (LH) and FSH. These hormones reach gonads through blood circulation and promote their growth and development. Meanwhile, the gonads secrete sexual hormones, affecting the hypothalamus and the hypophysis, and initiating sexual activity: i.e., chasing, natural courtship, spawning, and releasing milt.

Influence of Ecological Conditions on Gonad Development

If ecological conditions are favourable, the growth and development of fish will be normal. If the relevant ecological conditions are unfavourable, however, growth and development will be restricted. Excessively unfavourable conditions may result in death. The principal ecological factors are food availability, water temperature, water current, and DOC. These conditions constantly effect fish growth and gonad development.

Food

Only under rational nutritional conditions can the gonads fully develop. At the early developmental stages (II and III) of the ovary, the gonad index is generally

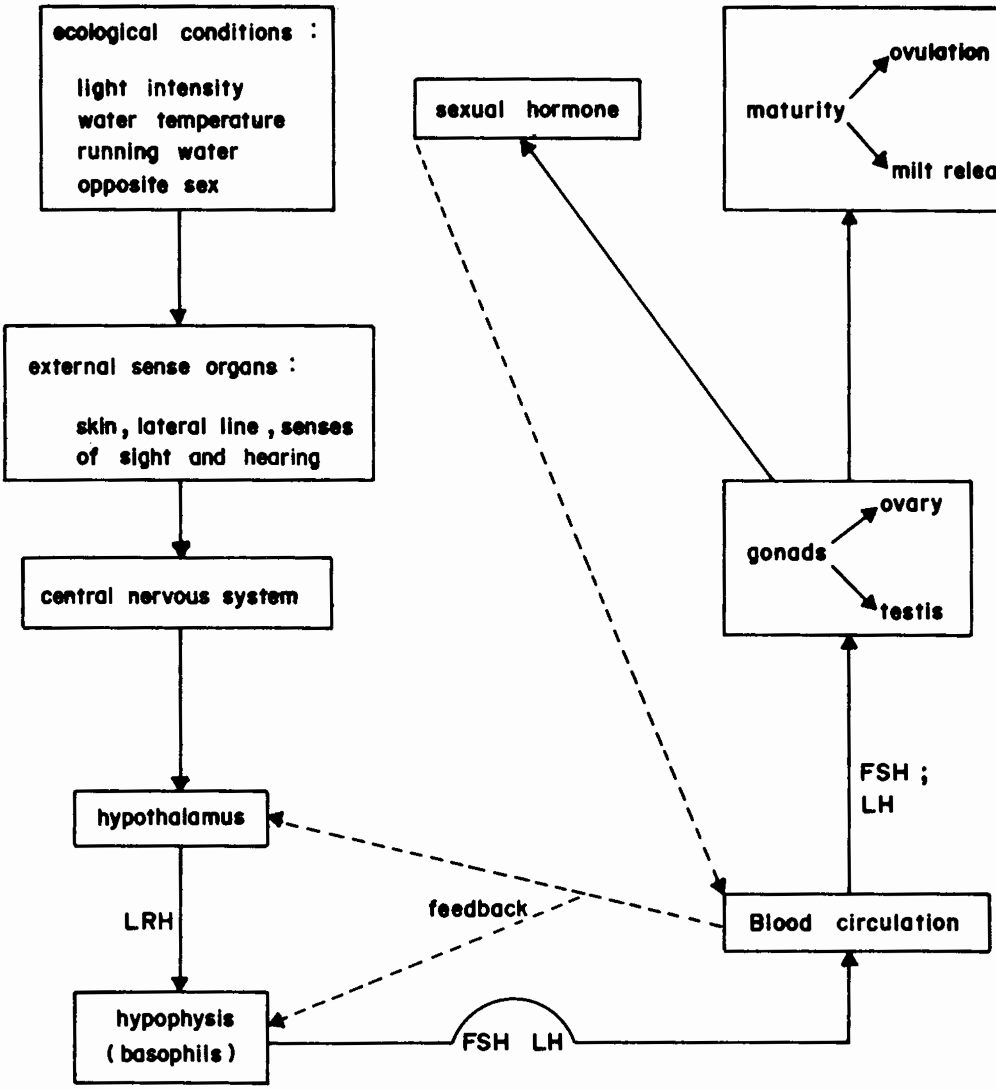


Fig. 1.24. Role of the central nervous system in controlling the reproduction of Chinese carp.

5-6 per cent. As the nutrient substance (egg yolk) accumulates and the fish ingests protein and fat, coverting surplus energy to fat for storage, by late spring (late April or early May), with the increased temperature, the ovary begins to grow quickly and the gonad index rapidly increases to 12-20 per cent. If the rearing conditions for spawners are good and there is sufficient food available in the autumn after spawning, the gonads will mature earlier and the fecundity will be high. If these conditions are not met, gonad development could be restricted or even inhibited.

Among the required nutrients (proteins, fats, carbohydrates, vitamins, and minerals), vitamin E is especially important to gonad development. Table 1.7 shows that supplying vitamin-rich feeds (wheat sprouts, rice sprouts, soybean; and peanut

Table 1.7. Relationship between feed composition and the fecundity of grass carp.

	Fine feeds (g/day/ind)	*Green feeds (g/day/ind)*	*No. of fish*	*Egg production (No./kg body weight)*
Corn, rice bran	125	577	51	38,214
Wheat sprouts, rice sprouts, soybean, peanut dregs	45	800	22	57,500
Rice, rice minced, barnyard grass seed, rice bran	105	240	65	27,236

dregs; also, lettuce leaves and *Ixeris denticulata*) in the early spring improves egg production. An abundant supply of nutritional feeds, however, is not sufficient to ensure proper gonad development. Proper nutrition must be combined with other favourable ecological conditions for the gonads to reach maturity.

Water temperature

Water temperature is a significant factor affecting metabolic rate, maturing age, and the developmental rate of the gonads (Table 1.8). Because of the dif-

Table 1.8. Effect of water temperature on maturity age and accumulated temperature.

	(Guangxi) 27.2°C	*(Guangdong) 25.0°C*	*(Jiangsu) 24.1°C*	*(Heilongjiang) 20.0°C*
Growth period[a] (months)	12	11	8	5.5
Accumulated temperature during growth period (degree x days)[b]	9,792	8,250	5,780	3,333
Maturity age (years)	2	2-3	3-4	5-6
Accumulated temperature during maturity period (degree x days)[c]	19,584	16,500-24,750	17,340-23,120	16,660-20,000
Average accumulated temperature during maturity period (degree x days)	19,584	20,525	20,230	18,315

Note: [a] The growth period is counted when the monthly average water temperature is above 15°C;

[b] Accumulated temperature during growth period (average water temperature during growth period) x (number of days);

[c] Accumulated temperature during maturity period = (accumulated temperature during growth period) x (maturity age).

ferences in water temperature and growth period between southern and northern China, silver carp show different maturity ages; nevertheless, the accumulated temperature required for maturity is basically identical: 18,000-20,000 degree days. This demonstrates a positive relationship between gonad developmental rate and water temperature. In northern China, raising the water temperature is an effective technique to ensure gonad maturity and an early induction of estrus during the brood fish culture period.

Water current

Letting fresh water into brood fish rearing ponds at a definite or indefinite time keeps water quality good, which is beneficial to growth. At the same time, it can regulate the composition of the natural food and raise the nutritional level of the brood fish. Running water stimulates gonad development, especially when the germ cells develop to stage IV. It accelerates metabolism and the transfer of stored nutrients to the gonads. Furthermore, experimental data indicate that running water may stimulate the hypothalamus to synthesize and release LRH, which further stimulates the hypophysis to release sex-stimulating hormone. Spawners are then induced into estrus (Table 1.9).

Table 1.9. Effect of running water on spawning and egg fertilization.

Running water treatment	*Body weight of spawners (kg)*	*Relative fecundity (eggs/kg of spawner)*	*Spawning rate (%)*	*Fertilization rate (%)*
Silver carp				
Before spawning	121.0	109,000	90	82
Slight, all year	215.0	130,000	100	82
None	169.0	67,000	85	50
Grass carp				
Slight, all year	101.5	101,000	100	89
Before spawning	108.5	116,000	100	88
None	60.0	60,000	91	30

Slight running water year round maximizes the spawning rate of silver carp. Slight running water year round and fresh running water before spawning have the same positive effects on the spawning rate of grass carp. If there is no running water, however, the fertilization rate drops to 50 per cent or lower.

Dissolved oxygen

Oxygen is essential for survival. When the DOC is 2 mg/L, normal physiological activities are drastically reduced and fish gasp for air. Also at this level, the excessive energy consumption by the fish negatively affects gonad development. In such a case, most of the induced brood fish fail to spawn properly. As spring approaches, the demand for oxygen becomes urgent, usually above 4-5 mg/L. If the water is clear with a high DOC, the brooders spawn normally. In brood fish culture, attention must be given to manuring, feeding amount, stocking density, supply of fresh water, and continuously improving the living conditions of the brood fish.

Besides food availability, water temperature, water current, and DOC, other ecological factors that affect gonad development and maturity include light intensity, salinity, and presence of the opposite sex.

Chapter 2

ARTIFICIAL PROPAGATION OF BLACK CARP GRASS CARP, SILVER CARP, AND BIGHEAD

Yu Shigang

In about 460 BC., Fan Li wrote *The Treatise of Pisciculture,* the earliest monograph on freshwater fish culture. He summed up the method of common carp culture in ponds in China and, therefore, the first pond fish cultured in China was common carp. Polyculture of black carp, grass carp, silver carp and bighead began during the Tang Dynasty (618-904 AD.).

The high per-unit yield of fish culture in China is due to the many merits of Chinese carps. In general, however, the pond production cycle does not go beyond 3 years; therefore fish gonads do not develop fully. Moreover, in the past it was believed that grass carp, black carp, silver carp, and bighead could not be propagated in ponds; fry were obtained mainly from the Changjiang River and the Pearl River. Collecting the fry in rivers and transporting them to the distant culture ponds required much efforts, increased the cost of production, and resulted in a high fry mortality rate. Furthermore, carp fry became mixed with the fry of wild fish. For these reasons, artificial propagation was seen as a better method of obtaining fry.

In 1958, aquaculture researchers in Guangdong Province obtained fry by injecting both silver carp and bighead brood fish with the hypophysis of common carp. In the same year, researchers in Zhejiang Province succeeded in inducing the spawning of silver carp and bighead by applying human chorionic gonadotropin (HCG). In 1960, the artificial propagation of grass carp was successful. In 1963, black carp fry were obtained by artificial propagation. Within 6 years the artificial propagation of all four cultured carps was successful and had been used for production purposes. Now, most of the fingerlings nurtured in ponds come from artificially propagated fry.

In 1974, synthetic luteinizing hormone-releasing hormone (LRH) was proven to be effective in the induction of spawning. In 1975, the highly effective LRH analogue (LRH-A) was synthesized. This analogue solved the problem of inadequate supply of inducing agents. Its wide application has significantly reduced production costs. At present, many advances are being made in the artificial propagation of Chinese carps.

Rearing of Brood Fish

"Brood fish" refers to the male and female fish used in artificial propagation. Only after a fish reaches sexual maturity can it be induced to spawn; whether the fish is properly reared or not will directly affect the results of induced spawning.

The rearing of brood fish therefore is an important step in the artificial propagation of cultured fish.

Collection of Brood Fish

Differentiation between male and female

The male to female ratio of parent fish must be controlled when they are cultured in ponds and induced to spawn. Consequently, it is important to correctly distinguish the male from the female. Sex is usually identified by the characteristics of the pectoral fins. Secondary sexual characteristics of Chinese carps are shown in Table 2.1.

Table 2.1. Secondary sex characteristics of male and female Chinese carp.

Species	*Male*	*Female*
Silver carp	There is a row of fine bony atenoid serrations on several of the foremost fin rays of the pectoral fin. They are coarse and thorny and present throughout the life of the fish.	Pectoral fin is smooth.
Bighead	Edges of the upper rims of several of the foremost pectoral fin rays are sharp and slant backward.	Pectoral fin is smooth.
Grass carp and black carp	The pectoral fin rays are thick and long, extending freely like sharp knives. In the reproduction season, pearl organs appear on the pectoral fins and opercula of mature male fish. They are coarse to the touch.	The pectoral fins are thin and short, spreading out spontaneously like a fan. No pearl organs appear.

Selection and transportation of parent fish

Parent fish may be captured from rivers, lakes, or reservoirs, or may be reared in ponds from fry, fingerling, or adult. In China, mature grass carp, black carp, silver carp, and bighead are captured from open bodies of water and, for a short time, in ponds as parent fish. This method requires much less time than rearing parent fish from fry.

The most appropriate time to collect parent fish is the autumn or the winter, when the water temperature is around 10°C. At this time, the fish are less active so there is less chance of serious injury to the fish, dissolved oxygen is abundant, and transportation is convenient. After selection, the parent fish are reared in ponds for the coming spawning season. Fish whose gonads do not develop well can be reared as reserve parent fish for the next spawning season. During the capture and selection of the parent fish, the male and female should be taken from different bodies of water or different drainage systems: parents from different bloodlines will improve the vitality of the next generation.

There are many methods for transporting the parent fish. Four of these are described here.

First, there is transportation by canvas tub or wooden barrel. Generally, this method is suitable for short-range transportation by truck or train. There should be 100 L of water for every 10 kg parent fish and the quantity of fish to be transported is determined according to water temperature, fish size, and time limitations. If the water quality deteriorates *enroute* the water must be changed. It is recommended that each fish be placed in a perforated plastic bag that is about 30 cm longer than the fish itself. The openings of the bag should then be bound and the fish and the bag placed in the barrel together. This will prevent injury to the fish.

Second, parent fish may be transported in plastic bags with oxygenated water. One plastic bag, which is made of a vinyl-film cylinder 30-35 cm in diameter and 50 cm longer than the fish body, can carry one parent fish. The water level must be as high as the fish's body. The fish and the water should occupy one-third of the bag. The openings of the bag must be tightly bound after oxygenation. The bag is then placed in a paper box for transportation by truck. For long-distance transportation, some spare bags, both empty and filled with oxygenated water, should be readily available.

Third is transportation by "perforated boat". If transportation by water is possible, a perforated boat should be used. Because water can come in and out through the holes in the hull of the boat, more fish can be transported using this method than with the other methods.

Fourth, fish may be transported after tranquilization. Tranquilization reduces both breathing frequency and metabolic rate, leaving the fish in an unconscious state. This greatly reduces the possibility of injuring the fish during transport and reduces the consumption of oxygen. Sodium barbital at a concentration of 13.3 ppm is an effective tranquilizer. With a water temperature of 10°C, fish can be tranquilized for more than 10 h. After being placed in the culture pond, the fish revive in 6-10 min.

Parent Fish Rearing Pond

Site selection

Rearing ponds should be close to a water source to facilitate water management. If possible, rearing ponds should be next to the spawning pond and the incubation pool. The pond should be 3-4 mu (15 mu = 1 ha) with a water depth of 1.5 m. Flat-bottomed ponds simplify catching and management. If the pond is too large and contains too many parent fish, multiple spawning inductions must be performed. If the pond contains several different catches of fish, gonad development may be adversely affected; in fact, gonads have been observed to degrade in such conditions. In the pond for rearing silver carp and bighead, the bottom should be choice loam with some humus (about 10 cm thick). Leakage must be prevented to save manure and keep the pond water fertile. In the pond for rearing grass carp and black carp, no humus is needed at the bottom and the water must be kept clear with a high oxygen content. Some leakage is allowable if it is convenient to irrigate the pond.

Pond clearing

The pond must be cleared without neglect to the rearing of the parent fish. It should be done each year, after artificial propagation. Pond clearing is important in preventing disease and improving water quality. In one year of rearing parent fish, a lot of leftover manure dregs and silt are deposited at the bottom of the pond. If they are not removed, they will dissolve and produce poisonous substances, such as H_2S and CH_4, which will contaminate the pond water and retard the growth and gonad development of the fish. If the pollution is serious, the fish might suffocate or become diseased. In clearing the pond, the surplus humus is removed after draining away the water. Pond-clearing chemicals can help kill pathogens, and wild fish. Some chemicals (e.g., quicklime) can improve bottom quality. After draining the pond, the dikes, outlet, and inlet can also be easily repaired.

Stocking of Parent Fish

Monoculture and polyculture

Parent fish can be cultured in either monoculture or polyculture. In monoculture, the pond contains only one species. In polyculture, the pond contains one major fish species and several other species to help fully utilize the natural food and maintain water quality. Grass carp and black carp prefer clear, fresh water; however, their excreta can grow large quantities of plankton, making the water fertile. In fertile water, grass carp and black carp reduce or stop feeding, adversely affecting their gonad development. Therefore, grass carp or black carp that are cultured as the major species in one pond should be mixed with some silver carp or bighead. Polyculture cannot only control plankton reproduction and adjust water quality, but also ensures the full utilization of the natural food in pond; thus, the major and minor species are mutually beneficial. However, there are some disadvantages to polyculture as well. For example, catching one species for spawning induction will interfere with the normal life of the other species. Frequent catching might not only result in injury to the fish but also cause the gonads to stop developing or even degenerate. However, measures can be taken to reduce these undesirable effects. For example, before induced spawning the minor and major species could be separated; alternatively, polyculture could be adopted with either reserve parent fish or commercial fish.

Sex ratio

The female to male ratio of the major species stocked in one pond should be the same as that during spawning induction, i.e., 1:1 or 2:3.

Stocking

Generally, the stocking rate of the major species is about 150 kg/mu; that of the minor species 50 kg/mu; this total gives a stocking rate of about 150-200 kg/mu. Stocking density varies with the condition of the pond, the rearing-management technique etc. The grass carp or black carp rearing pond is supplied mainly with artificial feeds. It is possible to raise the stocking density slightly if there is sufficient food and if the pond is easy to drain and irrigate. The stocking density of bighead should be lower because zooplankton grow more slowly than phytoplankton. In a polyculture pond with silver carp brooders as the major species, the stocking weights should be as follows: silver carp, 120 kg/mu; bighead, 25 kg/mu; grass carp, 25 kg/mu.

In a pond with bighead brooders as the major species, the stocking rate of bighead should be 100 kg/mu, with 30-40 kg/mu of grass carp. In the bighead brooder rearing pond, silver carp is not a minor species because they would compete with bighead so vigorously for food that the growth and development of the bighead brooders would be hindered. In a pond with grass carp brooders as the major species, the stocking rate of grass carp should be 150 kg/mu, with 40 kg/mu of silver carp and 10 kg/mu of bighead. In a pond with black carp brooder as the major species, the stocking rate should be as follows: black carp, 150 kg/mu; silver carp, 40 kg/mu; bighead, 10 kg/mu. Grass carp is not included in the black carp rearing pond because they would compete with the black carp for fine feed, adversely affecting the growth and development of the black carp.

Rearing Silver Carp and Bighead Brooders

Silver carp and bighead chiefly feed on natural food (plankton). By fertilization, a large quantity of plankton can be quickly produced so that the parent fish have a sufficient food supply. Therefore, fertilization, in accordance with water colour, is crucial to the success of rearing silver carp and bighead brooders. In the silver carp rearing pond, human feces is the principal manure (70 per cent); the remaining 30 per cent is animal manure. In the bighead rearing pond, there is 70 per cent cow manure and human excreta. Cow manure is suitable for the reproduction of zooplankton. A base manure should be applied before stocking; the general amount is 300-400 kg/mu. After stocking, additional manure should be applied at a rate dependent on condition of the pond and seasonal changes. Generally, additional manure is applied in small amounts with the frequency of application depending on the water colour. An average of 700-1000 kg of manure is applied each month.

Commercial feeds such as bean cakes, wheat bran, and rice bran can be supplemented in the winter or before spawning. Required yearly amounts of commercial feed are as follows: bighead, 20 kg; silver carp, 15 kg. The daily ration is 1-2 per cent of body weight.

Culture after spawning

After spawning, the weather gets hot. The brooders need special attention during this period. The weather, water colour, and water quality should be watched closely. Fertilization should be conducted in accordance with water quality. As mentioned earlier, fertilizer should be applied frequently and in small quantities. Fresh water should be added in the same manner to prevent deterioration of the pond water.

Autumn and winter cultivation

Before winter, manure should be heavily applied to make the water fertile. During the winter, small amounts of manure should be applied and supplemented with certain feeds. There is no need to add fresh water during the winter.

Spring cultivation

As spring approaches, the water depth should be controlled at about 1 m to raise the water temperature. This makes it easier for the water to become fertile. The amount of manure applied can be increased gradually. The compost heaped at the corner of the pond can be combined with animal wastes and spread into the pond. Manure spreading is carried out every other day or every other 2 days. Some fine feeds must also be added. Just over 2 weeks before spawning, manure application should stop. In the early spring, fresh water is added one or two times each month; this stimulates the development of the gonads.

Rearing Grass Carp and Black Carp Brooders

Reasonable feeding is the key to the success in rearing grass carp and black carp brooders.

Grass carp

Combining commercial feeds, green fodders and regular changes of fresh water is an effective way of rearing grass carp brooders. Appropriate commercial feeds include barley, wheat, wheat sprout, bean cake, and peanut cake. Appropriate green fodders include English ryegrass (*Lolium* sp.), clover, lettuce leaves and aquatic and terrestrial plants. At a water temperature of 10°C, grass carp begin feeding and their appetite increases with temperature. At water temperatures over 20°C, grass carp feed well. When the gonads mature, feeding decreases sharply. After spawning, however, the fish again increase their food intake. When the water temperature is over 30°C in July and August, feeding decreases again. When the water temperature reaches 70°C, feeding stops and overwintering begins.

Rearing after spawning – After spawning, special care should be taken in rearing. Green fodder should be supplied at 09:00-10:00 every day at a daily rate of 30-40 per cent of body weight. This schedule provides sufficient food, without leftover fodder. Commercial food is supplied at a rate of 100 g per parent fish every afternoon.

Rearing in the autumn and the winter – Grass carp requires less feeding as water temperature declines. Because the supply of green fodder is minimal at this time of year, commercial feeds are used. When the water temperature is below 10°C, feeding is not needed.

Rearing in the spring – At the beginning of spring, half of the pond water should be drained and replaced with fresh water, keeping the water depth at about 1 m. From early March, 50-100 g of wheat sprout or bean cake should be fed to each fish every day. The staple food is green fodder, which must be supplied as early as possible at a rate of 40-50 per cent body weight. Commercial food should be given only as supplement. Shortly before spawning, grass carp sharply reduce their food intake or stop feeding entirely. This indicates that the gonads have reached maturity. Each grass carp brooder needs 500 kg of green fodder and 20 kg of commercial food per annum. An accumulation of leftover feed and grass carp feces will make the grass carp brooder rearing pond overfertile. This must be avoided because it hinders the growth and development of grass carp. During the culture period, fresh water must be added at regular intervals, depending on the season and the fertility of the pond water. In winter, when the water temperature is low, one or two water changes per month is adequate. However, 1 or 2 months before spawning, the water should be changed three or four times with slight flows lasting 3-4 h each and raising the water level by 10 cm. About 2 weeks before spawning, fresh water should be added every day. Clear, fresh water is important in promoting the gonad development of grass carp brooders.

Black carp

Black carp mainly feed on snails and clams supplemented with small amounts of bean cake. The daily feeding rate is about 20 per cent of body weight. Food is spread on the flat bottom of the pond, 2-3 m from the dike and is supplied year-round. Each black carp needs 500 kg of snails and clams and about 15 kg of bean cake per annum. Like grass carp, black carp favour clear, fresh water; therefore, leftover feed must be avoided. Water must be changed at regular intervals although water changes need not be as frequent as those for the grass carp rearing pond.

Induced Spawning

In induced spawning, the mature parent fish are injected with spawning inducing agents. Without these agents, Chinese carp will not spawn in ponds.

The Fundamental Principle

The natural spawning of Chinese carps in rivers is controlled by certain environmental factors. When these ecological conditions stimulate the external sensory organs, the nerves of these external organs produce impulses that are immediately sent via the central nervous system to the hypothalamus. The hypothalamus then secretes LRH. The pituitary gland reacts to LRH by secreting two gonadotrophic hormones: luteinizing hormone (LH) and follicle-stimulating hormone (FSH). These hormones are transmitted through blood circulation. Stimulated by LH and FSH, the gonads are rapidly developed and mature from stage IV to stage V. After the dissolution of the follicle cell membrane, ovulation occurs and a sex hormone is secreted. The sex hormone acts in coordination with the gonadotrophic hormones, arousing sexual desire in the brood fish. The fish then engage in active sexual activities discharging eggs and milt.

The basic principle behind induced spawning comes from the biological mechanism of natural propagation. Because the external ecological conditions in the fish ponds cannot satisfy the reproductive requirements of the brood fish, the fish are injected with extraneous hormones. Some extraneous hormones (e.g., fish pituitary gland [PG] and human chorionic gonadotrophin [HCG] can take the place of the hormones directly secreted by the pituitary gland of the parent fish and directly stimulate the gonads. Other extraneous hormones (LRH-A) only stimulate the hypophysis of the parent fish, accelerating the secretion of gonadotrophin and inducing the parent fish to spawn or discharge milt.

Spawning Inducing Agents

LRH-A

The secretion activities of the hypophysis are directly controlled by the hypothalamus, which secretes LRH. In China, LRH was refined from the hypothalamus of sheep in 1971. Analysis showed LRH to be peptide of 10 amino acids; pyroglutamic acid, histidine, tryptophan, serine, tyrosine, glutamic acid, leucine, arginine, proline, and glycine amide. Its molecular weight is 1182. Artificially synthesized LRH has a high biological activity for cows, sheep, and humans. When it is used to induce spawning in Chinese carps, however, the dose must be 100 times higher than that for mammals because LRH is easily destroyed by fish protease. In 1975, LRH-A was synthesized. This analogue of LRH consists of nine amino acids (pyroglutamic acid, histidine, trytophan, serine, tyrosine, D-alanine, leucine, arginine, and proline) and acetyl amine. Its molecular weight is 1167. The 6th (glutamic acid) and the 10th (glycine amide) amino acids of LRH are replaced by D-alanine and acetyl amine in LRH-A. The biological activity of LRH-A is about 100 times higher than that of LRH to fish. The LRH-A available on the market is a white powder and is combined with mannite as a filler. It is soluble in water and should be stored in a dry, shady, airtight-environment.

Dosage – For female silver carp and bighead, the injection dose is 10 microgram/kg body weight. Two consecutive injections are more effective: 1-2 microgram/kg for the first injection and, 8-10 h later, 8-9 microgram/kg for the second injection. If LRH-A is used in combination with HCG, the dose of LRH-A is 2 microgram/kg for the first injection and, 8-12 h later, 8 microgram/kg combined with a dose of 200 IU/kg of HCG for the second injection. This treatment stimulates the ova to mature or promotes the polarization of nucleus and the rate of successful induction is high and constant. For the male fish, the dose should be reduced by half, and only one injection should be given (when the female gets the second injection).

Grass carp are more sensitive and responsive to LRH-A. Both males and females need only one injection: females 10 microgram/kg; males, 5 microgram/kg.

For black carp, LRH-A is used in combination with PG. The dose of LRH-A is 15 microgram/kg and the dose of PG is 1 mg/kg. Three injections are given. First, a 5 microgram/kg dose of LRH-A; second, 15 days after, another 5 microgram/kg dose of LRH-A; and third, 12 h later, a 10 microgram/kg dose of LRH-A and a 1 mg/kg dose of PG. For the male fish, doses should be reduced by half. Just one injection should be given at the same time the female receives the last injection. If maturity of the male fish is not achieved, i.e., the sperm cannot be squeezed out, a double injection method may be adopted. The dose of the first injection for the male is the same as that for the female and is given at the same time (15 days in advance). The second injection of the male is synchronized with the third injection of the female.

Common carp pituitary gland (PG)

The pituitary gland, or the hypophysis, lies beneath the diencephalon, connecting with the hypothalamus. When the fish's brain is lifted upside down, the PG is easily separated from the hypothalamus. It is buried in the sphenoid. The hypophysis excretes two gonadotrophic hormones: LH, which stimulates ovulation, and FSH, which promotes the development and maturity of the eggs and stimulates the development and maturity of the follicles.

Collection – Hypophysis can be collected from mature male or female common carp weighing more than 0.5 kg. It can also be collected from dead, unspoiled fish. The hypophysis of a common carp that has never spawned is the best. To remove the hypophysis, first, cut off the head of the fish, set the head on its cut surface with the snout facing upward, and use a knife to cut from the nostrils to the upper edge of the eyes and remove the front parietal bone. Turn the whole brain upside down with a pair of forceps and the hypophysis can be seen. Carefully remove the tissues around it with a pair of forceps and the hypophysis can be removed.

Preservation – If fresh hypophysis is used, it should be ground before use or dehydrated and defatted with pure acetone or absolute alcohol (use a volume about 15-20 times that of the hypophysis). The hypophysis can be preserved for future use after the acetone or alcohol has been renewed twice (immersed for 1-2 h each time). There are methods of preservation. First, the dehydrated hypophysis is dried on a piece of filter paper for 15-20 min and then stored in a tightly sealed, labeled, small, brown bottle. Second, the hypophysis is left in the second immersion liquid and stored in a tightly sealed, labeled, small, brown bottle. Both methods give good results. Generally, the hypophysis is still effective after 2 years of preservation.

Dosage – The estrus-inducing effect of PG on Chinese carps is immediately evident. For females, a dose of 4 mg dry weight/kg body weight should be used; for males, the dose should be reduced by half. After dehydration with pure acetone, the hypophysis of a 0.5 kg common carp weighs about 1 mg.

Human chorionic gonadotropin (HCG)

Human chorionic gonadotropin is a polypeptide hormone. Its molecular weight is 36,000. In physiological function, it is similar to LH and FSH. It promotes ovulation, gonad development, and sex-hormone secretion. The hormone is refined from the urine of women who are 2-4 months pregnant. It is secreted from the chorionic membrane of the placenta and is more effective on silver carp and bighead than on grass carp. At present, the ready-made material available on the market in China is "veterinary gonadotropin." It is a white powder that is soluble in water and must be stored in a cool, shady, dry, airtight environment.

Dosage – For silver carp and bighead, the recommended dose is 4-5 mg/kg (800-1000 IU/kg).

Injection

Preparation of injection

To prepare the PG suspension fluid, first calculate the required amount of PG based on the total body weight of the parent fish. Second, place the PG into a mortar (if the PG is preserved in liquid, dry it on a filter paper for 15 min) and grind thoroughly; add enough normal saline to suspend the ground PG. The volume of injections should be controlled at 2-3 mL for each parent fish.

When HCG and LRH-A are injected, the required dose must be combined with normal saline at a concentration of 0.7 per cent. When the powder dissolves, the solution is ready to be injected. It should be prepared right before use so as to prevent the suspension fluid from becoming ineffective.

Method of injection

Intraperitoneal injection is common. During injection, a brood fish is placed in a cloth bag, lying laterally in the water. The upper half of the fish is held above the surface. At the inner side of the basal part of the pectoral fin where it is scaleless, the syringe needle is inserted toward the head at an angle of 45° to the body's longitudinal axis and to a depth of about 1.5 cm. The fluid is then slowly injected.

Frequency and time of injection

There are two frequencies of injection: single and double. For the single injection, the predetermined dose is completely injected into the fish. For the double injection, the predetermined dose is divided into two separate dosages and injected twice. The amount of the first injection is usually 10-20 per cent of the total dose; 90-80 per cent is in the second injection. Milters always receive only one injection. The injection is given to the milter when the spawner receives the second injection. Both the single-injection and double-injection techniques give satisfactory results. The time of injection depends upon water temperature and working conditions. The brooders are usually controlled to spawn around midnight of at dawn. If the single-injection method is adopted, the injection is done in the afternoon or at dusk to allow the brooders to spawn at dawn. If the double-injection method is adopted, the first injection is given in the morning. The interval between the two injections is 8-12 h. If the water temperature is high, it is better for the brooders to spawn at midnight; fertilization rate and the hatching rate are enhanced.

Season for Spawning Induction

Choosing the most suitable season to induce spawning is an important step in the artificial propagation of Chinese carps. The optimum time depends on the weather and the gonad development of fish. The initial propagation period in Guangdong Province is early May; that in Jiangsu and Zhejiang provinces is from the middle of May to the middle of June. The optimum temperature range is 22-28°C. The sequence for spawning induction is as follows: grass carp, silver carp and bighead, black carp.

Selection of Parent Fish

A female fish with a bulging abdomen and a swollen, soft, elastic genital opening is the usual choice. When mature female silver carp and bighead are held out of the water, their ribs can be faintly seen. If the tail is raised, the contour of the ovary is seen to move forward. If the abdomen of a female silver carp or bighead brooder is exceedingly expanded and less elastic, the fish is overmature and should not be selected for spawning induction. For the mature male fish, if the abdomen is pressed gently, milt will be exuded.

For grass carp, feeding should be stopped 2 days before selection for induction. If a mature female grass carp is placed belly up and the contour of the ovary is seen to move downward on each side of the abdomen, the middle of the abdomen is indented, and the abdomen feels soft, the fish can be selected for induction.

Selection can also be based on the degree of maturity of the eggs. Collect a small amount of eggs from the genital opening and fix them in a solution of 85 mL of 95 per cent alcohol, 10 mL of 40 per cent formaldehyde, and 5 mL of glacial acetic acid for 2 or 3 min. The cytoplasm and yolk will then be transparent and the nucleus opaque. The nucleus, if observed in the centre of the egg, indicates that the egg has not yet matured, and the fish is not ready for induction. If the nucleus is eccentric, the egg is mature and the fish is ready for spawning. If the nucleus is vague or cannot be seen, the egg is overmature or degraded and the fish should not be induced.

Spawning

Response Time

Under normal conditions, there is a delay from the time of the last injection until the parent fish enters estrus. This period is called the response time.

Response times vary slightly depending on water temperature, the spawning inducing agent, the injection frequency, and the species induced. When the water temperature rises 1°C, the response time decreases 1-2 h. The double-injection method has a shorter response time than the single-injection method. For example, when the water temperature is 24-25°C and a silver carp is induced with a single PG injection, the response time is 12-14 h.; with the double-injection method, the response time is 7 or 8 h (counted from the second injection). The response time to PG injection is 1 or 2 h shorter than that to HCG injection; the response time to LRH-A injection is longer than that of PG injection. In addition, given the same hormone at the same dosage during the same season, the response times of various species are slightly different. Generally, grass carp show the shortest response times, followed by silver carp, and bighead and black carp showing the longest response time.

Natural Spawning and Fertilization

After injection, the parent fish are placed in the spawning pond to spawn or exude milt and complete the fertilization process. This is called natural spawning and fertilization.

Spawning pond

After the injection of the spawning-inducing agent, the parent fish need a pond with suitable ecological conditions in which they can perform estrus and spawn. The pond should also allow the convenient collection of fertilized eggs. The spawning pond is usually made of bricks and trowelled with cement. There are two common varieties: circular (Fig. 2.1) and elliptical (Fig. 2.2).

Circular spawning pond – The inlet of the pond is set at a 40° angle tangent to the pond wall. The bottom is concave and an outlet is usually installed in the centre of the bottom. The outlet passes, through an underground pipe, either directly to the incubators or to an egg collection chamber beside the spawning pond. A small cage is set in the chamber to collect the eggs carried by water from the spawning pond.

Elliptical spawning pond – The inlet and the outlet are situated on the same straight line. The water is 1 m deep. The bottom of the pond slopes downward to the outlet. There is an adjacent egg-collecting pond with an egg-collecting cage that is connected to the outlet of the spawning pond.

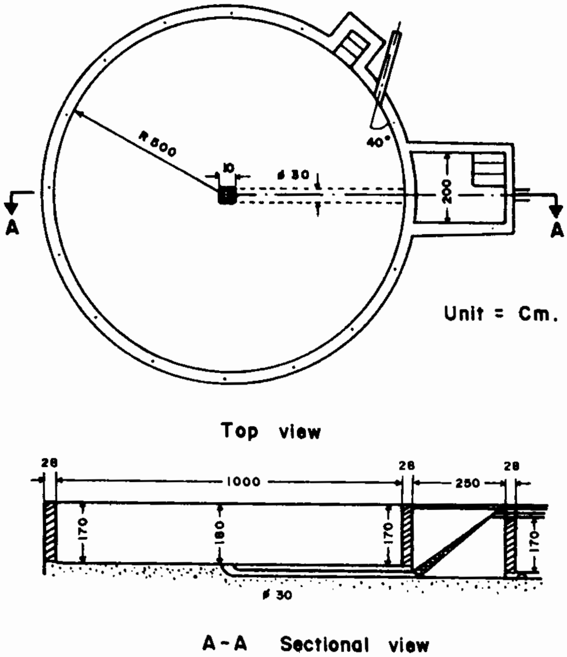


Fig. 2.1. Circular spawning pond (Unit = cm)

1. Valve
2. Egg collection chamber
3. Water pipe
4. Water inlet, 130 cm from bottom
5. Outlet (control the water level)
6. Egg-collecting net and cage

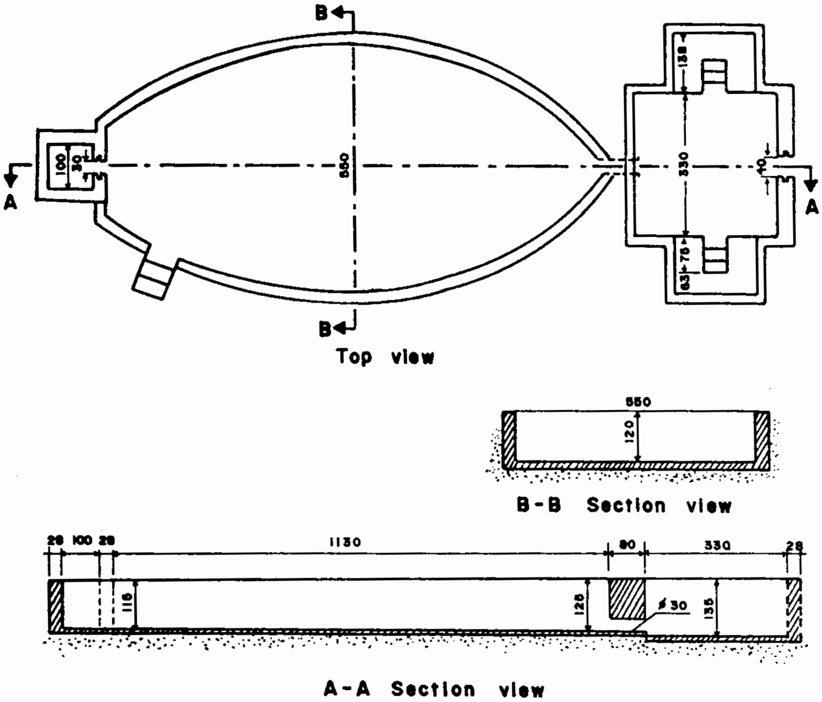


Fig. 2.2. Elliptical spawning pond. (Unit = cm)

Estrus and spawning

After injection and if the fish react normally to the spawning inducing agent, they will begin chasing each other excitedly. This phenomenon is called estrus. The chasing produces irregular ripples on the water surface. As the chasing continues, the fish may sometimes break the surface of the water. At the climax of estrus, the male hits the female's abdomen with its head. The female then lies on its side either underwater or on the surface; its abdomen and tail become extremely constricted and eggs are discharged. At the same time, the male nestles up to the female's abdomen and discharges milt. Sometimes, the male and the female are entangled and swing their pectoral fins as they spawn or discharge milt.

Methods of collecting fertilized eggs

There are two methods of collecting fertilized eggs. One method involves the addition of slowly flowing water to the spawning pond during estrus. This helps to bring the gametes together and raise the fertilization rate. After spawning, the blood fish are removed and the eggs are collected by flushing the pool. The eggs then flow into the egg-collecting cage, where they are collected and counted. Another method involves pouring water into the pond after spawning and flushing the fertilized eggs, which sink to the bottom, into the egg-collecting cage. This is called still-water spawning.

Methods of counting eggs

A volumetric method can be used to calculate the number of eggs. First, the capacity of a container is measured. The eggs in 10 or 20 mL are then counted and the total number of eggs in the container is calculated. On average, after absorption of water, there are 10,000 grass carp and silver carp eggs or 8,000 bighead eggs per litre.

Artificial Insemination

When the brood fish are in estrus and begin to spawn, they are immediately captured. Eggs and milt are collected to bring the mature egg and sperm together. This is called artificial insemination.

The eggs must be at the proper stage of maturity so that after fertilization they will develop normally. At a water temperature of about 28°C, after ovulation Chinese carp eggs keep fertile for 1-2 h until spawning. The time of egg and milt collection is dependent on the spawning-inducing agent used, species, water temperature, etc. These factors are key to the success of artificial insemination. For example, when the water temperature is 23°C, silver carp eggs develop from early maturation to proper maturation in 40 min. They become overmature 1.5-2 h after reaching proper maturity. Only properly matured eggs are able to develop normally; immature or overmature eggs develop abnormally.

After stripping, eggs remain fertile for 10-20 min if free from water; however, in freshwater the eggs lose their fertility in 1 min. In a 0.7 per cent saline solution, eggs remain fertile for 10 min.

The sperm of Chinese carps is active only after it is released into the water. In fresh water, sperm survive for 1 min. The sperm is most fertile for the first 20-30 s in fresh water. Sperm in normal saline can survive for 2-3 min.

There are two methods of artificial insemination for Chinese carps: the dry method and the semi-dry method. In the dry method, about 15 min after the beginning of estrus, the brood fish is captured and stripped. The eggs are collected with a basin (each basin should not contain more than 500,000 eggs). The semen is either directly squeezed onto the eggs or transferred with a pipette and dropped onto the eggs. The mixture is then stirred gently by hand or with a feather for about 1 min and a little clean water is added. The mixture is stirred again for 1 min, allowed to stand for 1 min, and the dirty water is then removed. After the eggs have been washed 3 times in this way, they are transferred to an incubator.

In the semi-dry method, the semen is diluted with a little normal saline and transferred onto the eggs by pipette. Otherwise, this technique is as the dry method.

During artificial insemination, number of eggs can be estimated by measuring the total weight of eggs stripped. Usually, before absorbing water, there are 700-750 grass carp and silver carp eggs and 650-700 bighead eggs per gram.

Incubation

Incubation not only involves bringing the egg through embryonic development to hatching out but also includes all the management work from hatching to stocking ponds.

The eggs of Chinese carps are semibuoyant. After the eggs have been fertilized and have absorbed water, the egg membrane expands to about 5-6 mm in diameter. In stagnant water, the eggs sink; in running water, they float. In rivers, fertilized eggs will float and hatch. The embryonic development is closely dependent upon environmental conditions: e.g., oxygen supply, water temperature, and water current.

Water Temperature and Dissolved Oxygen

For normal embryonic development and hatching of Chinese carp the water temperature must range from 17 to 30°C. The optimum range is 25-27°C. As water temperature increases, the speed of embryonic development also increases (Table 2.2).

The dissolved oxygen content of the water should not be below 4-5 mg/L; below 2 mg/L, the embryo will develop abnormally.

Table 2.2. Relationship between hatching time and water temperature of silver carp

Water temperature (°C)	18	20	22	24	25	26	27	28	28.5	30
Hatching time (hours from fertilization to hatching out)	61	50	33	31	24	21	19	18	17	16

Hatching Instruments and Operational Management

Hatching jar

Hatching jars (Fig. 2.3) are made of tinplate or plastic. Hatching vats are generally reformed earthenware vats (Fig. 2.4). The recommended volume of each container is 250 L and the density of eggs is recommended to be 1 egg/mL. The hood of the hatching jar (and hatching vats) is made of 50 mesh/in nylon netting. The water flows in at the bottom and out over the upper rim through the hood. The flow of water must be regulated so that the fertilized eggs will float to the

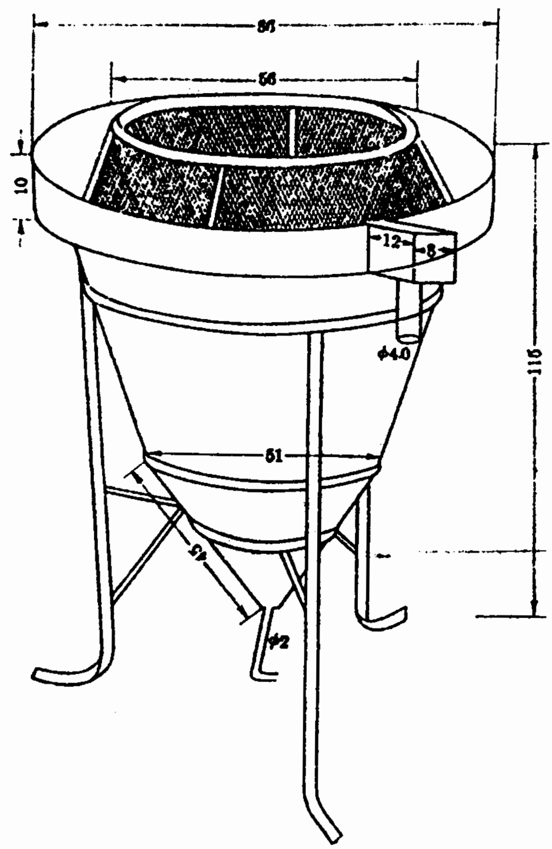


Fig. 2.3. Hatching jar. (Unit = cm)

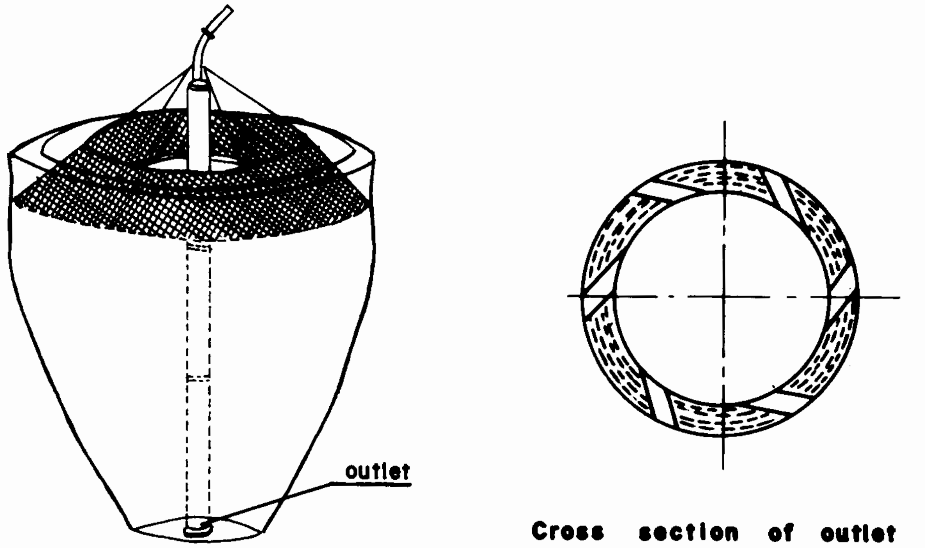


Fig. 2.4. A reformed earthernware vat which can be used as hatching instrument for small scale fish hatchery.

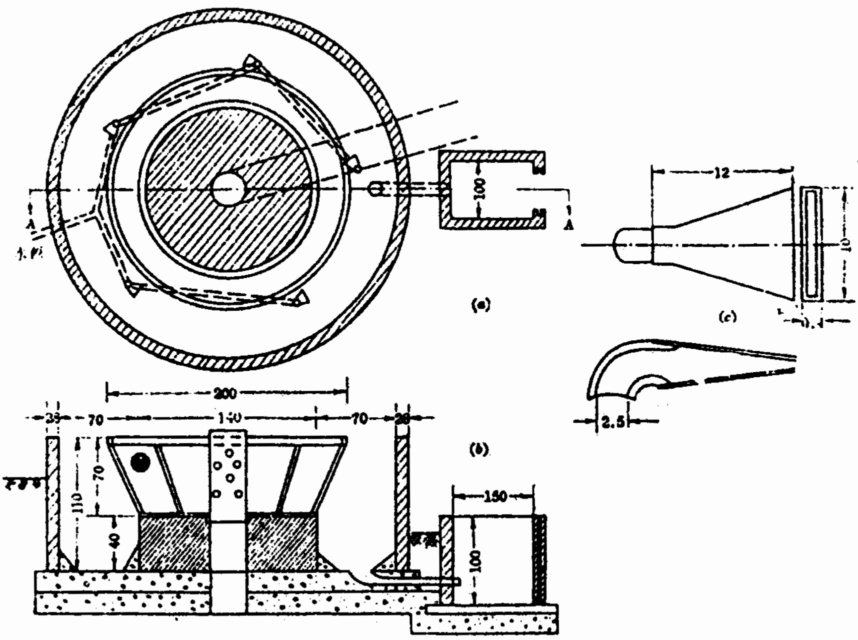


Fig. 2.5. Hatching circulator: (unit = cm)

a) top view,
b) sectional view,
c) nozzle.

surface. Debris and egg shell must be periodically brushed off the hood to allow the water to flow freely throughout hatching and prevent the newly hatched fry from escaping with the over flowing water.

Hatching circulator

The hatching circulator (Fig. 2.5) made of cement and bricks, consists of ring-shaped tank. There are two kinds of hatching raceway: single and double. The circular course is 1 m wide and 0.9 m deep, and the pond is 4 m in diameter. It can hold 8 m^3 of water and 8 x 10^6 eggs (10^6 eggs/m^3). The water exchange rate is about 260 L/min. No "dead corners" and an adequate flowing speed are essential qualities of a good circulator. The operational management is same as for hatching jars.

Calculating Fertilization Rate, Hatching Rate and Fry Survival Rate

When the eggs have developed to the middle gastrula stage (6-8 h after fertilization), 100 eggs should be randomly collected with a scoop net and placed in a white dish. Turbin eggs, white eggs, empty eggs, rotten eggs etc., should then be selected and removed. The fertilization rate can then be calculated:

$$\text{Fertilization rate (\%)} = \frac{\text{no. of fertilized eggs} \times 100}{\text{total no. of eggs}}$$

Hatching rate can also be calculated:

$$\text{Hatching rate (\%)} = \frac{\text{no. of hatched fry} \times 100}{\text{no. of fertilized eggs}}$$

In practice, however, it is difficult to obtain accurate values from which to calculate the hatching rate. Therefore, it is more common to calculate the survival rate:

$$\text{Survival rate (\%)} = \frac{\text{no. of fry stocked in nursery ponds}}{\text{no. of fertilized eggs}}$$

As soon as the air bladders of the fry have been filled with air, the yolk sacs have essentially disappeared, and the fry begin to take food actively (about 4-5 days after hatching); they may now be transferred to nursery pond.

Chapter 3

POND FERTILIZATION AND FISH FEEDS

Pond Fertilization

Yu Shigang

Significance of Pond Fertilization

China has a long history of pond fertilization for fish culture. Farmers adopted the method of manuring to rear fry ages ago. For example, "dacao" (green manure) is used in Guangdong and Guangxi provinces and human excrement (night soil) is used in Jiangxi and Hunan provinces to nurture fry into summer fingerlings. In fingerling-rearing ponds, fertilization is aimed at developing natural food organisms and saving artificial feeds.

Phytoplankton, the elementary producers of the pond, carry out photosynthesis, converting the inorganic materials in the water into the organic nourishment needed for their growth and reproduction. Fertilization supplies the phytoplankton with the materials essential for photosynthesis. As the phytoplankton photosynthesize and reproduce, zooplankton, which feed on phytoplankton, flourish. In turn, the fish, which feed on zooplankton, phytoplankton, and benthos, also flourish. Therefore, the importance of pond fertilization lies in the cultivation and propagation of various food organisms for the cultured fish.

The series of interrelations between predators and prey is called a "food chain." In culturing ponds, fish are the final link: e.g., phytoplankton--->silver carp; phytoplankton--->zooplankton--->bighead; aquatic plants--->grass carp; plankton --->benthos--->black carp. Usually animals use only 5-20 per cent of the energy in both animal and plant feeds. Utilization of energy is related to the length of the food chain: the shorter the food chain, the higher the rate of energy transfer. In other words, the higher the utilization rate of energy, the higher the fish production.

The biota of the ponds is in a constant process of growth and decay. Dead organisms are decomposed from complex organic materials into simple inorganic materials by bacteria. These inorganic materials dissolve in water and are utilized by phytoplankton in photosynthesis. Hence, the materials in the pond are in a constant state of circulation mainly through the food chain (Fig. 3.1). This is called "pond material circulation."

Varieties of Organic Manure

Organic manures are mainly farm animal excrement. Generally, the term refers to manures containing organic matter. Today, mainly organic manures are applied to fish ponds in China. The following manures are often used: feces and urine of livestock and poultry, night soil, green manure, compost, arnd silkworm

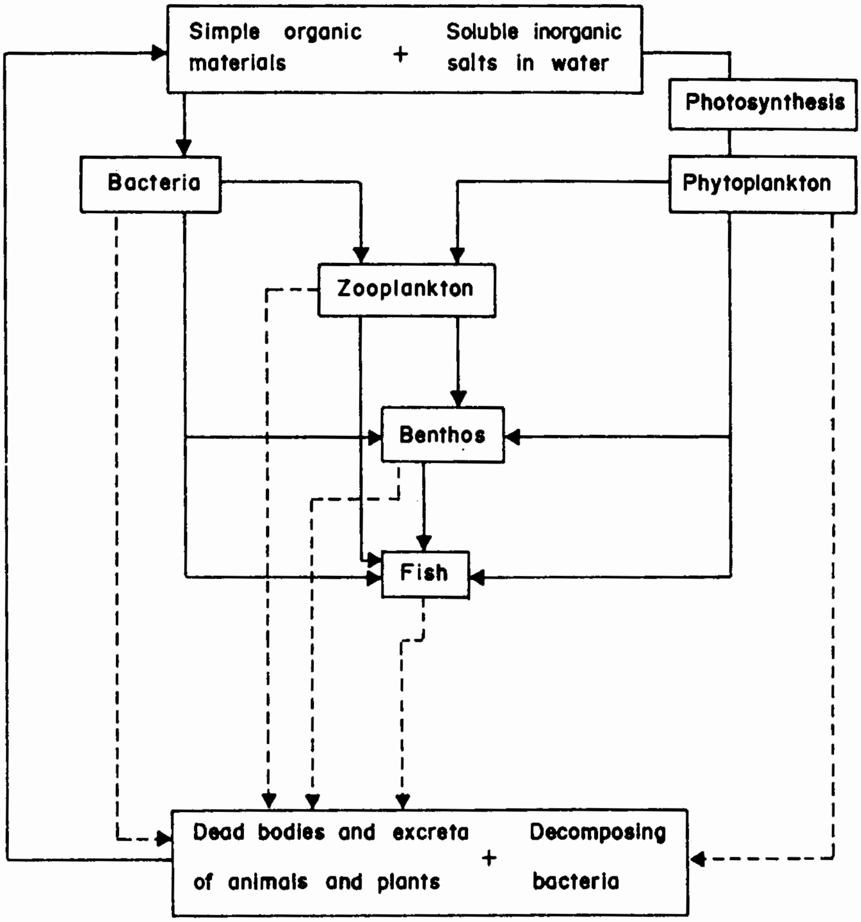


Fig. 3.1. Pond material circulation.

dregs. Only through decomposition by microorganisms is the organic manure converted to nutrients that the plants can absorb.

Feces and urine of livestock and poultry

Pig manure – Pig manure includes much organic matter and other nutritional elements such as nitrogen, phosphorus, and potassium and is a fine, complete manure (Table 3.1). Pig feces are delicate, containing more nitrogen than other livestock feces (C:N = 14:1), making them more susceptible to rotting. The major portion of pig urine is nitrogen in the form of urea. It decomposes easily.

Table 3.1. Nutritional elements in pig manure.

Item	*Organic matter (%)*	*Inorganic matter (%)*		
		N	P_2O_5	K_2O
Feces	15	0.6	0.5	0.4
Urine	2.5	0.4	0.1	0.7

The excretory amount of a pig is greatly associated with its body weight and food intake. A 50-kg pig discharges around 10 kg/day or 20 per cent of its body weight. A pig excretes 1000 kg of feces and 1200 kg of urine in the growing period of 8 months from pigling to adult. A pig's daily excretory amount is less than a cow's or a horse's; however, pigs are advantageous because of their faster growth, shorter fattening period, and suitability for pen culture. Also, pigs are raised on much larger scale, so it is beneficial to collect their manure.

Cattle manure – The elements of cattle manure are similar to those of pig manure (Table 3.2), but cattle are ruminants and the foodstuffs are repeatedly masticated, making the excrement quite delicate. Cattle manure contains less nitrogen than pig manure (C:N = 25:1). Cattle urine contains more nitrogen than pig urine (in the form of hippuric acid, $C_6H_5CONHCH_2COOH$); therefore, cattle excreta decompose slowly. The average daily excreta is 25 kg/cow, in which the ratio of feces to urine is about 3:2. The total annual amount of excrement for each animal is 9000 kg.

Table 3.2. Nutritional elements in cattle manure.

Item	*Organic matter (%)*	*Inorganic matter (%)*		
		N	P_2O_5	K_2O
Feces	14.0	0.3	0.2	0.1
Urine	2.3	1.0	0.1	1.4

Poultry manure – Poultry manures include the feces of chickens, ducks, and geese, and are rich in both organic and inorganic matter (Table 3.3).

Table 3.3. Nutritional elements in poultry manure.

Item	*Organic matter (%)*	*Inorganic matter (%)*		
		N	P_2O_5	K_2O
Chicken feces	25.5	1.63	1.54	0.83
Duck feces	26.2	1.14	1.44	0.62
Goose feces	23.4	0.55	0.50	0.95

Poultry manures rot quickly and their nitrogen is mostly in the form of uric acid, which cannot be absorbed directly by plants. Accordingly, poultry manures are more effective after fermentation. The annual amount of excrement per fowl is as follows: chicken, 5.0-5.7 kg; duck, 7.5-10.0 kg; goose, 12.5-15.0 kg. Although the annual excretory amount of each is comparatively small, the quantity of poultry culture is often great; therefore, the total amount of feces is significant.

Night soil

The composition of night soil (human excrement) (Table 3.4) is greatly dependent on the food consumed. Nitrogen is abundant (C:N = 3:1) and 70-80 per cent of it is in the form of urea. This facilitates easy decomposition.

Table 3.4. Nutritional elements in human excreta.

Item	*Organic matter (%)*	*Inorganic matter (%)*		
		N	P_2O_5	K_2O
Feces	20	1.0	0.5	0.4
Urine	3	0.5	0.1	0.2

On average, an adult excretes 790 kg/year of waste material. This is equivalent to 22 kg/year of $(NH_4)_2SO_4$ (Table 3.5).

Table 3.5. Yearly excretion of waste by an adult human.

Item	*Annual amount (kg)*	*Equivalent (kg/year)*		
		$(NH_4)_2SO_4$	*Calcium superphosphate*	*Potassium sulphate*
Feces	90	4.5	2.25	0.7
Urine	700	17.5	4.55	2.8
Total	790	22.0	6.80	3.5

Night soil to be used as manure must be fermented before application. This is easily done by storing the manure in anaerobic conditions for 2-4 weeks. The decomposition of human waste produces ammonia. Under airtight conditions, the accumulation of ammonia can sterilize human waste. Quicklime (1-2 per cent) and formalin (0.1-0.2 per cent) are effective in killing the harmful pathogens in night soil.

Silkworm dregs

Silkworm dregs are composed of silkworm feces and slough and mulberry residues. They are rich in organic matter: dried dregs are 87 per cent organic matter and 13 per cent nitrogen. They also make good fish feed: 8 kg silkworm dregs can produce 1 kg fish.

Green manure

All wild grasses and cultivated plants, if used as manure, are called green manures (Table 3.6). These manure rot and decompose easily, providing ideal environments for bacteria propagation. Therefore, they are good for application in fish ponds.

Table 3.6. Nutritional elements in green manures (% wet weight).

Item	*N*	P_2O_5	K_2O
Stems and leaves of broad bean (*Vicia faba*)	0.55	0.12	0.45
Rape (*Brassica napus*)	0.43	0.26	0.44
Alfalfa (*Medicago falcata*)	0.54	0.14	0.40
Wild grass	0.54	0.15	0.46
Branyard grass (*Echlnochloa crusgalli*)	0.35	0.05	0.28
Alligator weed (*Alternanthera philoxeroides*)	0.20	0.09	0.57
Water hyacinth (*Eichhornia crassipes*)	0.24	0.07	0.11
Water lettuce (*Pistia stratiotes*)	0.22	0.06	0.10

Compost

Mixed compost consists of green manure and animal waste. Mixing several manures together may produce a fertilizer that is more suitable to plankton reproduction. The ratio of the constituents depends upon the local sources of manure. Experimental data show the following two mixtures to be suitable for plankton reproduction: (1) green grass – cattle feces – human excreta – lime, 8:8:1:0.17; (2) green grass – cattle feces – lime, 1:1:0.02.

Lime is included in the compost mixture to neutralize the organic acids produced during rotting and decomposition. If these acids were allowed to accumulate, they would inhibit the microorganisms responsible for decomposing the organic matter. There are two methods of making compost; heaping and soaking.

Heaping method – The manure heap must be made in aerobic conditions. Spread out a layer of green grass, sprinkle some lime on it, add layer of fecal manure, and repeat the procedure. When the compost reaches 1.5-2 m, cover it with 5-6 cm of mud. The ingredients of the compost will rot and decompose. After 3-4 weeks the compost can be used.

Soaking – Dig a pit near the fish ponds and layer in green grass, lime and fecal manure, respectively and then add enough water to soak the compost ensuring there is no leakage. The compost can be removed for use after 10-20 days of fermentation at a temperature of 20-30°C.

Methods of Organic Manure Application

Application of Dacao

In Guangdong and Guangxi provinces, Dacao is commonly used to fertilize pond water. Dacao consists mostly of composite plants, with some gramineous plants and leguminous plants included. Dacao is applied by heaping it at a corner of the pond and turning the pile once every 2 days. The rotten parts will spread into the water. The roots and stems, which rot slowly, are dredged out of the ponds when the Dacao pile is depleted. The decomposition of green manure in water consumes a great amount of oxygen. Experimental data show that if 1000 kg of grass is applied to a 1-mu pond with a water depth of 1 m, there will be no available oxygen from the 2nd to the 6th day and all the fish will die. The peak of oxygen consumption because of decomposition is on the 2nd and 3rd days. For this reason, it is appropriate to apply green manures frequently and in small amounts, to frequently add fresh water to the pond, or to use aerators in the pond to guarantee sufficient oxygen for the fish.

Application of night soil

In Jiangxi and Hunan provinces, night soil is commonly applied to the fish ponds. Before application, one part night soil is diluted with two parts water. This dilution is then sprayed along the pond dikes once a day. The quantity depends on the fertility of the water and the size of the fish.

Application of livestock manure

The application of livestock manure as a base manure is similar to the method for green manure: heap the manures at a corner of the pond or in small piles in shallow water and with a sunny exposure, allow them to decompose and spread gradually into the water. If the manure is used as an additive, it is added in small quantities every 7-10 days.

Application of mixed compost

After fermentation, the compost is flushed. The liquid is collected and the residue is removed. This liquid is sprayed into the pond around the dikes. In the case of a large pond, the manure may be loaded on a boat, flushed in batches with pond water, and sprayed evenly over the pond. The manure dregs can be used to fertilize crops. Alternative method is to flip the compost and expose the liquid. The appropriate amount of manure liquid can then be ladled out and spread into the ponds.

The nutrients of the compost are quickly absorbed by phytoplankton. They consume less dissolved oxygen because the organic materials are already decomposed.

Effects of Manure Application on Natural Food Organisms

The application of organic manure results in the rapid multiplication of bacteria. Bacteria are added with the fertilizer and use the nutrients to reproduce. Also, organic detritus is rich with bacteria, which are an important food source for the lower aquatic animals and filtering fish.

The initial, predominant species of plankton depends closely on the properties of the manure applied. If organic manure is applied, phytoplankton, (*Ochromonas* spp, *Cryptomonas*) and zooplankton (*Urotrichia* spp.), which are fond of organic materials, will appear first. For inorganic manure, the initial, predominant species will be centric diatoms (*Centomonas* spp. and *Scenedesmus acuminatus*). There is a close relationship between the amount of manure applied and the make-up of the plankton community. Large amounts of manure will lead to the presence of some species of green algae (*Chlorophyta*) and blue algae (*Cyanophyta*); however, small amounts of manure will lead to the presence of *Navicula rostellata* and *Cyclotella stelligera*.

After each manure application, the nutrient content of the water increases, resulting in a planktonic peak. Phytoplankton that are easily digested by silver carp reach a peak after 4 days; those phytoplankton that are not so easily digested attain a climax in 5-10 days. Zooplankton reach a peak in 4-7 days. Protozoans will be the first zooplankton to reach a peak, followed by rotifers, cladocerans, and, finally, copepods. Protozoans multiply by binary fission, increasing the population very rapidly, and, therefore, reaching a peak first. Rotifers usually multiply by parthenogenesis, producing an average of 10-20 eggs during their lifetime. This process is less productive than binary fission and, therefore, rotifers reach a population peak slightly later than protozoans. Cladocerans also reproduce parthenogenically, but the span between hatching and sexual maturity is longer than that of rotifers; therefore, the cladoceran population peaks later. Copepods take longer time than cladocerans to get mature and its population becomes maximized later. The timing of manure application is crucial when preparing a nursery pond. Ideally, the peak in plankton population should coincide with the feeding demand of the fish fry.

Varieties of inorganic manure

Inorganic manures are also referred to as chemical fertilizers. According to composition, chemical fertilizers can be divided into three groups: nitrogenous, phosphoric, and potash fertilizers. The advantages of inorganic fertilizers are their exact composition, their fast effect, the lack of pollution, their beneficial effect on oxygen content (requiring no decomposition), the small amount required, and their convenient utilization. However, when chemical fertilizers are applied in ponds, the first link of the food chain is principally phytoplankton, which are not as nutritious to zooplankton as are bacteria. Therefore, the zooplankton population in ponds treated with inorganic manure often lags far behind that in ponds treated with organic manure. Moreover, in most chemical-fertilizer ponds, the predominant phytoplankton is *Chlorophyta,* which is not as nutritious as the predominant phytoplankton in ponds treated with organic manure *(Chrysophyceae, Bacillatiophyceae,* and *Cryptophyceae*). Another disadvantage is that the effect of inorganic fertilizer is rather short and it is difficult to control the water quality. Taking all these factors into account, therefore, the result of chemical-fertilizer application alone is no better than that of organic-fertilizers application.

Nitrogenous fertilizers

Liquid ammonia – Molecular formula: NH_4OH or $NH_3.H_2O$. Nitrogen content: 12-16 per cent. Liquid ammonia is an aqueous solution of ammonia, which is an important product of small-scale nitrogenous fertilizer factories and is easily synthesized at a low cost. Aqueous ammonia is readily volatilized and should not be exposed to the air for a long time.

Ammonium sulphate – Molecular formula: $(NH_4)_2SO_4$. Nitrogen content: 20-21 per cent. Ammonium sulphate is produced from liquid ammonia directly neutralized with diluted sulphuric acid. When pure, it is a water-soluble white crystal: 75 kg of ammonium sulphate will dissolve in 100 L of water at 20°C. It is easily conserved and applied.

Urea – Molecular formula: $CO(NH_2)_2$. Nitrogen content: 44-46 per cent. Under high heat and pressure, ammonia and carbon dioxide react to form urea. It is a white crystal with a high solubility in water. However, urea does not ionize when dissolved in water and, therefore, cannot be directly absorbed by plants. It can be utilized by plants only after it has been broken down by urease, excreted from urea-decomposing bacteria, and transformed into ammonium carbonate. This process is temperature dependent in normal ponds. At 20°C, total transformation into ammonium carbonate requires 4-5 days; at 30°C, 2 days.

Phosphoric fertilizers

Calcium superphosphate – Main contents: $Ca(H_2PO_4)_2.H_2O$ with 12-18 per cent P_2O_5. Subsidiary contents: $CaSO_4.2H_2O$, about 50 per cent. Calcium superphosphate is usually a white powder, and apt to absorb moisture. It is corrosive and has an acidic odour because it contains some free acids.

Methods of Inorganic Manure Application

Nitrogen is an essential nutritional element of plants. It is also an essential component of proteins, accelerates the formation of plant chlorophyll, and stimulates photosynthesis. For these reasons, nitrogen content is a decisive factor in phytoplankton production.

Nitrogen is commonly lacking in pond water, so nitrogenous fertilizers should be added. Generally, nitrogenous fertilizer should be used as an additive because of its quick effectiveness. A nitrogenous fertilizer with ammonium must not be mixed with strong alkaline materials e.g. lime; this would result in the volatilization of the ammonium. When using a nitrogenous fertilizer containing ammonium, the toxicity of ammonia must be considered. In aqueous solution, an equilibrium exists between ammonia (NH_3) and ammonium (NH_4^+).

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

In an acidic state, the equilibrium shifts to the right and the concentration of ammonium ions increases. In an alkaline state, the equilibrium shifts to the left and the ammonia concentration increases. At a water temperature of 25°C, the percentage of nitrogen as NH_3 at various pHs is as follows: ph 6, 0.05 per cent; pH 7, 0.49 per cent; pH 8, 4.7 per cent; pH 9, 32.9 per cent; pH 10, 83.1 per cent; pH 11, 98 per cent.

Ammonia is toxic to fish. It poisons juvenile rainbow trout at 0.3-0.4 mg/L. Chinese carps can tolerate concentrations up to 13 mg/L. Ammonia concentrations below this inhibit growth. The maximum NH_3 concentration permitted for fish farming is 0.1 mg/L. Therefore, the amount per application must be strictly controlled. In addition, ponds pH must be closely monitored to avoid applying NH_3 in strong alkaline water (e.g., just after pond clearing with lime); liquid ammonia is also alkaline itself. The amount of unionized ammonia increases with increasing water temperature. Therefore, special care is needed when nitrogenous fertilizer in the ammonia form is applied in the summer and the autumn.

The application amount of the nitrogenous fertilizer depends on its nitrogen content. In a pond with an area of 1 mu and a water depth of about 1.5 m, 1.5-2 kg N may be applied as base manure. After this, 0.5 kg N/mu is applied 3 or 4 times monthly. In average, 10 kg N are needed for the whole culture period. For example, if the nitrogen content of ammonium sulphate is about 20 per cent to apply 2 kg of nitrogen to a 1-mu pool as base manure, 10 kg of ammonium sulphate is required. The amount of ammonium sulphate required for a culture period can be calculated in the way: 50 kg.

To apply, make a solution and spread it near the dikes. In the case of liquid ammonia, put the container underwater and open the lid to let the liquid ammonia slowly diffuse out. In this way, volatilization can be avoided.

Most water sources lack phosphorus. Phosphoric fertilizer, besides being utilized by phytoplankton, will also accelerate the reproduction of azotobacteria and complement the nitrogenous fertilizer. The application amount can be calculated based on the phosphoric acid content of the fertilizer. A 0.5-1 kg/mu is used as base manure, the amount used for a culture period is about 5 kg. The method of calculation and application is the same as that for nitrogenous fertilizer.

Potassium is also an essential nutritional element of plants. However, it is usually sufficient in the water and there is no particular need to apply potash fertilizer.

Fish Feeds

Significance of Feeding

In addition to fertilizing ponds for the proliferation of natural food organisms, artificial feeds must also be used to meet the demands of various species of fish. Fish feeds are the prime material base of intensive fish culture. Applying artificial feeds in a fish pond can significantly raise per-unit yield. With common carp, for example, output does not exceed 25-30 kg/mu in extensive culture; in intensive culture, however, output will be as high as 200-250 kg/mu. This increase in yield is due to the direct effect of artificial feeding.

Plankton feeder output is also enhanced. The feed is directly consumed by the so-called feed eaters and, in turn, their excreta fertilizes the pond water. This multiplies the natural food organisms of the plankton feeders. In such a culture system, the yield of these species often accounts for one-third of the total fish output.

Requirements for Different Nutrients

The nutrients that fish require are the same as those required by other animals: proteins, carbohydrates, lipids, vitamins, and minerals. The demand for these elements forms the basis for the preparation and selection of artificial fish feeds.

Protein

Just like other animals, fish consume protein and break it down into its component amino acids via the enzymes of the digestive system. The amino acids are then absorbed internally and used for normal growth, mending wears, maintenance and reproduction. Protein is used as a source of energy when fats and carbohydrates are depleted; 1 g protein yields 4 Kcal. The dietary protein requirement of farmed fish is generally 25-40 per cent. Terrestrial animals such as chickens, pigs, or cattle usually require 12-17 per cent protein. Because fish are cold-blooded, they require comparatively low-energy feeds. Different fish have different feeding habits and, therefore, different requirements for protein. Carnivorous fish such as rainbow trout and eel demand feeds with high protein contents; herbivorous fish require less protein.

The nutritional value of the feed depends not only on the quantity but also on the quality of the protein, i.e., its amino acid conformation. Amid acids are the elementary units of proteins. Several amino acids are essential to fish growth and development and, therefore, must be present in the feeds. These amino acids are called essential amino acids. The rest of the amino acids, which may or may not exist in the feed, are called dispensable amino acids. They are needed in only small amounts or can be synthesized internally by the fish. The following 10 amino acids are essential to fish: isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine, arginine, and histidine. The proportion of these essential amino acids in the feed protein should reflect the amino acid composition of fish protein. Proteins of low nutritional value may be supplemented with the essential amino acids they lack.

Carbohydrates

Carbohydrates are also defined as polyhydroxy aldehydes or ketones. Through digestion, they are decomposed into monosaccharides, which are absorbed and utilized by the fish. Some monosaccharides are oxidized into carbon dioxide and water: 1 g carbohydrate yields 4 Kcal. Monosaccharides are transported to the liver and muscles and stored as glycogen or are converted into fat which serves as a reserve energy source during food shortages.

Cellulose, a carbohydrate, is the major component of plant cell walls. Among cultivated fish, only a few varieties such as tilapia and milkfish can digest cellulose; even then, the digestibility is low. Cyprinids appear to lack the cellulolytic enzyme and, therefore, cannot digest cellulose. A small amount of cellulose in the fish feed is beneficial, however, because it stimulates the digestive movements of the intestines, promoting the digestion and absorption of other nutrients.

Lipids

Lipids are also a source of energy; 1 g lipid yields 9 Kcal. During digestion, lipids are broken down into fatty acids and glycerol components, which are absorbed by the fish. Body fats are synthesized from excess fatty acids and glyceryl and are stored in subcutaneous tissues, muscles, spaces between connective tissues, and the abdominal cavity.

Lipids tend to deteriorate through oxidation, producing substances that are toxic to fish and destroy vitamin E in fish feeds (e.g., aldehydes and ketones). If fish consume too much deteriorated fish meal and silkworm pupae, which contain oxydized lipids, they will suffer from "thin-back" disease, muscular atrophy, and weight loss, and show a high mortality rate.

Vitamins

Vitamins are essential organic compounds required by fish in trace quantities. There are many varieties of vitamins with various physiological functions; however, all of them are essential if fish are to grow and develop normally. Some vitamins participate in the metabolic process: vitamin B_1, carbohydrate metabolism; vitamin B_6, protein metabolism; vitamin C, protein synthesis; vitamin D, calcium and phosphorus metabolism (formation of the skeleton).

It is difficult to determine the exact amounts of the various vitamins required by the fish. In Chinese fish culture, fresh feeds are added to prevent vitamin deficiencies. For example, if pelleted feeds are used in grass carp farming, green grasses will be supplemented to ensure a complete supply of vitamins.

Minerals

Minerals are essential elements in many aspects of fish metabolism and structure. For example, phosphorus and calcium are important components of the skeleton. A deficiency of either substance will result in deformity.

Both fish feeds and pond water serve as a source of minerals. Fish absorb calciferous and phosphorous salts and chlorine and sodium ions through their gill and skin.

Minerals enhance the utilization of carbohydrates, accelerate the growth of certain tissues (e.g., skeleton and muscles), and enhance the fish's appetite; therefore, minerals must be included in the preparation of fish feeds. Additives such as bone powder and table salt in fish feeds fulfill the requirements of the pond fish.

Evaluation of Nutritional Value of Fish Feeds

In feeding, we must be aware of the nutritional requirements of the fish and we must evaluate the nutritional value of the fish feeds. Besides the chemical analysis, nutritional value of fish feeds must be evaluated with other criteria such as digestibility, utilization rate, and food-conversion ratio via feeding trials.

Digestibility

The digestibility represents the percentage of nutrients absorbed by the fish.

$$\text{Digestibility (\%)} = \frac{\text{nutrient intake} - \text{nutrients remaining in feces} \times 100}{\text{nutrient intake}}$$

Digestibility is affected by many factors and it is possible for the same ration to have various digestibility. For example, if the same ration is fed to different species with different feeding habits and different digestive enzymes, their digestibilities are different. Enzyme activity is associated with temperature and digestibility rate will increase when the temperature rises within the adaptable temperature range. The presence of crude fibre in the diet will reduce the digestive rate of other components. The amount of food consumed by the fish will also affect the food digestibility; a proper food intake will maximize the digestibility.

Food-utilization rate

Food-utilization rate refers mainly to the utilization rate of the crude protein in the diet.

$$\begin{array}{l}\text{Utilization rate of} \\ \text{crude protein (\%)}\end{array} = \frac{\text{protein increase in fish body}}{\text{protein in consumed food}} \times 100$$

Because the quality of all food proteins is different, the efficiency of synthesizing fish body protein from food protein differs. In this sense, nutritional value not only depends on food-digestion rate but also depends on the utilization rate and quality of the protein.

Of the fodders listed in Table 3.7, *Wolffia arrhiza* gave the best growth rate for grass carp. The digestible crude protein content of *Potamogeton malainus* is higher than that of *Vallisneria spiralis;* however, the growth rate of grass carp fed *P. malainus* is less than those fed *V. spiralis.*

Table 3.7. Utilization rate of protein of several fodder (grasses) by grass carp fingerlings.

Fodder	*Food intake (g/day)*	*Digestible nutrients (g/day)*	*Digestable crude protein intake (g/day)*	*Utilization rate of crude protein (%)*	*Weight gain (g/day)*
Wolffia arrhiza	29.40	1.05	0.34	26.23	1.10
Lemna minor	25.40	0.77	0.32	26.30	1.03
Leersin japonica	11.54	1.42	0.32	22.78	0.90
Vallisneria spiralis	28.06	0.38	0.13	13.16	0.28
Potamogeton malainus	9.51	0.55	0.15	5.76	0.12
Potamogeton maackianus	5.43	0.35	0.08	4.25	0.06

Food conversion ratio

$$\text{Food conversion ratio} = \frac{\text{food consumed (wet weight)}}{\text{fish body weight gain (wet weight)}}$$

$$= \frac{\text{food applied}}{\text{total weight at harvest} - \text{total weight at stocking}}$$

In production, calculating the food-conversion ratio is a common method to appraise nutritional value. The food conversion ratio is also considered when preparing the food and when predicting fish yield.

The food conversion ratio is affected by many factors, particularly management. An improvement in management level can diminish the food conversion ratio i.e., the same amount of feed could result in a higher fish yield. There are mainly five factors that affect the food conversion ratio.

Feed preparation – Bean cakes must first be thoroughly soaked in water before they are fed to an adult fish or thoroughly soaked and ground up for juvenile fish. The soaking time should be controlled to avoid fermentation and rotting. If this occurs, the cakes will not be eaten by fish; however, the rotten cakes may be used as fertilizer. In general, the ground cake paste, wheat bran, and rice bran are placed on a feeding board and distributed into the pond. Any feed that sink to the bottom of the pond will act as fertilizer. If the brans and cakes were distributed as granulated feeds, food loss might be avoided and food consumption could be reduced.

Feeding regime – Feeds must be evenly spread over the pond and the amount must be controlled according to weather, water quality and fish appetite. Excessive amounts should be avoided to prevent wastage and the consequent high food conversion ratio. Frequent, small feedings are recommended.

Water quality – As far as water quality is concerned, oxygen content is the factor with the greatest influence on the food conversion ratio. The food conversion ratio of cultured common carp doubles if the oxygen content decreases from 3-6 to 0.5-2 mg/L.

Nutritional elements in the food – Fish at different developmental stages or with different feeding habits demand different nutritional elements in their food. To speed up growth and reduce the food conversion ratio, the nutritional elements of the food applied must comply with the physiological needs of the fish.

Species and age – The food conversion ratio of the same feed varies with species (Table 3.8). The food conversion ratio of dry silkworm pupae for common carp and rainbow trout are 1.3-2 and 6, respectively. The food conversion ratio also varies with age: in general, it is lower for the juvenile than for the adult fish.

Food conversion efficiency

Food conversion efficiency is the inverse of the food conversion ratio.

$$\text{Food conversion efficiency} = \frac{\text{total fish body weight gained}}{\text{total weight of feed intake}} \times (100)$$

Varieties of Fish Feeds

Plant feeds

Grain – Soybean, wheat, and maize are commonly used grain feeds. Soybean, which is a nutritional food, contains at least 38 per cent crude protein (Table 3.9) and is rich in essential amino acids. Soybeans are usually ground up into "bean milk" for feeding to fry. About 5-7 kg of soybeans can supply the milk required to raise 10,000 fish from fry to summerling. In nurturing fry, some bean milk particles are directly consumed by the fry but most become fertilizer for the proliferation of plankton. For grass carp brooders, wheat and rice sprouts are often supplied. These grains are rich in vitamins, especially vitamin E, which is beneficial to gonad development. For granulated feeds, wheat powder is often used as a binder.

Oil Cakes – Cakes are by-products of oil plants after oil pressing. Bean cakes, peanut cakes, cottonseed cakes, and rapeseed cakes are often used in fish

Table 3.8. Food conversion ratio (FCRs) of several common feeds for various species of fish.

Feed	*Species*	*FCR*	*Feed*	*Species*	*FCR*
Snails	Black carp	40	Silkworm		
			Fresh pupae	Black carp	3.5
	Common carp	50	Dry pupae	Black carp	1.5
Clams				Common carp	2
(*Corbicula*)	Black carp	80			
	Black carp	60	Aquatic		
			grass	Grass carp	90
Soybean				Bream	100
cake	Black carp	3			
	Common carp	3.5	Terrestrial		
			grass	Grass carp	40
Rapeseed				Bream	45
cake	Black carp	4.0			
	Common carp	4.5	Duck weeds	Grass carp	50
				Bream	50
Peanut			Rye grass	Grass carp	25
cake	Black carp	3			
	Common carp	4		Bream	30
Cotton			Sudan grass	Grass carp	40
seed cake	Grass carp	6			
Rye	Black carp	4	Pumpkin vine	Grass carp	35
	Grass carp	3	Wheat bran	Common carp	4
				Tilapia	4
Barley	Black carp	4	Rice bran	Common carp	3.5
				Tilapia	3.5
	Grass carp	3	Bean dregs	Grass carp	25
				Bream	25

farming. This type of feed is rich in crude protein (30-40 per cent; Table 3.9). If cakes are used to feed fry, they must be broken into pieces, soaked, and ground up into a milk. About 150-200 kg of cake is needed to nurture 10,000 fingerlings with a body length greater than 10 cm.

Cottonseed cakes are commonly used in carp culture in the USA and the USSR. This is not so common in China. However, China is a cotton-producing country and the use of cottonseed cake as a fish feed shows great potential. There is a little gossypol in cottonseed cakes, which is detrimental to livestock, but harmless to fish.

Wheat bran – Wheat bran is a by-product of the rice- and wheat-processing industry and is rich in vitamin B, apart from crude proteins, fats, and carbohydrates (Table 3.9). It is an important ingredient of compound feeds.

Table 3.9. Nutritional elements of various plant feeds (%).

	Moisture	*Crude protein*	*Crude fat*	*Crude fibre*	*Non-nitro-genous extract*
Soybean cake	11.3	39.1	7.1	4.5	32.0
Peanut cake	11.3	38.4	8.2	5.8	29.5
Cottonseed cake	9.3	35.0	6.0	10.1	30.3
Rapeseed cake	11.0	31.0	6.7	8.2	31.1
Rice bran	11.8	10.8	12.0	8.2	47.0
Wheat bran	13.1	10.9	3.7	8.9	55.3
Soybean	11.2	38.1	13.1	4.1	27.5
Barley	14.5	10.0	2.0	4.0	69.0
Maize	12.0	8.5	4.3	1.3	71.0

Green fodders – Green fodders include aquatic plants and terrestrial plants and are mainly used as feed for grass carp and breams and, sometimes, for common carp, crucian carp, and tilapia. The main aquatic plants used are *Wolffia arrhiza, Lemna minor, Vallisneria spiralis, Potamogeton malainus, Potamogeton maackianus, Hydrilla verticillata, Eichhornia crassipes, Pistia stratiotes,* and *Alternanthera philoxeroides.* The main terrestrial plants used are *Echinochloa crusgalli, Pennisetum alopecuroides, Lolium perenne, Sorghum sudanense, Pennisetum purpurlum* of the grass family; *Lactuca tenticulata* of the composite family; and various leaves and vines from melon and vegetable crops.

Water lettuce (*Pistia stratiotes*), water hyacinth (*Eichhornia crassipes*), and alligator weed (*Alternanthera philoxeroides*) must be minced or fermented before they are given to the fish. To ferment one of these aquatic plants, 100 kg is mixed with 3-4 kg rice bran and 0.5 kg yeast; the container is then sealed and stored for 2 days at 26°C. Alligator weed sometimes contains saponin, which is toxic to fish. If this is processed by adding a little table salt (2-5 per cent concentration), the toxicity is eliminated and the feed becomes palatable. When these aquatic plants are mashed into a paste with a high-speed masher, they are appropriate feeds for fry culture. The fry swallow the mesophyll cells in the paste, which are similar in size to zooplankton and phytoplankton. The material in the paste serves as manure for the reproduction of plankton and other natural foods.

Green fodders contain mostly water and cellulose. However, they also contain the principal nutrients, i.e., fat, protein and carbohydrate, and are rich in vitamins (Table 3.10). Green fodders are the principal feed for grass carp and wuchang fish and serves as supplemental feed for other cultivated fish.

Table 3.10. Composition of some green fodders (%).

Fodder	*Moisture*	*Crude protein*	*Crude fat*	*Crude fibre*	*Non-nitrogenous extract*
Wolffia arrhiza	96.02	1.25	0.41	0.38	1.52
Lemna minor	95.80	1.43	0.38	0.42	1.23
Vallisneria spiralis	96.77	0.61	0.09	0.66	1.17
Potamogeton malainus	89.41	2.11	0.17	2.17	4.89
Potamogeton maackianus	87.18	2.16	0.46	3.11	5.65
Leersia japonica	74.61	3.72	1.27	7.50	10.70
Sorghum sudanense	82.83	1.78	0.69	4.75	8.66
Lactuca tenticulata	88.95	3.02	0.95	1.60	4.20
Pistia stratiotes	91.90	1.20	0.40	1.80	2.90
Eichhornia crassipes	94.90	1.00	0.20	0.90	1.80
Alternanthera philoxeroides	77.50	3.22	0.80	2.62	11.62
Lolium perenne	85.35	4.17	0.59	3.54	4.43

Animal feeds

Animal feeds have a higher nutritional value than plant feeds because they give a more complete supply of nutrients and are richer in proteins and essential amino acids (Table 3.11). Among the cultivated fish species in China, most are herbivorous or omnivorous; the only carnivorous species is black carp.

Common animal feeds include fish meal, trash fish, silkworm pupae, freshwater shellfish (e.g., *Viviparus quadratus* and *Corbicula fluminea*), kitchen waste, and earthworms. *Viviparus quadratus* lives in rivers and lakes with a high fecundity

Table 3.11. Composition (%) of common animal feeds.

	Moisture	*Crude protein*	*Crude fat*	*Non-nitrogenous extract*
Fish meal	10.0	59.0	9.8	0.4
Silkworm pupae (Fresh)		17.1	9.2	
(Dry)	7.3	56.9	24.9	4.0
Snail	75.8	14.1	0.4	
Corbicula	85.0	5.3	2.0	7.0

and feeds on epiphytic algae. It has a meat rate of 22-25 per cent and a food-conversion ratio of 40 for black carp. *Corbicula fluminea* lives in the clay bottom of rivers and lakes and is collected with *Viviparus quadratus.* It has a meat rate of 13 per cent and a food conversion ratio of 60 for black carp. Both species are commonly fed to black carp.

In Japan and China, silkworm pupae are commonly used as fish feed. Fresh pupae are more effective but harder to preserve than dry pupae, which are rich in fats; however, these fats deteriorate easily through oxidization. Furthermore, the fish fed with silkworm pupae have off-flavour; therefore, pupae feeding is stopped 2-3 weeks before harvesting.

Pig blood is used as a binding agent for pelleted feeds. These feeds are effectively used in rainbow trout culture.

Formulated feeds

Advantages – Formulated feeds are composed of several materials in various proportions. In fish farming, formulated feeds have the following advantages:

- The ingredients of formulated feeds can complement one another and raise the food utilization rate.
- Proteins can supplement one another improving the essential amino acid conformation of the feed and raising the protein utilization rate.
- Food sources can be broadened by mixing feeds disliked by the fish with other preferred feeds.
- By adding a binding agent to produce pelleted feeds, the solution of nutrients in water is diminished and wastage is reduced.
- Drugs may be mixed into the feeds (indicated feeds) to control fish diseases.
- Formulated feeds are convenient to transport and preserve; they are suited to automatic feeding, which can lead toward the mechanization of fish farming.

Preparation – The feeding habits and nutritional requirements of the fish and the nutritional content of the food must be considered when making a nutritionally balanced feed. To achieve complete nutrition, many feedstuffs should be combined. The economics of formulating the feed should be considered; a good selection of cheap materials is preferable. Different formulas should reflect the different nutritional requirements of various species at different developmental stages; e.g., more protein for black carp than for grass carp; more protein for fingerlings than for adults. A moderate amount of binder should be added to ensure a high water stability of the feeds.

Some formulated pellet feeds have been tried on black carp because of a lack of snails and *Corbicula*.

- "320" straw powder pellet feed: "320" straw powder is made by fermenting "320" Basidiomycetes: straw powder, 50 per cent; bean cake powder, 10 per cent; fish meal powder, 5 per cent; barley flour, 15 per cent; wheat bran 10 per cent; rapeseed cake 10 per cent. The crude protein content is 20.14 per cent and the recommended daily feeding rate is 3-5 per cent of body weight. The food conversion ratio for 2-year-old black carp in monoculture is 2.

- Bean cake powder, 10 per cent; pupae, 10 per cent; barley flour, 30 per cent; rapeseed cake, 50 per cent; bone powder, 2 per cent; table salt, 1 per cent. The crude protein content is 28.1 per cent and the carbohydrate content is 38.9 per cent. The food conversion ratio for 2-year-old black carp in monoculture is 2.4.

- Bean cake powder, 25 per cent; fish meal, 4 per cent; barley flour, 16 per cent; rapeseed cake, 24 per cent; wheat bran, 26.5 per cent; mineral mixture, 1.5 per cent; plant oil, 3 per cent.

Formulated feeds have also been used with grass carp.

- Straw powder, 25 per cent; sesame stem powder, 25 per cent; bean cake powder, 25 per cent; ricebran, 25 per cent; waste flour (Binder), 10 per cent. The crude protein content is 23.35 per cent. The food conversion ratio is 2.8.

- Straw powder, 70 per cent; bean cake powder, 15 per cent; ricebran, 10 per cent; waste flour, 5 per cent; bone powder, 1 per cent; table salt, 0.5 per cent. The crude protein content is 15.07 per cent. The food conversion factor is 4.4.

- "320" green grass powder pellet feed: green grasspowder, 40 per cent; rapeseed cake, 20 per cent; fish meal, 5 per cent; bean cake, 15 per cent; silkworm pupae, 5 per cent; barley flour, 15 per cent. The crude protein content is 22.6 per cent. The recommended daily feeding rate is 3.5 per cent of body weight. The food conversion rate for grass carp and wuchang fish is 2.5-3.

If only pellet feeds are applied, the muscle, intestine and liver of grass carp accumulate a high amount of fat. This can have a pathological effect on the liver and, consequently, adversely affect growth. When green grass is also provided (5 days of pellet feeds followed by 2 days of grass application), this situation improves: no pathological change is observed. Nevertheless, every substance demanded by the fish cannot be included in a specific feed, no matter how complete the feed is. Therefore, it is important to also supply fresh, natural fodders (e.g., green grass for carp and snails for black carp) to promote the digestion of the artificial diet.

Chapter 4

REARING OF FRY AND FINGERLINGS

Zhu Lingen

Rearing fry and fingerlings involves nurturing 3-4 day-old postlarvae, which have begun to eat food, into fingerlings for pond stocking. Rearing is generally divided into two stages. First, fry are cultured for 18-25 days until they become juvenile fish about 3 cm long; these are known as summerlings. Second, summerlings are reared for another 3-5 months until they become fingerlings with a body length of 8-20 cm. Most "grow-out" ponds are stocked with such fingerlings and some are stocked with 2-year-old fingerlings.

Fingerlings and especially fry are delicate and small, and their power of movement and ability to feed are weak. Their diet is restricted, they have a low environmental adaptability, and they are vulnerable to predators. In addition, they have a high metabolic rate. Rearing should be carefully managed to maximize survival rate and produce healthy, well-developed fingerlings.

Biology of Fry and Fingerlings

Fish grow quickly during the fry and fingerling stages and during these stages they have different biological characteristics from adults, especially in terms of feeding habits, growth, and habitat preference.

Food Intake

The changes in feeding organs, feeding patterns, and food composition of fry and fingerlings have already been reviewed. Diet feed stuffs of animal are considered to be of the utmost importance for rearing fry and fingerlings because of their high metabolic rate, fast growth, and food intake. All of these rates decline as the body weight increases. Food intake varies with the type of food and the water temperature. At optimum temperature, the maximum daily food intake of grass carp fingerlings is 49.9 per cent of body weight; for silver carp and bighead 16.8 and 16.4 per cent, respectively. The daily food intake of juvenile grass carp is 32 to 71 per cent of body weight and they show maximum food intake from 0800 to 1600 hrs; this decreases sharply in the evening. The maximum food intakes of silver carp and bighead fingerlings are between 1200 and 2000 hrs, declining after 2000 hrs. Silver carp and bighead stop eating between 2400 hrs and 0600 hrs and the intensity of food intake increases significantly after 0800 hrs.

The retention time of food in the gut by fry and fingerlings is related to water temperature. Rotifera and daphnia *(Bosmina longirostris)* fed to grass carp fry and fingerlings remain in the gut for 0.5-3.3 h at a water temperature of 20-22°C;

when the water temperature reaches 30-32°C, food is digested in less than 1 h. Silver carp digest food in 1.3 h at a water temperature of 22-26°C and within 1 h at a water temperature of 30°C.

Growth Rate

Fry and fingerlings of various species have different growth rates. Even the same species show different growth rates at different developmental stages. Black carp, grass carp, silver carp and bighead fry and fingerlings all have high growth rates. Maximum growth rates occur as fry develop into summerlings; the daily growth rate is 15-25 per cent in length and 30-57 per cent in weight. In the first 10 days after stocking, the body weight of bighead and silver carp fry increase by 5 and 6 times respectively. On average, body weight doubles every 2 days. However, because these fish are small, the absolute increase in weight is rather low. The average daily increase in body weight is between 10 and 20 mg and the average daily increase in body length is 0.7 mm for bighead and 1.2 mm for silver carp. (Table 4.1).

Table 4.1. Growth of silver carp and bighead fry*

	Bighead		*Silver carp*	
Age (days)	*Body length (mm)*	*Body Weight (mg)*	*Body length (mm)*	*Body weight (mg)*
2	8.1	4	7.2	3
4	8.6	12	8.1	10
6	11.6	27	10.7	21
8	11.8	54	13.3	40
10	13.0	90	18.8	94
12	15.2	184	19.2	188

* Pond manure: Dacao
Stocking density = 140,000 fish/mu.

At the fingerling stage, the relative growth rate is 5 or 6 times less than that at the fry stage. Within the rearing period of 100 days, the body weight increases 9 or 10 times. On average, the body weight doubles every 10 days. However, the absolute increase in weight is remarkable (Table 4.2)

Different species of fry collected from rivers and polycultured in a manured pond have different growth rates (Fig. 4.1). Over the first 4 days, the growth of grass carp is fastest; bighead and silver carp are second. However, after the 8th day of rearing, silver carp shows the fastest growth; bighead is second; grass carp is third; and black carp shows the slowest growth. This situation continues until the fry become summer fingerlings. The growth rates of cultivated fish are not only genetically controlled but also closely related to ecological conditions such as nutrition, stocking density, water quality, and temperature.

Table 4.2 Growth of silver carp, bighead and grass carp fingerlings.

Age (days)	Silver carp: Body length (mm)	Silver carp: Body weight (g)	Silver carp: Ave. daily increase Length (mm)	Silver carp: Ave. daily increase Weight (g)	Bighead: Body Length (mm)	Bighead: Body Weight (g)	Bighead: Ave. daily increase Length (mm)	Bighead: Ave. daily increase Weight (g)	Grass carp: Body Length (mm)	Grass carp: Body Weight (g)	Grass carp: Ave. daily increase Length (mm)	Grass carp: Ave. daily increase Weight (g)
20	47	1.08			43.5	0.9						
27			3.1	1.4			5.0	5.2	57	1.5		
60	173	55.3			242	207.5					3.4	3.8
74			2.4	6.8			2.3	7.1	216	157		
120	318	420			376	633.0					2.6	8.4
134									372	661		

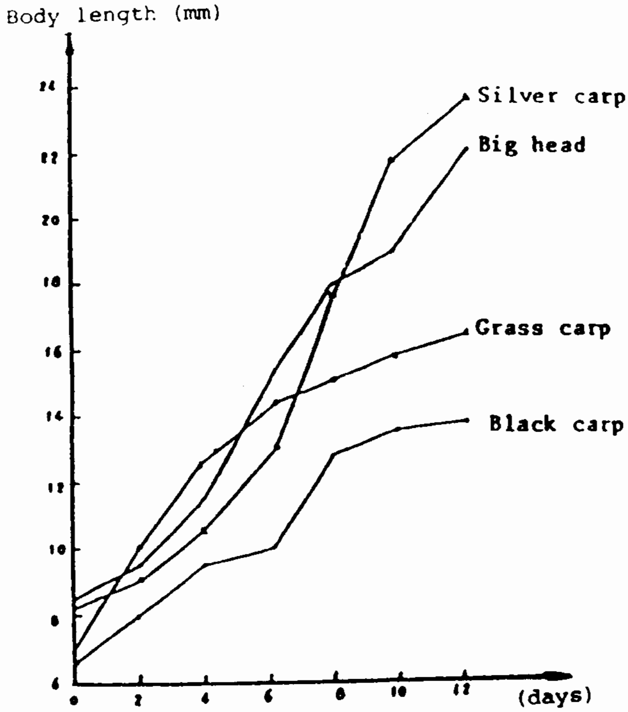


Fig. 4.1. Growth curves in 12 days after stocking.

Distribution and Environmental Requirements

Fry are more or less evenly distributed in the pond shortly after stocking. When fry reach a body length of about 1.5 cm, their distribution changes with their feeding habits. Grass carp and black carp begin to move to the middle and bottom layers of the pond and most of them live in the shallow places around the pond dikes where there is more macrozooplankton and benthos. Silver carp and bighead, however, gradually leave the pond banks and move to the central area of the pond, staying in the upper and middle layers.

Fry and fingerlings have much higher metabolic rates than juvenile or adult fish, particularly at the fry stage. For example, the oxygen-consumption rate and energy demand of silver carp fry are 5-10 times greater than those of summer fingerlings and 15-20 times greater than those of 2-year-old fingerlings. Therefore, a high dissolved oxygen content and an abundant food supply are essential for rearing fry and fingerlings. The optimum pH in nurturing ponds is 7.5-9. Fry can tolerate salinities of 4-5 per cent. Growth, is retarded, however, when salinity reaches 3 per cent.

Choice of Ponds and Pond Clearing

Choice of Ponds

Ponds should have the following characteristics: sufficient water supply, good water quality, and convenient irrigation and drainage; a rectangular shape, an area of 1-3 mu (15 mu = 1 ha) for fry, and 2-5 mu for fingerlings, and a water depth of 1.0-1.5 m for fry and 1.2-2.0 m for fingerlings; pond dikes that are solid and watertight, with even bottoms, little silt, and no aquatic weeds; a sunny exposure and plenty of sunlight.

Pond Clearing

Ponds are drained either in the winter or in the early spring. The excess silt and weeds are removed and pond dikes are repaired. At least 7 days before stocking with fry, ponds should be treated with chemicals to eliminate any predatory fish, pathogenic bacteria, parasites or other harmful organisms. This creates an environment conducive to the maximum growth and survival of fry and fingerlings. A small amount of silt must remain at the bottom of the pond to control water fertility and quality.

Quicklime

When clearing a pond, a water depth of 6-10 cm should be maintained. As soon as the quicklime is dissolved, the solution is spread evenly in the pond while it is still hot. The general dosage is 60-75 kg/mu; but increases to 125-150 kg/mu for an undrained pond with a water depth of 1 m. As quicklime absorbs water, it transforms into calcium hydroxide, $Ca(OH)_2$, raising pH above 11. Quicklime not only kills harmful animals and plants but also eliminates pathogenic bacteria. There are three major advantages of using quicklime for pond clearing. First, quicklime can maintain pH of the pond water at a weak alkalinity, which is conducive to optimum growth. Second, quicklime can release N, P, K, and other nutritional elements that are absorbed by the pond silt, thereby enriching the fertility of pond water. Third, calcium itself is essential to animals and green plants; therefore, by applying quicklime for pond clearing the pond itself is also fertilized.

Tea Cake

Tea cake is the residue of the fruits of *Camellia sasangua,* or *Camellia semiserrata.* After the fruit oil is extracted, the byproduct contains saponin ($C_{32}H_{54}O_{18}$), a hemolytic toxin. At a concentration of 10 ppm, saponin causes fish to die in 11 h. The general dosage is 40-50 kg/mu for a water depth of 1 m. Tea cakes are first crushed into small pieces, which are soaked in the water, and the next day they are evenly spread into the fish ponds.

Bleaching powder

Bleaching powder contains about 30 per cent chlorine. When dissolved in water, it transforms into hypochlorous acid and calcium chloride. The hypochlorous acid immediately releases free oxygen (O), which is toxic to many pathogens and other harmful organisms.

$$Ca(ClO)_2 + H_2O \dashrightarrow HClO + Ca\begin{matrix} Cl \\ OH \end{matrix}$$

$$HClO \dashrightarrow HCl + (O)$$

The usual dosage of bleaching powder is 13.5 kg/mu (20 ppm) for a water depth of 1 m. The bleaching powder is first dissolved in water and then evenly spread into the fish ponds.

Rotenone

Rotenone is extracted from the roots of leguminous plants *(Derris uliginosa* and *Derris elliptica).* The extracted solution contains about 25 per cent rotenone. The recommended rotenone concentration for pond clearing is 1.3 kg/mu (2 ppm) for a water depth of 1 m. The rotenone solution is diluted 10-15 times with water and then evenly spread into the fish ponds.

Rearing of Fry

Application of Base Manure

After clearing and before stocking the pond with fry, a base manure should be applied to the pond to propagate a planktonic community (rotifera, nauplii, microzooplankton, etc.). Zooplankton proliferate quickly after manure application. Peak populations occur in the following order: protozoans, rotifers and nauplii, microcladocerans, macrocladocerans, copepods. Pond stocking should be timed to ensure a sufficient supply of palatable, natural food at each growing stage of the fry.

The application time and quantity of base manure applied depend on the type of manure. Decayed manure and compost are applied 3-5 days before stocking at a rate of 150-300 kg/mu. Dacao or green manure is applied 5-10 days before stocking at a rate of 200-300 kg/mu. After stocking, additional manure should be regularly applied to stabilize the fertility of the pond.

Stocking Density

The growth and survival of fry are closely tied to the stocking density. This is because stocking density has a direct effect on food supply, water space, and water quality. The optimum stocking density for silver carp and bighead is 100,000-120,000 fry/mu; for grass carp and black carp 80,000-100,000 fry/mu. Lower stocking rates will decrease yield and increase producltion costs. Stocking density can be optimized with skillful farming and careful management.

Culturing Methods

Dacao

Dacao is commonly used as a green manure for nurturing fry. A base manure should be applied before stocking, and additional manure should be added according to water fertility and dissolved oxygen content. Dacao is applied at a rate of 150-200 kg/mu once every 4 or 5 days. Pond fertility is relatively unstable under Dacao application; therefore, application times and quantities should vary depending on water quality and weather. During the rearing period, commercial food should be added if poor growth is observed.

Soybean Milk

Soybean milk is made from soybean that has been soaked in water and then ground with some water. Milk yield varies with soaking time. The optimum soaking time is 6-7 h at a water temperature of 25-30°C. When grinding, it is proper to add some water so that 7.5-10 kg of milk can be produced from 0.5 kg of soybean. Bean milk is spread evenly into the fry ponds 2 or 3 times daily. Generally, the milk from 3-4 kg of soybean is sufficient for 1 mu of pond area. After rearing for 5 days, the milk from 5 kg soybean should be applied to a 1-mu area. However, the quantity of milk may be varied according to fry growth and pond fertility. Only a portion of the soybean milk is consumed by the fry; most of it serves as a fertilizer. Soybean milk gives a more stable water fertility than Dacao.

Mixture of Soybean Milk and Manure

In this technique, organic manure (Dacao or animal manure) is applied as the base manure before stocking. During the rearing period, either soybean milk or more organic manure is added to the pond depending on the water fertility. The usual amount of organic manure added is 150-200 kg/mu. This method combines fish feeding and pond fertilization and is easily practised.

Compost

Compost is a mixture of green grass and organic manure. After fermentation and putrefaction of the mixture, it is even used to rear fry. Before stocking, compost is applied once or twice as a base manure at a rate of 500 g/m^3 (333 kg/mu) of pond water. After stocking, manure should be applied twice daily. The amount applied depends on the water quality and pond fertility; the usual rate of application is 100-150 g/m^3 (60.6-99.9 kg/mu) of pond water. The additional manure, which is evenly spread into the pond, is the liquid part of the fermented compost. Application results in a significant reduction in oxygen consumption and a stabilization in plankton propagation. This is because the compost has already been fermented and putrefied and is applied frequently in small amounts.

Grass paste

Grass paste is prepared with water hyacinth, water lettuce, water peanut, etc., in a high-speed masher. Water peanut contains saponin which is toxic to fish. To decrease the toxicity of saponin, table salt is added to the paste at a rate of 0.2-0.5 per cent of the wet weight of water peanut. The nutritional elements in grass paste are easily consumed; therefore, grass paste should be applied twice a day, once in the morning and once in the afternoon, at a rate of 25-38 kg/mu, depending on the water fertility. Fry only consume the palatable granules (mesophyll cells, organic detritus) in the grass paste; the rest of the paste is rapidly decomposed by bacteria and fertilizes the pond.

Pond Filling and Pond Management

During the rearing period, filling the pond with water by installment is important to achieve the maximum growth and survival of the fry. During stocking, the optimum water depth is 50 cm. This is because the temperature of shallow water increases easily, accelerating the decomposition of organic manures, promoting the propagation of natural organisms, and fostering the growth of fry. In addition, because the water volume is comparatively small, less feed and manure are used. After rearing for many days, according to fry growth and water quality, fresh water should be let in to raise the water level, improve the water quality, expand the water space, and promote fish growth. The first addition of fresh water should be conducted 6 or 7 days after stocking. Fresh water should then be added once every 4 or 5 days, increasing the water level by 20-30 cm each time until water level reaches a maximum depth.

The condition of the ponds and the behaviour of fish should be observed twice daily. Every morning and afternoon, water colour and fry activities, including surfacing should be observed to determine the amount of feed and manure to be administered and if fresh water should be added. If the fry gasp for air at the water surface in early morning and continue to surface after sunrise, the dissolved oxygen content is too low and fresh water must be added accordingly.

If observed, harmful insects, frog eggs, etc., should be removed. Fry should be examined regularly for infection to prevent the spread of disease.

If, after stocking, the fry swim madly in groups along the pond dike, passage of fry should be obstructed with a net or a fragrant food (such as wine lees) should be used as a lure. Otherwise the fry will be unhealthy and exhibit a high mortality.

Training and Transferring of Summer Fingerlings

When fry are reared into summer fingerlings, they must be transferred into fingerling ponds for further nurturing. Before this the fish should be conditioned so that they are strong enough to tolerate the transferring operation. In addition, because of conditioning, fish do not secrete large amounts of mucus and excreta, which would pollute the water during transportation; therefore, the survival rate is improved. To condition the fish, it is caught in a net and placed in a crowded cage for 5 h beiore transferring. If summerlings are to be transported a long distance, the fish should be put in a second cage in a clear-water pond overnight. Conditioning of summerlings should be performed on days when the fish are not surfacing and started between 0900 and 1000 hrs. Care must be taken at all stages of conditioning to avoid injuring fish and special attention must be paid to the dissolved oxygen content in the cage to ensure the survival of fish.

Rearing of Fingerlings (from Summerling to Yearling)

Ponds and Base Manure

The requirements of fingerling ponds have been mentioned previously and the clearing of fingerling ponds is the same as that of fry ponds. The organic base manure should be applied 5 or 6 days before stocking at a rate of 200-400 kg/mu to provide the fish with an abundant supply of natural food.

Stocking Densities and Polyculture Ratios

It is best to select well-developed fingerlings of uniform size with bright colouration and thick dorsal regions. This type of fingerling is undoubtedly healthy. At the fingerling stage, feeding habits and habitat preferences change. In polyculture, the water body and the various natural foods available in the pond are intended to be fully utilized; however, all the fish prefer to feed on commercial food. Food competition will occur if many species are polycultured in one pond. As a result, the growth of some fish may be adversely affected and fingerling size will be difficult to control. In general, two or three species of fish are polycultured in one pond; there is one major species, the others are minor species.

In polyculture, the stocking ratio of different species should be determined according to the different feeding habits and relationships between the species. For example, with a high stocking density and high commercial feed input, silver carp and bighead polyculture is not practised because silver carp would *outcompete* bighead for food; this would adversely affect the growth of bighead. If these two species have to be polycultured, the only practical combination is a small proportion of bighead (10-15 per cent or less) mixed with silver carp, the major species. Similarly, grass carp have stronger ability to compete for food than black carp. Therefore, if these two species have to be polycultured, a small proportion of black carp is mixed with grass carp, the major species. Common polyculture combinations are grass carp mixed with silver carp and common carp, and black carp mixed with bighead (Table 4.3).

The stocking density depends mainly on the targeted size of fish for next transferring (Fig. 4.2.). Under good rearing conditions, the stocking density is about 10000 fish/mu.

To produce large fingerlings in a short time, "multiple-grade conveyor culture" is practiced. The stocking density is gradually attenuated and, thus, fish growth is not retarded (Table 4.4).

Rearing of Fingerlings

Feeding as the main approach

Grass Carp – In feeding grass carp, it is important to supply palatable, balanced green fodder at different developmental stages. After stocking, grass carp

Table 4.3. Stocking densities, polyculture ratios of summerling and targeted size of fingerling.

Major species			*Minor species*			
Species[a]	*Stocking density (fish/mu)*	*Targeted transfer size*	*Species*[a]	*Stocking density (fish/mu)*	*Targeted transfer size*	*Total stocking density (fish/mu)*
GC	2,000	50-100 g	SC	1,000	100-125 g	
			CC	1,000	13-15 cm	4,000
GC	5,000	13.3 cm	SC	2,000	50 g	
			CC	1,000	12-13 cm	8,000
GC	8,000	12-13 cm	SC	3,000	13-17 cm	11,000
GC	10,000	10-12 cm	SC	5,000	12-13 cm	15,000
BC	3,000	50-100 g	BH	2,500	13-15 cm	5,500
BC	6,000	13 cm	BH	800	125-150 g	6,800
BC	10,000	10-12 cm	BH	4,000	12-13 cm	14,000
SC	5,000	13-15 cm	GC	1,500	50-100 g	
			BH	500	15-17 cm	7,000
SC	10,000	12-13 cm	BR	2,000	10-12 cm	12,000
SC	15,000	10-12 cm	GC	5,000	12-13 cm	20,000
CC	5,000	10-12 cm	BH	4,000	12-13 cm	
			GC	1,000	12-13 cm	10,000
BH	4,000	13-15 cm	GC	2,000	50-100 g	6,000
BH	8,000	12-13 cm	GC	2,000	13-17 cm	10,000
BH	12,000	10-12 cm	GC	2,000	12-13 cm	14,000
BR	5,000	10-12 cm	BH	4,000	12-13 cm	9,000
BR	9,000	10 cm	BH	1,000	13-15 cm	10,000
BR	25,000	7 cm	BH	100	500 g	25,100

* BC, black carp; BH, bighead; BR, wuchang bream; GC grass carp; SC, silver carp.

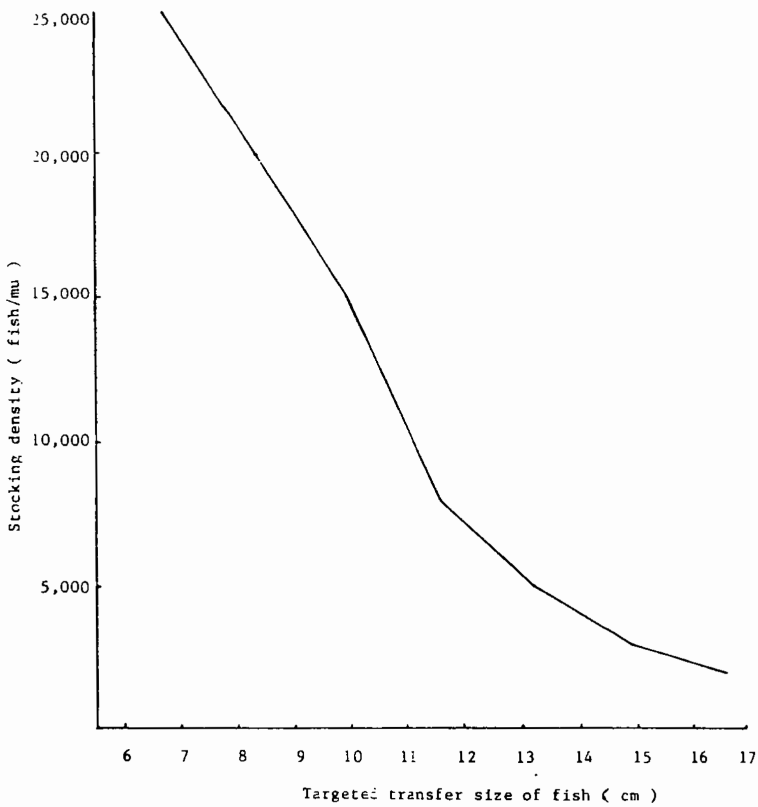


Fig. 4.2. **Relationship between stocking density and the target transfer size of fish.** ***(It is shown that larger fish can be obtained by reducing the stocking density of fish pond.)***

Table 4.4. Stocking models for fingerling rearing of grass carp (GC), silver carp (SC) and bighead (BH) in monoculture.

	Grade	*Stocking density (fish/mu)*	*Size of fish*		*Rearing period (days)*
			At stocking	*At end*	
GC	1	2,000-3,000	3 cm	10 cm	40
	2	500-700	10 cm	20 cm	50
	3	200	20 cm	350 g	60
SC	1	15,000-20,000	3 cm	5 cm	30
	2	4,000-6,000	5 cm	10 cm	20
	3	1,000-1,500	10 cm	17 cm	30
	4	150-200	17 cm	300 g	30
BH	1	12,000-16,000	3 cm	5 cm	30
	2	3,200-4,800	5 cm	10 cm	20
	3	800-1,200	10 cm	17 cm	30
	4	120-160	17 cm	300 g	30

fingerlings are fed *Wolffia arrhiza,* which is abundant and nutritionally complete. When grass carp reach a length of 7 cm, *Lemna minor* or *Hydrilla verticillata* is supplied. When grass carp reach a length of 8 cm (after 20 days rearing), other aquatic grasses are used (Table 4.5). It should be noted that feed amounts must be carefully controlled during the epidemic season of fish diseases. (The optimum amount of feed can be consumed in 5-8 h.) To prevent grass carp from competing for food with silver carp and bighead, they are fed grasses first. Silver carp and bighead are then fed commercial food.

Table 4.5. Feeding schedule for grass carp yearling.

Fish size	*Feed*	*Feeding duration (days)*	*Daily feeding rate (kg/10,000 fish)*
3-7 cm	*Wolffia arrhiza*	15-20 (from mid-June)	20-40
7-8 cm	*Hydrilla verticillata* and *Lemna minor*	15-20 (from mid-July)	75-100
8-10 cm	*Spirodella polyrhiza*	15-20 (from late July)	100-150
10-13 cm	*Vallisneria spiralis*	40-50 (from early Aug)	15-200
>13 cm	*Vallisneria spiralis* and commercial feed	80-90 (from late Sept)	75-150

Black carp – After stocking black carp summerlings, soybean cake paste or soybean dregs are supplied first in a fixed location (Table 4.6). Subsequent feeding will always be in the same place. The daily ration of soybean cake paste for 10,000 fish is 1-2 kg and should be supplied in two feedings; one between 0800 and 0900 hrs and the other between 1400 and 1500 hrs. At the same time, a considerable amount of *Wolffia arrhiza* is added as a supplement. When black carp reach a length of 10 cm, crushed snails can be offered (Table 4.6): the initial daily feeding rate for 10,000 fish is 35 kg and is gradually increased to 125 kg. All the snails should be supplied and consumed between 0800 and 1600 hrs. When feeds are changed, the two types (old and new) must first be mixed and given to the fish so that the taste of new food will be gradually accepted. The feeds must be fresh and well distributed and the feeding platforms kept clean.

Table 4.6. Feeding schedule for black carp yearling.

Fish size	*Feed*	*Feeding duration (days)*	*Daily feeding rate (kg/10,000 fish)*
3-5 cm	Soybean cake paste	15-20 (from mid-June)	4-5 (dry weight)
5-10 cm	Soaked soybean cake and rape seed cake	50-60 (from early July)	2.5-5 (dry weight)
10 cm-50 g	Crushed snails	30-40 (from early Sept)	35-125 (increase gradually)
>50 g	Soaked soybean cake	60-70 (from early Oct)	1.5-3 (dry weight)

Silver carp and bighead – Before rearing silver carp and bighead fingerlings, a base manure is applied to propagate plankton. At the initial stocking stage, silver carp, besides feeding on natural food should be given 1.5-2 kg soybean dregs per 10,000 fish daily. After 1 week of rearing, fish should be given 2-3 kg of wine lees or 0.5-1 kg of soybean cake paste per 10,000 fish daily. The daily amount of bean cake can later be increased to 1.5-2 kg per 10,000 fish. During the culture period, additional manure should be applied according to the fertility of the pond water. Bighead fingerlings are fed in much the same manner as silver carp, but the amounts for bighead should be at least twice those for silver carp.

Common carp and wuchang fish – In a pond with common carp as the major species, bean dregs and other commercial feeds are supplied daily at a rate of 1.5 kg per 10,000 fish. The food is applied to the shallow regions near the bank and amounts should be increased as the fish grow. In a pond with wuchang fish as the major species, bean cake paste is first given twice daily at a rate of 0.5 kg per 10,000 fish. *Wolffia arrhiza, Lemna minor,* tender grasses, and aquatic plants are then supplied. At the same time, organic manure is applied to increase the amount of natural food.

To raise the efficiency of food utilization and decrease the food-conversion factor, it is necessary to adhere to the feeding principles and methods, i.e., fixed feeding times and locations. To avoid wastage, food should be supplied on the fixed ground or platforms. These methods also allow the convenient observation of food intake and the elimination of debris. Grasses fed to grass carp and wuchang fish are put in triangular or square bamboo frames. Commercial feeds are usually put on platforms made of planks and frames with an area of 1-2 m^2. There is one platform for every 5,000-8,000 fingerlings. During the season when fish are vulnerable to disease, platforms should be disinfected regularly. Snails are commonly put on the solid bottom of the pond. The water depth here is about 70 cm.

Manure loading as the main approach

Manure loading is effective in rearing silver carp and bighead. In the 1st month after stocking, organic manure is applied once every 10 days at a rate of 200-250 kg/mu. In the 2nd month, the same amount of manure is applied once every 7 days. As the water temperature declines, the manure loading rate should also decrease. At that time, commercial food is added daily at a rate of 2-3 kg per 10,000 fish. Summerlings are stocked in a season when the water temperature is increasing; therefore, water quality must be carefully monitored to ensure a sufficient dissolved oxygen content.

Fertilization with barnyard grass

Barnyard grass *(Echinochioa crusgalli)* grows quickly and is usually planted in unoccupied fingerling ponds. When the grass is mature, enough water is introduced to submerge the grass. The grass then gradually rots and decomposes as a function of both fertilizer and food.

The precise method of barnyard grass fertilization is as follows: First, the ponds are drained in early May. A base manure is necessarily to be applied to sterile pond bottom. Barnyard grass seeds are then sowed at a rate of around 5 kg/mu; they sprout in 2 or 3 days. After 1 month, the barnyard grass can reach a height of 80 cm. Enough water is then introduced to submerge the grass (1.5 m). After the barnyard grass have been submerged for 5-7 days, the pond water is fertile. The usual stocking density of summer fingerlings is 5,000-7,000 fish/mu, with silver carp and bighead as the dominant species (Table 4.7). In such a pond, nitrogen and phosphorus contents are high. However, barnyard grass consumes a lot of oxygen during its putrefaction and, therefore, the dissolved oxygen content must be closely monitored.

Table 4.7. Yield and survival of fingerlings nurtured in the ponds with pre-planted barnyard grass as manure.

Species	*Stocking ratio (%)*	*Stocking size (cm)*	*Survival rate (%)*	*Size at time of transfer (cm)*	*Ave. yield (kg/mu)*
Bighead	63.3	3.7	84.2	15	87.0
Silver carp	18.2	6.0	59.6	22	70.5
Grass carp	9.9	7.0	22.6	29	41.5
Hybrid[a]	7.2	0.2	6.4	31	12.0
Black carp	1.4	5.0	53.6	20	3.6

[a] Origin of the hybrid is unknown.

Pond management

The ponds should be observed every morning and the activity of the fish and the water colour should be noted. If the fish gasp for air for a long time, fresh water should be added. In the afternoon, the feeding status of the fish must be determined so that the feeding schedule for next day can be planned.

The pond area should be kept clean. Any decayed debris should be immediately removed and feeding places should be frequently disinfected. Because of disease, food type, and other factors, fish may have different growth rates. Therefore, fingerlings should be sieved in August or September and cultured separately according to size to ensure a uniform final size.

Rearing of 2-year-old fingerlings

Black carp

From yearling to 2-year-old fingerling, the survival rate of black carp is only 30 per cent. This is due to their heavy food demand and susceptibility to disease. *Stocking* – The stocking densities and stocking ratios of the various fish species in the pond depend on the desired final sizes and yields (compare Table 4.8 and 4.9).

Table 4.8. Stocking and harvesting model of a 2-year-old black carp fingerling pond.

Species	*Stocking*			*Harvesting*		
	Size (g or cm)	*Number (fish/mu)*	*Survival rate (%)*	*Mean size (kg or cm)*	*Number (fish/mu)*	*Yield (kg)*
Black carp	13	660	30	0.50	198	75
Black carp	50-75 g	140	70	0.75	98	75
Silver carp	10	120	95	0.50	114	67.5
Common carp	3	3,300	40	8-10 cm	1,320	65.5
Total		4,220			1,730	272.5

Table 4.9. Stocking and harvesting model of a 2-year-old black carp fingerling pond.

Species	*Stocking*			*Harvesting*		
	Size (cm)	*Number (fish/mu)*	*Survival rate (%)*	*Mean size (kg or cm)*	*Number (fish/mu)*	*Yield (kg)*
Black carp	12-13	1,000	35	0.29	350	100.0
Grass carp	8-10	100	70	0.25	70	17.5
Bream	5-7	100	90	>17 cm	90	7.5
Silver carp[a]	12-13	1,000	95	0.13	950	120.0
Bighead[a]	12-13	200	95	0.13	190	25.0
Crucian carp[b]	2	3,000	90	6 cm	2,700	15.0
Bighead[a, b]	3	800	90	0.14	720	100.0
Total		6,200			5,070	385.0

[a] When silver carp and bighead with an initial body length of 12-13 cm reach 0.1-0.15 kg, they are transferred to the grow-out pond.

[b] Crucian carp are stocked in May and 3-cm bighead are stocked in late July and early August.

Management – At the 2-year-old fingerling stage, black carp stop eating commercial plant food and begin eating animal food (snails, *Corbicula sp.*, etc.). Feeding starts in March. At first, bran, dregs, bean cake, etc., are supplied once every 3 or 4 days at a rate of 3-5 kg/mu. In April, small snails are supplied once every second day at 25 kg/mu. Later, this rate is increased by 5 kg/mu at each feeding. All the food supplied should be consumed within 24 h, otherwise, water quality will deteriorate because of the decaying snails, and the fish may become diseased. In May and June, crushed snails can be given to the fish. Whole snails can be supplied as the fish grow bigger. Water quality must be determined daily and adjusted if necessary. Because black carp at this stage are very weak in adapting to the fertile water, any symptoms of disease must be immediately dealt with and over-feeding must be avoided. Black carp at this stage, also lack the ability to tolerate a low dissolved oxygen content; therefore, this aspect of water quality must be closely monitored (fish surfacing indicates low oxygen content).

Stocking – The stocking density and proportion of grass carp in polyculture are similar to those of black carp. The usual stocking density of grass carp is 800-1,000 fish/mu and minor species usually include silver carp, bighead, and black carp.

Management – The frequency and quantity of food given to 2-year-old grass carp fingerlings depend upon the growth of the fish, the acceptability of the food and the season. In March, bran, dregs, and other commercial feed are usually applied once every several days at a rate of 2.5-5 kg/mu. In April, duckweed *(Lemna minor)* is applied. After May, English ryegrass, lettuce leaves, *Vallisneria spirolis*, and tender terrestrial grasses are supplied. The feeding amount is based mainly on the weather; it is best to apply the food in the morning and have all the food consumed by 1600 hrs. The grasses must be fresh and any leftovers should be removed every afternoon to prevent deterioration of water quality.

Chapter 5

POND CULTURE OF FOOD FISH

Fei Yingwu

The intensive pond culture of food fish is mainly carried out in small, man-made ponds with a water depth of 1-2.5 m. The fish are fed commercial food and stocked at a high density to achieve high, stable production. Chinese aquaculturists have summarized their long experience in intensive fish culture into eight main points: water (deep and flexible), seeds (good stock, healthy) feeds (fine and adequate), polyculture, density (high but renewable), rotation, prevention (preventing diseases and eradicating enemies) and management (elaborate). These eight principles (harvesting and stocking) have effectively accelerated the development of pond fish culture in China. In 1983, the total freshwater fishery production in China was 1,840,700 t; 1,428,100 t (77.6 per cent) of this was from cultivation. The total fish production from ponds in 1983 was 1,030,000 t or 72.1 per cent of the total freshwater fishery production from cultivation. The total area devoted to freshwater cultivation in 1983 was 46,239,700 mu (15 mu = 1 ha); culture ponds accounted for 14,473,900 mu (31.3 per cent) of this area. Pond fish culture obviously plays an important role in the freshwater fisheries of China.

Rearing period refers to the time required to raise fish from the fingerling stage to a stage when the fish can be harvested. In China, rearing periods are determined by local conditions: climate, culturing methods, and market demand. Silver carp and bighead gain a substantial amount of weight in their 2nd year. By using proper culture techniques, silver carp and bighead fingerlings with a body weight of 50 g can reach 1-1.5 kg by the next Autumn. Black carp and grass carp grow rapidly during their 3rd year. A 2-year-old grass carp fingerling with a body weight of 0.5-1 kg may reach 3.5-5 kg by the following year. The rearing period in Jiangsu, Zhejiang, Hunan, and Hubei provinces for silver carp, bighead, wuchang fish, tilapia, and crucian carp, is 2 years; for black carp and grass carp, the rearing period is 3 years. Fish-rearing periods are much longer than those in livestock and poultry production; therefore, the economic benefit is lower. To correct this situation, experiments and reforms are now being conducted to shorten the fish-rearing period.

Requirements and Renovations of Ponds

Pond conditions greatly affect fish growth and fish yield. Under favourable conditions, the yield may be 2 or 3 times higher than that in ponds with unfavourable conditions.

Requirements of the Grow-Out Pond

Area

An area of 7-10 mu is considered optimal for an intensive culture pond. The fish have sufficient space for swimming and feeding and the water is adequately disturbed by the wind to prevent a shortage of dissolved oxygen and to regulate water temperature. In addition, the decomposition of manure and the propagation of plankton can be promoted.

Water supply and water quality

Fresh water should be added to the pond at regular intervals to adjust water depth, control water quality, and replenish the dissolved oxygen supply. The water source should be a river, lake, reservoir, or other large body of water because the dissolved oxygen content (DOC), pH, and temperature are likely to be stable and suitable for fish growth. The water discharged from factories and mines usually contains harmful chemicals, and should be avoided after fish culture.

Depth

The effective water depth varies with geography, climate, species, and culturing method. To fully utilize the pond and maximize yield, the pond should be as deep as possible. An increased volume of water stabilizes both water temperature and water quality and is thus beneficial to fish growth and allows the polyculture of various species. In Xihu, a village in the suburbs of Henyang, Hunan Province, and Helei, a village in the suburbs of Wuxi, Jiangsu Province, the common pond depth is around 3 m. In the winter and the spring, however, the water level is lowered so that the pond dikes can be used for fodder crop production. The average year-round water depth is about 2 m.

Bottom soil

Loamy soil is best at the bottom of a fish pond because it is effective in maintaining water level and fertility. In addition, the water will not become too turbid, the bottom silt will not be too thick, natural organisms will flourish, and operation and management will be relatively easy. Clay soil maintains water level and water fertility because of its low permeability; however, the water easily becomes turbid, the bottom silt is often too thick, and lot of nutritive salts are absorbed and cannot be used by the plankton. Therefore, a clay soil is not favourable for the propagation of natural organisms and not convenient for operation and management.

Pond environment

Rectangular fish ponds with well-formed pond dikes are recommended. The pond bottom should be flat and even to simplify rearing management and netting operations. Planting mulberry trees and crops onto pond dikes not only produces food for the fish but also protects the pond dikes from erosion. Large trees and buildings around fish ponds must be avoided; they would block the sunlight and hinder the winds. These two factors are essential in ensuring adequate water temperature, plankton growth, and DOC.

Pond Renovations

The old traditional fish ponds of Jiangsu and Zhejiang provinces were small and shallow with low dikes and poor water quality. Such ponds are subject to natural disasters and low productivity. In the early 1950s, high-yield grow-out ponds yielded only 300 kg/mu. As fish farming developed, the fish farmers discovered that the traditional fish ponds were unsuitable for achieving high and stable yields. All remaining old ponds should, therefore, undergo the following renovations.

Small ponds to large pond

There is a saying among Chinese fish farmers: "The broader the body of water, the larger the fish". In the past, farmers believed the optimum area of a grow-out pond to be 4-5 mu. In such ponds, however, water quality is difficult to control and dissolved oxygen is quickly depleted in high-density polyculture. In larger ponds, environmental conditions are comparatively stable. As the wind blows over the larger surface, waves appear and the DOC is increased. Thus, the old, 4-5 mu ponds are now being combined to form large, 7-10 or even 15 mu grow-out ponds.

Shallow pond to deeper pond

Pond depth directly affects fish yield. A water depth between 2 and 2.5 m is favourable for conducting high-density polyculture. In deeper ponds, the water will not be turbid during the harvest. In addition, water temperature and water quality are more stable in deeper ponds. However, if ponds are too deep, the exchange of surface water and bottom water will be limited and toxic gases will accumulate at the bottom of the pond because of a low DOC. These factors would limit fish growth and the propagation of natural organisms, with a consequent reduction in fish yield. The depth of a pond depends on its area and usually, the depth is kept between 1.7 and 2.5 m year-round.

Stagnant-water pond to free-exchanging pond

To facilitate irrigation, drainage, and water-quality regulation, stagnant-water ponds should be converted to free-exchanging ponds by combining and connecting the ponds to a freshwater supply. A favourable environment is essential to obtain high yields in intensive fish culture.

Low-dike pond to high-dike pond

Pond dikes should be high enough to prevent flooding and wide enough to be used for planting crop or raising livestock.

Fig. 5.1. Stable, high-yielding fish ponds in the suburbs of Wuxi, Jiangsu, P.R. China

These four renovations completely change fish-farming conditions and allow the fish output to be increased step by step. For example, in Zhang-zhuang village of Suzhou City which is a traditional fish-farming area from 1949 to 1970, the average annual yield was 200-250 kg/mu. Since 1973, the old fish ponds have been renovated every winter, resulting in average yields of 500, 700, and 750 kg/mu in 1979, 1982 and 1983, respectively. In the Helei fishery village in the suburbs of Wuxi, since 1975, 345 small ponds have been converted into 172 large ponds. The yield is now up to 1000 kg/mu.

The general criteria for a grow-out pond with a high, stable yield are as follows: area of about 10 mu; water depth of 2-2.5 m; good water supply that is easily accessible; and high and wide dikes (Fig. 5.1).

Stocking and Polyculture of Fingerlings

Stocking of Fingerlings

The demands of food fish culture require that grow-out ponds be stocked with fingerlings of a variety of species, in adequate quantities, of appropriate sizes, and with no injuries or diseases.

Pond clearing

After 1 or 2 years of culturing, silt and organic matter accumulate on the bottom of the grow-out pond. This allows the propagation of various harmful bacteria. Fish ponds, therefore, should be cleared once a year.

Pond clearing is normally performed in the winter. Some of the silt is removed from the pond. This will not only improve the living environment of the fish and increase the capacity of the pond but also provide good-quality manure for agriculture. After removing the excessive silt, the pond bottom is open to the air for sunning and freezing. Chemicals can then be used to eradicate all the wild fish, pathogens, parasites, etc. After pond clearing, fresh water and manure are introduced about 1 week before stocking.

Manure application and pond filling

Manure application enriches the nutritional value of the water and promotes the proper proliferation of natural food organisms. It is important to maintain the food supply and maximize fish yields. After pond clearing, a base manure should be applied as early and adequately as possible so that enough natural food is available during the early stages of cultivation. The usual dosage of animal manure, compost, or fermented green manure is 500-1000 kg/mu. Manure is spread evenly on the pond bottom or beside the remaining water and exposed to the sun for several days. The manure could also be mixed with the pond silt. This would keep the water fertile a little while longer.

After the application of a base manure, the pond is filled with fresh water. The initial addition should bring the water level to about 1 m. When this water becomes fertile, more fresh water is added. Alternatively, the pond could be filled with fresh water at a rate dependent on temperature and fish size.

Selection of fingerling

The selection of good-quality fingerlings is important in ensuring high fish yields. Large good-quality fingerlings have many merits: strong adaptability, high survival rate, fast growth, short culture period, high marketing rate and economic returns, etc. There are three criteria for selection and purchasing fingerlings: physique, size, and movement.

Physique – Strong, healthy, normally shaped fingerlings are desirable. The fingerling should have plump muscles at the dorsal and peduncle region. Fingerlings should have complete scales and fin rays and smooth, bright-coloured skin.

Size – Fingerlings of the same age should be of uniform size (length and weight). Standards are listed in Table 5.1.

Movement – Healthy fingerlings will jump violently in the hand; poor fingerlings will not. When healthy fingerlings are put on a plate, they jump constantly without opening their gill covers; poor fingerlings only jump slightly with their gill

Table 5.1. Standard body weight vs. body length of yearlings.

Silver carp			*Bighead*			*Grass carp*			*Wuchang bream*		
Length (cm)	*Weight (g)*	*No./kg*	*Length (cm)*	*Weight (g)*	*No./kg*	*Length (cm)*	*Weight (g)*	*No./kg*	*Length (cm)*	*Weight (g)*	*No./kg*
16.50	45.4	22	16.50	49.4	20	19.47	88.8	11.6	13.20	25.0	40
16.17	41.6	24	16.17	44.4	22	19.14	82.8	12.2	12.87	23.8	42
15.84	38.4	26	15.84	40.6	24	18.81	80.0	12.6	12.54	21.9	46
15.51	35.6	28	15.51	37.5	26	17.49	64.1	16.0	12.21	17.2	58
15.18	34.4	30	15.18	35.6	28	17.17	56.3	18.0	11.88	14.4	70
14.85	31.3	32	14.85	32.2	30	16.17	45.3	22	11.55	12.8	76
14.52	29.4	34	14.52	31.3	32	14.85	32.8	30	11.22	12.2	82
14.19	27.8	36	14.19	29.4	34	14.52	31.3	32	10.89	11.3	88
13.86	26.6	38	13.86	27.8	36	14.19	29.4	34	10.56	10.0	96
13.53	25.0	40	13.53	26.6	38	13.86	27.2	36.8	10.23	9.4	106
13.20	22.8	44	13.20	25.9	42	13.20	20.9	48	9.90	8.3	120
9.90	9.6	104	9.90	10.3	98	9.90	9.30	108			

covers open. When healthy fingerlings are placed in a net cage, they swim actively in groups with their heads downward and caudal fins upward; only their caudal fins can be observed on the water surface. Poor fingerlings swim slowly or alone.

Disinfection of fingerlings before stocking

Disinfection of fingerlings should be conducted before stocking (see Chapter 6, Fish diseases).

Stocking time

Fingerlings should be stocked as early as possible. In the Changjiang River basin, fingerlings are usually stocked in early February when the air and water temperatures are low. At that time, fish are lethargic and, therefore, will not be easily injured during netting and stocking. The occurrence of disease and the mortality rate are also reduced. Earlier stocking also implies earlier feeding and a longer growth period. Early stocking should not be performed on rainy, snowy, or cold days to avoid the possible frostbite of fingerlings during netting and transportation.

Polyculture

Polyculture is a prominent farming technique in Chinese freshwater fish farming. Polyculture in China dates back to the Tang Dynasty (618-907), and, because of its long history, is more efficient than the polyculture in other countries. It is practiced at every rearing stage of fish farming (brood fish, fingerling, and food fish). High yielding grow-out ponds may now be stocked with a mixture from 8 to 10 species in different combinations of sizes and ages.

Advantages of polyculture

Polyculture facilitates full utilization of the natural food organisms in the pond water. There are three kinds of natural organisms (plankton, benthos, and epiphytic algae) and organic detritus in still-water ponds. Fish production can be greatly increased through polyculture of various species with different feeding habits: silver carp and bighead, which feed on plankton; grass carp, *Parabramis pekinensis*, and *Megalobrama* which feed on grasses; black carp, which feeds on snails and other benthos; common carp and crucian carp which prefer benthos and some organic detritus; mud carp and *Xenocypris* which feed on organic detritus and benthic algae; and the omnivorous tilapia. When these species are mixed, the natural food organisms are fully utilized and production is maximized.

Polyculture also allows the full utilization of the available space in the pond. The major cultivated carps occupy different habitats in the pond. Compared with monoculture, polyculture can increase both the stocking amount per unit area and fish output.

Beneficial interactions between the compatible species cultured in the same pond, become evident in polyculture. Under reasonable polyculture, all species are mutually beneficial. Thus, the production of each species is increased. Grass carp, black carp, common carp and wuchang fish are regarded as "feed eaters" or "food feeders"; silver carp, bighead, and tilapia are known as "plankton feeders". In grass carp monoculture the pond water easily becomes too fertile; however, this can be counteracted by mixing silver carp and bighead which will feed on the natural organisms propagated by the manure of grass carp. The consequent decrease in pond fertility is beneficial to grass carp growth. Through the beneficial interactions between species, one kind of food can be "doubly utilized". It is said that in polyculture "one grass carp can provide enough food for three silver carp through proliferating natural organisms."

Polyculture raises the utilization rate of artificial feeds. Different species of various sizes will consume different sizes of feeds. This reduces feed wastage and improve water quality.

Stocking density

Stocking density also known as per-unit stocking amount or stocking rate, refers to the quantity of fry or fingerlings per unit of water area. It is usually expressed as the number of weight of fish per mu. In intensive fish-farming systems (such as industrialized fish farming, fish farming in flowing water, or fish culture in a net cage), the stocking density is expressed as the number or weight of fish per unit area (square metres) or water volume (cubic metres) because of the high stocking density and high utilization rate.

The stocking density must be reasonable because it is inversely proportional to the quality of marketable fish under the same pond conditions and culturing measures. Excessive stocking densities produce fish below marketable size; therefore, fish yields are not improved. If the stocking density is too low, the per-unit area production is also low, although the fish grow faster and reach larger sizes. A reasonable stocking density can ensure the desirable size and quality of fish products.

Pond conditions, seed supply, species availability, fish sizes, feeds, and operating techniques should all be taken into consideration in determining the stocking density. The data from the previous year (sizes, yields, survival rate, marketing rate, food-conversion rate, etc.) should be used to determine if a change in stocking density is required. If the fish grow well, the food-conversion rate is not higher than the average, no serious surfacing occurs during the culture period, and all species reach the marketable size at the end of production, the stocking density can be considered optimum. If some species of fish are not achieving marketable size and the food-conversion rate is high, the stocking density should be considerably reduced. Optimum stocking densities vary with the level of development of production. Therefore, the stocking density should be determined by local conditions to obtain a good harvest.

Apart from feeds and water space, water quality (DOC in particular) is the major factor affecting stocking density. The DOC in pond water is closely related to the growth and survival of the fish. Oxygen demand varies with species, age, sizes of fish and water temperature. For Chinese carp, DOC should be above 3 mg/L (Table 5.2). The optimum DOC is around 5.5 mg/L. The respiratory rate of cyprinids increases when the DOC is below 2 mg/L. If it continues to drop, the fish will break the surface gasping for air. Asphyxiation occurs from 0.1 to 0.8 mg/L, depending on the species (Table 5.2).

Table 5.2. The DOC requirement (mg/1) of the major cultured fish in China.

	Black carp	*Grass carp*	*Silver carp*	*Bighead*	*Common carp*	*Crucian carp*	*Wuchang fish*	*Tilapia*	*Mud carp*
Asphyxia	0.6	0.4	0.8	0.4	0.3	0.1	0.6	0.4	0.2
Minimum	2	2	2	2	2	1	2	1.5	2
Normal	5	5	5.5	5	4	2	5.5	3.5	4

Dissolved oxygen content not only affects respiratory rates, but also feeding rates. Under normal conditions, the higher the DOC, the greater the food intake, the lower the food-conversion factor and the faster the growth of the fish (Table 5.3). For grass carp, when the DOC was increased from 2.73 to 5.56 mg/L, the food-conversion rate declined 4.2 times and the body weight increment increased 9.8 times. A similar experiment was conducted outside China on rainbow trout. It also shows that the higher the DOC, the better the growth of the fish and the lower the food-conversion rate (Table 5.3).

Table 5.3. The effects of DOC on the growth and food conversion rate (FCR) of rainbow trout.

DOC (mg/l)	*Body weight gain (g)*	*FCR*
12.43	11.6	2.3
6.36	5.3	5.6
2.65	1.4	8.4

It is clear that the DOC is closely related to the respiration, ingestion, growth, and survival of the fish. In static fish ponds, the DOC is mainly dependent on the photosynthesis of phytoplankton and the diffusion of the air against the water surface, the former being more important than the latter. During the day, the upper layer of water usually becomes saturated with oxygen when photosynthesis is high. Nevertheless, the oxygen easily escapes from the water into the air.

In a fish pond, the respiration of the fish is not the leading factor in oxygen consumption, accounting for only 5-15 per cent of the total consumption. The oxygen consumption of natural food organisms (e.g., zooplankton) accounts for less than 4.5 per cent; benthos, 0.2 per cent; the oxidative decomposition of manure applied and pond silt, about 8 per cent; and the decomposition of artificial food and fish feces, about 32 per cent. Microbacteria (including phytoplankton) consume about 50 per cent of the dissolved oxygen.

Because of the different histories of fish culture, climates, food sources, and consumer habits in China, various fish-farming systems, which are practical in respect to local conditions, have been developed. Even in one place, there may be different polyculture farming systems with different fish yields. Usually, five to nine species of fish are polycultured in one grow-out pond. Among the species cultured, however, only one or two species are major species, and dominate the pond in number or weight; the rest are minor species. Because there is a wide variety of minor species, their rearing can result in high yields, low cost, and a high economic return. Both the major and the minor species play important roles in total output.

The selection of the major species and their stocking ratios depend on the availability of fingerlings, feeds and manures, farming techniques; pond conditions, and market demand. Because fish-farming conditions differ from place to place, it is difficult to work out a standardized stocking model. Tables 5.4 to 5.9 give practical examples for reference. With proper rearing management, these models will be productive.

Table 5.4. Stocking model using aquatic macrophytes as the main fish feeds.

Species[a]	*Stocking size (cm)*	*Fish/mu*	*Total stocking weight (kg/mu)*	*Survival rate (%)*	*Yield (kg/mu)*		*Weight gain (times)*
					Gross	*Net*	
GC	0.25-0.5	100	33.7	80	110	71.3	2.8
BR	13	160	3.5	90	30	26.5	8.6
SC	13	200	5.0	95	100	95.0	20.0
BH	13	50	1.3	90	30	28.7	24.0
CC	10	40	1.0	90	20	19.0	20.0
CrC	6.5	100	0.5	70	10	9.5	20.0
Total		650	50.0	87	300	250.0	6.0

[a] GC, grass carp; BR, bream (Wuchang fish); SC, silver carp; BH, bighead; CC, common carp: CrC, crucian carp

Table 5.5. Stocking model using terrestrial grasses as major fish feeds.

Species	*Stocking size (cm)*	*Fish/mu*	*Total stocking weight (kg/mu)*	*Survival rate (%)*	*Yield (kg/mu)*		*Weight gain (times)*
					Gross	*Net*	
Grass carp							
2-year-old	0.25 kg	80	20.0	90	70.0	50.0	3.5
yearling	13	100	2.5	80	20.0	17.5	7.0
Wuchang fish	13	140	3.5	85	25.0	21.5	6.1
Silvar carp							
yearling	0.15-0.25 kg	140	28.0	95	75.0	47.0	2.7
summerling	3.3	180	0.1	85	28.5	28.4	285.0
Bighead yearling	0.15-0.25 kg	35	7.0	95	20.0	13.0	2.9
summering	3.3	50	0.025	85	9.0	9.0	360.0
Common carp	10.0	30	0.5	80	15.0	14.5	29.0
Crucian carp	6.6	100	0.5	80	10.0	9.5	19.0
Tilapia	3.3-5.0	400	0.4	–	40.0	39.6	106.6

Table 5.6. Stocking model using organic manure.

Species	*Stocking size (cm)*	*Fish/mu*	*Total stocking weight (kg/mu)*	*Survival rate (%)*	*Yield (kg/mu)*		*Weight gain (times)*
					Gross	*Net*	
Silver carp	13.0	300	7.5	95	165.0	157.0	22.0
Bighead	13.0	60	1.5	95	35.0	33.5	23.3
Grass carp	16.0	50	2.5	75	27.5	25.0	11.0
Wuchang fish	13.0	100	2.5	90	15.0	12.5	6.0
Common carp	10.0	30	0.5	80	12.0	12.0	25.0
Crucian carp	6.6	120	0.5	80	10.0	9.5	20.0
Total		660	15.0		265.0	250.0	17.7

Table 5.7. Stocking model using aquatic and terrestrial grasses as the main fish feeds.

Species	*Stocking size (cm)*	*Fish/mu*	*Total stocking weight (kg/mu)*	*Survival rate (%)*	*Yield (kg/mu)*		*Weight gain (times)*
					Gross	*Net*	
Black carp							
2-year-old	0.4 kg	100	40.0	90	125.0	85.0	3.1
yearling	13.0	140	3.5	75	40.0	36.5	11.4
Wuchang fish	13.0	300	7.5	80	40.0	32.5	5.3
Silver carp							
2-year-old	0.15 kg	250	37.5	98	140.0	102.5	3.7
summerling	3.3	300	0.15	85	37.5	37.4	250.0
Bighead yearling	0.15 kg	65	9.75	98	35.0	25.3	3.6
summering	3.3	80	0.05	85	10.0	10.0	200.0
Common carp	13.0	30	0.8	80	12.5	11.7	15.6
Crucian carp	6.6	100	0.5	80	10.0	9.5	20.0
Tilapia	3.3	500	0.25	–	50.0	49.5	200.0
Total		1,865	100.0	–	500.0	400.0	5.0

Table 5.8. Stocking model using terrestrial grasses as the main feeds, with grass carp as the major species and a target net yield of 500 kg/mu.

Species	*Stocking size (cm)*	*Fish/mu*	*Stocking weight (kg/mu)*	*Survival rate (%)*	*Yield (kg/mu)*		*Weight gain (times)*
					Gross	*Net*	
Grass carp	0.5 kg	1,600	80.0	85	250	170.0	3.1
Wuchang fish	13.0	300	7.5	80	45	35.0	6.0
Silver carp	13.0	320	8.0	98	180	172.0	22.5
Bighead	13.0	80	2.0	95	45	43.0	20
Common carp	11.0	40	1.0	90	20	19.0	20
Crucian carp	6.6	100	0.5	70	10	9.5	50
Tilapia	6.0	400	1.0	–	50	49.0	5.0
Total		1,400	100.0		600	5.0	6.0

Table 5.9. Stocking model using green manure, animal manure and domestic sewage.

Species	*Stocking size*	*Fish/mu*	*Stocking weight (kg/mu)*	*Survival rate (%)*	*Yield (kg/mu)*		*Weight gain (times)*
					Gross	*Net*	
Silver carp							
stocked in Jan.	0.2 kg	300	60.0	98	255	165.0	3.8
stocked in May	0.05kg	300	15.0	98	75	60.0	5.0
Bighead							
stocked in Jan.	0.2-0.35 kg	60	12.5	98	50	37.5	4.0
stocked in May	0.05kg	60	3.0	98	15	12.0	5.0
Grass carp	0.125 kg	100	12.5	80	60	47.5	4.8
Wuchang fish	13.0 cm	50	1.0	80	10	9.0	10.0
Common carp	10.0 cm	50	1.0	80	25	24.0	25.0
Xenocypris	10.0 cm	1,000	14.0	80	100	86.0	7.1
Crucian carp	6.6 cm	100	0.5	–	10	9.5	20.0
Tilapia	4.0 cm	500	0.5	–	50	49.5	100.0
Total		2,500	120.0		620	500.0	5.2

Harvesting and Stocking in Rotation

Harvesting and stocking in rotation is a procedure whereby fingerlings of different sizes are stocked into the pond at the same time. As the fish grow, the pond becomes overcrowded. Consequently, marketable-size fish are caught in batches and are replaced by an appropriate amount of smaller fish to maintain the optimal stocking density during the entire culture period and increase the fish yield per unit area. In the past, fingerlings were stocked at the beginning of a year and harvested at the end of a year. Part of the pond was wasted at the initial stage of rearing and fish growth was retarded at the later stages. This has been changed by harvesting and stocking in rotation. In short, rotary harvesting and stocking is an operating procedure, i.e., "to stock fingerlings of different sizes at the same time, harvest by stages, catch the edible-sized, and leave or re-stock the smaller ones."

Advantages

This method balances the carrying capacity of the pond with the fish growth. At present, high-density stocking is commonly practiced to obtain high yields. In high-yield fish ponds, the stocking density is usually around 150 kg/mu reaching 250-300 kg/mu or even higher, with 8-10 different species in more than 10 different sizes. As the fish grow, the pond becomes crowded and, correspondingly, the space occupied per fish becomes less. If the living space is limited, fish growth is impaired. In addition, the growth rate decreases as the fish gets larger. Based on observations in Guangdong, the body weight of a silver carp can increase by 0.4-0.6 kg/month when there is less than 30-40 kg/mu of fish. If the fish density is over 30-40 kg/mu, the monthly body weight increment of a silver carp is only 0.05-0.3 kg. Bighead behaves similarly, with a crucial density of 125-160 kg/mu. Harvesting and stocking in rotation can maintain a reasonable fish density so as to fully utilize the pond and the applied feeds.

Harvesting and stocking in rotation allows the grow-out pond to be used for interfarming fingerlings, and laying the foundation to maintain high, stable fish yields.

To achieve high yields in fish farming, there must be an adequate supply of reasonably sized, healthy fingerlings. As food fish farming develops, fingerling shortages become a major problem because stocking amounts continue to increase; the fingerlings cultured in fry or fingerling nursery ponds cannot meet the stocking demand of grow-out ponds. By harvesting and stocking in rotation, not only are grow-out pond yields increased but also fingerlings for next-year's stocking can be obtained from the grow-out ponds. Thus, high and stable fish yields are ensured. Harvesting and stocking in rotation also reduces the seasonal variation in fresh fish supply and speeds up capital return. From June to October, fresh fish can be harvested monthly for marketing. This hastens capital return and is beneficial to expanding production.

The primary method of harvesting and stocking in rotations is to harvest them by stages and in groups, catching and edible-sized fish and leaving the smaller ones. This method is more adaptive to rural areas because it does not need special fingerling-storage ponds. Rotary harvesting is conducted 2 or 3 times per year and midterm harvest may account for 30 per cent of the total annual output.

In Jiangsu, Zhejiang, Hunan, and Guangdong provinces, fingerlings are stocked several times and harvested in stages, catching the edible-sized fish and supplementing the pond with smaller ones. The time of harvesting and stocking differ according to the production condition of the fish farm and special nursery ponds are required to rear fingerlings. Harvesting times mainly depend on the growing period and the intensity of farming. In Hunan and Guangdong provinces, rotary harvesting can be performed 6 to 8 times per year because of the long growing period; in Jiangsu and Zhejiang provinces, there are only 4 or 5 harvests per year. Fingerlings must be re-stocked after the first two or three harvests. The extent of this supplementary stocking is determined by the production target.

Harvesting

Rotary harvesting is usually conducted in summer and autumn. At high water temperatures, fish are active and have a high feeding intensity; therefore, they are unable to tolerate a long period of handling and crowding. Rotary harvesting should be performed when it is cool and the fish are not surfacing. In addition, the fish should be fed less the day before harvesting to minimize jumping and the dirty drifts should be removed before harvesting. The fish are caught in a net cage between two boats. The boats should constantly move around the pond to wash away any mucus on the skin or mud on the fish gills to prevent asphyxiation caused by overcrowding. The operation must be done as quickly and gently as possible. Fish that are under the marketable size should be returned to the pond as soon as possible.

During harvesting, fish consume more oxygen because of their violent movement and the pond water becomes turbid as the silt at the bottom gets turned up. After harvesting, aerators should be turned on and fresh water added to the pond.

Multiple-Grade Conveyor Culture

Multiple-grade conveyor culture is a special farming technique practiced by fish farmers in Guangdong province. This method is different from rotary harvesting and stocking: fingerlings of different sizes are reared in separate ponds based on fish growth and are transferred in sequence into other ponds. Ponds are usually divided into five grades: one for each size of fish. When the marketable fish are harvested, fingerlings are transferred in sequence to the next grade of pond for further culturing. This farming technique, which can increase fish yields, allows a more reasonable stocking density during the fingerling-rearing period. Under the same conditions and in the same time, this technique can produce a greater number of larger fingerlings than other techniques. Therefore, the rearing times in the grow-out pond can be increased and larger fish will be produced. Consequently, fish yields and economic efficiency will be improved.

Multiple-grade conveyor culture is based on polyculture. In Guangdong province, grass carp, bighead, silver carp and mud carp are usually the major species for polyculture (Table 5.10), particularly, grass carp and bighead carp. Recently, attempts have been made to increase grass carp output because grass carp have a higher potential yield and economic value. Bighead are the major species in traditional polyculture because they grow faster than silver carp, reaching marketable size sooner; several harvests of marketable bighead can be guaranteed in 1 year. In addition, bighead do not jump during netting, so the chance of injury is minimal.

Table 5.10. Stocking in a grow-out pond (grade 5)

Species[a]	*Stocking size (kg)*	*Desired size (kg)*	*Stocking density (fish/mu)*	*Culture period (days)*
Bighead	0.5	1.0-1.5	22	40
Grass carp	0.25-0.50	1.3-1.5	40-80	60-180
Mud carp	0.056-0.063	0.13-0.17	950	180
Silver carp	0.25-0.60	0.7-1.0	20-40	90-180

[a] Other species are commonly polycultured in grow-out ponds (fish/mu) = common carp, 20; tilapia, 500-1,000; Wuchang fish, 50; black carp, 5-10; snakehead *(Ophiocephalus)*, 30-50.

In polyculture, it is necessary to avoid competition between species with similar feeding habits: e.g., silver carp and bighead; silver carp and mud carp; grass carp and wuchang fish. At the fingerling stage, polyculture of silver carp, bighead, and mud carp is rare. At the adult stage, the stocking proportions of the minor species should be strictly controlled to ensure the sufficient growth of the major species.

The rationale of multiple-grade conveyor culture is the maintenance of the optimal carrying capacity by regular netting and transferring or harvesting. At the optimal carrying capacity, fish will show maximum growth, otherwise, fish growth will be retarded. The monthly weight increase of bighead is 0.4-0.6 kg when the total stocking weight of fish is below 30-40 kg/mu. If the total stocking weight of bighead is over 30-40 kg/mu, the body weight increment is reduced to 0.05-0.3 kg/month. Similarly, mud carp grow faster when its total weight is below 125-160 kg/mu; above this density, the growth rate decreases. Based on natural conditions and updated technical standards of Guangdong, optimum stocking rates and carrying capacities are shown in Table 5.11.

Table 5.11. Stocking density and carrying capacities of various species in a multiple-grade conveyor culture system.

Species	*Initial stocking density (kg/mu)*	*Carrying capacity at late stage (kg/mu)*
Bighead	10.5-20	30-40
Mud carp	44-80	125-160
Grass carp	32-50	90-100
Silver carp	7-13	20-30

It is important to properly set up the pond area of five grades so that fingerlings produced from one grade can meet the demand of the next. To avoid restrained fish growth caused by pond overpopulation or a disjointed production caused by an insufficient number of fingerlings in a certain grade of pond, carrying capacities must be closely monitored. The area alloted to each grade of pond should be based on the total pond area, the number of grades, the culturing period of each grade, the stocking rates, and the target production. Experience has shown that grow-out ponds (grade 5) normally account for 65 per cent of the total area; large-sized fingerling (grade 4), 23 per cent; medium-sized fingerling ponds (grade 3), 7 per cent; small-sized fingerling ponds (grade 2), 3 per cent; and holding ponds (grade 1), 2 per cent. Stocking sizes, transfer sizes, stocking densities, and culturing periods of grass carp, bighead, and mud carp are listed in Tables 5.12, 5.13 and 5.14.

Table 5.12. Multiple-grade conveyor culture system for grass carp.

Grade	*Stocking size*	*Transfer size*	*Stocking density (fish/mu)*	*Culture period (days)*
I	Hatchlings	2.5 cm	150,000	20-25
II	2.5 cm	7.5 cm	8,500	35-45
III	7.5 cm	10-20 cm	800	30-50
IV	10-20 cm	0.05-0.5 kg	200-260	60-150
V	0.25-0.5 kg	1.0-1.5 kg	70-80	130-150

Table 5.13. Multiple-grade conveyor culture system for grass carp

Grade	*Stocking size*	*Transfer size*	*Stocking density (fish/mu)*	*Culture period (days)*
I	Hatchlings	2.5 cm	150,000-200,000	10-25
II	2.5 cm	8.5 cm	4,000	20
III	8.5 cm	16.5 cm	800	40
IV	16.5 cm	0.2-0.25 kg	200-250	40
V	0.2-0.25 kg	0.5-0.6 kg	70-90	40
VI	0.5-0.6 kg	1.0-1.25 kg	27-33	40

Table 5.14. Multiple-grade conveyor culture system for mud carp

Grade	*Stocking size*	*Transfer size*	*Stocking density*	*Culture period (day)*
I	Hatchlings	2.5 cm	400,000	35
II	25 cm	5.0-6.3 g	30,000	150-180
III	5.0-6.3 g	16.7-25.0 g	5,000-9,000	150-180
IV	16.7-25 g	55.5-62.5 g	2,000-3,000	180
V	55.5-62.5 g	125-167 g	900-1,100	150-180

Shortening the Fish-Rearing Period

In China, the Changjiang River and Pearl River basins and the Taihu District in Jiangsu province are the traditional fish-farming areas. The traditional farming techniques developed from over 1000 years of practice are adaptive to the state of the art and are still valuable to fish farming today. The traditional fish-farming system, however, was restricted by the social system, natural conditions, economic structure, farming techniques, and other objective historical factors. Science and technology are now progressing rapidly and being widely applied in agriculture and animal husbandry. Fishery scientists have recognized that the traditional fish-farming system cannot meet present-day demands. The traditional system requires 2 or 3 years to rear fry into food fish; for black carp 4 years. There is a long culturing period and a great demand for stocking seeds. The stocking rate is high, fish growth is slow and the food-conversion factor is high. The traditional fish-farming system has many links in the chain of production and is susceptible to natural disasters. The expenditure for maintenance is high, the return on investment is slow, and economic efficiency is comparatively poor. Like other productive systems, however, the traditional fish-farming system has become a fixed practice, even if it still can be improved.

Silver carp and bighead fingerlings and common carp summerlings can reach a body weight of more than 0.5 kg in November when they are polycultured at a low stocking density in a black carp yearling pond. They can also approach that body weight when they live in lakes, reservoirs, and rivers, as long as there is an abundant natural supply. Silver carp and bighead are artificially controlled to reach a body weight of 10-100 g in the traditional fish-farming system; therefore, the culturing period is prolonged to 2 years or more. Over the past 10 years, experiments on shortening the culturing period have been carried out in Jiangsu, Zhejiang, Hubei, Liaoning, Beijing, etc. The resulting new methods are being applied and leading to better production rates. There are two methods of shortening the culturing period.

May stocking, November harvest

If the target fish yield is 350-400 kg/mu, the harvest size of bighead, silver carp, common carp and grass carp should be around 0.5 kg at the end of a year; that of wuchang fish, *Carassius carassius,* and tilapia should be above 125 g. The stocking rate of silver carp should be 150 fish/mu; bighead 100 fish/mu; grass carp 300 fish/mu; *Megalobrama amblycephala,* 120 fish/mu. They are all summerlings with body weights of about 0.5 g. The total stocking rate is about 1400 fish/mu and the total stocking weight is around 600-800 g/mu.

The pond area is 1-10 mu with a water depth of 1.5-2.5 m. Ponds are drained in middle or late April and cleared thoroughly. Stable manure should be applied at a rate of 1000 kg/mu 15 days before stocking. Seeds of *Wolffia arrhiza* are planted in the ponds 4 or 5 days after filling of water at a rate of 15-20 kg/mu. *Wolffia* should be framed at one corner of the pond and allowed to propagate naturally. After planting *Wolffia*, it is necessary to turn the manure and splash water over the seeds. When *Wolffia* and zooplankton are present in sufficient quantities to meet the demand of fingerlings, ponds can be stocked (late May or early June) with healthy, conditioned, uniform-sized summerlings. To rear fry into food fish in the same year, the rapid growth of fish at this stage must be maximized. It is most important to plant *Wolffia* well because it is the food most palatable to juvenile fish. When summerlings are stocked for the first 1.5 months, the growth and propagation rates of *Wolffia* surpass the consumption rate by fish. Feeding platforms should be set up to let the fish get used to feeding at a fixed position. The higher temperatures in July are not suitable to *Wolffia* growth. At that time, when the body weight of grass carp will be about 75 g and of wuchang fish, about 13 g, aquatic and terrestrial grasses can be applied instead of *Wolffia*. Some fine feeds should also be supplied on the feeding platforms. If *Wolffia* is not cultured, it is necessary to apply more fine feeds or to collect wild *Wolffia arrhiza* or *Lemna minor* for the fish.

Based on the desired sizes of various species at different development stages (Table 5.15), fish should be regularly sampled to assess their growth and adjust the amount of feeding and manuring. The water colour of the pond should be oil green or yellowish brown with a tranparency of 25-35 cm. Enough fresh water to raise the water level 10-20 cm should be added every 10-15 days to maintain good water quality. By late July, fish will require a substantial supply of grass and fine feeds. Green grasses supplied in the morning should be consumed by dusk, when the water temperature is higher. The consumption rate of green grass is 50 per cent of the total body weight of grass carp and wuchang fish. Fine feeds are supplied after the grass. The amount of fine feeds applied is about 2 per cent of the total weight of fish in the pond. The food should be fresh, and of an appropriate size. Feeding quantities depend on the weather, the water quality, and the appetite of fish. The details of feeding and manuring in a pond with a net yield of 350-400 kg/mu are shown in Table 5.16.

Table 5.15. The desired sizes (g/individual) of various species at different times.

	Silver carp	*Bighead*	*Grass carp*	*Wuchang fish*	*Crucian carp*	*Tilapia*
Stocking size	0.6	0.5	1.4	0.5	0.5	0.2
Late June	27	65	40	15	7.5	7
Early Aug	180	315	195	40	25	57.5
Mid-Sept	400	550	495	75	100	80
Mid-Oct	470	600	570	110	135	165
Mid-Nov	520	690	585	125	165	165

Table 5.16. Feeding and manuring amounts (kg) in a pond with a net fish yield of 350-400 kg/mu.

	Apr.	*May*	*June*	*July*	*Aug*	*Sept*	*Oct*	*Total*
Pig and cow manure	1,000 (40)	750 (30)	750 (30)				2,500	
Green fodder								
Wolffia	Until mid-July, *Wolffia* grown in the pond is the main food for fry							
Terrestrial grass				500 (14.3)	1,000 (28.6)	1,250 (35.6)	750 (21.4)	3,500
Fine feeds[a]		5 (2.5)	10 (5)	30 (15)	50 (25)	65 (32.5)	40 (20)	200

Note: Values in parentheses are percentages of the total.

[a] Equal parts of bean, barley, rapeseed cake, and rice bran or wheat bran.

With sufficient base manure, additional manure can be applied in small amounts at regular intervals according to the fertility of the pond water. Generally, organic manure is applied daily at a rate of about 25 kg/mu. Alternatively inorganic fertilizer is applied once every 3-6 days as ammonium sulphate or ammonium bicarbonate (1-2 kg/mu) and as calcium superphosphate (0.5-1.0 kg/mu).

To culture fry into food fish in the same year, the stocking density should be low so that the food in the pond is plentiful, the fish growth is fast, and the survival rate is high. The usual final fish yield is around 450 kg/mu (Fig. 5.2).

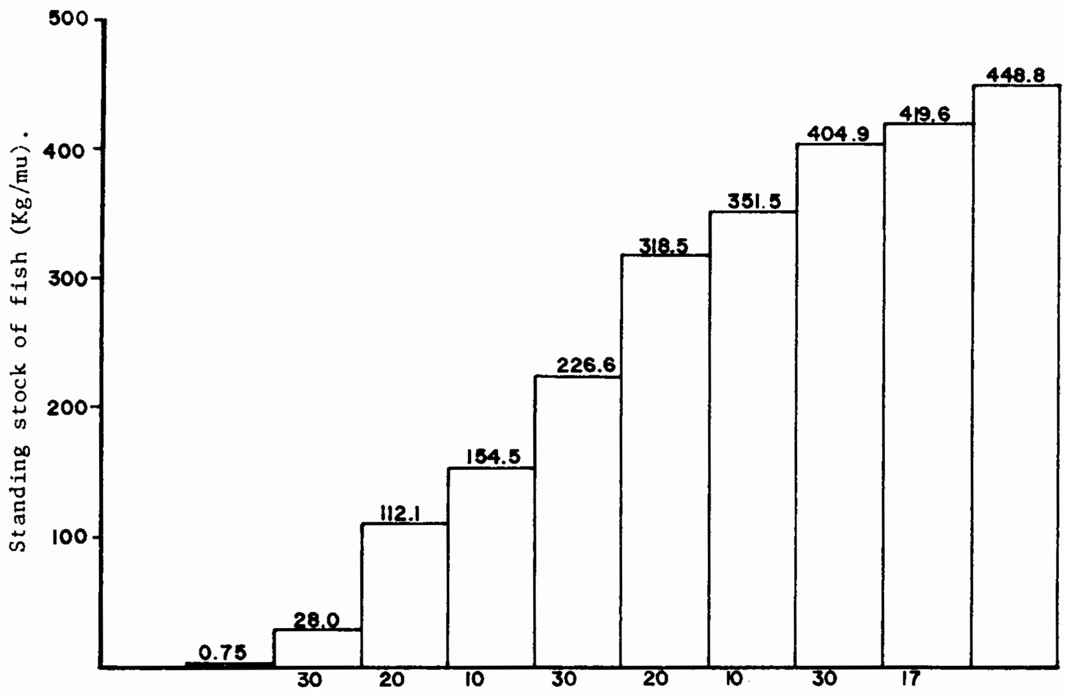


Fig. 5.2. Increase of standing stock (Kg/mu) of fish in pond where summerlings are grown into food fish in the same year.

The survival rates of bighead, silver carp, common carp, wuchang fish, and *carassius carassius* are all above 90 per cent. The survival rate of grass carp is generally about 70 per cent. Hemorrhagic disease is common in grass carp. Therefore, certain measures should be taken to prevent disease and raise the survival rate. Every 10 days after the middle of July, supplementary feeds soaked in 3-5 per cent salt solution should be supplied for 3 consecutive days every 15 days, bleaching powder should be used to sterilize the feeding platforms at a rate of 0.25 kg/mu every 20 days, quicklime emulsion (15 kg/mu) spread over the pond. Every 20 days after the middle of August, medicated food for enteritis should be given for one course of treatment (about 1 week). There is a total of three courses during a culture period. The prevention and treatment of fish diseases guarantees high yields.

Year-Round Culturing

Fish ponds are seldom used from November to the following May. At the initial stocking stage, fish ponds are not fully utilized because summerlings are small and the stocking density is low. To increase yield, fish farmers should rear fingerlings into food fish over the entire year, provided conditions are appropriate. The method is as follows:

Three fish ponds of similar size are required. In pond A, fish are harvested in early May. Any fish under marketable size are transferred to ponds B or C. Pond A is then drained and cleared to culture *Wolffia arrhiza.* In late May, the pond is filled and stocked with summerlings. Stocking densities are as follows (fish/mu): silver carp 750; bighead 500; grass carp 900. In ponds B and C, marketable silver carp, bighead and grass carp are harvested in early July and then restocked with large fingerlings of silver carp, bighead and grass carp from pond A. The stocking rates of silver carp and bighead should be low so that they may reach marketable size in the same year; however, the stocking rate of grass carp should be higher because they are reared into larger fingerlings for the next restocking. In November, the marketable-sized fish in all three ponds are harvested. Those fish under marketable size (silver carp, bighead, and grass carp in pond A and grass carp in ponds B and C) are harvested in next May (pond A) or July (ponds B and C). This method can significantly increase the total fish yield (Tables 5.17 and 5.18).

With this farming method, there are five harvests of food fish and four harvests of large fingerlings per year. In pond A, there is one harvest of food fish in May and silver carp, bighead, and grass carp fingerlings with a body weight of 75 g are harvested in July and used to stock ponds B and C. At the end of the year, pond A produces silver carp and bighead fingerlings of 250 g and grass carp fingerlings of 500 g for the restocking of all three ponds. In ponds B and C, one harvest of food fish occurs in July and, at the end of the year, the ponds produce another batch of food fish and some grass carp fingerlings for re-stocking in the following year. This farming technique combines multiple-grade conveyor culture (Guangdong) and harvesting and restocking in rotation (Jiangsu). To achieve the desired yield of fish from the three ponds, careful management throughout the culture period is essential. It is particularly important that *Wolffia* be properly cultured at the initial stage in pond A to ensure the quality and quantity of fingerlings for re-stocking. The details of feeding and manuring for all three ponds are shown in Tables 5.19 and 5.20.

Management of Rearing Food Fish

Feeding

In high-density, polycultured ponds, each fish gets only a small amount of natural food. Therefore, supplemental feeds and manures are essential to ensure the normal growth and high yield of fish. Feeding is the most important aspect of

Table 5.17. Stocking and harvesting in pond A.

Species	*Before early May of the same year*							*After late May of the same year*						
	Stocking				*Harvesting*			*Stocking*			*Harvesting*			
	Time	*Size (g/fish)*	*Fish/ mu*	*Total weight (kg/mu)*	*Time*	*Size (g/fish)*	*Total weight (kg/mu)*	*Time*	*Size*	*Fish/ mu*	*Time*	*Size (g/fish)*	*Fish/ mu*	*Total weight (kg/mu)*
Silver carp	Before the end of February	250	80	20	The first ten days of May	550	40.0	The last ten days of May	Summerlings	750	July	75	300	22.5
											Nov	250	400	100.0
Bighead		250	40	10		660	20.5			500	July	75	200	15.0
											Nov	250	260	65.0
Grass carp		500	100	50			90.0			900	July	75	600	45.0
											Nov	500	250	125.0
Crucian carp hybrid										80	Nov	500	75	37.5
Crucian carp										120	Nov	150	110	16.5
Wuchang fish		75	60	4.5		150	9.0			120	Nov	150	110	16.5
Total			280	84.5			159.5			2,470			2,305	520.0

Note: The net food fish yield in this pond is only 75-100 kg/mu in early May. The pond can also be used to spawn carp, crucian carp and Wuchang fish or as a fodder plantation.

Table 5.18. Stocking and harvesting in ponds B and C.

Species	*Before early May of the same year*							*After late May of the same year*						
	Stocking				*Harvesting*			*Stocking*				*Harvesting*		
	Time	*Size (g/fish)*	*Fish/ mu*	*Total weight (kg/mu)*	*Time*	*Size (g/fish)*	*Total weight (kg/mu)*	*Time*	*Size*	*Fish/ mu*	*Total weight (kg/mu)*	*Time*	*Size (g/fish)*	*Total weight (kg/mu)*
Silver carp	Before the end of Feb.	250	150	37.5	The first 10 days in July	550	75	The first 10 days in July	75	150	11.25	Nov	550	75.0
Bighead		250	110	25.0		600	50		75	100	7.5	Nov	600	55.0
Grass carp		500	250	125.0		1,150	250		75	300	22.5	Nov	500	125.0
Common carp hybrid			80	0.05								Nov	500	37.0
Crucian carp	The second 10 days in May		120	0.075								Nov	150	16.5
Wuchang fish			120	0.075								Nov	150	16.5
Tilapia			500	0.3								Nov	150	75.0
Total				188.0										400.0

Table 5.19. Feeding and manuring (kg/mu) in pond A.

	Food fish culture			*First harvest of fingerlings*				*Second harvest of fingerlings*						*Total*
	Feb. & March	*Apr. & May*	*Total*	*May*	*June*	*July*	*Total*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Total*	
Manure	380	276	656	1,330	1,060		2,390			1,196	713		1,909	4,955
Fine feed														
Oil cakes										8			8	8
Rice and wheat bran									23	54	76		153	153
Green fodder														
Wolffia				22									22	
Lemna minor		300	300	114	328		1,136	818	1,050	410	265	133	2,676	4,112
Terrestrial grasses		237	344	626					36				36	662

Note: Before May the net yield of food fish is 87.35 kg/mu. After the second 10 days in May, the yield of the first harvest of fingerlings is 72.13 kg/mu, the second harvest yield is 404.7 kg/mu. The total yield is 564.18 kg/mu.

Table 5.20. Feeding and manuring (kg/mu) in pond B and C.

	First harvest of fingerlings							*Second harvest of fingerlings*						*Total*
	Feb.	*March*	*Apr.*	*May*	*June*	*July*	*Total*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Total*	
Manure	688	300	250	310	375		1,923			1,625	337		1,962	3,885
Fine feed														
Oil cakes														12
Rice and wheat bran				50	60	28	138		34	73	84		191	329
Green fodder														
Wolffia and *Lemna*					485	200	685	1,325	850	1,350	1,225	125	4,875	5,560
Terrestrial grasses		90	904	1,000	155		2,149		23	35			58	2,207

Note: The net yield of food fish in the first harvest is 215 kg/mu; second harvest yield is 397 kg/mu. The total net fish yield is 612 kg/mu.

intensive fish culture and responsible for most of the management work around the grow-out ponds. The expenditure on feeds normally accounts for more than 50 per cent of the total production cost. Therefore, the selection and processing of fish feeds and feeding technique will significantly affect the output, production cost, and economic efficiency of fish farming.

Allocation of fish feeds

In fish farming, it is necessary to work out a feeding plan. The total food demand for 1 year should be determined based on the target fish production, the expected body weight increment of each species, and the food-conversion rate and monthly feed demand according to the water temperature and monthly fish growth. Feed and manure allocations also depend on their local availability; this should be a major determining factor in setting production goals. The monthly feed and manure requirements in Jiangsu province are shown in Table 5.21.

Table 5.21. Feed and manure demand in grow-out ponds in Jiangsu province.

	Feb.-March	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Total*
Ave. water temperature (°C)	below 12	16	23	26	31	32	26	20	12	
Manure (%)	35	10	10	7	5	5	14	10	4	100
Aquatic and terrestrial grasses[a]	10 (2)	15 (4)	20 (10)	28 (14)	30 (18)	30 (22)	27 (17)	25 (10)	10 (3)	195 (100)
Snails and clams[a]	10 (2)	15 (4)	20 (7)	22 (8)	28 (15)	28 (20)	30 (24)	26 (15)	10 (5)	185 (100)

[a] Number of applications with the per cent of the total in parentheses.

Feeding techniques

The feeding habits of the various species must be known to ensure feeds are supplied properly. On the one hand, we much achieve high yields and, on the other hand, we should economize on feeds. Therefore, feeds should be supplied according to the season, the weather, water quality, and food intake ("four observations").

Seasons – More feed should be provided from June to October when the air temperature is comparatively high. Fish have a good appetite and grow rapidly when the air temperature reaches 28°C. June to October is also the growing season for aquatic weeds, molluscs, and terrestrial grasses. The fish feed supplied over this period accounts for about 80 per cent of the total yearly allocation. A small amount of food should be supplied shortly after initial stocking in early **spring,**

when air temperature is low and fish have a poor appetite to stimulate the appetite of the fish. Feeding is reduced in late autumn when the air temperature drops below 10°C. The appetite of the fish and their ability to search for food gradually decline from late October to the end of the year, when the fish are harvested.

Weather – More feed should be provided when the weather is good and the DOC is high. Feed application should be reduced or discontinued when the weather is stifling. A good time for feeding is after a foggy period because of the low air pressure.

Water quality – If the pond water is fertile and fish have a good appetite, more feed can be applied. If the pond water is sheer, the quantity of feed should be increased; however, feed application should be decreased if the pond water is overfertile.

Food intake status – Normally, all the feed should be consumed in 7-8 h. If all the feed is not consumed in this time, the fish have an abnormal ingestion status and the quantity of feed should be reduced.

Fixed quality, fixed quantity, fixed time, and fixed position of feeding ("four fix") are important in a proper feeding schedule.

Fixed quality – Feeds should be fresh and palatable with a high nutritive value. Spoiled foods should be discarded to prevent disease.

Fixed quantity – Fish should be provided with a fixed amount of food every day. Uneven feeding will cause poor digestion, bad absorption, and slow growth. Daily feeding rates are mainly dependent on the ingestion status of the fish.

Fixed time – Feeding is usually done before 1000 hrs every day. To raise the food-utilization rate, fish should be fed when the DOC is high.

Fixed position – Feeds such as molluscs, pellets, and fine feeds should be supplied at a fixed position (e.g., on a fixed feeding platform). This allows easier examination of the fish. Floating feeds may be supplied in a floating framework.

Manuring

Like fry and fingerling ponds, grow-out ponds need fertilization. A heavy supply of base manure should be added to newly dug ponds because these ponds initially have little or no silt and this would make it difficult to get the water fertile. Therefore, organic manures (animal manure, green manure, or stable manure) are used at a rate of 400-500 kg/mu as the base manure. After the decomposition and mineralization of the base manure through exposure to the sunlight for 3 or 4 days, the pond can be filled with fresh water.

Fingerlings can be added after another 7 or 8 days. Additional manure should be applied evenly, frequently, and in small amounts to ensure the continued propagation of natural food organisms.

Daily Routine of Pond Management

High and stable fish yields can only be ensured through the daily routine of pond management, which should be performed carefully, diligently, and unremittingly throughout the rearing period.

Surfacing

The pond should be examined two or three times daily for fish surfacing at dawn, food intake in the afternoon, ingestion status of the fish at sunset, and fish gasping for air. From late spring to mid summer, when the weather changes suddenly, the pond should be examined around midnight for fish surfacing. Surfacing is common due to high water temperatures, intense decomposition of organic materials, the cessation of photosynthesis by phytoplankton at night, and the oxygen consumption of other aquatic life.

Forecasting surfacing – When the weather is hot and the water temperature is high or the water is fertile, surfacing will occur at dawn or around midnight. Fish are not diseased, however, they do lose their appetite; this indicates that the pond water lacks dissolved oxygen. When the pond water is overfertile or when there is a sudden deterioration of water quality caused by the weather, the decomposition of large amounts of plankton not only consumes dissolved oxygen but also produces toxic substances such as hydrogen sulphide (H_2S) and ammonia, which will cause serious surfacing.

Diagnosis of degree – The degree of surfacing is based on the time of surfacing, the location of surfacing, the species sequence of surfacing, and the fish response during surfacing. Surfacing before dawn is not serious. As the sun rises, photosynthesis of phytoplankton accelerates and the DOC of the pond water increases, alleviating the hypoxic condition. Surfacing in the evening or around midnight is more serious. Because the hypoxic condition is enhanced by the respiration of plants throughout the night, the surfacing of fish will become more and more serious. Surfacing at the centre of a pond is less serious than surfacing all over the pond.

Fish swim deeper in the water when scared. However, if fish show no response and appear to be in a coma when frightened, surfacing is serious and the dissolved oxygen in the pond water is depleted. Different species surface at different times because of their different oxygen-consumption rates and asphyxiation points. The order of seriousness, from slight to severe, is as follows: wuchang fish (slight); silver carp and bighead (moderate); grass carp and black carp (serious); common carp and crucian carp (severe). When common carp and crucian carp surface, fish mass mortality will result.

Remedies for surfacing – When symptoms of hypoxia appear, measures should be taken to increase the DOC of the pond water (addition of fresh water). When pumps are used, the outlet should be placed horizontally to ensure that the fresh water enters at one level. All the surfacing fish will be attracted to the fresh water area where the DOC is higher.

Water Quality

Water quality is closely related to fish growth and yield. During production, water colour is the indicator of water quality, and there are various means of controlling water quality: feeding and manuring, use of aerators, adding fresh water, and turning the pond silt.

There are four types of water: "fertile", "sterile", water bloom, and deteriorated. Experience has shown that pond water should be kept "fertile" including "flexible" and "crisp". "Fertile" water is biologically active and rich in plankton. "Flexible" water frequently changes colour. There are diurnal and monthly variations. A common saying among fish farmers is "brown in the morning and green at night." This diurnal variation is due to a change in the dominant species of phytoplankton. "Crisp" water is fertile but not turbid, moderately transparent and has a high DOC.

"Fertile" water has a heavy water bloom of a desirable species of phytoplankton with a biomass from 20 to 100 mg/L. "Flexible" means that there is diurnal vertical movement of *Gonyostomum* and other flagellates. "Tender" or "bright" means that algae are experiencing exponential growth' cell multiplication and feeding are accelerated during this period (He Zhihui 1985).

Aeration

Impeller aerators (Fig. 5.3) are commonly used in China. They have three functions: oxygenation, water stirring, and gas exposure.

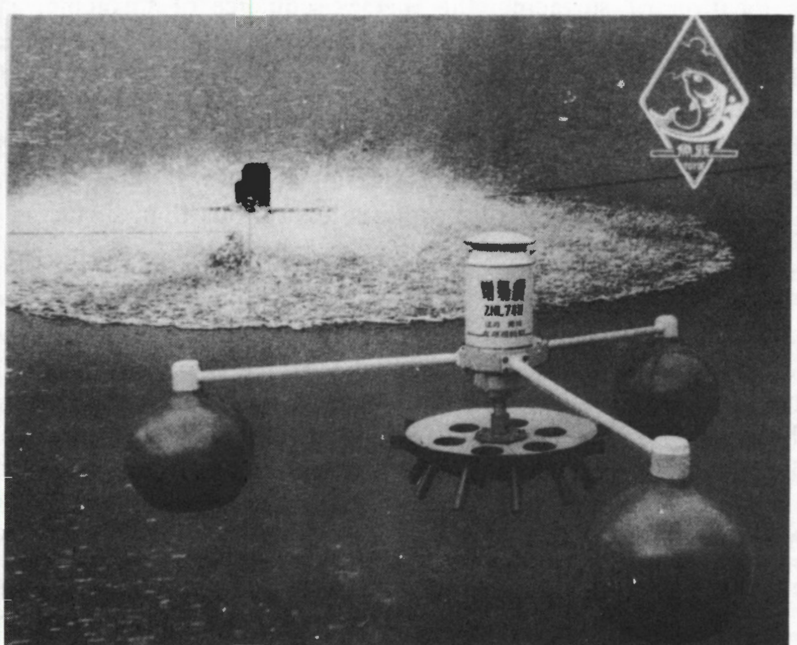


Fig. 5.3. Impeller aerator. "Zhengyangji" in Chinese means "oxygen enhancing machine."

The aerator need not be turned on for the whole day; it should be only used for a short time at one or two critical moments in the day. The time and period of operation of the aerator should be set according to the diurnal fluctuation of water quality to maximize its utilization and effect and minimize its energy consumption. There are three main reasons to use aerators in stagnant fish ponds: to break the metalimnion and avoid the loss of oxygen to the atmosphere, to prevent the depletion of oxygen at the bottom of the pond, and to directly increase the DOC.

On days with good weather, aerators are operated around noon to break the metalimnion and maximize oxygen utilization. The operation time should be short. In a pond of 3-5 mu, a 3 kw impeller aerator should be activated for 30 min. In a pond 7-10 mu, 1 h of aeration is required.

On a cloudy day, the aerators should be used early next morning. This is because photosynthesis is rather weak on a cloudy day and the DOC is low. After one night, the DOC will decline to a minimum. Aerators should be activated from 0300-0500 hrs to sunrise.

Aerators are often operated at midnight on rainy days before surfacing occurs. However, aerators are not used at dusk during the day when the weather is rainy because photosynthesis is weak and the DOC is low in the upper water layer, and therefore, the aerator would have little or no effect.

When an aerator is used rationally, fish surfacing and asphyxiation can be controlled. In addition, the recycling of material in the ponds can be accelerated, the distribution of dissolved oxygen can be improved, and the metabolic intensity of the fish can be increased, thereby decreasing the food-conversion factor, purifying the pond water, stabilizing water quality, and preventing disease.

Chapter 6

MAIN FISH DISEASES AND THEIR CONTROL

Li Shaoqi

Significance and Principles of Disease Control in China

Significance

The prevention of fish diseases is essential for the betterment of the fisheries industry, the improvement of farming production, and the increase in fish resources. Because of the complexity of their environment, fish are susceptible to viral, bacterial, fungal, and parasitic infections. These infections will adversely affect growth and development and a serious infection can be fatal. An outbreak of disease jeopardizes regular aquaculture and threatens fish yields. Therefore, controlling disease is one of the most vital tasks in fish culture.

Principles

The principle of fish disease control in China is all-round prophylaxis: "prevention is better than treatment". In the event of an outbreak of disease, fish should be treated in the early stages. However, because of the difficulty in observing the activities of the fish, it is difficult to correctly diagnose and treat an infection in its early stages. In addition, because many diseases severely interfere with the feeding process, orally administered drugs may be ineffective. Parenteral drug administration is an alternative; however, dip treatments are confined to small containers or spread measures to fish ponds. This type of treatment is impractical for large lakes, rivers, and reservoirs. Therefore, prevention is the key to disease control.

Major Types of Fish Diseases

Infectious Diseases

Infectious diseases are mainly caused by viruses, bacteria, fungi, or unicellular algae ("ichthyomicrobial diseases"); e.g. bacterial enteritis, bacterial gill rot, and bacterial erythema. Infectious diseases account for 60 per cent of the production lost as result of disease. For this reason, the study of infectious disease is of primary significance to the development of aquaculture.

Characteristics

Infectious diseases can be divided into acute, subacute, and chronic forms based on the clinical picture. For example, if enteritis of grass carp or black carp occurs in an acute form, it develops rapidly and soon results in a high rate of mortality; it can also quickly disappear. Chronic enteritis, however, kills only a few fish per day but lasts a long time.

Bacterial pathogens of infectious diseases are not strictly parasitic microorganisms. If the conditions for parasitism are unsuitable, saprophytic relationship will develop. Bacterial pathogens have a high adaptability to environmental changes. For example, the enteritis pathogen of grass carp and black carp will be ineffective if the water temperature is below 20°C; however, a water temperature between 20 and 25°C will enhance its virulence. The main epidemic season runs from late spring to early summer. Zoospores of *Saprolegnia* become attached to the fish skin and, if the host has been previously injured, the zoospores will grow and multiply, and the fish will become infected.

Most pathogens of infectious diseases show a preference for certain species and certain organs (organotropism). For example, bacteria of enteritis only affect grass carp and black carp. Likewise, branchiomyces parasitize only the gills.

There are three stages in the course of an infectious diseases: a latent period, a symptomatic period, and an attacking period. There are two types of infection: pure (one causative agent) and mixed (two or more pathogens on a single fish). Examples of a mixed infection are grass carp suffering from both saprolegniasis and gill rot and a black carp with enteritis and red skin disease.

Mode of infection

There are two sources of infection: primary and secondary. A primary infection originates within the pond. The pathogen may infect the fish directly or through the discharge of pathogenic agents into the water occasionally, "healthy" fish act as disease carriers and an outbreak of disease will occur under certain conditions. A secondary infection originates outside the pond. For example, a disease-free pond could be polluted with pond water from a diseased pond, diseased or contaminated silt, feeds and equipment. Pathogens are commonly spread through these vehicles.

Resistance

Infectious diseases normally attack the fish through tissues and organs (skin, gills, intestines or excretory organs). Fish, however, do possess resistance mechanisms against pathogenic microbes. For example, skin texture and mucous membranes of the fish function as barriers to infectious microorganisms. Pathogenic microbes entering via the digestive tract will be attacked by various disinfecting secretions. White blood cells, lymphoid tissue cells, and reticuloendothelial cells of the spleen, liver, and blood vessels can eliminate foreign bodies, including pathogenic microorganisms. In addition, fish blood contains bactericidin, which is toxic to pathogenic bacteria.

Invasive Disease

Invasive diseases are caused by animal parasites such as trichodinasis, ichthyphthiriasis, lernaesis, argulusis, etc. Fish carrying parasites or the carcasses of diseased fish is a primary source of invasive diseases. Contaminated feeds, gears, pond water, silt, etc., are secondary sources. For example, mature oocytes of *Eimeria* or mature myxosporidia may enter the water with the fish and precipitate to the bottom of the pond. The pond silt is contaminated as a secondary source of invasive disease.

Like infectious diseases, invasive diseases often appear in different seasons. This is because the pathogens and the fish are influenced by external factors (location, climate, physico-chemical properties of the water, farming skills, etc.) and internal factors (growth and physiological status). Invasive pathogens may also be species specific or organotropic.

Other Diseases

Physical and chemical factors or the influence of other organisms within the pond may retard growth or even kill the fish. For example, gasping and suffocation may upset the physiological balance of the fish and if serious, cause mass mortality.

General Knowledge of Disease Control

Prevention of Disease

The concept that "prevention is better than treatment" is fundamental to the maintenance of a healthy stock of fish. Because fish are schooling animals, they are hard to observe individually, making the diagnosis and treatment of disease difficult. In addition, some fish diseases are still essentially incurable, e.g., diplostomulumsis. Therefore, preventive measures are essential to the control of disease.

Pond regulation

Pond regulation is effective in improving environmental conditions, preventing disease and raising fish yields. There are two main aspects (see chapter 4) to pond regulation: pond trimming and pond disinfection.

Rearing management

A reliable person should be responsible for the daily management of the pond (stocking, feeding, manuring, disease prevention, etc.). The "four fix" feeding procedure, which benefits fish yield and disease prevention, should be used (see chapters 4 and 5). Variations in water quality must be observed carefully. According to these observations, fertilizers or fresh water should be added. Pond inspection is essential in the morning, particularly in dismal weather or after a torrential rainfall during the epidemic season (May to September). Besides, it is necessary to remove the weeds along the pond sides and clear the feeding platforms to prevent the occurrence of disease. Netting, transferring, and transporting should be performed with great care.

Fingerling disinfection – Fingerling disinfection can be performed during their transfer to a larger body of water. The procedure can be done in a boat, cabin, jar, pail, cage, etc., depending on local conditions.

Feeding disinfection – Hang small bamboo baskets containing bleaching powder or cloth bags containing a mixture of copper sulphate and ferrous sulphate (5:2) around the feeding platform. When the fish come to feed, their skin will be disinfected.

Hanging basket method – This method prevents bacterial diseases in fish such as grass carp that mainly feed on buoyant food. Place a triangular or square bamboo frame at a shallow corner of the pond. Along the frame, hang three to six small bamboo baskets with their tops 3 cm out of the water and put a small stone inside each basket to make them stand vertically in the water. As soon as feeding begins in the spring, add 100-150 g of bleaching powder to each container daily. After hanging the containers, duck weed or tender grass can be used to attract fish (Fig. 6.1). Clean the container after feeding. To prevent bacterial diseases in black carp, the containers are placed in a line, attached to a bamboo rod, and sunk to

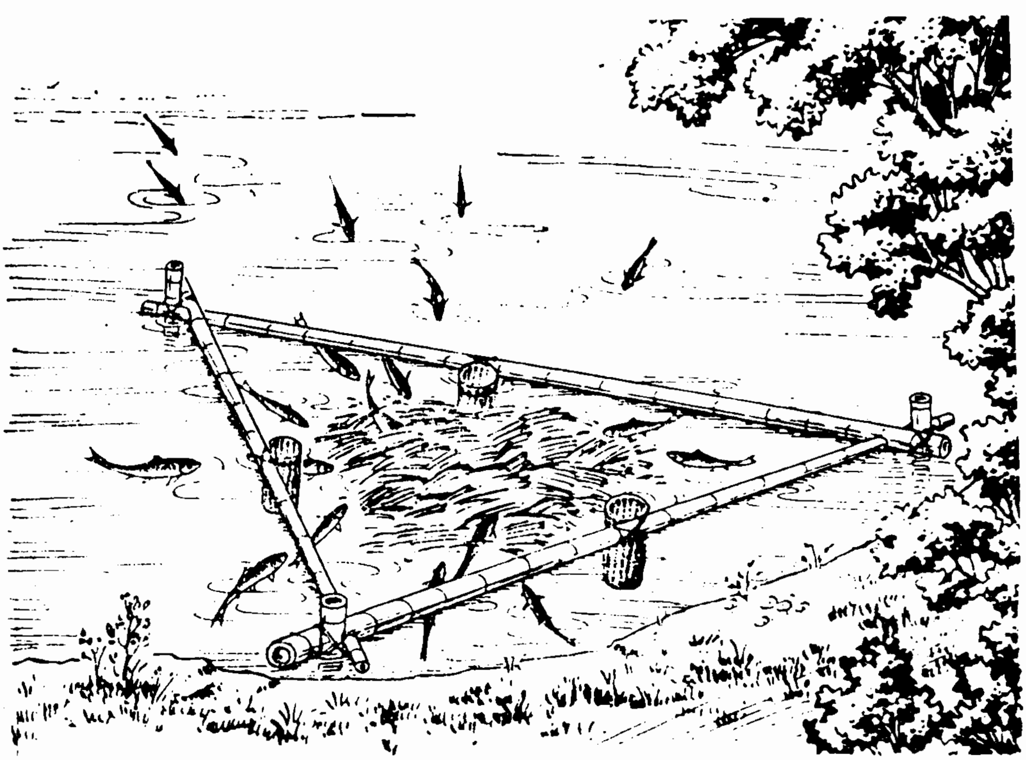


Fig. 6.1. Hanging bag, bleaching powder method for the control of bacterial red skin and gill rot diseases of grass carp.

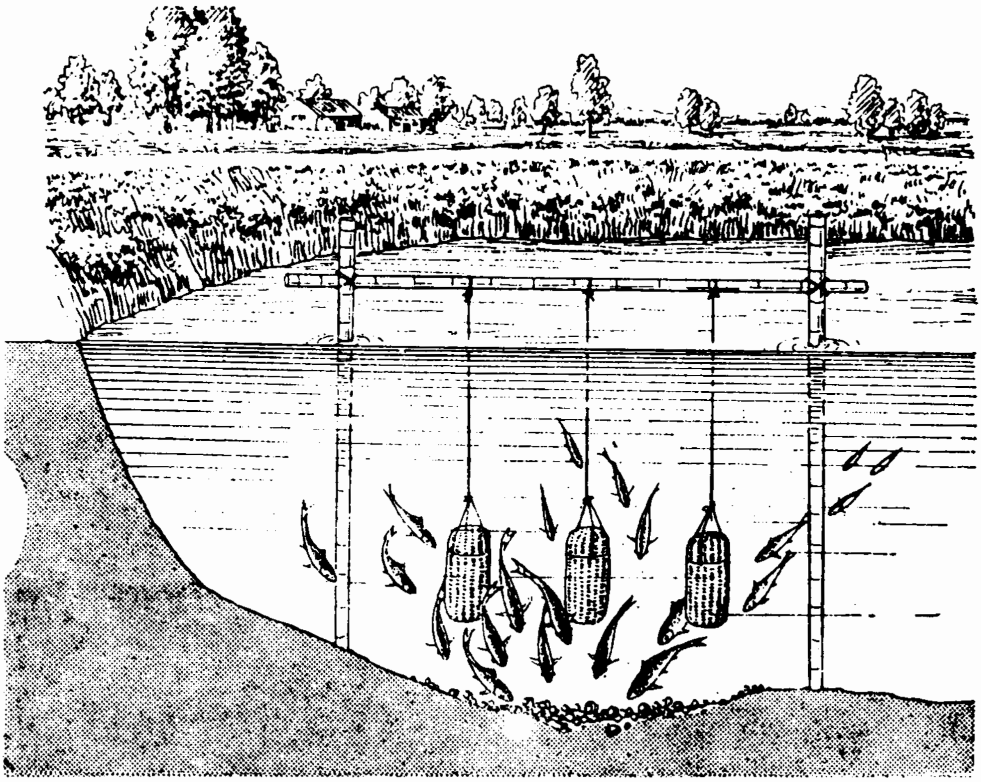


Fig. 6.2. Hanging basket, bleaching powder method for the control of bacterial red skin disease of black carp.

15-18 cm above the bottom (Fig. 6.2). Each container is covered with a lid to keep the bleaching powder in.

Hanging bag – This method is similar to the hanging basket method except that the bleaching powder is substituted with a mixture of copper sulphate and ferrous sulphate. The chemicals ooze out of the fine-cloth bag slowly (the shortest duration for this process is 3-4 h). The number of bags hung daily and the chemical dose depend on water depth and size of feeding place. With a 3x3x3 m triangular frame, Table 6.1 gives appropriate dosages at various water depths. Six bags are used (two per side) (Fig. 6.3).

Table 6.1. Dosage of chemicals in each fine-cloth bag.

Water depth (cm)	*Copper sulphate (g)*	*Ferrous sulphate (g)*
83	250	100
66	200	80
49	150	60
33	100	40

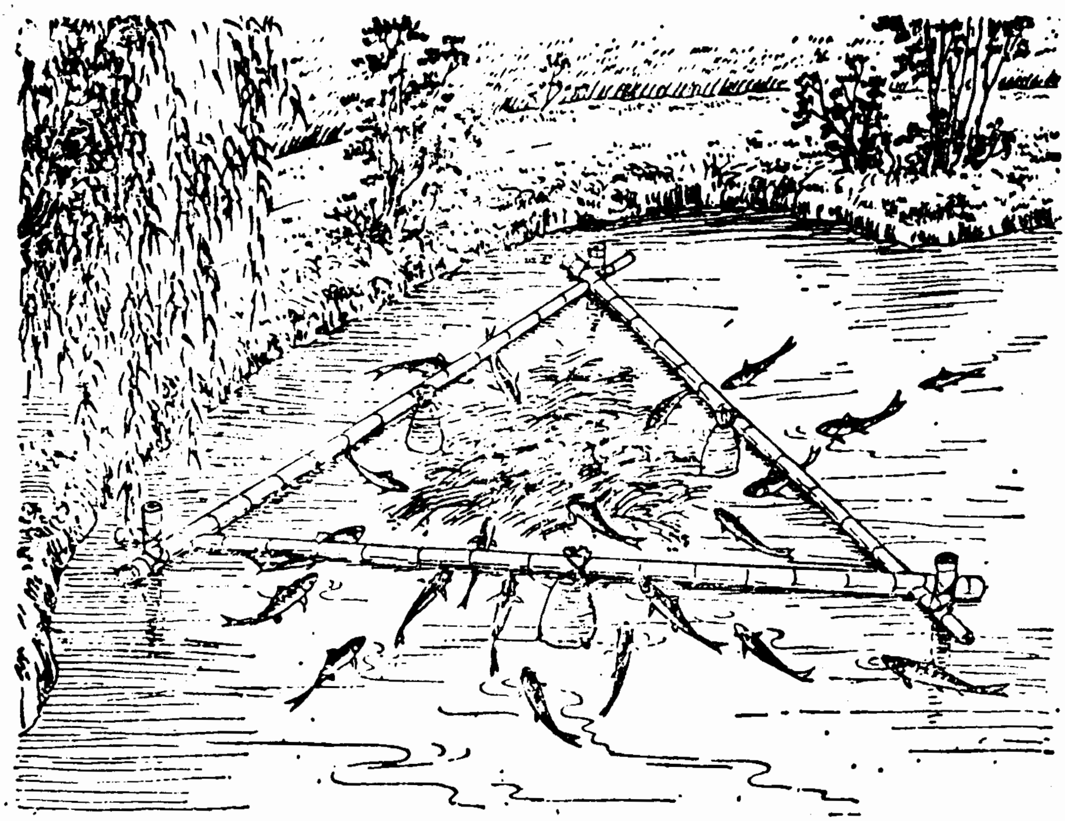


Fig. 6.3. Hanging bag method with copper sulphate and ferrous sulphate to control parasitic gill disease of grass carp.

There are many other chemical treatments used in the disinfection of fingerlings (Table 6.2).

Feed, feeding platform and equipment disinfection

Contaminated or spoiled feeds may introduce pathogenic bacteria to the pond. Leftover feeds, which decompose in the water, facilitate the rapid multiplication of pathogenic bacteria. For this reason, feeds and manures must be disinfected before application. Animal feeds such as snails must be washed and supplied to the fish when they are fresh and alive. As for plant feeds, aquatic grasses are disinfected by immersing them in a 6 ppm bleaching powder solution for 20-30 min. Before organic manure application, 120 g bleaching powder is mixed into 500 kg manure.

In addition to the hanging basket and hanging bag methods of feeding area disinfection, during the epidemic season (May-September), a solution of 250 g bleaching powder in 12 L water should be spread over the area once or twice monthly.

Table 6.2. Some solutions for fingerling disinfection.

Chemicals	*Dosage (ppm)*	*Water temperature (°C)*	*Immersion duration (min)*	*Target*	*Precaution*
Bleaching powder	10	10-15 15-20	20-30 15-20	Bacterial skin and gill diseases.	Immersion duration depends on the health of fish and water temperature; the chlorine concentration must be above 10%; the solution should prepared on the spot.
Copper sulphate	8	10-15 15-20	20-30 15-20	Cryptobiosis, costiasis, trichodinosis & chilodonelliosis.	
Copper sulphate & bleaching powder	8[a], 10[b]	10-15	20-30	Bacterial gill rot, red-skin, cryptobiosis, costiasis, trichodinasis, chilodonellasis, trichophryiosis, etc.	Dissolve the two chemicals in separate tanks before mixing.
Potassium permanganate	20 20 10	10-20 20-25 10-20 25-30	20-30 15-20 60-120 60-120	Gyrodactyliosis, dactylogriosis, trichodinosis, chilodonelliosis, lernaesis.	Immersion duration depends on the health of fish; prepare solution on the spot; avoid immersing in direct sunlight.
Malachite green	10		20-30	Dermatomycosis	
Sodium chloride	30,000-50,000		5	Dermatomycosis	Dosage depends on the health of fish and water temperature.
Dipterex (90% of crystal)	2,000-2,500		3-15	Gillrot, red skin, enteritis	Add fish (and solution) to pond when they begin to become irritated and start moving their head in the immersing tank.

[a] Dosage of copper sulphate; [b] Dosage of bleaching powder.

The equipment used during the epidemic season (nets, pails, dip nets, etc.) must be disinfected after each use. Large nets can be exposed to sunlight for 1 or 2 days and wooden pails can be sterilized by immersing them in a quicklime solution or in a 10 ppm copper sulphate solution for 5 min.

Pond treatment

Spreading chemicals over the entire pond is a common method of disease prevention. Before or shortly after stocking fry, 1 g of 2.5 per cent dipterex should be sprayed over the pond. This treatment is particularly needed for weedy ponds. Three months later, the pond should be treated with a 0.7 ppm solution of copper sulphate and ferrous sulphate (5:2). After June, bleaching powder (1 ppm) should be sprayed over the pond once or twice monthly.

To improve deteriorated pond water, for each metre of depth, 20-25 kg/mu quicklime should be added. This will improve water quality and prevent disease. The quicklime chunks should be dissolved in a little water, and the solution diluted, stirred, and sprayed evenly over the pond.

Medicated feeds

During the epidemic season of grass carp enteritis, medicated feeds are an effective preventive measure. Use 1-2 kg garlic per 100 kg of fish once a day for 6 consecutive days. Pulp and blend the garlic with the feed; disease prevention is enhanced if 40 g of table salt is added to every 5 kg of food. For adult fish, mix the pulped garlic with some binder and spread the mixture onto fresh grass feed. Apply the feed after it is dry. Medicated feed may also be given in a pellet form.

Chinese medicine for disease control

Controlling disease with Chinese herbal medicines has many advantages. These include the vast supply of materials, the proven effectiveness, the low cost, and the relative ease of teaching the techniques involved. In production, farmers have been using various Chinese herbal medicines to control diseases and getting good results. For example, in Zhejiang Province, *Euphorbia humifusa* and *Acalypha australis* are used for enteritis and, in Guangdong Province, *Thysanospermum diffusum* is used to cure bacterial skin disease, gill rot, and enteritis. The Institute of Hydrobiology, Academia Sinica, has recently reported promising results with the application of Chinese tallow tree (*Sapium sebiferum*) with Chinese rhubarb (*Rheum officinale*) for "white-head-and-white-mouth" disease and bacterial gill rot.

Establishing a quarantine system

Geographic and climatic conditions can produce epidemic diseases in certain regions. The disease of grass carp yearlings caused by *Bothriocephalus gowkongensis* and branchiomycosis of mud carp used to occur only in Guangdong and Guangxi provinces. Likewise, oodiniosis was localized to Jiangxi Province and Liang County, Guangdong Province while ichthyophthiriasis was unique to Hunan and Hubei provinces. However, as the freshwater farming industry develops rapidly and the transportation of fry and fingerlings among provinces becomes more frequent, local diseases are tending to spread. Quarantine work should now be emphasized. The transportation of diseased fish should be strictly prohibited.

Diagnosis

Disease diagnosis is the first step toward effective treatment, and care must be taken in making a diagnosis. The fish must be alive or recently dead and the body must be kept damp. Try to keep the dissected organs as complete as possible. Keep the autopsy instruments clean to avoid intercontamination of pathogens among organs. Use distilled water for microscopic observation of the skin and use 0.85 per cent normal saline for microscopic observation of the internal organs. Preserve the samples for further identification if there is any doubt about the pathogens or the clinical signs. If complications are discovered during the diagnosis, diagnose the primary and secondary disease and implement the appropriate treatments separately or simultaneously.

Methods of diagnosis include surveying the pond and examining the fish with the naked eye and microscopically.

Survey the diseased pond – Determine if the water source is seriously polluted. If it is, find the source of the pollution. Observe the behaviour of the diseased fish and take an inventory of the rearing status (pond clearing, stocking density, feeding, preventive methods, and mortality, etc.).

Naked-eye observation

Body – Put the diseased fish on an enamel ware plate and examine the head, eyes, gill cover, scales, and fins for visible pathogens such as nematodes, *Argulus, Glochidium,* and *Saprolegnia.* It is also possible to see the pathogens of bacterial erythrodermatitis, albinoderm, stigmatosis, and furunculosis with the naked eye.

Gills – Inspect the gills, with an emphasis on the gill filaments. Observe the colour of the gill lamella, the quantity of mucus, and the congestion and putridity of filament tips after an opercular incision is performed.

Internal organs – Mainly check the intestines. Begin to observe abdominal hydrops and visible parasites, (e.g., *Ichthyoxenus, Nematodes,* cysts of *Myxosporidia, Ligulos,* then observe other internal organs. Extract the internal organs with a knife and scissors and separate the liver, gall bladder, air bladder, etc. Finally, open the intestine to search for any signs of pathological change.

Microscopic examination

Normally, only the skin, gills, intestines, eyes, and brain need be observed microscopically.

Skin – Scrape a little tissue and mucus from the skin, put them on a slide with a drop of distilled water, and observe the combination under a microscope after pressing with a coverslip. One should always start with the low power objectives. Samples from at least three different points on the skin should be inspected. Common parasites on the skin are *Trichodina, Ichthyophthirius, Chilodonella, Costia, Glochidium,* and *Myxosporidia.*

Gill – Place some gill filaments and mucus onto a slide. The following parasites may be identified through microscopic observation: *Dactylogyrus, Gyrodactylus, Cryptobia,* and *Myxosporidia.*

Intestines – Transfer a little mucus from the anterior intestinal wall to the slide. Nematodes, *Eimeria,* and *Myxosporidia* may be seen.

Eyes – Press the entire ocular bulb or crystaline body on the slide. Cysts of *Diplostomulums* are an indicator of diplostumulumsis.

Brain – Open the central cavity of a fish with whirling disease. White cysts of myxosporidia in the lymphatic fluid beside the brain should be observed. Remove the cysts and place them on a slide; after crushing with a coverslip, the spores can be seen.

Disease Control

Infectious Diseases

Hemorrhagic septicemia (Fig. 6.4)

Pathogen – Reovirus is spherical or hexagonal in shape, with an average diameter of 69 mm. The electron-dense area in the middle of the particle has an average diameter of 32 mm. This "nucleus" is surrounded by a membrane that is about 20 mm wide. Another variety of the virus shows an even electron distribution throughout and has no "nuclear membrane." This particle has an average diameter of 52 mm and is found in the includion bodies of the nucleus or cytoplasm. The viral particles always appear in sanguifying (blood-making) tissues of the kidney and are not found in red cells or granular white cells. The virus is sensitive to ether, acid, and alkali, and insensitive to drugs of the tetracycline family. It shows a high resistance to heat (Table 6.3).

Table 6.3. Heat resistance of reovirus.

Temperature (°C)	*Treatment period (h)*	*Fish mortality after infection (%)*
65	1	0
60	3	10
55	1	100
41	18	100

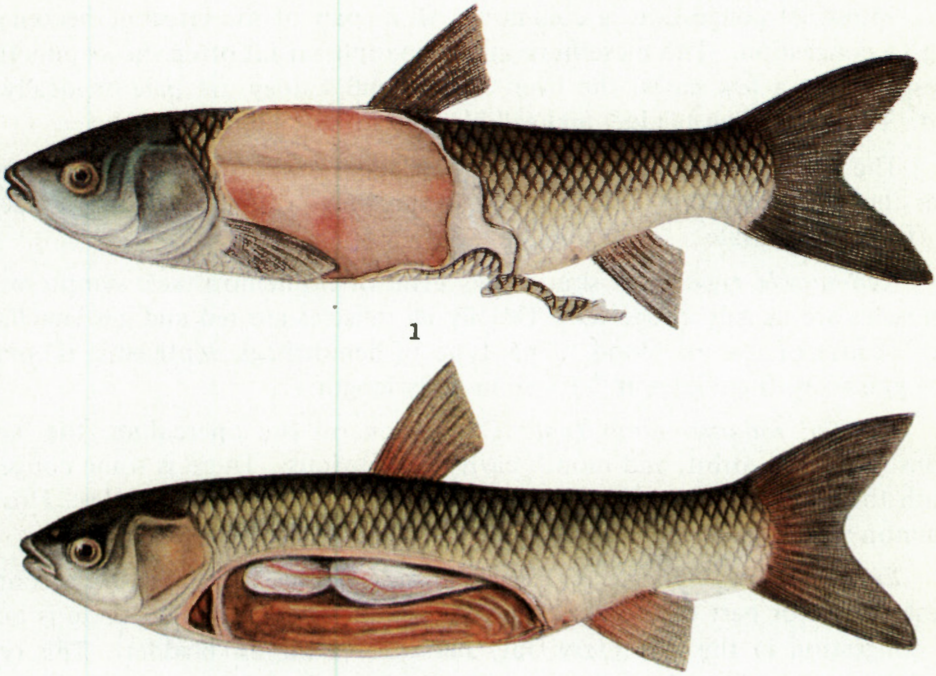


Fig. 6.4. Grass carp with hemorrhagic septicaemia symptoms. This disease can be easily diagnosed observing the muscle congestion (1) and the congested operculum, fin base, intestine and air bladder etc. (2).

Fig. 6.5. Black carp infected with erythroderma.

Symptoms and pathological changes – The main symptom of this disease is congestion. The fish usually becomes dark and slightly red. If you observe diseased juvenile fingerlings against the light, hypodermic hyperemia can be seen. Some fish show congestion around the mouth, lower jaw, skull or orbit, and exophthalmos (abnormal protrusion of the eyeball). Congestion of the operculum and fin base are visible after peeling away the skin of the diseased fish. The musculature of the fish shows punctiform or lump congestion. In serious cases, the entire musculature becomes bright red with "white gill" (i.e., bright red patch congestion appears on the operculum); some diseased fish show no gill discolouration. As for the internal organs, intestinal congestion is common. All or part of the intestine becomes red owing to congestion. The mesentery and its peripheral fat often shows punctiform congestion. In a few cases, the liver, spleen, and kidney are pale or locally congested. The walls of air bladder and gall bladder are often bloodshot.

The disease can be classified into three types based on symptoms and pathological changes. Each type is distinct; however, they occur together in the fish and are difficult to separate.

Red-muscle type: The skin shows little or no hemorrhagic symptoms, but the muscles are heavily congested. Usually all muscles are red and gill lamellae are white because of loss of blood. This type of hemorrhagic septicemia is common among grass carp fingerlings at 7-10 cm in body length.

Red-fin, red-operculum type: Congestion on the operculum, the base of the fins, the skull, orbit, and mouth cavity are obvious. There is some congestion beneath the scales and, possibly, some spotted congestion in the muscles. This type is common among grass carp fingerlings over 13 cm in body length.

Enteritis types: Instead of the skin and muscles, the intestine is seriously congested. All or part of the intestine is bright red. Occasionally, there is punctiform congestion in the mesentery, fat, and wall of the air bladder. This type is ubiquitous among grass carp fingerlings.

Epidemic situation – Hemorrhagic septicemia is one of the most common and harmful viral diseases encountered during the fingerling-nurturing period. The epidemic season is long (June-September), incidence is high, and mass mortality of grass carp fingerlings is common. Grass carp and black carp are both susceptible to this disease, with the former as the main victim. The disease is widespread in China and reaches its peak incidence in August when the water temperature is above 27°C. It gradually diminishes after mid-September when the water temperature drops below 25°C.

Control measures – There are three strategies of control.

First, vaccinate the fingerlings with deactivated virus. This will produce a resistance that may last up to 14 months.

Second, decoct 250-550 g of pulverized Chinese rhubarb or Chinese sweet gum leaves (*Liguidambar taiwaniana*) overnight and, after blending it with the feed, give it to the fish for 5 consecutive days. Next, spray the pond with enough Dyrene such that the pond water has a copper sulphate or copper acetate concentration of 0.6 or 0.7 ppm or a copper chloride concentration of 0.7 ppm. If copper sulphate is used, 2 days treatment is required per course, and two courses are needed to achieve good results.

Third, use improved farming techniques and ensure proper pond management.

Erythroderma

Pathogen – *Pseudomonas fluorescens* is a short, rodlike bacteria with round ends. It measures 0.7-0.75 x 0.4-0.45 μm and exists either singly or in pairs. It is motile with a single polar flagellum, has no gemma, and is gram negative. Agar colonies of *P. fluorescens* are circular in shape, semiopaque, and greyish white. The colonies produce a yellowish green pigment after a 24-h incubation.

Symptoms and pathological changes – Symptoms include inflammation, bleeding from the skin, and a loss of scales, particularly on the sides of the abdomen. Blood shot on the fin base, necrosis of the terminal of fins, and red blotches around the upper and lower jaws are also symptomatic of erythroderma. Occasionally, congestion and inflammation along the intestines also occurs (Fig. 6.5).

Epidemic situation – Erythroderma is a common disease of grass carp and black carp and is widespread on all farming sites. Mechanical lesions obtained during stocking or netting allow the bacteria to invade the fish. Frostbite also facilitates infection. In addition, wounds may result from fish rubbing against solid objects in the water. Because of these factors, erythroderma is a year-round disease.

Prevention – Thorough pond clearing and disinfection and gentle netting, carrying, and stocking are effective preventive measures. A promising method of prevention involves dipping fingerlings in a 5-10 ppm bleaching powder solution for 30 min before stocking. The fingerlings may also be vaccinated.

Treatment – Because the pathogenic bacteria not only infect the skin and the muscle but also invade the blood, medicine should, therefore, be administered both internally and externally.

Internally, sulphathiazole should be given orally once a day for 6 consecutive days. The 1st-day dose should be 10 g/100 kg fish; the dose for the remaining 5 days is 5 g/100 kg fish. The medicine is mixed with the feed using a binder. Externally, bleaching powder (containing 30 per cent available chlorine) should be spread over the pond to a concentration of 1 ppm. Alternatively, Chinese gall (*Galla chinesis*) could be applied at a concentration of 2-4 ppm.

Enteritis

Pathogen – Although still under debate, some people believe the pathogen to be *Aeromonas punctata* f. *intestinalis,* which is a short rod-shaped bacteria with two round ends. It measures 0.4-0.5 x 1-1.3 μm and exists mostly in pairs. It has a single polar flagellum, no gemma, and is gram negative. Agar colonies of this pathogen are round and a semiopaque, brownish pigment is produced around the colony after 1 or 2 days of incubation. The bacterium is pathogenic under certain conditions. Pathogenicity increases at a suitable water temperature (around 25°C) as water quality deteriorates, as air pressure decreases, and when fish are overfed.

Symptoms and pathological changes – The diseased fish has an expanded abdomen with red blotches; the fins are congested and decayed, the anus is red and swollen, and, when slight pressure is applied to the abdomen, a yellow mucus is released from the anus. Ascites can be seen if the abdomen is dissected. The intestinal walls show hyperaemia and inflammation. Cells of mucous membrane ulcerate and drop off, becoming bloody mucus and blocking the intestine. The diseased fish shows a loss of appetite, swims slowly and alone, and soon dies.

Epidemic situation – Enteritis is common among grass carp and black carp, with a few cases in bighead and common carp. Underyearlings of grass carp and yearlings of grass carp and black carp are more likely to contract the disease and show a high mortality, commonly ranging from 50 to 90 per cent. Therefore, enteritis is one of the most harmful diseases to cultivated fish in China. The disease is commonly found everywhere in farming sites, but the season of prevalence and degree of incidence differ slightly with respect to climate and rearing management. Generally, there are two distinct epidemic seasons: May to June for 1-2 year old grass carp and black carp, and August to September for underyearlings of grass carp. The disease is often complicated with bacterial gill rot.

Prevention – Maintaining water quality strictly following the "four disinfection" and "four fix" techniques is vital to the prevention of enteritis. During the epidemic season, feeding should be limited and prophylaxis performed regularly.

Treatment – Integrate oral administration with external administration. Externally, bleaching powder should be sprayed into the pond to a concentration of 1 ppm or quicklime should be scattered over the pond at a dose of 15-25 kg/mu per metre water depth. The following medicines can be mixed into feeds.

- Sulphaguanidine: for the first day, use the medicine in a dose of 1 g for every 10 kg of fish; the dose for the next 5 days is 1 g for every 20 kg of fish.
- Chinese gall: when enteritis and gill rot appear simultaneously, spray a decoction of the Chinese gall over the pond to a concentration of 2-3 ppm. Meanwhile, feed the fish with furazolidone for 6 days at a dose of 1 g/100 kg fish; for a serious case, double this dosage in the first treatment.
- Garlic: add 1-2 kg garlic/100 kg fish daily for 6 consecutive days.
- *Euphorbia humifusa:* add 500 g dry herb or 2500 g fresh herb for every 100 kg of fish daily for 3 consecutive days.
- *Acalypha australis:* add 500 g dry herb or 2000 g fresh herb for every 100 kg of fish daily for 3 consecutive days.
- Water knotweed (*Polygonum hydropiper*): add 500 g dry herb or 2000 g fresh herb for every 100 kg of fish once daily for 3 consecutive days.
- *Andrographis paniculata:* add 2 kg dry herb or 3 kg fresh herb for every 100 kg of fish daily for 5-7 consecutive days.

Euphorbia humifusa, A. australis, and *P. hydropiper* can be used separately or in combinations of two or all three. Disease resistance can be fortified through vaccination.

Bacterial gill rot

Pathogen – Myxococcus piscicolus is a slender, soft, and easy to coil bacterium. Its length varies greatly (2-37 μm, it is gram-negative, and a colony on pep-

Fig. 6.6. Grass carp infected with enteritis.

Fig. 6.7. Grass carp infected with gill rot disease shows the dark discolouration at the gill filaments.

tone agar diffused to pseudomycorrhiza is about 3 mm in diameter. Growth stops after 5 days of culture.

Symptoms and pathological changes – Diseased fish are black in appearance, especially the head. The gill filaments, which are often covered with mud and mucus, are putrid and pale. In a serious case, hyperemia and inflammation are found on the inside and outside of the opercula. The epidermis of the opercula often rots away leaving a transparent area. Histological studies of bacterial gill rot in grass carp found that it can be divided into chronic and acute types. The chronic disease lasts longer, with prevalent cellular hyperplasia. The acute disease is short with inflammatory dropsy or cell necrosis as the main symptoms (Fig. 6.7).

Epidemic situation – Bacterial gill rot affects grass carp, black carp, bighead, common carp and other fishes; grass carp is the main victim. It is one of the most serious diseases of grass carp, occurring year-round on all fish farms. It seldom appears when the water temperature is below 15°C and begins to occur when the water temperature is above 20°C. Its optimum temperature range is 28-35°C. Therefore, it is more prevalent in the spring, summer, and autumn than in the winter. The disease is often accompanied by enteritis.

Control – There are eight methods of controlling bacterial gill rot. When the disease is prevalent, disinfect the pond water and the pond sides weekly with dissolved bleaching powder at a rate of 0.25 kg/mu. For prevention purposes, bleaching powder baskets should be hung around the feeding platforms or bleaching powder should be spread into the pond water to a concentration of 1 ppm.

- Add a dry powder of Chinese tallow tree (*Sapium sebiferum*) leaves to the pond water to a concentration of 6.25 ppm. If fresh leaves are used, the dosage should be increased four times. The solution is prepared by immersing the leaf powder in 2 per cent quicklime solution for 6-12 h, (powder:quicklime, 1:2). Boil this solution for 10 min or until the pH reaches 12 before spraying.

- Add Chinese rhubarb (*Rheum officinale*) to the pond to a concentration of 2.5-3.7 ppm. Immerse the rhubarb in 0.3 per cent ammonia water (rhubarb:water, 1:20) for 12 h before spraying.

- Spray the pond with erythromycin to a concentration of 0.3 ppm. Then mix erythromycin with the fish feeds and apply this mixture for 6 consecutive days. Use 4 g erythromycin for every 100 kg of fish for the 1st day; and reduce this dosage in half for the remaining 5 days.

- Add pulverized Chinese gall to the pond water to a concentration of 2-4 ppm.

- Spread a solution of maple leaves over the pond. For each mu of pond, and 10 kg water to 20 kg of pulped Chinese sweet gum leaves before application.

- Spray the pond water with quicklime to a concentration of 20 ppm.

- Enhance immunity by vaccinating grass carp before transferring or stocking.

Vertical scale disease

Pathogen – *Pseudomonas punctata* seems to be responsible for vertical scale disease; however, Japanese data indicate that the pathogen is *Aeromonas* sp.

Symptoms and pathological changes – The skin of the diseased fish appears rather rough, and some scales (especially on the posterior part of the body) are stretched out, resembling pinecones. Thus, this disease is also called the "pinecone

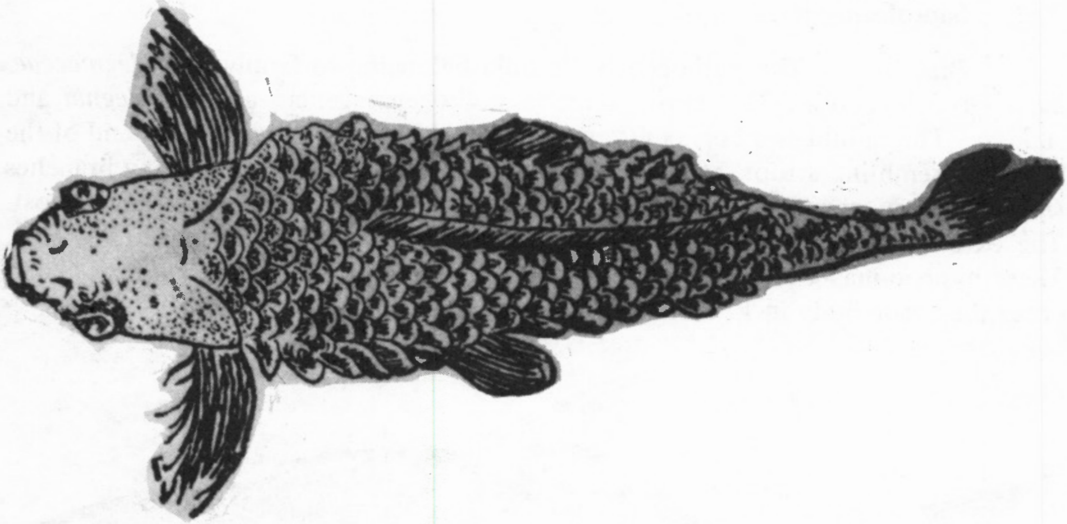


Fig. 6.8. Common carp infected with vertical scale disease.

disease." The scale capsule contains a semiopaque or sanguineous liquid that makes the scale vertical. If slight pressure is applied to the scale, the liquid will exude from the scale base and the scales will immediately drop off. Other symptoms include congestion on the fin bases, mild bleeding and inflammation on the skin, reddish ulceration on the desquamated area, exophthalmos (protruding eyeballs), and abdominal distension. As the disease develops, fish swim slowly, show dyspnea, and the abdomen turns upward. The fish will die 2 or 3 days later.

Epidemic situation – This disease mainly infects common carp, crucian carp, grass carp, silver carp, and, occasionally, goldfish (*Cyprinus auratus*). It usually occurs in northeastern, central, and eastern China. The disease is prevalent during spawning and overwintering of common carp. Normally, the disease first appears between late April and early July. The average mortality of parent fish as a result of vertical scale disease is 45 per cent. The maximum recorded mortality was 85 per cent and the mortality of yearling common carp may be over 50 per cent. The outbreak of the disease is related to injured skin, contaminated pond water, and poor disease resistance.

Control – There are four main methods of controlling vertical scale disease.

- Avoid injuries during netting, transferring, and stocking.
- Drain the spawning pond of parent common carp in the winter and disinfect the pond with quicklime or bleaching powder.
- Mix impure aureomycin or terramycin with the feed in a dose of 5 per cent of the feeding amount to make a pelleted feed.
- Inject 3-6 mg chloromycetin into the abdominal cavity.

Saprolegniasis

Pathogen – The pathogen is a mould belonging to family *Saprolegniaceae*, class *Phycomycetes*. The most common pathogenic genera are *Saprolegnia* and *Achlya*. The mould is a coenocytic mycelium without a cell wall. One end of the mould, resembling a root, attaches to the wounded part of the fish. Many branches (mycelia) then penetrate the skin and muscle and extract nutrients from the host. The external portion of the mould is flocculent and consists of hyphae (Fig. 6.9). These hyphae may be up to 3 cm long. On a dead fish, the mould can spread and cover the entire body in 12-24 hours.

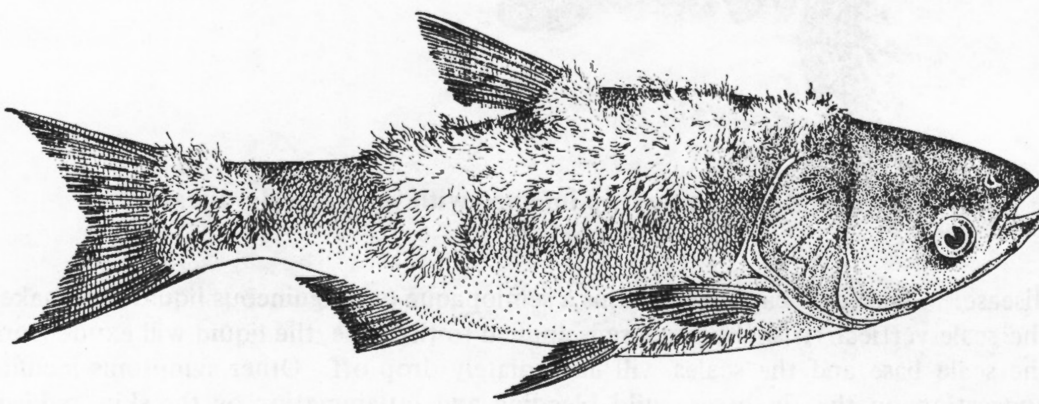


Fig. 6.9. Bighead infected with saprolegniasis.

Symptoms and pathological changes – There are no abnormal signs in the initial stages of infection. When the disease becomes visible, the mould has already penetrated the skin. The mycelia penetrate deep into the muscles, permeating tissue cells and branching heavily. Hyphae develop into a grey, flocculent mass (Fig. 6.9). The mould secretes a substance that decomposes tissues and because of the irritation, the fish secretes a great deal of mucus. The diseased fish behaves abnormally, fidgeting and rubbing against solid materials. As the mould continues to grow, morbid muscle rots and the fish loses its appetite, moves slowly, and eventually dies.

Epidemic situation – This disease is common in all farming areas year-round. It can affect any developmental stage of all the cultured species. The mould invades wounds inflicted during netting, transporting, and stocking. Saprolegniasis is particularly prevalent in overwintering ponds with a high stocking density.

Control – There are eight methods of controlling saprolegniasis.

- Disinfect the pond with quicklime.

- Avoid lesions caused by catching, transporting, or stocking.

- Select healthy parent fish and smear them with 1 per cent malachite green ointment or sulfa ointment.
- If the disease occurs in an eel-culturing pond, sprinkle the infected pond with malachite green solution or methylene blue solution to concentrations of 0.15-0.2 and 2-3 ppm, respectively. If there is no apparent effect, repeat the same dosage 3-4 days after the first application.
- To prevent saprolegniasis of eggs, raise the rate of fertilization. Choose fine days for artificial spawning and hatch the eggs indoors under showering water.
- Disinfect viscid eggs by immersing them with a 7 ppm malachite green solution for 10-15 min for 2 consecutive days. Afterwards, sprinkle the hatching shelf in the morning and evening with 10-15 kg of a 10-100 ppm malachite green solution until the fry are hatched.
- Apply malachite green solution every 6-8 h to the circular incubation tank to make the water light green. Repeat this procedure until hatching. This method diminishes mould infection and improves hatchability.
- Immerse the egg nests in 3-5 per cent formalin for 2-3 min or in a 1-3 per cent table salt solution for 20 min.

Invasive Diseases

Cryptobiosis branchialis

Pathogen – *Cryptobia branchialis* is a flattened creature with a wide anterior end and a narrow posterior end (like a willow leaf). The body length measures 5-12 μm. There are two flagella, both originating at the anterior end. One stretches forward and is called the anterior flagellum. The other forms an undulating membrane along the surface of the body and stretches posteriorly; it is called the posterior flagellum. In the middle of the body there is a round nucleus; in front of this nucleus there is an ovoid kinetonucleus (Fig. 6.10). Around the nucleus there are chromatin granules. The endosoma is in the centre of the nucleus. The posterior flagellum of the live parasite penetrates into the epidermal tissue of the gill of a fish (Fig. 6.10). When leaving the host, the anterior flagellum and undulating membrane move the body forward.

Symptoms and pathological changes – The parasite generally fixes itself to the gill of the host destroying the epithelia on the gill lamella and producing thrombi (blood clots) in the blood vessels of the gill lamella. This inflammation of the branchial organs retards normal blood circulation. Meanwhile, the mucus secreted in response to the irritation will cover the intact part of gill; thus, respiration is impeded. If the disease is allowed to continue, the fish will experience dyspnea and eventually die of suffocation.

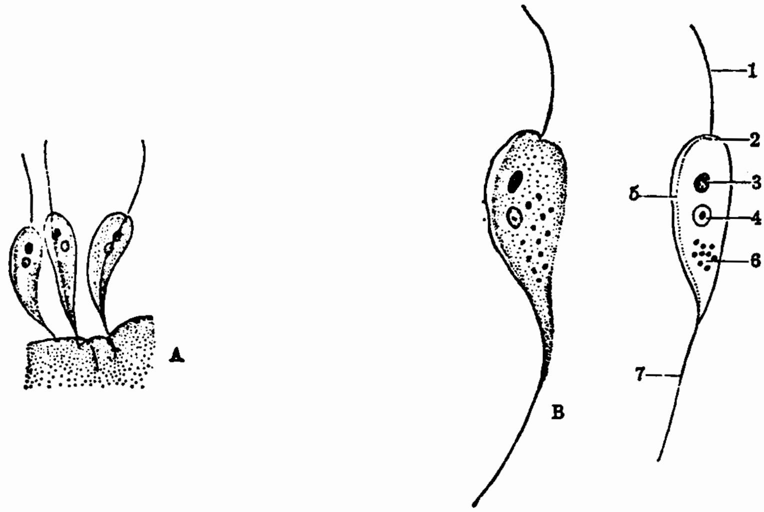


Fig. 6.10. *Cryptobia branchialis:* (A) attached to the gill of a fish; (B) basic morphology.

1. anterior flagellum
2. blephroplast
3. kinetonucleus
4. nucleus
5. undulating membrane
6. food granule
7. posterior flagellum

Epidemic situation – *Cryptobia branchialis* is not host-specific. It can invade any freshwater fish (especially pond fish), cause disease, and result in mass mortality. Grass carp summer fingerlings are especially susceptible. The disease has been reported from fish farms throughout China. The epidemic season runs from May to October, with a peak from July to September often in the acute form.

Control – There are four methods of controlling *Cryptobia branchialis.*

- Bathe the fingerlings in a 8 ppm copper sulphate solution for 20-30 min before stocking.
- Disinfect the feeding area with a mixture of copper sulphate and ferrous sulphate by the hanging bag method during disease prevalence.
- Treat the infected pond with a mixture of copper sulphate and ferrous sulphate to a concentration of 0.7 ppm.
- Bathe the fish with a 2-3 per cent table salt solution for 5 min.

Myxosporidiasis

Pathogen – The many parasitic species of the order Myxosporidia, class Sporozoa, have the ability to parasitize any organ or tissue of all varieties of fish. Over 100 species that are parasitic to freshwater fish have been found in China. Some species can become epidemic. A spore of Myxosporidia consists of two identical chitinous shells surrounding plasmodium (Fig. 6.11). The line where the

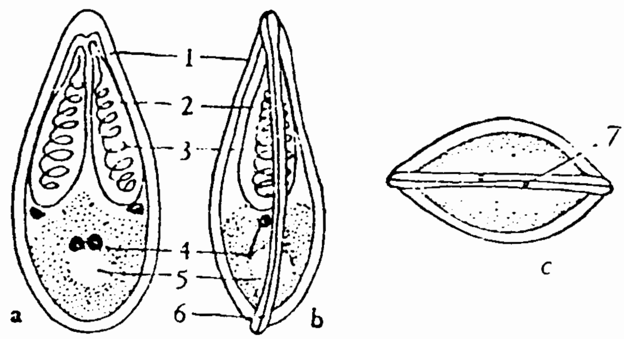


Fig. 6.11. Principal structures of a spore of Myxosporidia. (a) shell view; (b) sutural view; (c) top view.

1. sporoshell
2. polar vacuole
3. polar filament
4. embrvonic nucleus
5. iodiophilous vacuole
6. sutural line
7. polar vocuole pore

two shells join is called the sutural line. There is a ridge along the sutural line called the sutural ridge. The side with the sutural ridge is called the sutural side or lateral side. The side without the sutural ridge is called the shell side or front side. The plasmodium consists of a polar capsule(s) and the sporolasm. The number of polar capsules varies with species but is usually, from one to four. Each polar capsule contains a spiral polar filament. The number of nuclei inside the sporoplasm varies depending on the developmental stage of the spore. Some species contain an iodinephilous vacuole that can be stained brown with Lugol's solution.

Myxosporidia parasitize the host generally in the form of a cytocyst. The most dangerous Myxosporidia that parasitize fish skin are seen in Fig. 6.12. Myxosporidia that commonly parasitize fish gills are seen in Fig. 6.13. Myxosporidia that commonly attack the intestines are seen in Fig. 6.14. *Myxobolus lieni* (Fig. 6.15) parasitizes the central nervous system and sensory organs of silver carp and bighead, causing whirling disease.

Control – There are three methods of controlling myxosporidiasis.

- Eradicate the spore by sterilizing the pond with 100 kg/mu of nitrolime (CaN_2) or 125 kg/mu of quicklime. In the fry and fingerling stages of silver carp (June-September), sprinkle dipterex powder into the pond to a concentration of 5 ppm twice monthly to prevent whirling disease of silver carp.
- Bathe mud carp with 1 per cent crystal dipterex (90 per cent effective element) for 3-10 min and, at the same time, sprinkle crystal dipterex into the pond to a concentration of 0.2-0.3 ppm. This effectively controls myxosporidiasis of mud carp.
- To control *Myxobolus artus,* feed 2 g paludrine to every 10,000 fry 5 days after fry nursing for 6 consecutive days.

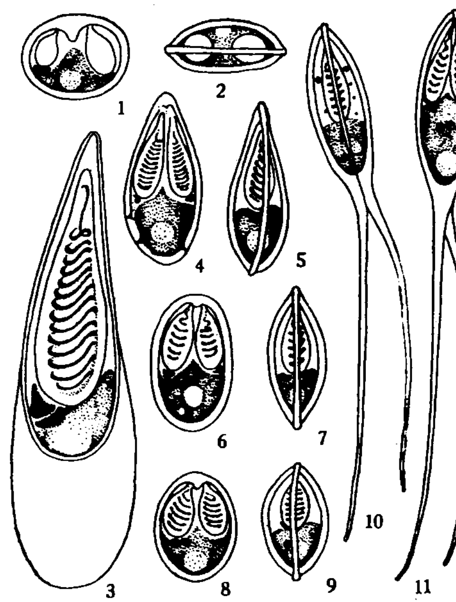


Fig. 6.12. *Myxosporidia* commonly found on the skin of cultivated fish.

1-2. *Myxobolus abitus*
3. *Thelohanellus rohitae*
4-5. *Myxobolus koi*
6-7. *Myxobolus ellipsoides*
8-9. *Myxobolus cyprinicola*
10-11. *Hennerguya sinensis*

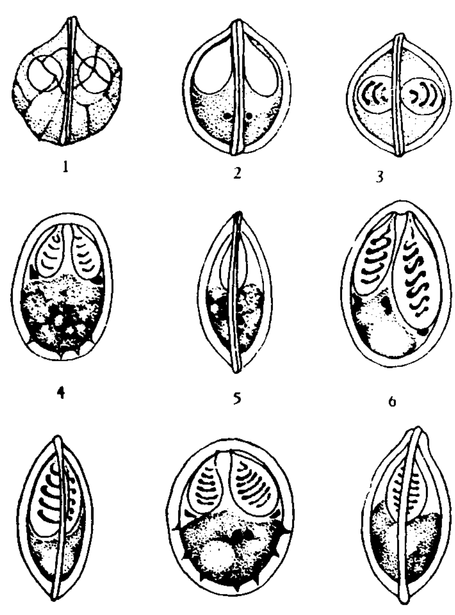


Fig. 6.13. *Myxosporidia* commonly found on the gills of cultivated fish.

1-3. *Sphaerospora amurensis*
4-5. *Myxosoma varius*
6-7. *Myxobolus musculi*
8-9. *Myxobolus dipar*

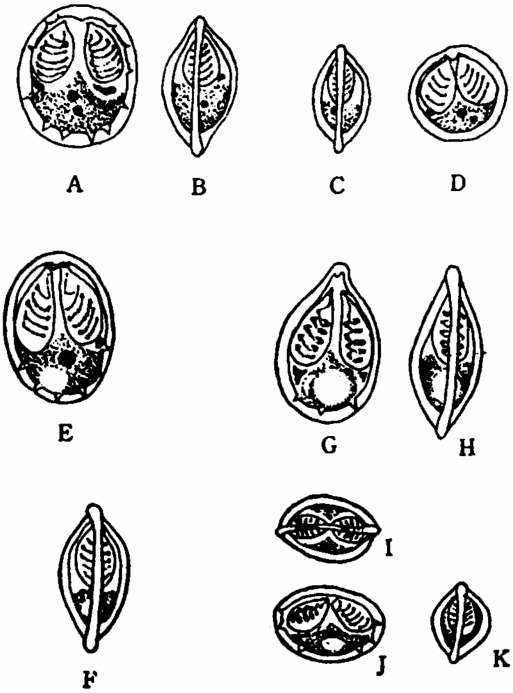


Fig. 6.14. Myxosporidia easily found in the intestines of cultured fish.

A. *Myxosoma sinensis*
B. *M. sinensis*, sutural view
C. *Myxosoma lieni*, side view
D. *M. lieni*, sutural view
E. *Myxobolus symetricus*, side view
F. *M. symetricus*, sutural view
G. *Myxobolus lomi*, side view
H. *M. lomi*, sutural view
I. *Myxobolus artus*, side view
J-K. *M. artus*, sutural views

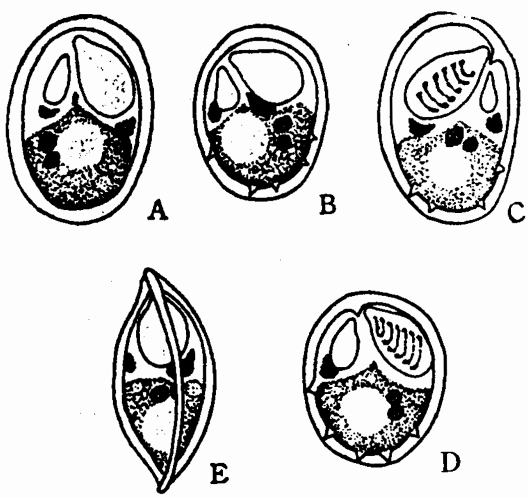


Fig. 6.15. *Myxobolus lieni* parasitising the brain of silver carp.

A-D. Shell views of the spore   E. Sutural view of the spore

Ichthyophythiriasis

Pathogen – The pathogen, *Ichthyophthirius multifilis,* varies considerably with developmental stage (Fig. 6.16).

Symptoms and pathological changes – The skin, fin rays and operculum become covered with many white protuberant pustules; for this reason, ichthyophythiriasis is also called "white dot disease." These white dots are a proliferation of epidermal cells with mucus secreted because of the irritation caused by the drilling of parasites on the epidermis. In a serious case, the skin is covered with a white membrane. The diseased fish swims and responds to stimulus slowly, spending much of its time near the surface. It also continually rubs itself against other objects or jumps out of the water. The damage caused by the parasites and secondary bacterial infection results in epidermal inflammation, local necrosis and desquamation, and the rotting and splitting of fin-rays. Parasites on the branchial tissues destroy the gill lamella and stimulate the secretion of mucus. The branchial epithelia around the parasites proliferate. Infection also results in the congestion of gill veins or histological anemia of the gills. The parasite may invade the cornea and cause inflammation and blindness. Ichthyophythiriasis results in mass mortality because of dyspnea and a loss of appetite (starvation).

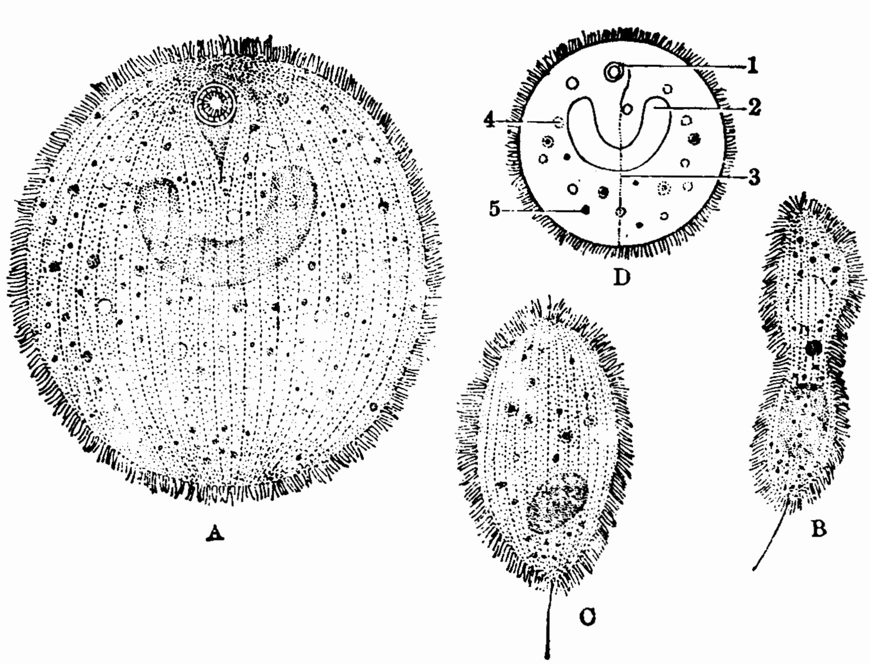


Fig. 6.16. ***Ichthyophirius multifiliis***

A,D, mature stage

1. cytostome
2. macronucleus
3. ciliary yarn
4. contractile vacuole
5. food particle

C,B, Larval stage

Epidemic situation – This disease occurs throughout China, and is one of the major protozoan diseases. Freshwater fishes of all developmental stages are vulnerable to infection with fingerlings as the main victim. Ornamental fish in aquaria or petty cement tanks may also become infected. The optimum water temperature for the proliferation of the parasite is 15-25°C. Therefore, early winter and late spring are its prevalent seasons. Fish in high-density, overwintering ponds are more susceptible to the disease.

Control – There are four methods of controlling ichthyophythiriasis.

- To prevent transmission of the disease, disinfect the pond with quicklime, rear fry at a reasonable density, quarantine and disinfect fingerlings before stocking.
- Bathe the fingerlings with a solution of 0.05 ppm malachite green and 25 ppm formalin twice daily. This should not be done in grow-out fish ponds.
- Immerse fingerlings in 0.2-0.4 ppm malachite green for 2 h. This method was developed by the Beijing Fishery Research Institute.
- Methylene blue can be used to combat the disease or infected fish can be treated with sea water (salinity over 1 per cent). These methods are commonly used in Europe.

Trichodinasis and trichodinelliasis

Pathogen – Many species of the genera *Trichodina* and *Trichodinelia* are responsible for these diseases. Viewed laterally, the parasite resembles a hat; in aboral view, the parasite resembles a round plate. The convex part of the parasite is called the adoral end. Opposite of the adoral end is the aboral end. At the aboral end there is a counterclockwise adoral groove stretching to the cytostome (Fig. 6.17). On each side of the adoral groove there is a line of cilia, forming an oral zone that extends to the vestibule. The cytostome is linked with the cytopharynx and, near the cytopharynx, there is a contractile vacuole. The shape of macronucleus varies with species (horseshoe shaped, sausage shaped, etc.). The micronucleus is rod shaped or sphere shaped and generally close to the outer margin of the macronucleus end. At the aboral end there is a posterior girdle of cilia. There are two rows of rather short cilia: upper marginal and lower marginal cilia. Some species have a thin, transparent membrane called the border membrane, behind the lower marginal cilia (Fig. 6.17). The aboral end is concave and its most conspicuous structure are a circular denticulating ring and a chitinuous striated ring. The denticulating ring is formed by many denticles joined together. The number and shape of the denticules and the number of radiant rays on each denticle differ with species. The parasite attaches itself to the skin or gill of the host with its adhesive disc. Some times the parasite contracts its border membrane, moves its posterior girdle of cilia, and slides over the skin and gill. When swimming freely, the parasite spins like a wheel with its aboral end forward. Reproduction involves a sexual longi-

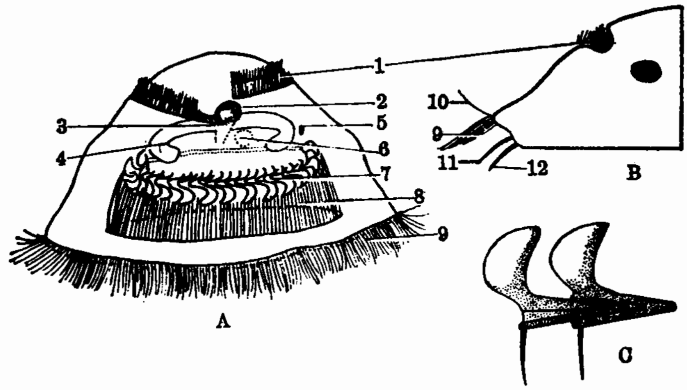


Fig. 6.17. Structure of *Trichodina* showing lateral view (A), partial cross section (B) and two segments of the dentivulating ring (C).

1. adoral groove and oral cilia zone	7. denticulating ring
2. cytostome	8. striate
3. cytopharynx	9. posterior girdle of cilia
4. macronucleus	10. upper marginal cilia
5. micronucleus	11. lower marginal cilia
6. contractile vacuole	12. marginal membrane

tudinal division and sexual conjugation. The optimum temperature for the reproduction of *Trichodina* is 20-28°C.

Symptoms and pathological changes – *Trichodina* can infect fish at any developmental stage, but the main victims are juvenile fish, especially those under 5 cm in body length. Generally, the parasites do not infect adult fish. *Trichodina* mainly invades the skin of juvenile fish, feeding on the tissue, and destroying the skin. *Trichodinelia* mainly parasitizes the gills, concentrating on the branchial periphery or between the gill filaments. With a serious infection, the gill tissue rots and the cartilage becomes exposed. As a result, respiration is seriously impaired and the fish dies.

Epidemic situation – Trichodinasis is a dangerous disease during the fry and fingerling stages. It is prevalent throughout China and especially on farms along the Yangtze River valley and the West River valley. Every year from May to August, when fry are nurtured to summer fingerlings, there is a serious outbreak of trichodinasis and a high mortality of fry and fingerlings. The disease is more likely to occur in small, shallow ponds with poor water quality and high fish density and trichodinelliasis under conditions of continuous rain.

Control – There are four methods of controlling trichodinasis and trichodinelliasis.

– Disinfect the fingerlings with 8 ppm copper sulphate solution for 20-30 min or with a 1-2 per cent aqueous solution of table salt for 2-10 min.

- The reproduction of *Trichodina* can be inhibited by adding 15-20 kg/mu of chinaberry (*Melia azedarach*) leaves once a week. Sprinkling 25-30 kg/mu of a decoction of fresh chinaberry branches and leaves is also effective.
- Treat the pond with a mixture of copper sulphate and ferrous sulphate (5:2) to a concentration of 0.7 ppm.
- Formalin at a concentration of 30 ppm can kill *Trichodina* on juvenile eel gill; however, this treatment also adversely affects water quality and appetite.

Dactylogyrosis

Pathogen – Many species of the genus *Dactylogyrus* are responsible for this disease. The following four pathogenic species parasitize cultured fish in China.

- *Dactylogyrus lamellatus* parasitizes the gills, skin, and fins of grass carp. It is flat, 0.192-0.529 mm long, and 0.072-0.136 mm wide, (Fig. 6.18).

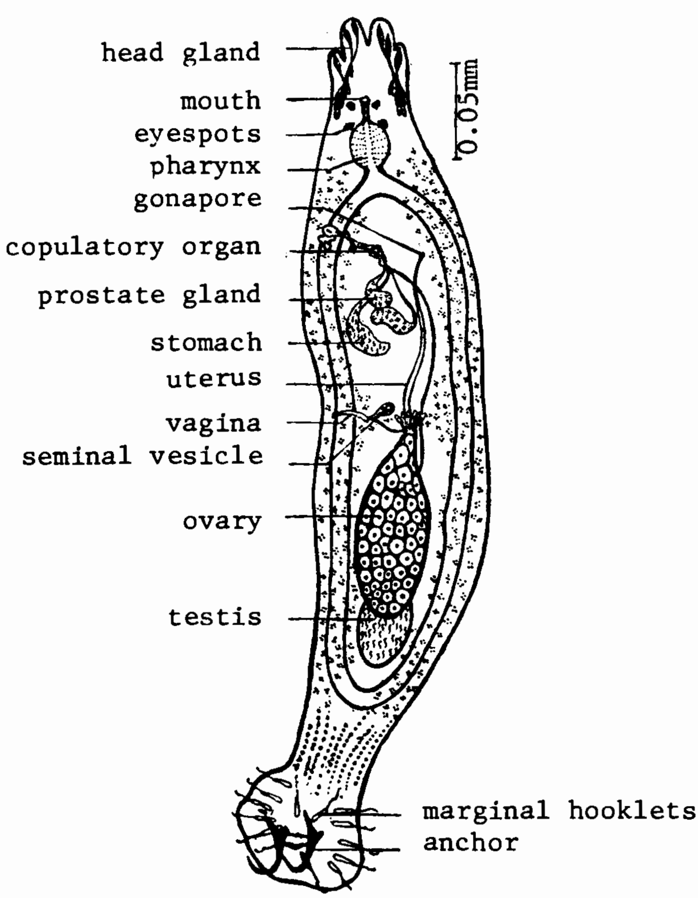


Fig. 6.18. The ventral view of a *Dactylogyrus lamellatus* Achmerov.

- *Dactylogyrus aristichthys* parasitizes the gills of bighead.
- *Dactylogyrus hypopthalmichthys* parasitizes the gill filaments of silver carp.
- *Dactylogyrus vastator* parasitizes the gill filaments of common carp, crucian carp, and pet fish.

Symptoms and pathological changes – An infestation of one of the above species of *Dactylogyrus* causes the fish to secrete more mucus; in addition, gills become pale, the operculum opens, dyspnea occurs, and there is evident dropsy of the gills (more distinct in bighead). The infected fish swims slowly and is anemic. The number of monocytes and coenocytic leukocytes increases.

Epidemic situation – Dactylogyrosis is a common disease, prevalent in late spring and early summer. The optimum temperature for the parasite is 20-25°C. The disease is mainly found on silver carp, bighead, and grass carp.

Control – There are four methods of treating dactylogyrosis.

- Before stocking, bathe fingerlings in 20 ppm potassium permanganate for 15-30 min.
- When the water temperature is 20-30°C, spread 90 per cent crystal dipterex into the pond to a concentration of 0.2-0.3 ppm.
- Treat the pond water with 2.5 per cent dipterex powder to a concentration of 1-2 ppm.
- Sprinkle a mixture of dipterex and sodium carbonate (1:0.6) into the pond water to a concentration of 0.1-0.24 ppm.

Sinergasilusis

Pathogen – Females of some species of the genus *Sinergasilus* parasitize fish gills. The following three species of *Sinergasilus* parasitize cultivated fish.

- *Sinergasilus polycolpus* (Fig. 6.19) parasitizes the interior side of the gill filament tips of silver carp and bighead and the gill rakers of silver carp.
- *Sinergasilus undulatus* parasitizes the interior side of gill filament tips of common carp and crucian carp.
- *Sinergasilus major* (Fig. 6.19) parasitizes the interior side of the gill filament tips of grass carp, black carp, catfish, trout, and freshwater salmon.

The body of the adult female is slim and cylindrical, with three distinct sections: head, thorax, and abdomen.

The head is triangle shaped and has five pairs of appendages. The second pair of antenna has developed into a hook capable of attaching to gill filament

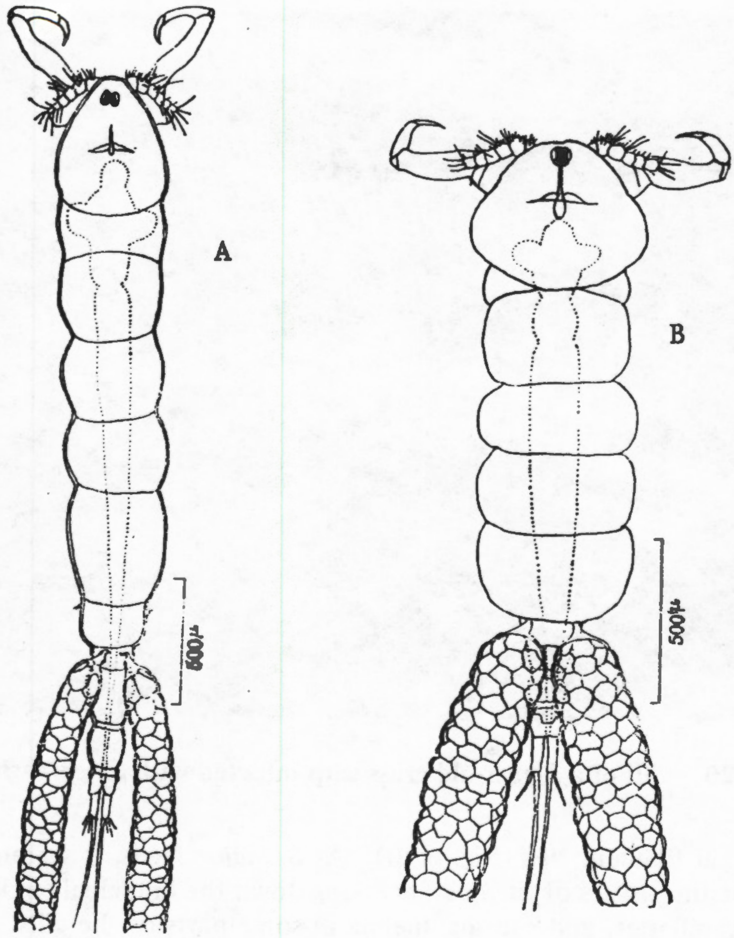


Fig. 6.19. Female *Sinergasilus major* (A) and *Sinergasilus polycolpus* (B).

tissues. The width of the first four thoracic segments equals their length. The fourth segment may be somewhat wider than it is long. The fifth thoracic segment is comparatively small. The sixth segment is a narrow genital segment on which a pair of ovisacs can be seen hanging down during the breeding season. There are five pairs of biramous swimmerets on the thorax. The abdomen has three segments, with short pseudosegments between the first and second and between the second and third segments. There is a pair of caudal furca at the tail end. The male is many times smaller than the female and has a pair of maxillipeds on its head to embrace the female during mating.

Symptoms and pathological changes – Sinergasilus major is more harmful than *S. polycolpus* and *S. undulatus.* It usually invades grass carp that are over 2 years old and occasionally parasitizes gill filaments of large underyearling grass carp. The female parasite clutches the gill with its second antennae, wounding the gill tissue and causing local inflammation of the gill filaments and curving and deforma-

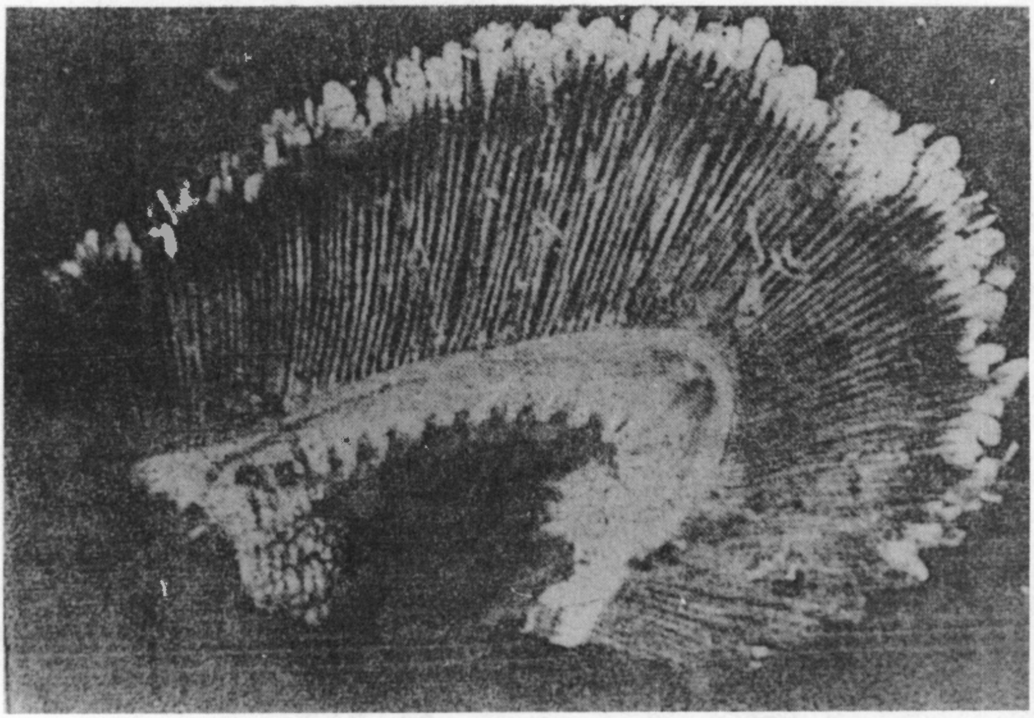


Fig. 6.20. Gill of a 2-year-old grass carp infected with *Singergasilus major*.

tion of the gill filament tips (Fig. 6.20). As *S. major* feeds, it secretes an enzyme that dissolves the tissues of the host, breaking down the branchial epidermis, damaging nearby capillaries, and causing anemia in some parts of the gills. The diseased fish displays an uneasy behaviour, often jumping out of the water.

Epidemic situation This disease is widespread throughout China. The reproductive period lasts from April to November along the Yangtze River valley. The epidemic season is from May to September. *Sinergasilus major* mainly attacks grass carp over 2 years of age; *S. polycolpus* is usually found on silver carp and bighead over 2 years of age. A serious infection can be lethal.

Control – There are four methods of controlling sinergasilusis.

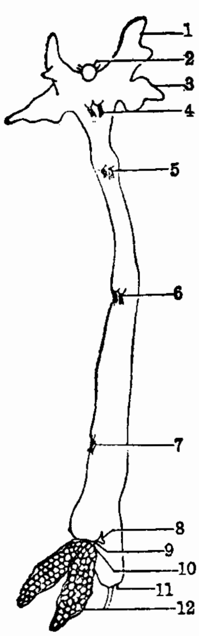
- Because of the strict selectivity of the pathogen, rotary farming effectively prevents infection.
- Before stocking, bathe the fingerlings with a 7 ppm solution of copper sulphate and ferrous sulphate (5:2) for 30 min.
- Spray the pond with a solution of copper sulphate and ferrous sulphate (5:2) to a concentration of 0.7 ppm.
- Treat the pond with mixture of 2.5 per cent dipterex powder and ferrous sulphate (1.2:0.2) to a concentration of 1.4 ppm.

Lernaesis (anchor worm)

Pathogen – some species of the genus *Lernaea* are pathogenic to Chinese carp. The following three species are the most prevalent.

- *Lernaea polymorpha* parasitizes silver carp, bighead, and wuchang fish.
- *Lernaea cyprinacea* parasitizes common carp, crucian carp, silver carp, and bighead.
- *Lernaea ctenopharyngodontis* parasitizes grass carp.

The female parasite is needle shaped. The body is 6-12.4 mm long and consists of a head, thorax, and abdomen. There is no distinctive demarkation between the three sections. On the head, there is a pair of dorsal horns and a pair of abdominal horns. They function as anchors, enabling the parasite to fix itself to the host's musculature; this parasite is also known as the "anchor worm." The shape of the cephalic horns differs from species to species; the thoracic region is long and cylindrical. The anterior portion is narrow, becoming broader toward the posterior end. There is a pair of genital pores at the end of the abdomen. In the reproductive season, a pair of long (2-3 mm) ovisacs can be seen hanging down from the genital pores. The thoracic region of the female parasite has five pairs of swimming legs (Fig. 6.21). After feeding, the thorax expands and extends. This causes the five pairs of swimmerets to degenerate and split apart. The male is small and only occasionally parasitic.



1. Ventral horn
2. Head lobe
3. Dorsal horn
4. First swimming leg
5. Second swimming leg
6. Third swimming leg
7. Fourth swimming leg
8. Fifth swimming leg
9. The front part of genital segment is protuberant.
10. Ovulation pore
11. Caudal furca
12. Egg sac

Fig. 6.21. Structure of a female *Lernaea*.

After parasitizing a fish, the female develops into three phases: "baby parasite", "mature parasite", and "old parasite." The baby parasite resembles a fine white hair and has no ovisacs. The mature parasite is transparent, making its intestines visible, and there is a pair of green ovisacs near the genital pore. When touched, the parasite becomes erect. The old parasite is rather turbid and soft and carries many protozoans (e.g. *Epistylis*). Such parasites quickly die and fall off the fish.

Symptoms and pathological changes – Initially, the diseased fish behaves uneasily, has a poor appetite, is thin, and moves slowly. The areas that *Lernaea* has penetrated are inflammed and swollen, and tissues are necrotic. The wounds are often invaded by *Saprolegnia.* On a juvenile fish, four or five *Lernaea* 6-9 cm long can be lethal. On a young fish, just one or two parasites can retard growth or cause deformation.

Epidemic situation – Lernaeasis is widespread in Guangdong, Guangsi, and Fujian provinces. In these areas, incidence is high and intensity is great. The season of prevalence is long. The epidemic season along the Yangtze River valley lasts from April to October (when the water temperature is 15-33°C) and coincides with *Lernaeas,* reproductive season.

Control – There are five major methods of controlling *Lernaea.*

- Bathe the fingerlings attacked by *Lernaea* with a 10-20 potassium permanganate solution for 1.5-2 h before stocking.
- Spray the pond three or four times with 90 per cent crystal dipterex to a concentration of 0.3-0.5 ppm every 3 or 4 days.
- Bathe diseased grass carp for 1.5-2 h with a 20 ppm solution of potassium permanganate at a water temperature of 15-20°C, or with a 10 ppm solution at 21-30°C. For diseased silver carp and bighead, immerse the fish in a potassium permanganate solution of the following concentration at the following water temperature: 33 ppm, below 10°C; 20 ppm, 10-20°C; 12.5 ppm, 20-30°C; 10 ppm, over 30°C.
- Because of the strict selectivity of *Lernaea,* rotation culturing and immunization are effective preventive measures. Immunized fingerlings are resistant to *Lernaea* for 1 year. Stocking fish into a large culture pond reduces the incidence of lernaeasis.
- Change the water quality suddenly, e.g. add 400 kg/mu of fermented cow dung or pig manure or 100-150 kg/mu of distiller's dregs for every metre of water depth.

Other diseases and fish enemies

Inappropriate water temperature and water quality, mechanical lesions, insufficient feeding, and foreign chemical substances may all cause diseases, which may be fatal. These diseases include gas bubble disease, horse-running disease, and deformity (Fig. 6.22).

In the fry-nurturing stage, diseases caused by lower plants are common: e.g., silkweed and filamentous green algae (Fig. 6.23). Diseases caused by animals are also frequently observed: e.g., water centipede and fish killer (*Kirkaldyia deyrollei*) (Fig. 6.24). Frogs are also serious predators of fry and fingerlings.

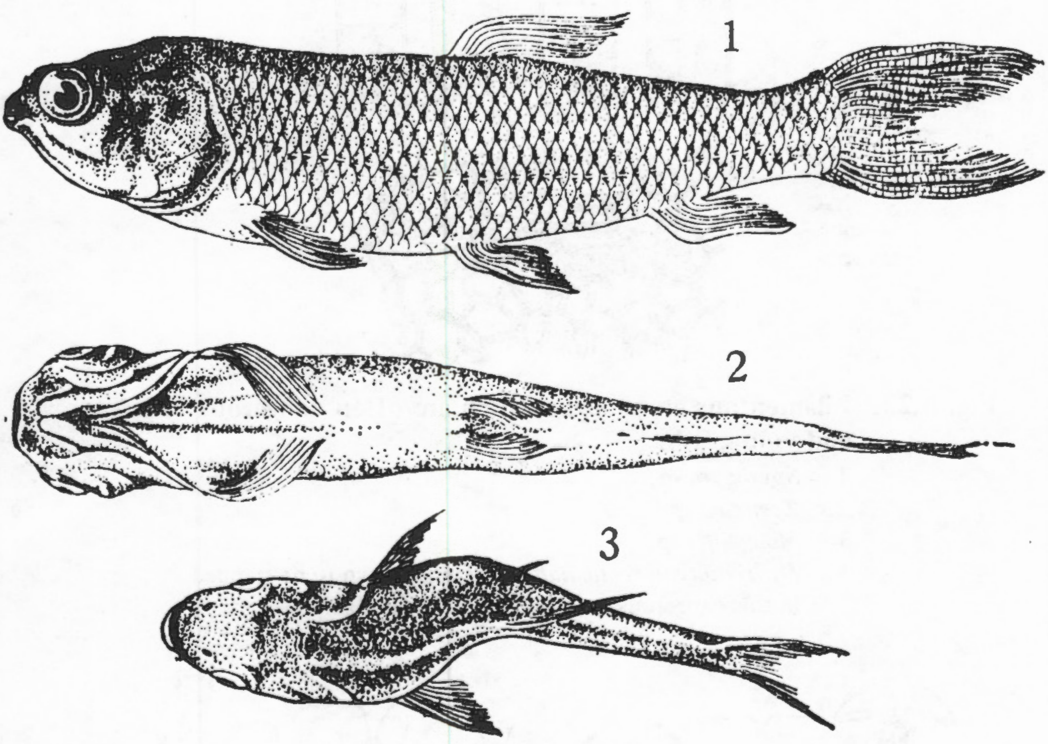


Fig. 6.22. Grass carp fingerling suffering from deformity.

1. Lateral view;
2. Ventral view;
3. Dorsal view.

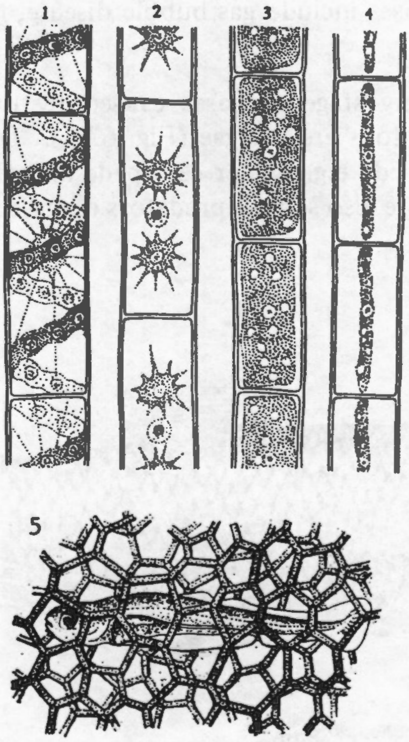


Fig. 6.23. Filamentous green algae which are often dangerous to larvae and young fish.

1. *Spyrogyra* sp;
2. *Zygnema* sp;
3-4. *Mougeotia* sp;
5. *Hydrodictyon recticulatum*, a fry is shown to be trapped in this dangerous, web-like filamentous alga.

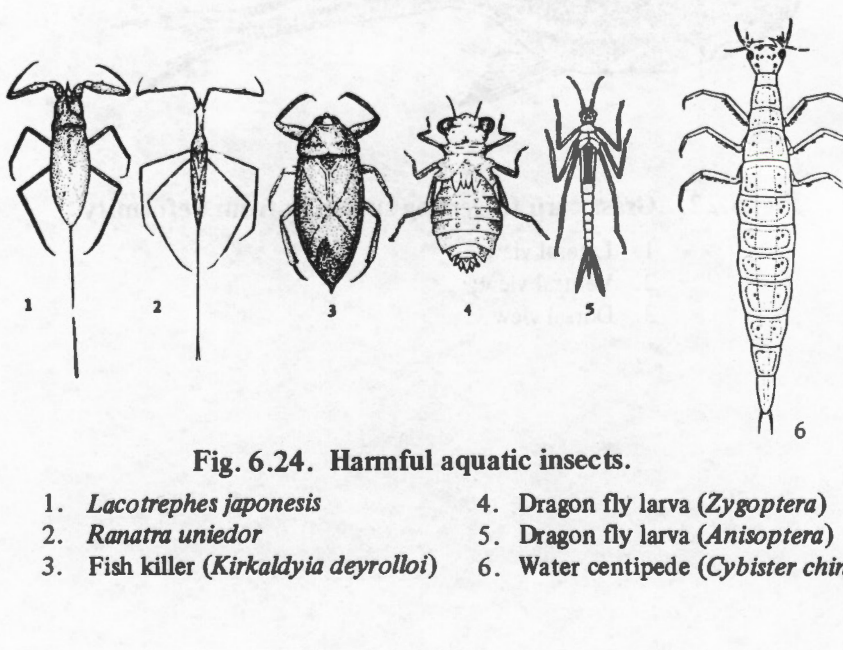


Fig. 6.24. Harmful aquatic insects.

1. *Lacotrephes japonesis*
2. *Ranatra uniedor*
3. Fish killer (*Kirkaldyia deyrolloi*)
4. Dragon fly larva (*Zygoptera*)
5. Dragon fly larva (*Anisoptera*)
6. Water centipede (*Cybister chinenses* Shar)

Chapter 7

INTRODUCTION OF CHINESE INTEGRATED FISH FARMING AND SOME MAJOR MODELS

Yang Huazhu
Hu Baotong

Introduction of Integrated Fish Farming

Chinese integrated fish farming is so broad in scope and has so many models that there is no comparative farming system in the world. The Chinese system had developed its own characteristics and has attracted world attention. The reason for this is the full systems's development and utilization of local natural resources and subsequent production of food and attainment of economic self-sufficiency.

Advantages of Integrated Fish Farming

Artificial ecosystem with no waste

In developed countries, farming becomes more intensive as industry develops. As farming becomes more intensive, waste material accumulates. In Japan, for example, cattle, pigs, and chicken produce more than 70 x 10^6 t/year of waste material. If this excreta is not disposed, the environment becomes polluted and people's health jeopardized.

Livestock and poultry manure are good organic fertilizers for fish farming: 40-50 kg of organic manure will produce 1 kg of fresh fish. Combining fish farming with mulberry cultivation, sericulture, and silk extraction from cocoons allows the pupae to be used as fish feed and the worm feces and wastewater from the processing factory to be used as pond fertilizers. The dregs, lees, and wastewater obtained from starch processing and wine brewing may also be used as fertilizers. Pond silt can be used as fertilizer for fodder crops, which in turn, can be used to raise livestock and poultry or as fish feed. Thus, a recycling ecosystem is formed (Fig. 7.1).

Increasing the food supply

The limited supply of protein food is currently a serious problem in China and around the world. Therefore, using only pelleted grain and animal protein fish feeds is not economical and reduces the food available for human consumption. If grains such as wheat are used in fish culture, output could reach 4815-9750 kg/ha. However, the average food conversion factor of grain is 3, i.e., 3 kg grain (dry weight) will produce 1 kg fresh fish. This conversion rate is unsuitable for countries in need of food. Natural food organisms cultured in fish ponds using organic manure could completely replace pelleted feeds. Fertilizing with animal manure will not change the quality of fish. Being cultured, the daily output could reach 15-33kg/ha

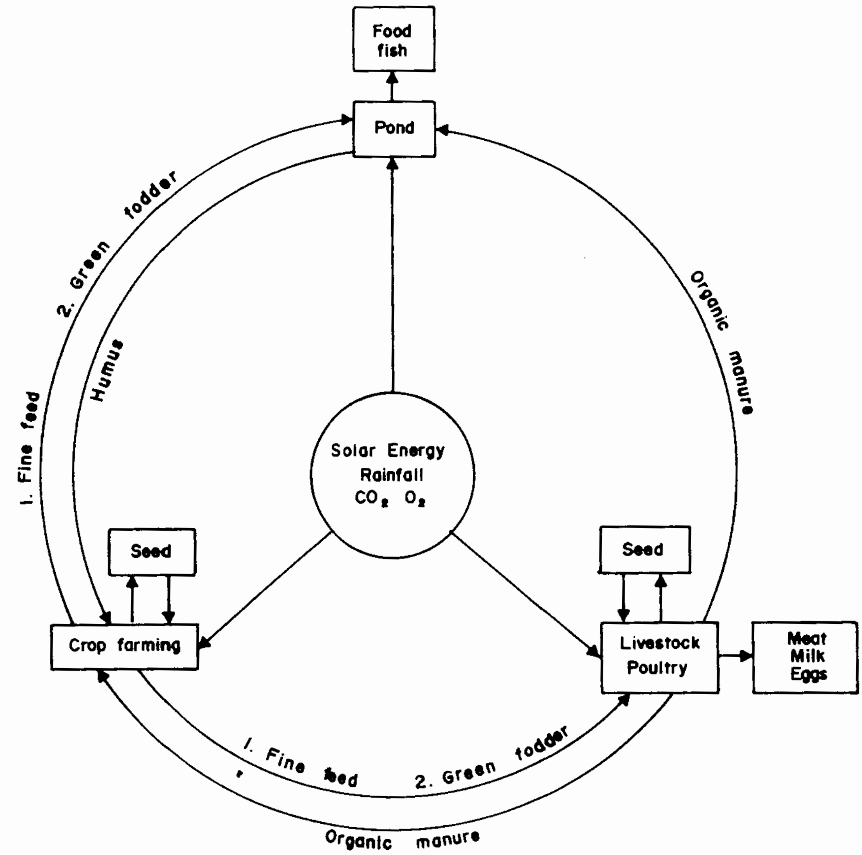


Fig. 7.1. Recycling of material in a well managed integrated fish farm.

or even higher. For example, the Helei Fish Farm in Wuxi not only has 69.4 ha of fish ponds but also has a dairy with 100 cows, pig-pens with 1,000 pigs, and duck yards producing 10,000 eggs/day. It is now a subsidiary food-production base that integrates aquaculture, industry, and commerce. Fish farming is combined with livestock and poultry farming, with fish farming having priority. The fish farm not only supplies enough fertilizer to produce a large quantity of fish but also produces pork, eggs, milk, poultry etc.

The scope of integration in an integrated fish farm can be considerably wide. Geese and ducks may be raised on the pond, pond dikes may be used for fruit tree and mulberry cultivation or for raising pigs, and dike slopes may be used for fodder crops. Thus, an integrated fish farm can produce not only fish but also meat, milk, eggs, fruit, vegetables, etc. Integrated fish farming can fully utilize the water body, the water surface, the land, and the pond silt to increase the food available for human consumption.

Employment

Because of the varied nature of an integrated fish farm, more jobs are available than on a unitary fish farm. For example, on Helei there are 149 jobs related to integrated farming of fish and other products. Among these there are 48 people involved in duck farming, 19 in cow farming, and 14 in pig farming.

Increased output and economic benefit

The current problem in aquaculture is the prohibitive cost of pelleted feeds. This is related to the shortages of energy and protein. The integrated fish farm produces feeds and fertilizers for itself, thereby saving energy and reducing expenditures. For example, in 1981, Helei Fish Farm produced 5.5×10^6 kg of pig manure, 1.85×10^6 kg of cow dung, 1×10^6 kg of duck manure, and 9.5×10^6 kg of wastewater from the silk-extracting workshop. Therefore, the total amount of organic fertilizer produced was 17.85×10^6 kg. The utilization of animal excreta as fertilizer could reduce the production costs of a fish pond by about 97 yuan/mu.

Helei Fish Farm began to raise ducks, cattle, and pigs in 1976, became involved in the food-processing industry in 1979, and began to actively trade produce in 1980. From 1977 to 1981, the fresh fish yield increased from 115,000 to 600,000 kg (the same area). The yield of livestock and poultry increased from 135,000 to 490,000 kg. By 1981, the average per-capita income had increased by 120.8 per cent since the establishment of the fish farm in 1966 (Fig. 7.2). The annual net fish production of integrated fish farm in China could reach 6,000 kg/ha by using only organic manure.

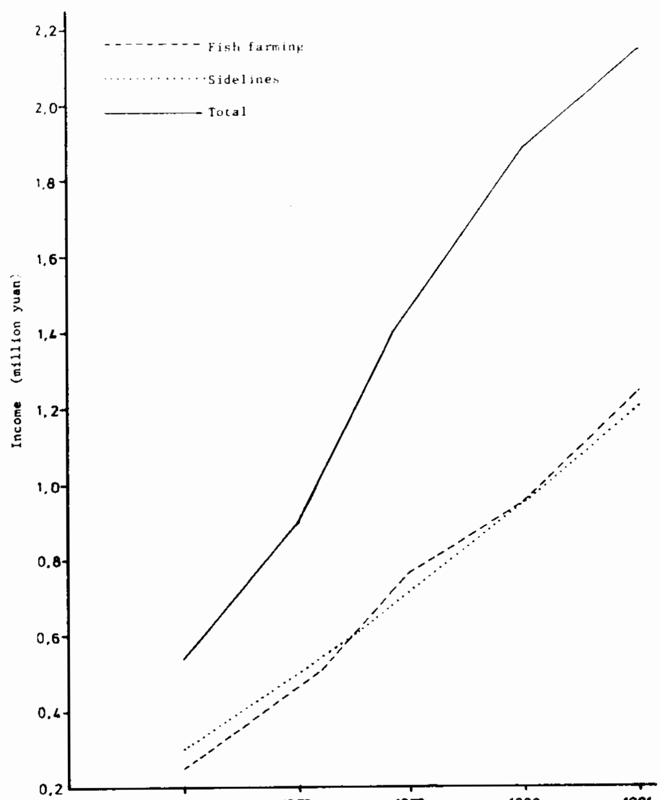


Fig. 7.2.(a) Increase of income of Helei Fish Farm, Wuxi, from 1977 to 1981.

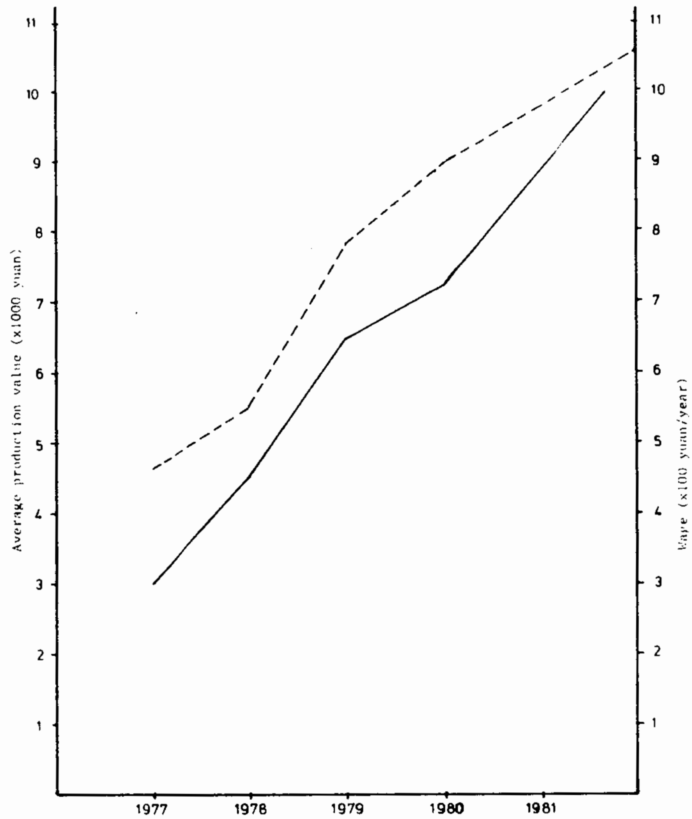


Fig. 7.2.(b) **Average production value and wages of workers of Helei Fish Farm, Wuxi, from 1977 to 1981.**

The Characteristics of Chinese Integrated Fish Farming

China is a vast country with a large population and varied natural environments. The agricultural structure and economic conditions of each locality can be quite different. Therefore, various integrated fish-farming practices have developed into complicated structural networks unique to local conditions. The Pearl River Delta is located south of the Tropic of Cancer. The annual solar radiation is 110 kcal/cm^2, the average temperature is 22°C, there are 2 or 3 days of frost per year; there is more rain and higher temperature in the summer (maximum temperature, 37°C; relative humidity, 76-85 per cent), and the annual amount of sunshine ranges from 2000 to 2500 h. Such geographic and climatic conditions are conducive to the cultivation of mulberry trees, sericulture, and fish farming. Hence, the farmers of the Pearl River Delta have been able to take advantage of local natural resources by integrating mulberry cultivation and sericulture with fish farming, leading to the establishment of a complete "mulberry plot-fish pond" man-made ecosystem.

In the same geographical region, the items of integration may be completely different. Helei Fish Farm, Xinan Fish Farm, Helei First Fishery Brigade, Wangzhuang Fish Farm, and the Municipal Fish Culture Farm in Wuxi have different items of integration (Figs. 7.3, 7.4, 7.5 and 7.6). Liutan village has recently incorporated agriculture, sideline occupations, aquaculture, and commerce into its integrated system. The farm site was originally a 17.33-ha water-logged paddy field, subject to annual flooding and with a low yield of agricultural crops. Based on the topography of the land, the farmers restructured the land into 10.67 ha of fish ponds in the winter of 1979 and the spring of 1980. The farm consists of 15 grow-out ponds (8 ha) and 11 fingerling ponds (2.67 ha). Apart from pig raising, green fodder farming is the major item of integration. There is 1.33 ha of pond dykes, and this area is used for the cultivation of ryegrass (*Lolium perenne*) and sow thistle (*Ixeris denticulata*). A wild rice stem (*Zizania latifolia*) field was used to cultivate duckweed, with an average yield of 37,500-45,000 kg/ha. Grass carp and wuchang fish are the dominant cultured species, with a yield of 5250 kg/ha (45 per cent of the total fish production). This example indicates that maximum efficiency of an integrated fish-farming system can only be obtained through the proper use of the natural conditions and the agricultural characteristics of the particular region.

Socio-economic conditions should be considered when developing an integrated fish-farming system. The development of a diversified economy depends on the harmonious interaction between socio-economic conditions, agricultural production, and regional environmental conditions. Because the development of an integrated fish-farming system is site-specific and because each site is unique, the integrated systems in China are becoming more and more complex. Simple models involving the mono-integration of fish-cum-animal husbandry, fish-cum-poultry, or fish-cum-crops are disappearing in China, except in small-scale individual farms.

There are various methods of utilizing organic wastes in an integrated fish-farming system.

Fresh animal manure can be applied directly to the fish ponds. Pigpens, poultry coops, and pens for ducks and geese can be constructed on the dikes or above the ponds. Fresh manure thus enters the ponds directly, and energy losses as a result of processing and transportation are avoided. Livestock feeds that are not fully digested can be directly utilized by the fish. The number of animals should be compatible with the pond area.

Residues of anaerobic fermentation to produce biogas can be used to fertilize fish ponds. The compost remaining after fermentation can also be used for pond fertilization.

Animal manure can be used indirectly through one or two trophic levels in a food chain. For example, animal manure is used to grow fodder crops that are used to feed herbivorous fish, it is also used to produce earthworms or other animal feedstuff for carnivorous fish, or as a component of pelleted feeds.

Poultry manure can be used to feed pigs and pig manure can, in turn, be used for pond fertilization.

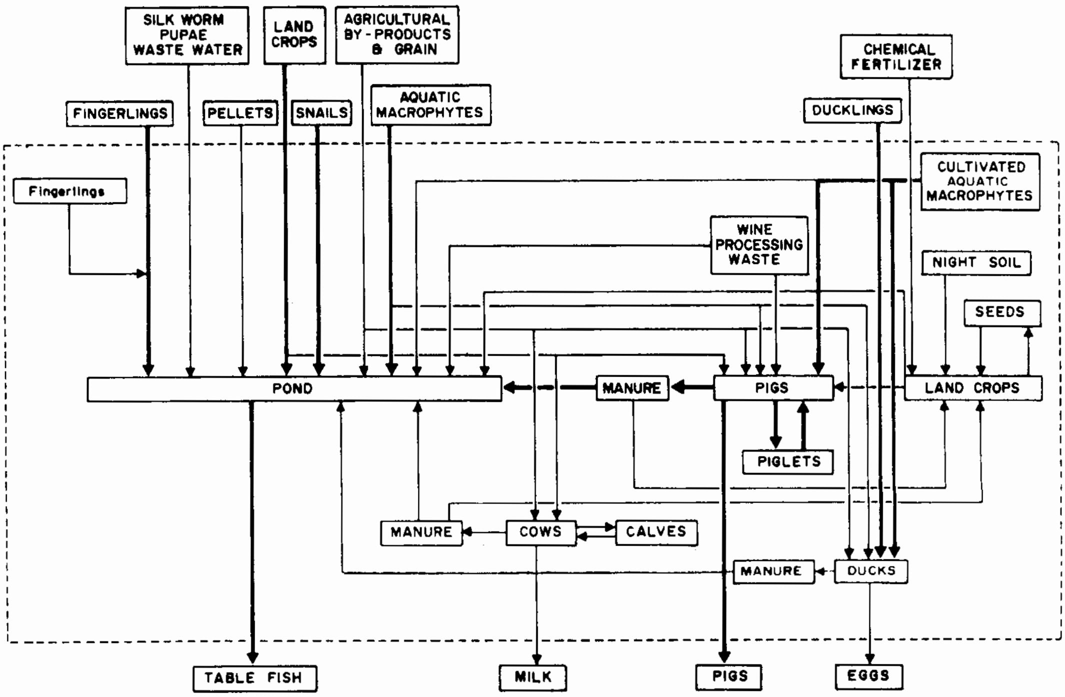


Fig. 7.3. Xinan Fish Farm, Li Yuan People's Commune.

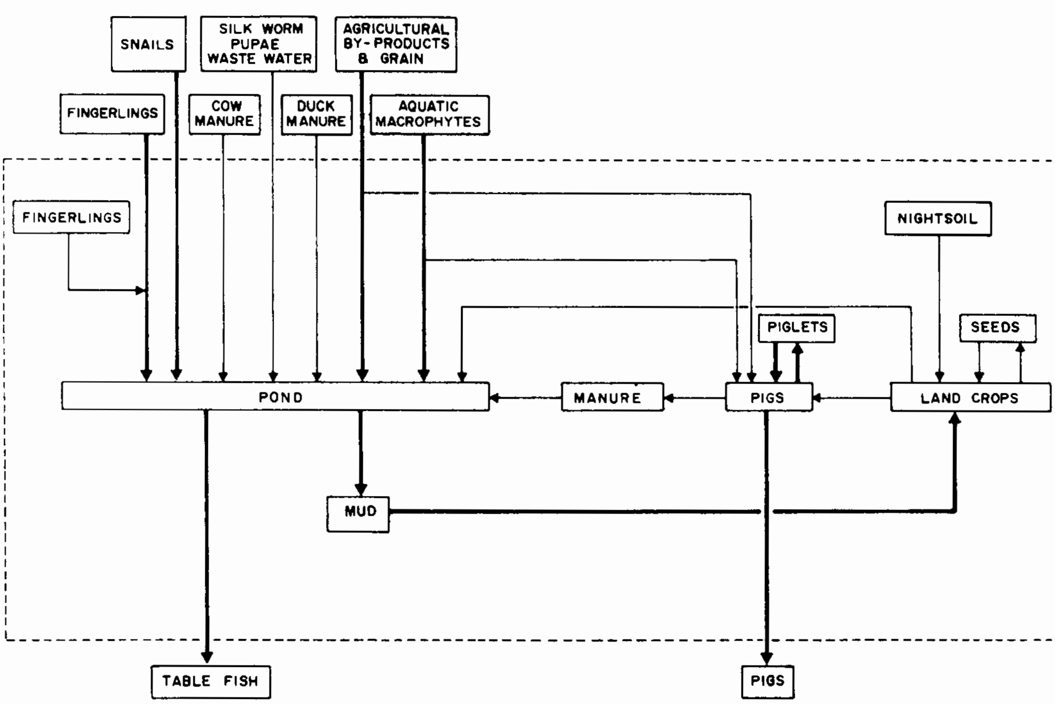


Fig. 7.4. Fishery Team Number 1, Helei People's Commune.

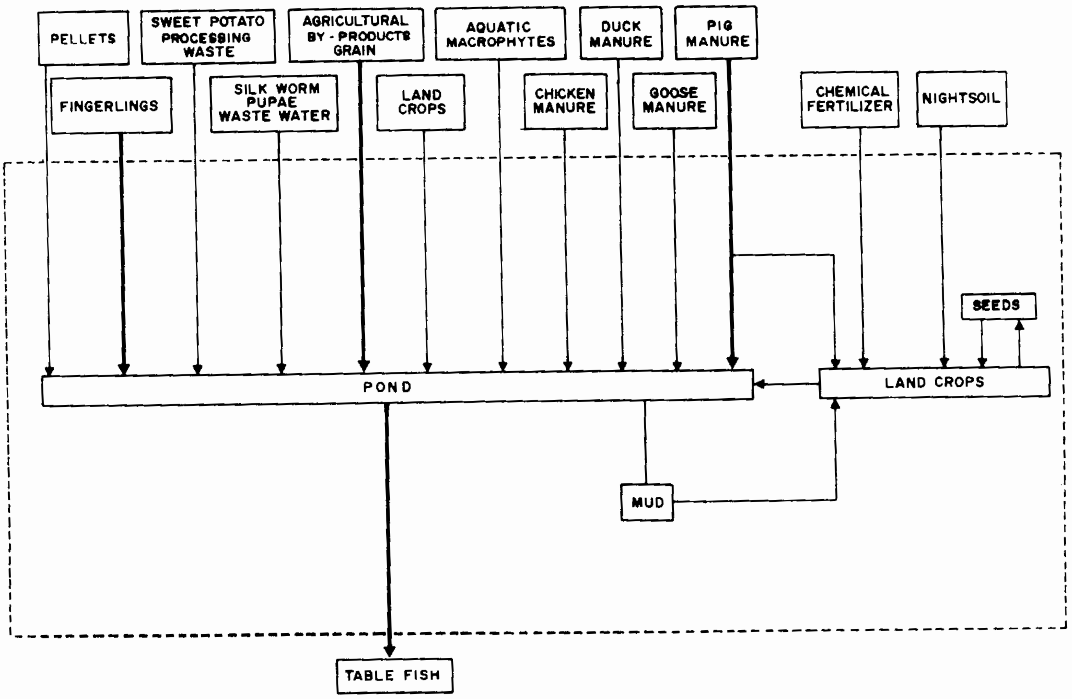


Fig. 7.5. Wang Chuan People's Commune Fish Farm.

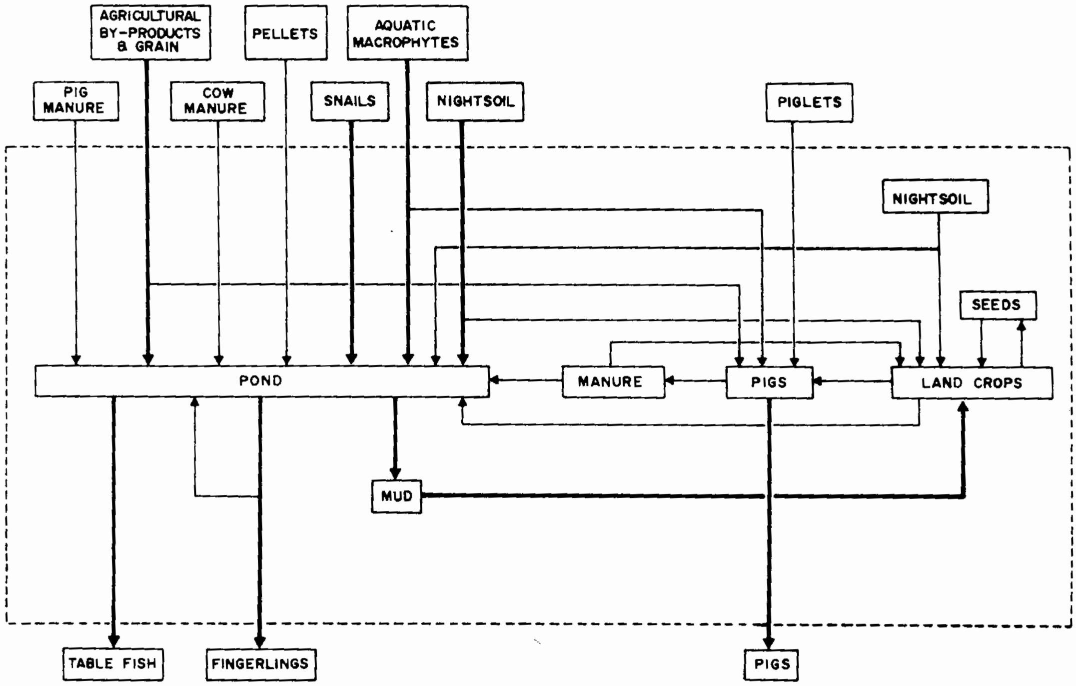


Fig. 7.6. Wuxi Fish Farm, Li Yuan People's Commune.

Further Development and Research Needs

The prosperity of the agricultural economy and the application of new technology stimulated and improved production in integrated fish farming. For example, the use of mechanized aerators to a certain extent, raised the production efficiency of classical Chinese fish culture. Although integrated fish farming has long been practiced in China, much experience has been gained through years of improvement, and considerably high yields have been achieved, the scientific basis for some of the existing techniques still needs clarification.

To raise further the efficiency of integrated fish farming, the biological basis of integrated fish-farming must be studied and aquaculture technology must be developed. In theory, two ecosystems must be clarified. First, the structure and function of the integrated fish-livestock-crop ecosystem must be studied, with the goal of establishing an optimal ecosystem. Second, the pond ecosystem must be studied.

Structural research concerns the biological interactions between fish, livestock, and crops and their matched proportions. Material cycling and energy flow should be measured to clarify their biological and quantitative relationships. In the integrated ecosystem, crops are producers, livestock and fish are consumers, and aquatic and soil microorganisms are decomposers; it is a complete ecosystem. In this system, proper energy circulation demands that there be no wastage in any link of the system and the production not be hindered by a lack of energy. For these reasons, the fish pond ecosystem must first be thoroughly studied.

A manure-loaded pond is a semiclosed, artificial ecosystem. Animal manure added to the pond is decomposed by bacteria. The conversion of animal manure into fish protein is a complex process involving physical, chemical, and biological (food chain) factors. To investigate the relationships between biological and non-biological factors, the cooperation of scientists from various disciplines such as aquaculture, ecology, botany, microbiology, and chemistry is required.

Integrated Management of Fish and Crop Farming

Fish-cum-crop integration is the oldest and most popular form of integrated fish farming in China. Fish farming and crop cultivation can be combined because of the demand for fish feeds and the excess of pond silt. On the one hand, abundant silt deteriorates the pond water and, on the other hand, pond silt is a high-quality manure for crop cultivation. These crops can in turn be used as fish feeds. Therefore, pond silt is the link in fish-cum-crop integration.

Formation and Function of Pond Silt

Large quantities of feed and manure are added to the fish ponds every year. This results in a considerable amount of residue settling on the bottom of the pond. Moreover, fish and aquatic animal excrement and bodies, and alluvial soil also settle on the bottom of the pond. The organic material decomposed by bacteria forms a great deal of humus, which combines with the sludge on the bottom of the pond to form silt.

The thickness of the silt depends on many factors. Even in the same pond, silt thickness may vary with location. The mean silt thickness in a high-yielding earthen pond with a target yield of 500 kg/mu and no slope protection is 10-20 cm. This translates to an annual accumulation of 50-95 m^3/mu (100-190 wet weight).

An appropriate amount of silt is beneficial to the pond as a fertilizer; however, an excessive amount of silt is detrimental to water quality. It accumulates rapidly when large quantities of feeds and manures are applied. The pH of the water will decline, the biological oxygen demand (BOD) will increase, and nitrites and gases such as NH_3, H_2S, CH_4 and PH_3 will accumulate and harm the fish. The median tolerated limits (Tlm) of silver carp and bighead to NH_3 over 24 h at a temperature of 25°C are 0.91 and 0.46 mg/L, respectively. Grass carp is more susceptible to NH_3 (Lei Xingzhi et al. 1983). Surplus nitrites will induce haemorrhagic septicemia in the fish. Silt contains a lot of ichthyopathogenic parasites and other harmful organisms. The thicker the silt, the more the pond water will deteriorate. Fish yield is directly affected. Thus, excess silt should be removed after the pond is drained.

There is a large amount of organic matter sediment in pond silt. Pond silt often lacks oxygen so that the fermentation of organic matter is restricted. Part of oxidation is hindered and part of it proceeds in a reversible reaction. Thus, large quantities of transition and inorganic reduction materials settle to the bottom of the pond and the surface of the pond silt. These materials have a strong affinity for oxygen. In an intensive fish pond, convection of the upper layer and the bottom layer often occurs at night. When the upper-layer water, with a high dissolved oxygen content, comes down, the oxygen consumption of the inorganic material in the pond silt abruptly increases; inorganic reduction material and water respiration also increase. This is the main reason why fish surface and gasp for air during the night.

Silt is a high-quality manure containing several nutritive elements (Tables 7.1 and 7.2).

The nitrogen content of the annual accumulation of pond silt per mu is equivalent to 481 kg of ammonium sulphate (Table 7.2). In the Pearl River Delta and the Taihu Lake basin, pond silt is removed 3 to 6 times every year. Generally, two-thirds of the silt is removed annually and per mu, this is equal to 1.2 t of NPK fertilizer. The quick-acting component of the silt is equivalent to 119 kg of fertilizer. As a fertilizer, silt increases the thickness of the cultivation layer, improves the soils particle structure, strengthens its ability to absorb N, P and K, and improves the soil's capacity to hold water. It is also a slow-acting fertilizer, which is beneficial to late crops.

If only silt is used as a fertilizer, 100 kg of silt (dry weight) can produce 10 kg of ryegrass. The annual removal of 50 m^3/mu of silt is sufficient to cultivate 6

Table 7.1. Nutritive content of various silts.

Silt variety	Organic material (%)	Total N (%)	Total $P(P_2O_5)$ (%)	Total $K(K_2O)$ (%)	NH_3 N (ppm)	NO_3 N (ppm)	Quick-acting P (ppm)	Quick acting K (ppm)
Pond silt	2.45	0.20	0.16	1.00	273	6	97.0	245.0
Silt in pig manured pond	2.10	0.20	0.33	2.39				
Silt in pond with composite feeds and manures	3.23	0.21	0.27				22.5	562.2
River silt	5.28	0.29	0.36	1.82	1.25	1.4	2.8	17.5

Table 7.2. Equivalent weight of fertilizers (kg) to pond silt.

Fertilization	Total NPK		Quick-acting NPK	
	100 kg/dry silt	Annual dry silt/mu	100 kg dry silt	Annual dry silt/mu
Ammonium sulphate (21% N)	0.962	481	0.134	67
Urea (46% N)	0.435	217	0.061	31
Calcium superphosphate (16% P as P_2O_5)	1.000	500	0.061	31
Potassium oxide (60% K as K_2O)	1.667	834	0.041	21

mu of rice, producing 500 kg rice/year. If the same amount of silt is used to cultivate ryegrass, production could reach 6000 kg/mu. The yield per unit of paddy field using 10-15 t of silt composed with green grasses is close to that obtained when 5 t of composed animal manure is used. In addition, the cost of digging silt in China is less than the cost of purchasing animal manure from outside the fish farm.

Feed Demand Fish Farming

The demand for both commercial feeds and natural food organisms in fish farming is great; however, their supply can be limited. In addition, transportation costs and energy consumption are surprisingly high. A fish pond with a target net yield of 250 kg (100 kg of herbivorous fish, 100 kg of plankton-eating fish, and 50 kg of omnivorous fish) needs 1500 kg of aquatic grass, 1000 kg of vegetables, and 150 kg of grains in addition to 3000 kg of pig manure. To meet the demand of commercial feeds and natural foods and to reduce costs, fish farming should be combined with crop cultivation.

Feasibility of Fish-cum-Crop Integration

Aquaculture can provide large amounts of silt and fertile water for agriculture and land on fish farms has much agricultural potential. The average pond dyke is 3 m wide with a slope gradient of 1:1.5 to 1:3. The mean area of a fish pond is 10 mu. The average ratio of arable land area (pond dyke and slope) to water surface area is 1:5. There is more arable land before May, when the water level in the pond is low. With an extra 0.3 mu of forage field attached to 1 mu of fish pond in addition, all the areas already available the ratio of arable land area to water surface area could reach 1:2 or even higher. Aquatic plants can also be planted on scattered, unused surface.

It is necessary and feasible to integrate fish farming with crop production to fully utilize pond silt, arable land, and water surface. As a result, the demand for fish feeds can be wholly or partially satisfied.

Fish-cum-Terrestrial Crop Integration

All or most parts of the crops planted in the fodder crop field and corner plots on the pond dykes and slopes are used as green fodder for the fish and as fertilizers for the ponds. This is the most popular pattern in fish-cum-crop integration.

Crop variety

Crops that are palatable to the fish, rich in nutrition, resistant to disease, easy to manage and have well-developed roots to protect the slope should be used. If the crop serves as a straw manure, it should decompose easily (Table 7.3). The average yield of some leguminous plants (e.g. *Trifollium repens, Trifollium pratense, Medicago sativa, Astragalus sinicus*) can reach 5000-7500 kg/mu. These grasses serve as both feeds and fertilizers. The average yield of some gramineous plants (e.g., *Pennisetum purpureum, Phalaris arundinacea, Pennisetum alopecuroids x Pennisetum purpureum*) can reach over 10,000 kg/mu. The seeds and young crops of other grains such as barley, wheat, maize, and rice are also palatable fish foods. The tender, juicy vines and leaves of sweet potatoes (*Ipomoea batatas*) and squash (*Cucurbita* sp.) are pulverized and fed to grass carp in the Wuxi area. Cooked tuber and squash are fed to feed eaters.

Collection of production period

Ingestive variation between fish is due to different growth characteristics and environmental conditions. Among environmental conditions, seasonal variations in water temperature are important. Production periods, therefore, must be collocated with peak fish ingestion times to synchronize daily foddergrass production

Table 7.3. Main terrestrial fodder crops and green manure.

Varieties	*Yield (kg/mu)*	*Sowing time*	*Seed (kg/mu)*	*Sowing type*	*Harvesting time (months)*	*Use*	*Food conversion rate (FCR)*
Rye grass and *Lolium pcrenne*	5,000-10,000	Aug-Sept	2.0-2.5	Spreading drilling and transplanting	June-Dec.	Stalk as food	17-23
Sudan grass	7,500-13,000	April	2	Drilling, spreading dibbling and transplanting	May-Oct.	Stalk as food	19-28
Ixeris denticulata	5,000-75,000	Mar-Aug	1	Drilling, spreading	May-Sept.	Leaves as food	30-35
Symphytum peregrinum	7,500-12,500	Mar-Apr	2,500 seeds	Transplanting	May-Oct.	Leaves as food	40-45
Chinese cabbage	2,000-3,000 (per crop)	4-5 crops a year	0.75-3	Spreading and transplanting	4-5 crops a year	Leaves as food	40-45
Cabbage	2,000-4,000 (per crop)	3-4 crops a year	0.75-2	Spreading and transplanting	3-4 crops a year	Leaves as food	40-45
Broad bean (young plant)	3,000-7,500	Oct-Nov	10-15	Dibbling	Jan. & Apr. (cutting)	Stalks as food	40
Soybean	50-130	Mar or June	6.0-7.5	Dibbling	July & Oct.	Bean milk as feed, bean cake as manure	3

with daily fish feeding. The periods of lowest ingestion by cultivated fish in the Changjiang River drainage are February-March and November-December. Peak ingestion occurs between June and September accounting for 50 per cent of the annual total ingestion (Fig. 7.7).

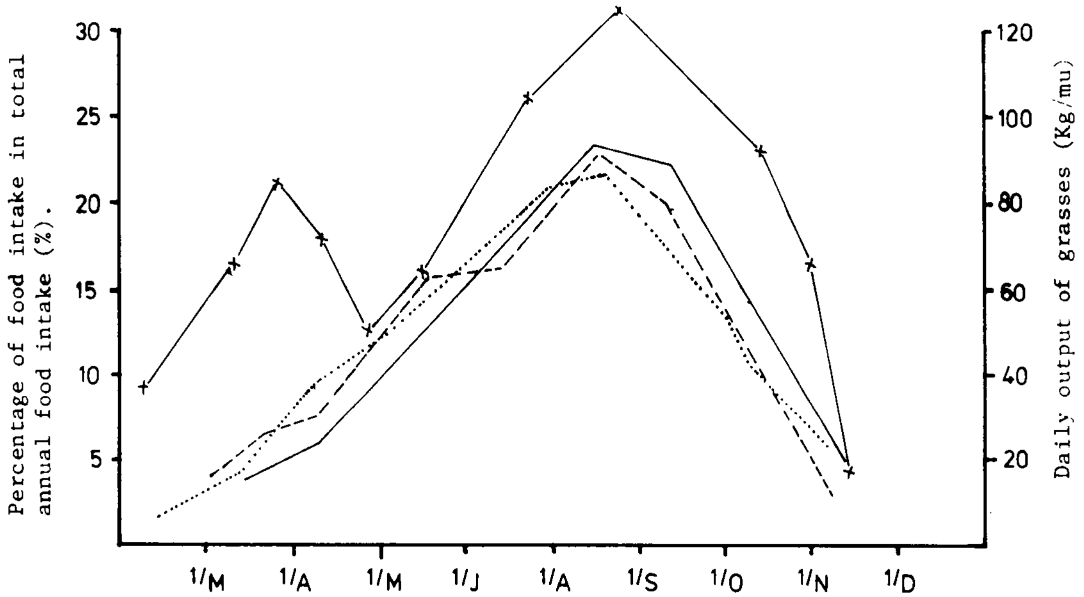


Fig. 7.7. Annual variation in food intake of fish (——, in Shanghai area; - - - - - -, in Linhu area; . . . . . ., in Wuxi area.) and daily output of ryegrass and Sudan grass (x – x).

The production mode of Italian ryegrass and sudan grass coincides with fish feed demands. Ryegrass is sowed in September, transplanted in October and mowed in December in the Changjiang River drainage. Peak production occurs between April and May (Table 7.4). Enough ryegrass alone is produced on the integrated fish farm to sustain the fish. Sudan grass is sowed in mid-April and mowed for the first time when it reaches 50 cm in height, just before ryegrass withers and dies. Peak production occurs between June and September (Table 7.4). The daily output is about 100 kg/mu. The annual production of the two grasses can reach 15,000 kg/mu under proper management. There are three other methods of collection. First, gramineous grasses (ryegrass, sudan grass) and leguminous fodder grasses can be intercropped. Using this method the unit area output of the two families of fodder grasses will be increased and the quality will be improved. Second, an ensiling method can be adopted if there is a surplus of ryegrass or ryegrass can be pelleted with other materials to ensure a sufficient feed supply during the crop change in June. Third, sowing and transplanting can be conducted in stages and the grasses can be mowed in turn (Fig. 7.8).

In the Changjiang River drainage, sudan grass seeds are sowed by stages in April and can be mowed in mid-May. To maintain the fertility of the land, pond

Table 7.4. Monthly production (kg/mu) of sudan grass and rye grass.

	Dec-Feb	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sept*	*Oct*	*Total*
Sudan grass				250	2,350	4,000	3,000	1,400	400	11,400
Rye grass	1,800	1,250	1,800	2,000	650					7,500
Total[a]	1,800 (9.5)	1,250 (6.6)	1,800 (9.5)	2,250 (11.5)	3,000 (15.9)	4,000 (21.2)	3,000 (15.9)	1,400 (7.4)	400 (2.1)	18,900 (100.0)

[a] Values in parentheses are percentages of the total grass production.

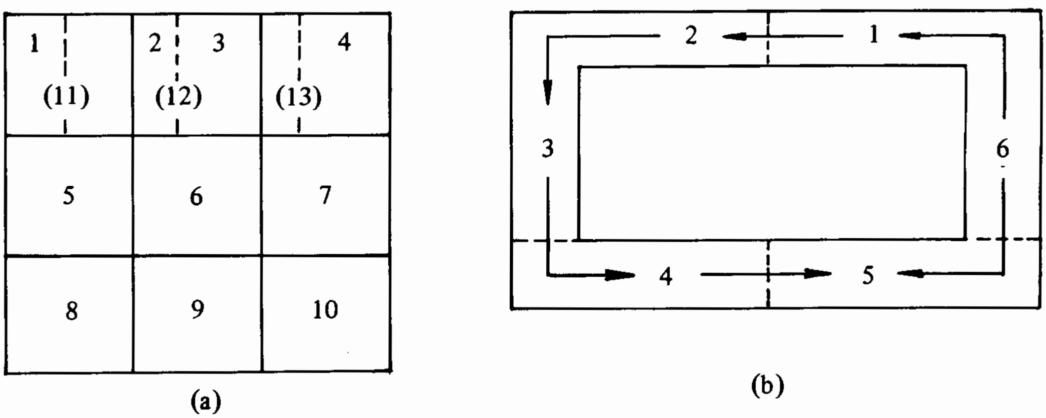


Fig. 7.8. Rotational operation of fodder crop plots.

(a) fodder crop plots 1, 2, 3, 4 initial mowing areas
(b) pond dyke

silt must be fully utilized and some additional organic fertilizers must be used. In addition, the grasses should be harvested such that a "stubble" remains in the field.

Water surface to crop area ratio

The water surface to crop area ratio refers to the total area of cropland collocated with 1 mu of culture pond. The following factors must be taken into consideration: source and cost of feeds and fertilizers; quantity of land; yield and stocking ratio of the various fish and crop species. For a self-sufficient system, the necessary crop area can be calculated by one of the following methods.

Non rotational cultivation – If only one kind of fodder crop is cultivated, the crop area can be calculated using equation 7.1:

$$S \quad \frac{\sum_{f=1}^{n} Y_i F_i}{PN} \qquad [7.1]$$

Where S is the crop area (mu) collocated with 1 mu of fish pond Y_i is the target net yield (kg/mu) of herbivorous fish and other grain feeders in polyculture pond, F_i is the food-conversion factor of the same feed for herbivorous fish and other grain feeder, P is the average output of the crop (kg/mu) and N is the number of consecutive crops (N >-1). If several food conversion factors are approximately the same or if there is only one food-conversion factor, equation 7.1 can be simplified:

$$S = \frac{Y F}{P N} \qquad [7.2]$$

If several crops are planted at the same time, the crop area of each species can be calculated separately according to their different feed requirements and then added together. Another method involves using the most common feed as a standard to calculate the numerator of the equation, i.e., the feed demand:

$$M = \sum_{i=1}^{n} Y_i F_i \qquad \text{or } M = YF$$

The demand of other feeds is calculated according to equation 7.3:

$$m = M' \times \frac{f}{F} = M\ R \qquad [7.3]$$

When m is the amount of the other feed (kg), which is equivalent to the deficient part of the standard feed needed, M' is the unavailable standard feed, f is the food-conversion factor of the other feed, F is the food-conversion factor of the standard feed, and R is the ratio of the other feed to the standard feed.

After the requirement of each crop is calculated, it should be divided by the average annual yield of the crop per mu, i.e., the denominator of equation 7.1. The total and specific areas of crop fields can then be calculated. For example, if 50,000 kg of clover is required, 10 mu of fields must be cultivated: however, if only 6 mu of clover are planted, only 30,000 kg can be produced. The remaining demand for 20,000 kg of clover should be met by Chinese cabbage. The food-conversion factor of clover is 25; that of Chinese cabbage is 40. Each Chinese cabbage crop can produce 2000 kg/mu. According to equation 7.3, the shortage of clover (20,000 kg) is equivalent to 32,000 kg of Chinese cabbage. This demand can be met by planting five crops of Chinese cabbage on 3.2 mu. The total area of crops, therefore, is 9.2 mu. If the feed supply is not adequate for the system, the purchase requirement can be calculated using equation 7.3.

Rotational plantation – When two or more crops are planted in rotation in a year, only one crop should be used as the standard feed because it is difficult to calculate fish yield in the middle of the production period.

$$M = \sum_{i=1}^{n} Y_i F_i \qquad \text{or } M = YF$$

We can calculate the requirement for the whole year. The requirement for the standard feed in certain period of rotational cultivation can then be calculated using the following equation:

$$M = \sum_{i=1}^{n} Y_i F_i r \qquad = YFr$$

The area of a certain crop in a specific period of rotational cultivation can be calculated as follows:

$$S = \frac{\sum_{i=1}^{n} Y_i r f_i}{PN}$$

$$\text{or} \qquad S = \frac{Yrf}{PN} \qquad [7.4]$$

For example, a fish farm wishes to produce 300 kg of grass carp (net yield) by planting grass to feed the fish. In the first half of the year, ryegrass is planted; in the second half, sudan grass is planted. Ryegrass yields 6,000 kg/mu; sudan grass, 10,000 kg/mu. The food-conversion factors are 20 and 30 respectively. The food intake in the first half of the year accounts for 30 per cent of the total annual food intake. What is the crop area collocated with each mu of fish pond (water surface)?

Assuming ryegrass is the standard feed, the demand for the whole year is 6000 kg/mu. Therefore, 1800 kg is needed for the first half of the year. They should plant 0.3 mu of ryegrass. According to the equation 7.4, the demand for sudan grass is as follows:

$$M = 300 \times (1 - 30 \text{ per cent}) \times 30 = 6300 \text{ kg}$$

Therefore, 0.63 mu of sudan grass, should be planted.

Grains, melons, and yams can only be used 3 months after planting. Therefore, with a long period of cultivation, the requirements for grains, melons, and yams should be calculated separately and should be planted 6 to 12 months before fish rearing.

In the Changjiang River drainage, about 0.3 mu of ryegrass, including pond dykes and slopes, is collocated with 1 mu of fish pond. There is also about 0.6 mu sudan grass or *Pennisetum alopecuroids* X *Pennisetum purpureum*. If the water and manure are well managed, grass yields can reach 8000 kg. This amount of grass might be converted into 400 kg of fish (net yield), if over 300 kg are herbivorous and the rest are filter-feeding or omnivorous fish. If the crop area is expanded, surplus fodder can be silaged and used as feed for the second half of the year. Thus, the crop area could be somewhat reduced. The areas devoted to the two crops may be equal.

Fish stocking models – In many fish farms, the main or sole source of feed and fertilizer is the cultivated pasture grasses. The major species should be: silver carp and bighead (20-30 per cent) and assorted omnivorous fish (10 per cent). The omnivorous fish not only can utilize residues and detritus but also clean the fish pond for the herbivorous fish. To supply natural food organisms to silver carp and bighead after stocking, mow the grass and make a compost to fertilize the pond water, or stock silver carp and bighead 2 weeks after stocking grass carp. If the farm produces a lot of compost, the proportion of omnivorous fish may be increased a little.

The use of pond silt

Pond silt can be directly used as a base manure for fodder crops. The silt should be harrowed and smoothed after it dries; the seeds can then be sowed. There is no need to harrow with a transplant field. To save labour and time, the seedlings could be interpolated. If the silt is used as an additional manure, it should be dressed-top to the roots of the plant. In the summer, silt is applied to the fields with water. This method is beneficial to the release and diffusion of nutritional elements. It also improves the dissolved oxygen content of the bottom layer of water.

Pond silt and grass can be used to make a compost. There is usually a surplus of pond silt in the winter and a shortage of pond silt in the summer. Therefore, in the winter dig a pit 5 x 5 m with a depth of 1 m near the crop field and fill it with pondsilt and grass (straw manure and stable matted grass are preferable) and cover the pit with mud. After fermentation, the manure is more effective. The compost is usually used as a base manure, but is sometimes mixed with water and used as a top-dressing.

Pond silt is a safe manure. The amount applied is not necessarily limited, with an average rate of 5-15 t/mu or a thickness of up to 35 cm.

Economic efficiency

Fish-cum-crop integration increases the number of feed and fertilizer sources, the feed source is relatively stable, the cost could be reduced by one third, and the quality of feed and fertilizer is high. In addition, the energy consumed in transporting and purchasing feeds and fertilizers could be reduced.

Fish farming is seasonal work. The input of labour varies greatly. In the slack season, excess labour can be used for crop production. This provides more jobs and increases incomes.

A well-managed fish-cum-crop integration is a self-sufficient system. Pond silt is used to fertilize the fodder crops that, in turn, are used to feed the fish. As the fish grow, pond silt accumulates. This cycle fully utilizes the sunlight, land, pond silt, and fertile pond water and improves the ecological condition of the pond; it has been reported that planting grass on pond dykes reduces the soil erosion by 57 per cent.

Rotation of Fish and Grass

Because of the noncontinuity of fish farming production, most nursery ponds and grow-out ponds are left fallow for a period of time, e.g., a yearling rearing pond is left fallow from November to June of the next year. During this period, fish ponds can be used to plant green fodder or green manure crops, leading to the full utilization of the fish ponds.

Single-pond rotation

Fish and grass are "rotated" in the same pond. This method is usually adopted after transferring the fingerlings to other ponds.

Drain the pond, trim the pond dyke, smooth the bottom, dig a drainage ditch, and then sow ryegrass or barnyard grass seeds on the pond bottom and the slope. The seeds of ryegrass are broadcasted in November at a rate of about 2 kg/mu and barnyard and rice seeds are generally sowed in late April or early May in Jiangsu Province. To extend the growing period, germinated seeds could be sowed in the first 10 days of April at a rate of 5-6 kg/mu.

After sowing, birds and water depth must be controlled and different field management techniques must be adopted for different plants. Ryegrass is a dry crop and cannot endure waterlogging. Barnyard grass seedlings prefer to grow in water with a depth of 5-6 cm. During their growth period, both grasses can be used as green fodder. Ryegrass can be harvested four times, with a yield of 3000-5000 kg/mu; barnyard grass and rice can be mowed once with the yield of about 2000 kg/mu.

The last rationing plants should be submerged for fermentation as manure; The amount of grass should be controlled to 4-5 kg/m^2, and water should be added to a level of about 2 m. These controls will ensure sufficient oxygen in the pond water. Summerlings are stocked 11-15 days later. After stocking, water quality must be closely monitored, adding fresh water accordingly.

Barnyard grass can be mowed and submerged in stages on the basis of their growth and then different summerlings can be stocked by groups.

Multipond rotation

With a set of fish ponds, a few can be used to grow grass or green manure crops. Because grow-out ponds have a short fallow period, a few ponds are drained and planted with grass as early as possible and stocked with fish later than the other ponds. This extends the growing period of the grass. The other ponds are stocked with fish first. This system continues on a rotational basis. One or two fish ponds, used to grow crops, can provide feed to the fish in the other ponds (Fig. 7.9).

Effects of fish and grass rotation

Fish and grass "rotation" fully utilizes the potential productivity of the fish ponds to provide both green fodder crops for fish and green manure crops to pro-

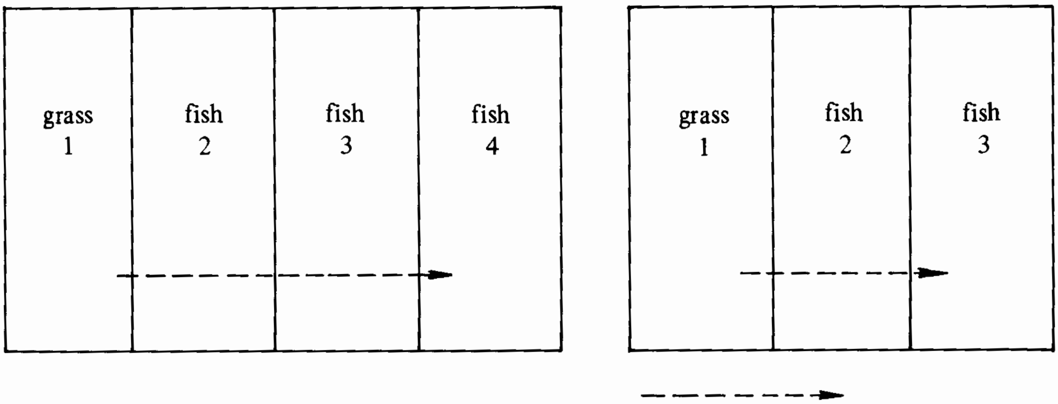


Fig. 7.9. Multi-pond rotation.

pagate the natural food organisms in the pond. At the Suzhou Municipal Fish Farm, phytoplankton reach a peak density of 3 x 10^8/1 and the growth of summerlings is 1.8-2.5 mm/day in the first month. If the annual yield of barnyard grass in a pond is 5000 kg, 40 kg of grass can be transformed into 1 kg of fingerlings. It can economize on 0.5-0.8 kg of commercial feeds and reduce 10 per cent of the cost.

In this system, crops utilize the nutrients in the pond silt. After submergence, crop nutrients return back the pond, improving water quality and increasing soil fertility. In practice, fish yields do increase after the submergence of crops. For example, Suzhou Municipal Fish farm, which adopted this method had experimented in 1979, increased average annual yield ever since: from 150 to 391 kg/mu in 1982.

Fish-cum-Aquatic Plant Integration

In a network of rivers such as the lower reaches of the Changjiang River, a fish farm is often near lakes, rivers, waterlogged areas, or inlets and outlets of irrigation canals. These bodies of water are rich in nutrients, especially effluent from cities and fish farms. Fish farmers in southern China often culture aquatic plants in these water bodies. The principal aquatic plants cultured are the "three Ap's" i.e., water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratistes*), and water peanut or alligator weed (*Alternanthera philexeroides*). Secondary aquatic plants include duckweeds such as *Spirodela polyrhiza, Wolffia arrhiza,* and *Lemna minor.*

The output of aquatic macrophytes is highest with greeen fodder crops. The yield ranges from 15 to over 25 t/mu. In fact, aquatic macrophytes grow too fast, causing many problems in the tropics and subtropics. Aquatic macrophytes, however, have a high nutritive content (Table 7.5).

Water hyacinth is known as the "king of aquatic plants". Per unit area, it produces 6-10 times more protein than soybean. Aquatic macrophytes are easy to manage with less labour and lower costs. One person can manage about 50 mu of

Table 7.5. Nutritive contents of "three aquatic plants".

	Dry matter (%)	*Crude protein (%)*	*Crude fat (%)*	*Non-N extract (%)*	*Crude fibre (%)*	*Ash (%)*	*Ca (%)*	*P (%)*	*Yield (ton/mu)*
Alligator weed	9.2	2.18	0.18	2.49	1.19	1.25	0.23	0.03	15-25
Water lettuce	4.6	1.07	0.26	1.63	1.10	1.30	–		10-20
Water hyacinth	7.3	1.90	0.25	2.21	1.11	1.33	0.11	0.03	10-26

three aquatic plants and can produce 13.1 crude protein in 6 months. The cost of 1 t of three aquatic plants (including wages) is only about 1 Yuan.

To produce feeds in a variety of sizes for the various species of fish, the three Ap's are processed in different ways. To nurture fry, three Ap's should be mashed into a paste. After filtering out the residue of the leaves, the paste is sprinkled over the whole nursery pond. Table salt, 2-5 per cent of the weight of the plant should be added to the water-peanut paste to counteract the toxic effects of saponin. The equivalent ratio of the three Ap's to soybean in fish farming is 17.5:1 to 25:1; 5 kg soybean will nurture 10,000 summerlings, as will 87.5-125 kg three Ap's. However, soybean costs 13-18 times that of three Ap's. In addition, when supplied with three Ap's, fry grow faster and with higher survivability than with soybean. For example, the Zhang Aquaculture Brigade, Wuxian County, stocked 80,000 fry in 1977, after 16 days of nurturing, the transfer size was 3.33 cm with a 94.6 per cent survivability from the pond supplied with water-peanut paste; in the pond supplied with soybean milk, however, the transfer size was 2.93 cm with a 92.8 per cent survivability.

The three Ap's are especially good to rear fingerlings of silver carp and bighead. The plants should be mashed into a paste, but the residue could not be removed. To rear adult fish, with herbivorous fish as the major species, three Ap's are often pulverized with a green fodder crops pulverizer and fed to the fish.

Experiments show that about 45 kg of three Ap's can be converted into 1 kg of fish. The macrophytes per mu can be converted into more than 400 kg of fish. If rice and wheat brans are used as feeds, 1600 kg of brans is needed to produce the same amount of fish. The cost of three Ap's is about 10 per cent that of brans, but three Ap's are less effective if they are not processed. Moreover, since the contents of N, P, and K in three Ap's are high, grass paste could also serve as manure in fish ponds.

The three Ap's are also palatable to various animals in integrated fish farms. For this purpose, they need little or no processing. The rate of utilization, therefore, is high: with a small amount of wheat and rice brans, 900-1000 kg of three Ap's can rear one piglet to an adult with a body weight of 60-70 kg. The excreta of one pig can be converted into more than 40 kg of fish per year. In Helei Fish farm, water hyacinth is fed to ducks at a daily rate of 150 g/duck with a little wheat and rice brans. Feeding 22,000 ducks, this method can save 10,000 Yuan over 6 months. The excreta of one duck (about 52 kg) can be converted into 3 kg of fish per year.

Dyke Pond System

On some farms, the broad dyke crown around a fish pond is devoted to economic crops (mulberry, sugarcane, fruit trees, etc.) or to intercropping grains and grasses; mulberry plot-fish pond is the most common combination. According to historical records, mulberry cultivation and fish farming can be traced back to the 5th century B.C.; however, a well-linked dyke-pond system did not exist until the 16th century. Most dyke-pond systems are in the Pearl River delta and the Taihu Lake basin.

This system includes mulberry cultivation, sericulture, silk extraction, and fish farming using silkworm feces, silkworm pupae, and waste water. Mulberry is the producer, silkworm is the first consumer and fish are the second consumers, ingesting the silkworm feces directly (Fig. 7.10; 7.11.). In the fish ponds, there are four energy-flow patterns:

- Silkworm feces are directly consumed by the fish and part of the detritus is filtered by the filter-feeding fish.
- Inorganic nutrients in the silkworm feces are utilized by phytoplankton and heterotrophic bacteria and these phytoplankton and bacteria are, in turn, consumed by filter-feeding fish, either directly or indirectly.
- Leftover feeds and fish feces are decomposed by hydromicrobes, releasing inorganic nutrients; and then, the same process occurs as in paragraph above.
- At the same time, pond silt which is composed of all kinds of sediments returns to the pond dyke and the new material cycle begins.

Pond silt

Pond silt is the main source of manure for crops on the pond dyke. Silt from 1 mu of pond can fertilize 1-2 mu of pond dyke. In the winter, pond mud (more silt than water) is removed from the fish ponds after draining and applied between mulberry bush lines on the pond dyke or bailed (with a little water) onto the pond dykes and spread evenly after drying. Winter crops are then planted between mulberry bush lines. In the summer and the autumn, liquid silt, known as "nihua" (less silt than water) is bailed onto the pond dyke after mulberry leaves have been picked once or twice. This is performed 2 or 3 times in the Pearl River delta and 5 or 6 times in the Taihu Lake basin every year. Soil is increased in fertility and, when the base thickness of the soil plants increases by 5-6 cm, subsequent crops also benefit.

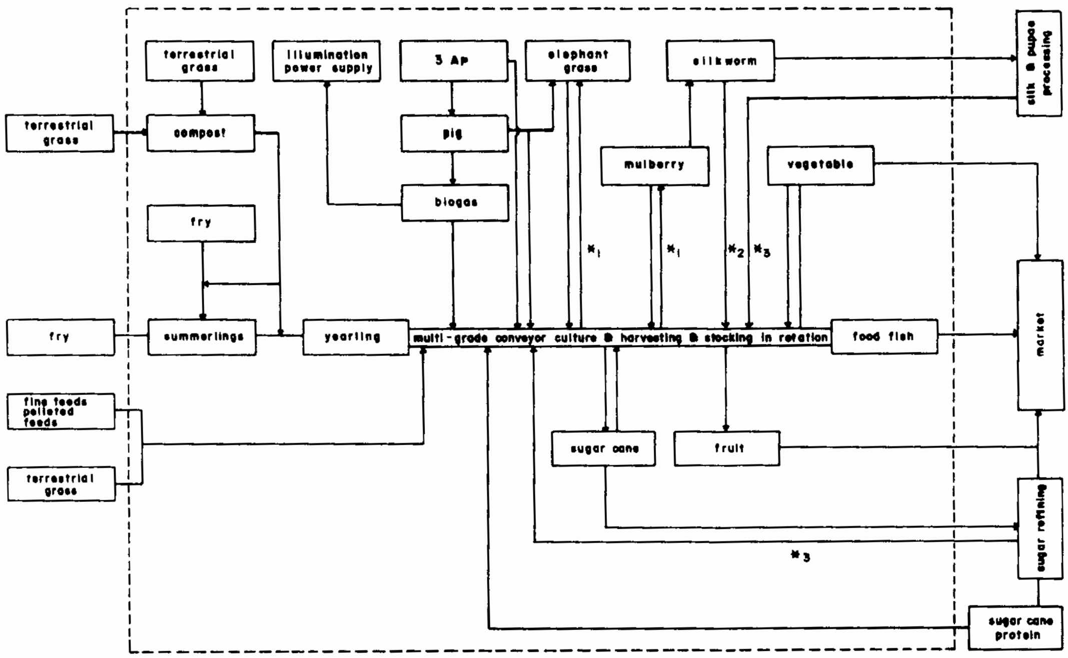


Fig. 7.10. Network of Dyke-Pond System in Pearl River Delta.

Note: *1 Silt; *2 Silkworm dregs; *3 by products and the wastes from sugar refining and silk extracting; dash line means out of the unit

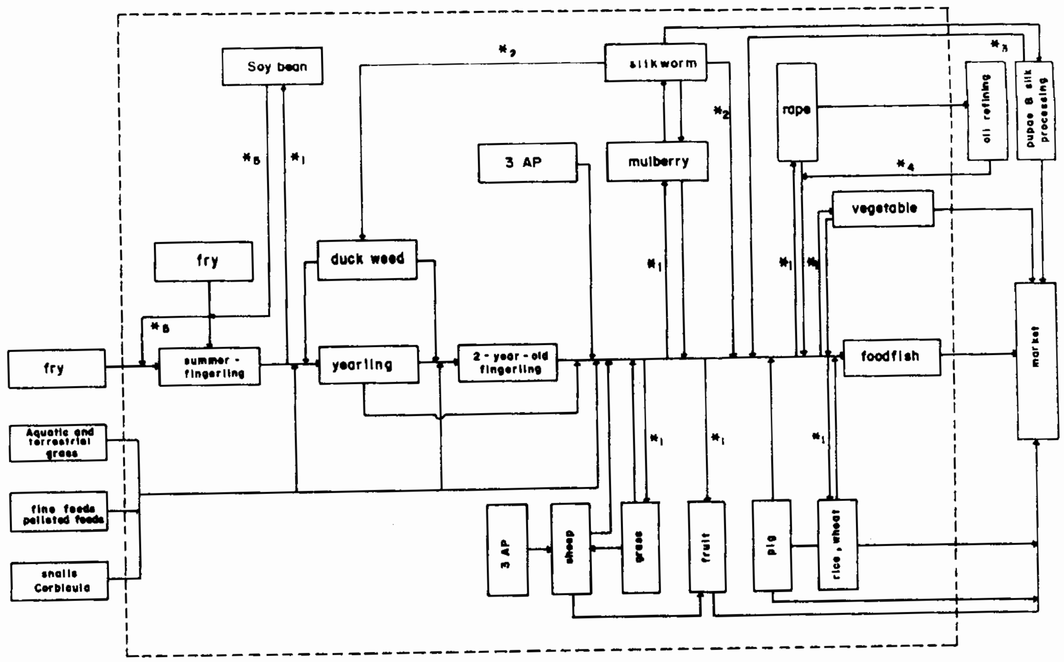


Fig. 7.11. Network of Dyke-Pond System in Taihu Lake Basin.

Note: *1 silt; *2 silkworm dregs; *3 pupae and waste water from pupae; *4 rapeseed cake; *5 soyabean milk; dash line means out of the unit

Feeds

Mulberry plots supply fish feed directly or indirectly. Pasture grass, vegetables, and mulberry leaves, can be grown, harvested, and applied directly to the pond. Grasses and vegetables, which are planted after mulberry leaves are harvested in the autumn, can be harvested at a rate of 3000 kg/mu. This converts into about 100 kg/mu of herbivorous fish and 40 kg/mu of other fish.

To provide feeds indirectly, silkworm wastes, which are a mixture of silkworm feces, worm sloughs, and mulberry leaf residues, can serve as both fertilizers and feeds. They are rich in nutrients (organic material, 87 per cent; N, 2.2-3.5 per cent; P_2O_5, 2.0-2.5 per cent; K_2O_2, 1.5-2 per cent; several trace elements), having a higher nutritive content any livestock or poultry manure. Mulberry plots can annually produce 2400-2500 kg/mu of mulberry leaves. When fed to silkworms, 100 kg of mulberry leaves can produce 30-50 kg of silkworm waste. Therefore, a 1-mu mulberry plot produces an average of 980 kg/year of silkworm waste. The food-conversion factor of silkworm wastes in fish ponds is 8; therefore, 980 kg of silkworm waste (1-mu plot) can be converted into around 125 kg of fish.

Pupae, which are by-products of the silk extraction of cocoons, are an appropriate feed for herbivorous fish and grain feeders. Pupae are 55.8 per cent protein and 29.1 crude fat. Their food-conversion factor is 1.5-2.0. In the Pearl River delta, a mulberry field annually produces 160-175 kg/mu of pupae. Of this, about 130 kg/mu can be obtained and used as fish feed. This amount of pupae can be converted into 90 kg of grain feeding, herbivorous, filter-feeding, and omnivorous fish. Wastewater, which is obtained when cocoons are steamed and processed at the factory, contains large amounts of protein detritus and soluble protein. According to practice, 200 kg of wastewater can be converted into 1 kg of fish. Around 2500 kg of waste water can be obtained from the processing of cocoons gained from sericulture on a 1-mu mulberry plot. Therefore, 12.5 kg of fish can be produced with the wastewater obtained from a 1-mu plot.

Integrated Management of Fish-Livestock-Poultry Farming

Fish-cum-Duck Integration

Fish-cum-duck integration is common in China. This type of integration utilizes the mutually beneficial biological relationship between fish and duck.

History

Duck raising in fish ponds is an ancient practice in Asia and Europe. In 1934, the German scientist, Probst, conducted the first experiments on integrated fish-cum-duck farming. He raised ducks in common crop fish ponds and found that one duck could increase annual fish yield by 0.9-1.7 kg/mu. Because the output of fish in the experimental fish pond at that time was rather low, the increase in fish yield as a result of the ducks was conspicuous. The outbreak of World War II halted this research.

After World War II, there was a shortage of food, especially animal protein, in Europe and Asia. This prompted the development of intensive commercial fish farming. Hungary, Czechoslovakia, and East Germany began conducting large-scale management experiments on fish-cum-duck integration around 1952.

To date, fish-cum-duck integration is chiefly practical in China, Hungary, East Germany, Poland and the Soviet Union. Fish-cum-duck integration has developed into a fixed model of integrated fish farming. In recent years, this model, either on the scale aspect or on the managerial aspect, has been developing very rapidly. This is especially true in areas containing a network of rivers (e.g., Jiangsu and Zhejiang provinces).

Beneficial interactions

A fish pond is a semi-closed biological system. In fish ponds, there are many aquatic animals and plants, most of which are natural food organisms of fish, some are detrimental to fish but can be utilized by ducks. Fish ponds provide ducks with an excellent, essentially disease-free environment. Ducks consume juvenile frogs, tadpoles, and dragonfly larvae, thus eradicating many predators of fry and fingerlings. Furthermore, the protein content of these natural food organisms of duck is high. Therefore, duck raising in fish ponds reduces the demand for protein in duck feeds. For ducks raised in pens, the digestible protein content in the feed must be 16-20 per cent; for ducks raised in fish ponds, the digestible protein content can reduce to 13-14 per cent. This can save 200-300 g available protein for each duck, equivalent to 2-3 per cent the duck feed. Duck dropping go directly into the pond, providing C, N, and P and stimulating the growth of natural food organisms. This direct fertilization of the pond has two merits: first, there is no loss in the availability of manure; second, direct fertilization is more homogeneous and avoids any heaping of duck dropping. For these reasons, raising ducks on fish ponds promotes fish growth, increases fish yields and eliminates pollution problems that might be caused by excreta in a duck pen.

The organic substance content of duck dropping is 3-5 times that of human excreta; the N content is 1.5-2.2 times and the K_2O content is 2.6-3.1 times that of human excreta. The quality and quantity of duck excreta, however, are dependent on species, feeds applied, culturing management, and climatical conditions. In Europe, the stocking rate of ducks in the summer is generally 300-500 ducks/ha and each duck produces about 7 kg of dropping during the 36-day fattening period. If 500 ducks are raised, 3500 kg of excreta would be produced in that period. The moisture content of duck excreta is 56.6 per cent; organic substance, 25.2 per cent; C, 10 per cent; P_2O_5, 1.4 per cent; N, 1 per cent; K_2O, 0.62 per cent; Ca, 1.8 per cent; and others. Each egg-laying duck annually produces 7.5-10 kg (dry weight) of excreta (equivalent to 70 kg wet weight). Each egg-laying duck raised at the Helei Fish Farm Wuxi, annually produces 40-45 kg (wet weight) of manure.

Duck feeds are fully utilized in fish-cum-duck integration. Duck lose 10-20 per cent (23-30 g/day) of their feed. This feed can be directly consumed by fish.

Fish-cum-duck integration also promotes the recycling of nutrients in the pond ecosystem. In shallow areas, a duck dips its head to the pond bottom and turns the silt to search for benthos. By virtue of this digging action, nutritional elements deposited in the pond humus will be released. Ducks also act as pond aerators. Their swimming, playing, and chasing disturbs the surface of the pond and aerates the water.

Barash et al. (1982) reared common carp, tilapia, silver carp, and grass carp with ducks in 400 m^2 pond. Ducks were fed with a nutrient-balanced feed pellet. At the beginning of the test, duck manure was applied at a rate of about 85 kg/ha (dry weight). At the end of the test, the rate of application was 95 kg/ha (dry weight). There were no other manure or feed inputs other than duck excreta and spilt duck feed (Table 7.6). Compared with raising ducks in pens, the growth rate, feed efficiency, and vitality and cleanliness of the eiderdown and skin of the ducks raised in fish ponds were better. Daily fish yields reached 36.5 kg/ha. (Table 7.7).

Based on Table 7.7, duck raising in fish ponds has three advantages over raising ducks in pens. The feed efficiency and body weight of each duck is improved. The higher feed efficiency also implies that the split feeds are utilized by the fish. The food conversion factor in fish-cum-duck integration was reduced

Table 7.6 Daily amounts (g) of duck excreta and split feed input into fish ponds.

Time (days)	*Excreta*		*Feed*	
	Wet wt.	*Dry wt.*	*Applied*	*Spilt*[a]
21-30	127	68	194	29(15)
31-40	248	74	227	34(15)
41-50	420	73	248	37(15)

[a] Values in parentheses are the percentages of feed split

Table 7.7. Comparison of duck raising in fish ponds and in duck pens.

	Fish pond			*Duck pen*		
Item	*1977*	*1978*	*Average*	*1977*	*1978*	*Average*
Food conversion factor	3.58	4.01	3.84	3.74	4.13	3.93
Increment of body weight (g/duck)	2,162	1,780	1,935	1,962	1,638	1,801
Survival rate	96.7	99.0	97.8	95.0	93.7	94.3
Daily fish output (kg/ha)	39.1	33.9	36.5	43.4	29.5	36.5
Fish-cum-duck food-conversion factor	2.73	2.55	2.64	–	–	–

from 3.84 to 2.64. The survival rate is increased by 3.5 per cent because fish ponds provide a clean environment for the ducks. Without additional feeds, only dropping and leftover feed, the daily fish output was 36.5 kg/ha. It was originally believed that if fish and ducks were raised in the same pond, the ducks would eat the small fish. Based on many years of experience at the Helei Fish Farm, ducks can swallow a fish with a body weight below 4 g. However, above 5 g, the fish is able to escape from the duck. On Helei Fish Farm, the recovery rate does not decline when silver carp summerlings are stocked in fish-cum-duck ponds. Fry ponds and yearling ponds, however, are unsuitable to raise ducks because the fish are too small and the stocking density is high. Fish-cum-duck integration should only be practiced in fingerling or grow-out ponds.

Duck raising methods

Large groups on open water – This is the "grazing' type of duck raising. The average number of duck in a grazing group is about 1000. The ducks are generally let loose to graze on the rivers, lakes, and reservoirs during the day and are kept in pens at night. This method is appropriate for large bodies of water (lakes, reservoirs, etc.) and fish reproduction. As for fish-pond farms, this method of integration cannot effectively utilize the duck manures, and the only benefit would be the economic return from the duck themselves.

In a centralized enclosure – In this method, a relatively large duck shed, including a workshop for administration, is constructed in the vicinity of the fish ponds with a cemented area of dry and wet runs outside. The average stocking rate is about 4 ducks/m². The dry and wet runs must be cleaned daily. During cleaning, the sluice of the wet run is opened to allow organic manure to be flushed into fish ponds through a manure ditch. After this, the sluice is closed and the wet run is filled with fresh water. This method is advantageous for its centralized management mechanisms, but is unable to fully utilize the leftover and undigested duck feed. It is also unable to take advantage of the duck-fish symbiosis.

In the fish pond – This is the most common method of integrated fish-cum-duck farming. The dikes of grow-out or 2-year-old fingerling ponds are partly fenced to form a dry run and part of the water area or a corner of the pond is fenced with used material to form a wet run. The net pen is installed by 40-50 cm above and below the water surface to save net material. In this way, fish can enter the wet run for food and ducks cannot escape under the net. In a large pond, a small island is constructed at the centre of the pond for demand-feeding facilities. Stocking densities in China are higher than those in other countries, averaging 4.5 individuals/m² of pen shed including the dry run and 3-4 individuals/m² for the wet run.

In the early years of integrated management, fish-cum-duck management went everywhere in the fish ponds to feed; this pattern has been improved. The duck-raising area has been set up to connect the duck shed, the dry run, and the wet run. Whether fish-cum-duck integration succeeds or not primarily depends on technical measures of duck raising. Both meat ducks and egg-laying ducks can be raised in fish ponds. In the summer, 14-day ducklings are accustomed to life on the water surface. The food stocks of meat ducks grow quickly, reaching marketable size (2 kg) in fish ponds in 48-52 days; slow-growing stocks need 55-56 days. Ducks should be marketed as soon as they reach the marketable size or they will lose their feathers, resulting in decreased food efficiency, body weight, and commodity value.

The number of ducks to be raised in fish ponds depends on the quantity of excreta per duck, which, in turn, depends on the species of duck, the quality of feed applied, and the method of raising. In raising Beijing ducks, about 7 kg excreta/duck can be obtained during the 3-day fattening period. The egg-laying Shaoxin ducks raised in Wuxi annually produce 42.5-47.5 kg manure/duck; hybrids of Shaoxin and Khaki-Combell ducks annually produce more than 50 kg/duck. The stocking rate of ducks also depends on climatic conditions and the stocking ratio and density of the various fish species in the pond. In Europe, the stocking rate is usually around 500 individuals/ha. As a result, the increment of fish yield will be 90 kg/ha. In tropical and subtropical zones, Woynarovich (1980) recommended that the stocking rate should be 2250 individuals/ha. In Hong Kong, the optimum stocking rate is 2505-3450 individuals/ha; in Wuxi, 2000 individuals/ha. For meat ducks, the stocking rate should be reduced because of the greater production of excreta. In the Taihu district, 7 or 8 fish species are polycultured in fish ponds. The stocking ratio of the various species remains unchanged when ducks are raised. If the number of ducks exceeds 3000/ha, filter-feeding fish and omnivorous fish should be increased and herbivorous fish should be reduced.

Organic-material stacking won't occur in fish-cum-duck integration on fish pond as long as the stocking rate of ducks is appropriate and the amount of excreta does not exceed the transforming power of the fish pond. Ducks swim loosely in the wet run to search for food, their excreta drop evenly into the wet run, and the fertilization effects of the dropping are felt throughout the pond.

Economic efficiency

The integrated management of fish-cum-duck farming, especially raising ducks on the fish ponds, is economically efficient. In 1980, the Helei Fish Farm conducted a comparative test between two adjacent, 1-ha ponds (13 and 21). Pigsties were set up on the dyke between the two ponds. Pond 13 was stocked with 2207.5 kg of fingerlings and 1900 egg-laying ducks without any input of manure. Pond 21 was stocked with 2188.5 kg of fingerlings. The species and size of fish and the feeds applied were the same in both ponds. The output of pond 13 was 12,234 kg; that of pond 21 was 10,464 kg (85 per cent of pond 13).

The stocking rate of egg-laying ducks was 1830-1920 ducks/ha. Apart from economizing input of 300,000 kg organic manure/ha, fish yields can be increased by about 17 per cent over ponds without duck raising. Based on the data and calculations, the average rearing period of a duck is 10 months and 2.5-5.5 kg of fish is produced by raising one duck. Each egg-laying duck also produces around 200 eggs/year (260-300 eggs/year for hybrids). The Helei Fish Farm raises around 20,000 ducks/year, providing 850,000 kg of duck manure. In 1980, the farm showed a net profit of 42,000 Yuan from duck raising. With 48 farmers, this translates to an average annual income of 881.25 Yuan/farmer.

An accurate economic analysis of fish-cum-duck integration is impossible because of the variations in production costs, duck yields, and fish yields in different countries. Even in the same district, fish and duck species, stocking densities, quality and efficiency of feeds, rearing-management techniques, and climatic conditions vary greatly. Examples, such as the following, however, can be cited.

In 1981, the Helei Fish Farm raised 22,000 ducks. Apart from providing 1,000,000 kg of duck manure, 212,695.9 kg of duck eggs and 6059 kg of duck meat were harvested. This translates to 24,315 kg marketable of animal protein, which is equivalent to 215,560 kg of grass carp protein. The total annual income was 57,740 Yuan: 10,800 Yuan from duck meat, 42,000 Yuan from duck eggs, and 4,940 Yuan from duck excreta. Duck raising accounted for 24.62 per cent of the total profit of the farm.

From the viewpoint of input-output relationships, fish-cum-duck integration is the best model of integrating fish, livestock, and poultry. From a micro-economic standpoint, the economic efficiency of fish-cum-pig integration is not as good and profit is low. Fish-cum-chicken integration lacks any symbiotic relationship and, although a symbiosis exists in integrated fish-cum-geese farming, the egg-laying rate of geese and the market demand are rather low. Protein inputs and outputs in integrated fish-cum-duck and fish-cum-cow farming are similar; however, it is much easier to raise ducks than to raise cow and the economic efficiency and income generated from fish-cum-duck farming far exceeds that of fish-cum-cow farming. For example, in 1981, a worker at the Helei Fish Farm produced 292.6 kg of protein from cows while his counterpart produced 506.6 kg of protein from ducks (73 per cent higher). The net profit per capita of fish-cum-cow farming is 1,067.9 Yuan; that of fish-cum-duck farming is 1,427.08 Yuan (33.6 per cent higher).

Integrated management of fish-cum-duck farming can be further developed to achieve even higher economic efficiencies. High-yield aquatic plants can be cultivated as duck feeds and wastes from integrated fish farming and the city proper can be used to raise earthworms, an additional feed for ducks. At the output end, products (fish, ducks, and eggs) could be further processed before marketing. This could considerably increase economic efficiency and income.

Fish-cum-Pig Integration

Fish culture combined with pig raising is a traditional integrated fish-farming model in China. However, simple fish-cum-pig integration is becoming less common in China; this pattern is usually part of a fish-livestock-agriculture integration, which is a complete man-made ecosystem. Some other countries are now also engaged in fish-cum-pig integration. Since 1974, Dr. Buck has conducted experiments on the utilization of pig manure in fish farming. In 1977, he polycultured Cyprinidae in a test pond with silver carp as the major species. The annual output was 4585 kg/ha.

From economic viewpoint, pigs can be raised at loss, a balance, or a profit. Combining pig raising with duck raising and fish farming, not only increases economic efficiency but also increases social and ecological efficiency. The leftovers and residues from kitchens, aquatic plants, and products and wastes from agriculture and side occupations are often used as pig food. Pig excreta, in turn, are used as organic manure in fish ponds. Pork is a main subsidiary food of the people and pig excreta make a high-quality manure. For these reasons, fish-cum-pig integration is common in rural China.

Pig-manure application

To effectively utilize the pig manure, the method of application must be appropriate. There are two types of pigsties in China: the simple pig shed constructed on the pond dyke or over the water surface and the centralized hog house. Both types have advantages and disadvantages. The simple pigsty is more suitable to households because of its lower cost and because of small-scale farms. The pig excreta can automatically flow or be flushed into the fish ponds; this saves much labour. If the area of a fish pond is less than 8 mu, a pigsty can be set up on the pond dyke and pig wastes will flow directly into the pond. If more than 30 pigs are raised in the same spot, there is too much manure for the direct-flow method. Manure is often heaped near the pigsty, causing a partial deterioration in water quality. Fish surfacing increases (dissolved oxygen content decreases) when pig manure sinks to the bottom of the pond or when too much manure flows into the pond.

In a centralized hog house, it is easy to concentrate the manure into a storage pond or a sedimentation basin. The application amount can then be controlled by various means. Centralized hog houses are suitable to large-scale integrated fish farms.

After dilution, the manure can be spread along the pond dyke manually from a small boat. In a large fish pond, the use of a boat and a mechanical spreading apparatus will facilitate an application of manure. When an outboard motor boat is used for fertilization, an iron cage loaded with manure is hung alongside the boat. The grids of the cage are 2.0-2.5 cm apart. When loaded with manure, the cage must hang 10-20 cm below the water surface. As the boat moves, the resulting current will spread the manure evenly throughout the pond. Alternatively, the manure can first be diluted and then pumped evenly from the boat into the pond.

The liquid manure in a sedimentation basin of a large-scale integrated fish farm can be piped to the pond and then sprayed over the pond surface. Each nozzle should deliver an average of 200 l/min of liquid manure and should be fixed 0.5-1.0 m above the water surface. The nozzle can also serve as an aerator by spraying water when the dissolved oxygen content of the pond water is low. In fish-cum-pig integration, the water quality must be constantly monitored. This is because of the lack of oxygen in the pond and the digotiophic pond water. Besides, the production period of pigs should match the demand of pig manure in fish farming.

The productive periods of pig and fish farming are quite similar. There are two cycles of hog production every year: mid-February to mid-August and mid-July to mid-January. Of the total manure applied to the fish pond, 60 per cent is applied during the first half of the year. Base-manure application peaks in January and February and the application of additional manure peaks in June and July. Usually, no manure is applied after mid-October. Growth and manure production peaks during the latter part of the first production period. The excreta produced can just meet the fertilizer demand of fish farming. The excreta produced from November to January serves as the base manure for fish farming in the next year.

Number of pigs to be raised

The number of pigs raised per unit area of fish pond on integrated fish farms ranges from 1 to 5/mu. The precise number of pigs to be raised depends on the amount of manure required to maintain a sufficient supply of fish food. This is calculated through production experiments in line with local conditions. In China, a fish pond is often given various kinds of organic manures (e.g., pig manure, cow dung and other animal manures). Therefore, the quantity of pig manure must be reduced correspondingly.

The capacity of a fish pond to accept animal manure depends upon the techniques of application and the nature of the manures. In Hungary, the growth period of fish is 150-180 days. If pig manure is applied by stacking in a corner, the rate of application is 100-134 kg/mu of fish pond. If the so-called "Hungarian" carbon-manuring technique is adopted, fresh pig manure mixed with pond water is spread over the whole pond at a daily rate of 20-40 kg/mu. This is equivalent to 1000-1500 kg/day of condensed liquid manure or 1.2-2.5 m^3/day of solid pigsty wastes.

In theory, the maximum capacity of a fish pond to accept manures is 2 to 3 times the above mentioned values. However, manure capacity depends on environmental conditions, the quality of the manure, managerial techniques, etc.

Cultured fish species

The production efficiency of fish-cum-pig integration depends on the full utilization of the food organisms by the fish in the pig-manured pond. In the 1950's, when pig manure was first used in Hungary to culture fish, two problems were discovered. First, because of uncontrolled manure application, water blooms of *Aphanizomenon flosaquae* and other blue-green algae appeared frequently, causing the disappearance of *Daphnia* spp.. Second, carp could not directly utilize the plankton resulting in a waste of primary productivity.

Filtering species should be stocked in a manured pond. Silver carp and bighead are the best species to control plankton. They can both consume over

220 μm. If the water temperature is above 22°C, silver carp and bighead can filter and eat more plankton and a great amount of detritus and bacteria in a given unit of time. The feed formed after fertilization could be utilized more than ever. In a mono-pig-manured pond, a few grass carp might be stocked to control *Aphanizomenon flosauae* and submerged vegetation. In a monoculture of common carp, 50 kg of pig manure can be converted into 1.25-1.5 kg of fish; in polyculture with common carp as the major species, 50 kg of pig manure can be converted into 1.75-2.0 kg of fish. In polyculture with silver carp as the major species, 50 kg of pig manure can be converted into 3 kg of fish. Because of the varied feeding habits of tilapia, this species serves as a cleaner in pig-manured ponds. In Hubei Province, silver carp, bighead, and tilapia are the main species in pig-manured polyculture; grass carp, common carp, crucian carp, and *Xeno cyprinus* are minor species (Table 7.8).

Table 7.8 The proportion of polycultured species (% of total output) at Honghu and Linghu fish farms.

Fish farm	*Species*[a]							*Net yield (jin/mu)*
	SC	*BH*	*TI*	*CrC*	*CC*	*GC*	*XC*	
Honghu	–	60	21	–	4.9	7.6	6.5	899.0
Linghu	60	10	–	6	10	8	6	864.7

[a] SC, silver carp; BH, bighead; TI, tilapia; CrC, crucian carp; CC, common carp; GC, grass carp; XC; *Xeno cyprinus*

Economic efficiency

Economic efficiency is apparent if the wastes of pig raising are utilized. In Hunan Province, three pigs can support 1 mu of fish pond. In polyculture with silver carp and bighead as the major species, the output of fish could reach 150-200 kg/mu. In tropical and subtropical zones, the temperature is higher and biological processes are generally quicker. Therefore, more pig manure can be decomposed in the pond and, with the proper fish species in polyculture, the utilization rate of pig manure will be higher.

Fish-cum-pig integration can reduce production costs. In 1981, Xinan Fish Farm, Wuxi, produced 3,388,000 kg of pig manure, including 50 per cent flush water. This saved the Fish Farm 14,229.6 Yuan in manure expenditure. The profit from pig raising alone was significant; however, the total revenue increased significantly because pig wastes replaced artificial feeds and inorganic fertilizers, which accounted for 58.8 per cent of the cost of fish farming.

Fish-cum-Cow Integration

Fish farming using cow manure has long been practiced in China. Since the founding of the People's Republic of China, cow farming has developed rapidly, promoting fish-cum-cow integration, which is common in southern China. Integrating fish and cow farming reduces the necessity to purchase fertilizers and fish feeds, and increases the income generated by the fish farm. Moreover, cow manure can be dispersed by hand, saving money, labour, and energy and improving the environment. Employing a part-time worker to conduct small-scale fish-cum-cow integration will not only generate more income for the farmer but also supply fish and milk to the market.

Biological basis

Among all livestock excreta, cow excreta is the most abundant and, in terms of availability, the most reliable. A 460-kg cow annually produces 13,600 kg of feces and 9000 kg of urine. The nutritive content of cow dung, however, is a little less than that of pig excreta (Table 7.9). If 0.024 kg of fresh cow manure is applied to 1 m^3 of water every day, inorganic N and P will be 0.897 and 0.024 mg/L, respectively. These levels are close to the inorganic N (0.97-2.06 mg/L) levels in high-yield fish ponds. The N/P ratio will be 36.9, which is a little higher than the value of the N/P ratio in phytoplankton. This difference limits the population of large phytoplankton. Nevertheless, the average amount of phytoplankton in a cow-manured pond still reaches 19.2+-6.5 mg/L, which is higher than that in control ponds and close to the lower limit of optimum food density (20-100 mg/L) of silver carp and bighead. The average biomass of zooplankton will be 5.61 mg/L, which is much higher than that in an unmanured pond and the zooplankton/phytoplankton ratio will be 1:3.4. Both values are comparable to those in fertile fish ponds. The amounts of organic detritus and bacteria not only surpassed those in unmanured fish ponds but also exceeded those in the pig-manured ponds (Table 7.10).

The increase in natural food organisms, detritus, and bacteria in fish pond enables filtering and omnivorous fish to grow faster. According to experiments conducted at the Chinese Freshwater Fisheries Research Centre, the output of silver carp, bighead, common carp, and Japanese crucian carp in a cow-manured pond is 3.5, 2.8, 3.3, and 2.2 times the outputs in an unmanured pond, respectively (Table 7.11).

The conversion factor of cow manure is 3.15 in dry weight or 21 in wet weight at an average weekly manuring rate of 0.17 kg/m^3 in filtering and omnivorous fish farming. In silver carp and bighead culture, it is 3.3 in dry weight or 26 in wet weight at the same manure input. Further investigation has shown that about 200 kg of cow urine can be converted into 1 kg of silver carp or bighead.

Cows are ruminants and because of the repeated grinding and digestive decomposition catalyzed by the many micro-organisms in the rumina, cow manure is very fine. Cow manure particles sink at 2.6 cm/min; pig manure particles sink at 4.3 cm/min. If the same amount of manure is applied, after 24 h, the density of suspended organic detritus below 0.65 μm in the cow-manured pond (40 mg/L), around 150 per cent is higher than in the pig-manured pond. This 40 mg/L of cow

Table 7.9 Composition of cow and pig excreta.

	Moisture (%)	*Organic material*	*N*	P^2O_5	K_2O
Milk cow dung	85	11.4	0.36	0.32	0.20
Cow dung	80-85	14.6	0.30-0.45	0.15-0.25	0.05-0.15
Pig manure	85	15.0	0.50-0.60	0.45-0.60	0.35-0.50
Cow urine	92-95	2.3	0.60-1.20	trace	1.30-1.40
Pig urine	97	2.5	0.30-0.50	0.07-0.15	0.20-0.70

Source: FFRC Agricultural technical handbook.

Table 7.10 Quantity of natural food organisms in cow-manured and fertile, high-yield ponds.

	Phytoplankton (mg/L)		*Zooplankton (mg/L)*	*Bacteria (ind/mg)*	*Organic detritus (mg/L)*
Cow-manure pond	19.15	6.50	5.61	5.18×10^4	64.44
High-yield pond	46.2	47.8	10.1-15.1	–[a]	67.9-111.2

[a] not available in the original table

Table 7.11. Yield of fish in pond receiving cow manure and in pond without manure.

Species	*Pond receiving cow manure*				*Pond without manure*			
	Gross yield (kg/mu)	*Net yield (kg/mu)*	*Daily weight gain (g/fish)*	*Survival rate (%)*	*Gross yield (kg/mu)*	*Net yield (kg/mu)*	*Daily weight gain (g/fish)*	*Survival rate (%)*
Silver carp	54.4	36.2	0.71	99	15.5	–3.0	0.08	69
Bighead	11.0	6.8	0.55	100	3.9	–1.0	0.04	75
Common carp	17.9	14.6	0.92	93	5.5	0.6	0.06	93
Koy[a]	33.8	12.8	0.37	100	15.7	–2.8	–0.29	100
Total	117.2	70.4		98	40.6	–6.2	–	82

Note: Duration of culture, 115 days; volume of water, 53.4 m^3.

[a] Japanese crucian carp, *Carassius auratus cuvieri.*

detritus accounts for 55 per cent of the total suspended particles in the pond, which is the highest percentage when compared with pig-, duck, or chicken-manured ponds. The suspensibility of cow manure not only enables the fish to obtain more feed but also reduces oxygen consumption caused by manure stacking and avoids the formation of harmful gases. The BOD of cow manure is lower than that of other livestock manures (Table 7.12) because the cow forage has already been decomposed by microorganisms in the rumina. The BOD of 1 kg of cow manure in 5 days is 20.6 g, 32 per cent lower than the BOD of pig manure (30.0 g). (Table 7.12)

Table 7.12 Oxygen demands of different animal manures.

Oxygen consumption index[a]	*Manure*		
	Cow	*Pig*	*Chicken*
BOD (mg/day)	3.66	5.48	6.27
COD (mg/day)	13.7	14.01	14.51

[a] BOD, biological oxygen demand; COD, chemical oxygen demand.

Over 1 week, the lowest DOC recorded in a cow-manured pond was 1.8 mg/L; in a pig-manured pond, the lowest DOC was 1.0 mg/L. The average DOCs in cow- and pig-manured ponds are 4.0 and 3.3 mg/L, and respectively. For these reasons, fish farming using cow manure is safer than fish farming with other animal manures. The Wuxi Centre conducted an experiment in 1983 on the different livestock manures in fish farming. The fish survival rate in cow-manured ponds was around 98 per cent (Table 7.11).

Cow feed mainly on grass and during the grass-growing season (about 7 months), an adult cow requires 9000-11000 kg grass. Around 3000 kg of this grass, however, is leftover. That period of time is the highest ingestion season of herbivorous fish; therefore, this wasted fodder can be utilized as fish feed; the food-conversion factor of terrestrial wild grass is 40-50. In addition, the matted grass in the cow shed can be used as compost for the pond. The leftover fine fodder for cows can also be used as fish feed.

Management

Cow sheds should be built close to the fish ponds to simplify the handling of the cow manure. The feces and urine may be collected separately. In this case, the former is transported by conveyer, boat, or car and spread evenly over the pond and the latter is pumped directly into the fish ponds. If the floor of the cow shed is higher than the pond dike, a manuring ditch can be dug to collect the feces and urine together and the mixture can be flushed directly into the fish ponds. This method saves time and labour. These methods, however, often result in the stacking of manure and uneven fertilization. The best method is to mix the feces and urine and evenly pump them into the fish ponds. A hose pipe with a spray nozzle gives the best results. For a large pond, a boat dragging a stern manure bucket can be used. The manure is spread evenly by the waves.

The area of fish pond to be matched with one milk cow depends on many factors including the amount of cow manure and wasted food; the species ratio and target output of fish; the sediment of the pond; the quality and quantity of pond humus; and the quality and quantity of other manures and feeds applied. If the fish culture depends entirely on cow manure and wasted cow feed and the net production target is 250 kg, of which 10 per cent is herbivorous fish and 90 per cent is filtering and omnivorous fish, each milk cow can provide manure and feed for a pond area of 2 mu. If the proportion of herbivorous fish and grain-feeders increases, the method of calculation is shown in the empirical equation (see Chapter 8) related to manure demand and quantity of livestock and poultry in model plan.

The frequency of manuring depends on the conversion of the cow manure, which changes seasonally, and the fluctuation of food organisms in the fish ponds. In 1983, the Freshwater Fisheries Research Centre measured nitrogen concentration and food organism populations at different water temperature in a fish pond manured once a week. All nutritive factors had two peaks during the week. The highest peak appeared when the water temperature rose. From this study, the following guidelines on frequency of manuring were established. In late winter and early spring, with sufficient base manure, manure should be applied in large quantities once every 5-7 days. In spring and autumn, manure should be added once every 3 days. In summer, manure should be applied in small quantities everyday, making adjustments according to weather, water colour, and fish growth.

Cow feces and urine are beneficial to filtering and omnivorous fish culture. Therefore, silver carp and bighead are usually the major species with assorted omnivorous fish (common carp as main minor species) and herbivorous fish (15-20 per cent). The optimal output of herbivorous in fish-cum-cow integration should be around 12 per cent of the total output of the pond. With more herbivores, supplemental feeds must be applied.

Economic benefits

Fish-cum-cow integration produces both milk and fish, increases revenues and decreases expenditures, reduces unemployment, and saves energy. After three births, each black-and-white milk cow produces around 5000 kg of milk annually, which contains 155 kg of protein. Milk for calves accounts for 500 kg/year, leaving 4500 kg/year for the market. Each cow also provides feed and manure for fish farming, annually producing 500 kg of fish or 55.8 kg of protein. Therefore, each cow annually provides 210.8 kg of protein, which is equivalent to 3.7×10^6 kcal. Fish-cum-cow integration increases protein output by 36 per cent and caloric output by 10.6 per cent over unitary cow farming and, over unitary fish farming, increases protein output by 2.7 times and caloric output by 9.5 times.

The average output value of each milk cow is over 3100 Yuan/year, reducing the cost of fish farming by 50 per cent. Fish-cum-cow integration also employs one worker for every four cows. The provision of feeds and manure for fish farming by the cows saves energy in transportation. The initial investment, however, is much greater. About 2500 Yuan is required for each milk cow and associated facilities. Despite this, the profit rate of milk-cow raising is high; 100 yuan net profit can be gained from 300 yuan fixed capital. Therefore, in terms of net profit and cost saving, the initial investment will be recovered in 3 years.

Models of Fish-Livestock-Crop Integration

Fish-livestock-crop integration is a combination of fish-cum-livestock and fish-cum-crop models; i.e., animal manure and pond silt from fish-cum-livestock integration are used as fertilizers and crop products from fish-cum-crop integration are used as feedstuffs for both fish and livestock. The most popular fish-livestock-crop integration models are pig-grass fish and vegetables-pig-fish. The former develops more rapidly than the latter and will be discussed here.

In fish-cum-pig integration, all pig excreta is used to fertilize the fish ponds with plankton feeders as the major species. In pig-grass-fish integration, however, part or all of the pig excreta is used as fertilizer for terrestrial and aquatic fodder plants with high-yielding pasture grasses as the major crops. Green fodder crops are used to culture herbivorous fish and to rear filter-feeding fish. Some pig excreta may go directly to the fish ponds. Finally, the accumulated pond silt returns to the land as crop fertilizer (Fig. 7.12). Thus, both terrestrial and aquatic primary pro-

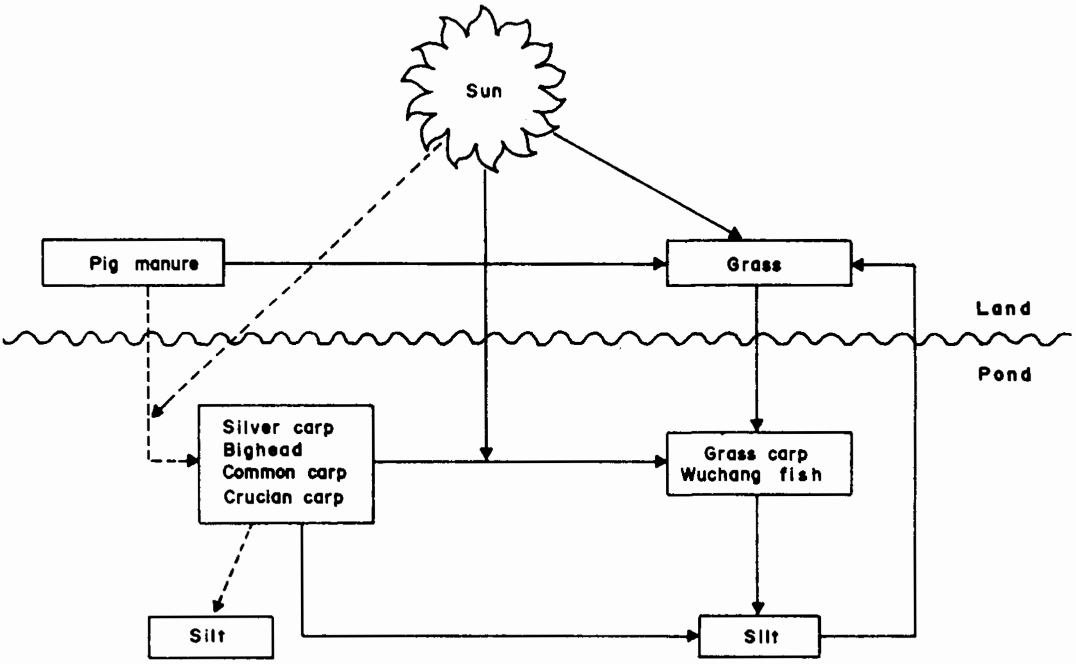


Fig. 7.12. Nutrient cycle and energy flow in pig-grass-fish integration
(– – – – – : fish–pig) (——— : pig–grass–fish)

ductivity is fully utilized. Pig-grass-fish integration has a more rational and effective structure than fish-cum-pig integration and can compensate for insufficient manure in fish-cum-grass integration.

Ecological Efficiency

Utilization efficiency of light energy

The productivity of photosynthesis depends on the amount of light that, in turn, depends on light intensity and photoperiod. Terrestrial pasture grasses directly absorb light energy and, under artificial control, can be avoided. The radiant energy entering the water is lower than that on land because the water surface reflects and diffuses the light. The light entering the water is also reduced because of the shading of pond dike. If the gradient of a pond dyke is 30°, the sunshine time along the pond dyke at water level is one-third less than that at the top of the dykes. The lower the water level and the smaller the pond area, the shorter the sunshine time. Because there is a large amount of suspended and dissolved substances and a great number of plankton, which propagate rapidly, in fish ponds, autoshading occurs. This phenomenon is hard to control. Experiments at the Freshwater Fisheries Research Centre, the transparency and the amount of suspended substances in the pond are in inverse proportion. In a natural pond, the coefficient of correlation (r) is –0.9083. The regression equation is as follows:

$$Y = 87.1877 - 0.352\,X$$

where Y is the transparency (centimetres) and X is the amount of suspended substances (milligrams per litre).

Larcher (1980) demonstrated that radiation intensity is inversely proportional to water depth, decreasing exponentially as water depth increases. When the sky is evenly clouded, according to synchronous measurements, the light intensity on the soil surface with 40 cm of ryegrass which is the maximum height, is 900 lx. This is 13.4 per cent of the light intensity at the surface of the ryegrass (6.9 klx), and 1.8 per cent of the light-intensity saturation point of photosynthesis of phytoplankton (20 klx). During the growing or rationing phase before mowing the ryegrass, the relative light intensity in the pond, however, cannot be increased artificially. Therefore, the net photosynthesis of phytoplankton is much less than that of terrestrial plants.

Terrestrial grasses also have a greater ability to photosynthesize than do phytoplankton. The intake of energy and the primary productivity of terrestrial grasses are higher than those of phytoplankton. Manured with pond silt alone, the yield of ryegrass can reach 4500 kg/mu in April and May; the average daily output in May is 82 kg. The average daily yield of Sudan grass can reach more than 100 kg/mu.

The net daily output of oxygen produced by phytoplankton in Wuxi and Xiamen is 8-10 g O_2/m^2. The net daily yield of phytoplankton is 42.3-52.9 kg/mu

(Xing-zhi et al, 1977). In the Wuxi high-yielding fish pond, the net daily yield of phytoplankton in the peak period is 41 kg wet weight/mu. This is only 50 per cent of the net yield of ryegrass and 41 per cent of the net yield of Sudan grass.

According to the balanced equation of photosynthesis, 1 kg of O_2 produces 6.1 kg of phytoplankton (wet weight); 1 kg O_2 also produces 3.51 Mcal of energy. Therefore, 1 kg of phytoplankton holds, on average, 0.575 Mcal of energy. The daily output of plankton from May to August is 41 kg/mu; this translates into 23.575 Mcal of energy. For ryegrass, 1 kg holds 1.035 Mcal. The daily output of ryegrass in May holds 84.87 Mcal, which is 3.6 times that of phytoplankton. For Sudan grass, 1 kg holds 0.75 Mcal. The daily output of Sudan grass from June to September is 77.25 Mcal, which is 3.3 times that of phytoplankton. In the case of ryegrass and Sudan grass, primary productivity is 2-4 times that of phytoplankton in high-yielding fish ponds and the output of energy 3.3-3.6 times that of phytoplankton. The yield of terrestrial grasses can be further increased through the cultivation and extension of good varieties of seeds, rotation systems and intercropping with leguminous grasses, and scientific management. Increasing the primary productivity of phytoplankton, however, has proven difficult so far.

The utilization rates of the primary productivity of phytoplankton and terrestrial grasses by fish are different. Furthermore, the propagation of required phytoplankton seeds in the pond. He Zhi-hui (1983) calculated the consumption of phytoplankton in high-yielding fish ponds in Wuxi. The phytoplankton consumption of silver carp, bighead, tilapia and crucian carp, either directly or through zooplankton, accounted for 82 per cent of the biomass of phytoplankton (70 per cent of the zooplankton are consumed by plankton feeders). In comparison, the utilization rate of ryegrass with a height of 50 cm or Sudan grass with a height 1.2 m by fish is 100 per cent.

Utilization of two primary productivity

Compared with adding manure to the pond water, pig-grass-fish integration utilizes the high, effective primary productivity of terrestrial grasses and, at the same time, uses the primary productivity in the fish ponds. In this system, herbivorous fish, which are stocked to give a net yield of 400 kg/mu, are the major species. The mean loading capacity of herbivorous species is 190 kg. The daily ingestion of Sudan grass by herbivorous fish is 22.5-30 per cent of body weight (average 25 per cent). Thus, the daily ingestion of Sudan grass by herbivorous fish is 48 kg/mu. The daily amount of excreta of herbivorous fish is 24 kg/mu. On the basis of a study by the South-Western Normal College of China (1977), the N and P contents of grass excreta are 1.102 and 0.426 per cent; these levels are 3 and 2 times those of pig excreta, respectively. At least, the daily excreta of the herbivorous fish is equivalent to 24 kg of net pig manure. During the 250 days of the ingestion period the amount of excreta of herbivorous fish is equivalent to 6000 kg of net pig manure or the net excreta of six pigs. This is close to the total amount of manure applied to a fish pond with silver carp and bighead as the major species. Thus, growing grass using pig manure can provide sufficient fodder grass to the herbivorous fish, the excreta of which, in turn, can supply enough nutritive elements so that the primary productivity of the fish pond can reach the mean level of the pig-manured pond.

In Wuxian, the Zhangzhuan Aquaculture Brigade, which has adopted pig-grass-fish integration, all the pig manure is used to grow grass. No additional manure is applied to the fish pond with herbivorous fish as the major species, which account for 55-72 per cent of the total stocking amount. The water is green or brownish green with a transparency of 10-35 cm (in pond 33, with the herbivorous fish accounting for 72 per cent of the stocking amount, the average transparency is 17.5 cm). According to He Zhi-hui (1983),

$$Y = 153.69 - 3.06 X$$

where Y is the biomass of phytoplankton (milligrams per litre) and X is the transparency (centimetres). The biomass of phytoplankton of pond 33 is about 100 mg/L. The biomass of phytoplankton in the high-yielding fish ponds of Wuxi is between 20 and 100 mg/L. This indicates that the excreta of herbivorous fish can fertilize the pond water and provide sufficient plankton to satisfy the demand of the plankton feeders.

Pig-grass-fish integration avoids certain ecological defects caused by the direct application of pig manure in the ponds. The direct application of pig manure increases the BOD and lowers the dissolved oxygen levels, especially if stacking manure application at 10-day intervals is adopted. The BOD ranges from 29.09 to 30.75 g/kg. According to experiments conducted at the Freshwater Fisheries Research Centre, Wuxi, when pig manure is spread evenly into the pond at weekly rates of 0.12 and 0.29 kg/m^3, the average BOD_1 values are 4.10 and 5.48 mg/L respectively. At 5-30, the average dissolved oxygen content is only 1.0 mg/L. The Zhangzhuan Aquaculture Brigade adopted pig-grass-fish integration in 10 ponds and supplement mollusc and fine feeds with no other manures in the fish ponds. The carrying capacity of nine ponds ranged from 779.3 to 1350.5 kg/mu; one pond had a carrying capacity of 475.3 kg/mu. All the dissolved oxygen levels were high. The minimum dissolved oxygen level was 2 mg/L. In pond 10, with the highest carrying capacity, the average dissolved oxygen level was 4.6 mg/L.

Because this system utilizes two primary productivities and avoids some ecological defects, there is a greater potential to increase fish yields. Many studies outside China report a general daily fish yield of filter-feeding and omnivorous species of 15-31 kg/ha in a manured pond when the species are monocultured or polycultured as major species. Generally speaking, the daily yield of plankton feeders in the Taihu Lake district is 300-400 kg/mu. It is difficult to surpass these values and, moreover, the economic efficiency will be reduced if the yield increases. Nowadays, in most fish ponds with a daily yield of 500 kg/mu, herbivorous fish are cultured as the major species with grass as the main food and without or with just a little manure application.

The excreta of 1 kg of herbivorous fish can fertilize the pond water and produce 0.2-0.5 kg of silver carp and bighead. The larger the size of the herbivorous fingerlings, the more they ingest and the more plankton feeders they can support. In grass carp rearing pond with gross yield of 110-150 kg compared with grass carp rearing pond with gross yield 50-100 kg, the net yield of plankton-feeders is 37.5 kg higher.

In the fish-pig link, filter-feeding fish and omnivorous fish feed on detritus and bacteria. The relationship between the fish yield and both detritus and bacteria depends on their quality rather than on their quantity. Therefore, yield cannot be estimated only according to the amount of detritus in the water. Lin Wanlian also proved that to use pig manure to grow grasses for fish farming, so far as part of detritus, which can be utilized by fish, is concerned, is done at a loss. Nevertheless, the beneficial effects of pig-grass-fish integration can make up for this loss. In addition, detritus has detrimental effects.

Economic Efficiency

On the basis of ecological principles, pig-grass-fish integration is economically more efficient than fish-cum-pig integration. In 1979, the Zhangzhuan Aquaculture Brigade performed a productive test. They found that 50 kg of pig excreta (pigsty effluent, 50 per cent) or 50 kg of nightsoil produced 56 kg of terrestrial grasses. The food-conversion factor of ryegrass and Sudan grass is 18.4-27.5 (average, 27). Thus, 100 kg of pig excreta can be converted into 4.2 kg of herbivorous fish, which facilitates the rearing of 1.5 kg of filter-feeding and omnivorous fish. This gives a total fish yield of 5.7 kg. According to the tests of the Freshwater Fisheries Research Centre, Wuxi, 100 kg of pig excreta can be converted into 2.5 kg of fish and 50 kg of net pig excreta, through growing grass, can produce 3.2 kg of fish, increasing the output by 133 per cent. Herbivorous fish, which are the dominant species in pig-grass-fish integration, meet the demand of the market and are profitable. If 100 kg of pig excreta is used to grow grass and then to culture fish, the resulting increment is 2.90 Yuan, which is 1.34 times that obtained when pig excreta is applied directly.

Collection

In the pig-grass link, the guideline is to facilitate grass planting and manure application. If the grasses are only planted on pond dykes, a simple pigsty can be built near the pond. If there is a fodder field beside the pond dyke, a centralized pig shed near the fodder field could be constructed. The ratio of pig to grass depends, firstly, on the yield of pasture grasses; below a critical level, the higher the yield, the greater the number of pigs. . Secondly, the ratio depends on the utilization of pond silt; the more pond silt used, the fewer the number of pigs. Thirdly, the ratio depends on the quality of soil and pig manure and the varieties of pasture grasses; on the basis of production tests for ryegrass and Sudan grass grown year-round, the best collocation is 5-6 pigs/mu.

Web of Integrated Management

To raise the energy utilization efficiency, to decrease costs, and to increase production and income, several models could be interwoven to an integration web through longitudinal and transverse nutrient cycling and energy flow in line with the local conditions. To date, three integration webs have been developed.

Multilevel Comprehensive Utilization Web

Because of different utilization of nutrients by various specialized trades, these trades can be connected in a series using nutrient and energy flows. An integration web can be regarded as a number of connected nutrient cycles and energy flows. The general form is recycling of animal manure (Fig. 7.13).

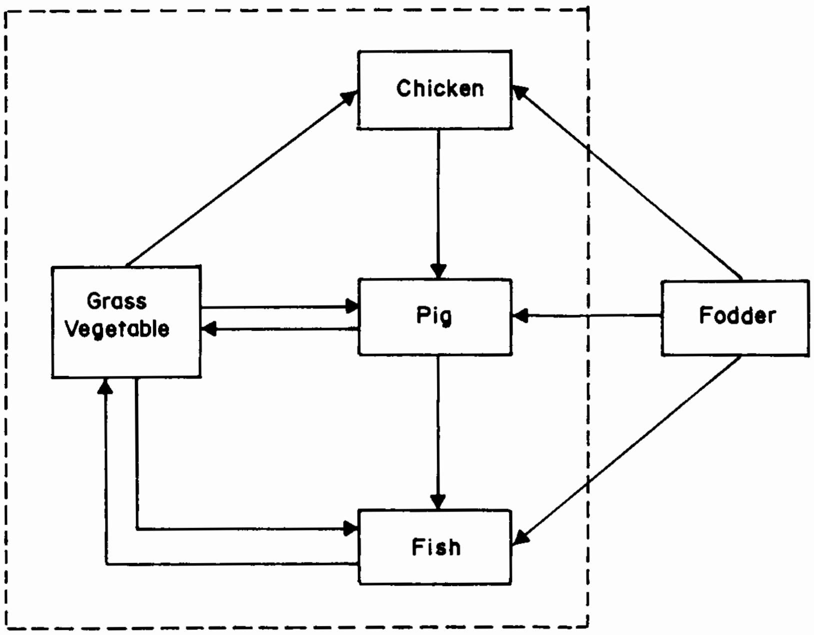


Fig. 7.13. A multilevel integrated fish farming web of chicken-pig-fish.

For example, in recycling chicken manure, spilled and undigested chicken feeds can be fully utilized. Shan Bei Livestock and Aquaculture Farm uses this kind of integration web. Not only can chicken manure be fully utilized, but it can also save about 25 kg of fine pig feed, increasing net income by 47 yuan/pig. Furthermore, after simple deodorization and sterilization, chicken manure can be mixed with fine feeds into composite pellets, which can be used to feed chickens. Chicken manure can then be fed to pigs for a second time.

In Zhejiang Province, there is a common multilevel, comprehensive, utilization model: cow-mushroom-earthworm-duck-fish or cow-mushroom-biogas-earthworm-duck-fish. Cow dung can be used to grow mushrooms; cow urine can be used for fish farming; mushroom soil can be used for earthworm culture; earthworms are fed to ducks; and duck excreta is applied to fish ponds. The levels can be rearranged in line with the local conditions. Thus, the different constituents of cow excreta are utilized at different levels and the new constituents produced at the following level can be utilized by the next level, etc. (Fig. 7.14).

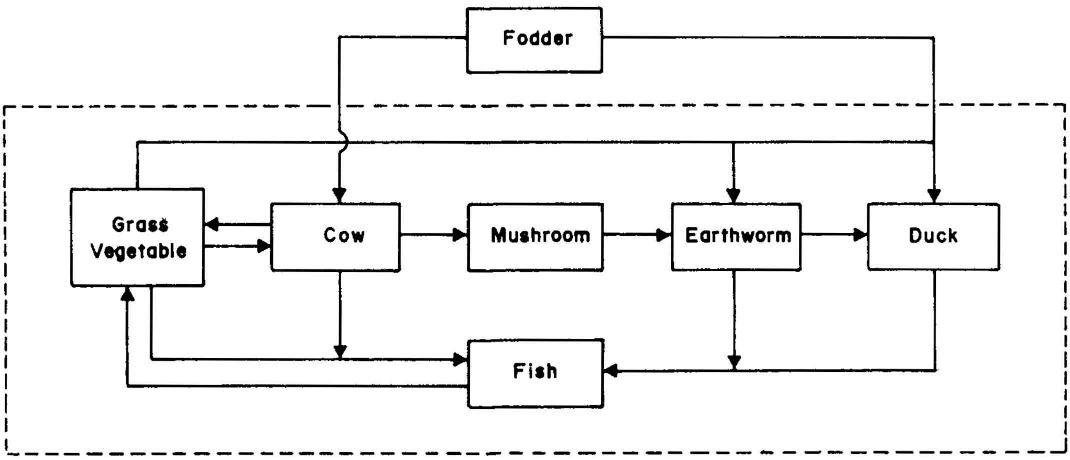


Fig. 7.14. A web of integrated fish farming of cow-earthworm-duck-fish.

Parallel Connected Web of Multitrades

With fish farming at the centre, there may be a parallel connection of multi-trades, e.g., fish-livestock-crop, to create sources of feeds and fertilizers. The products and wastes are utilized among all the trades. Most integrated fish farms adopt this kind of integration web (Fig. 7.15). In Xiang Yang Aquaculture Farm, for example, fish farming is combined with pig, cow, and geese raising. Animal manures are used for fish farming, for crops such as pasture grasses, squash, sweet potatoes, and water hyacinth, *Spirodella* spp. and *Wolffia arrihza,* which are used as feeds for fish, pig and geese. Although soybean is planted on the pond dykes in the latter part of the year, water hyacinth can supply 80 per cent of the green fodder for fish and pigs.

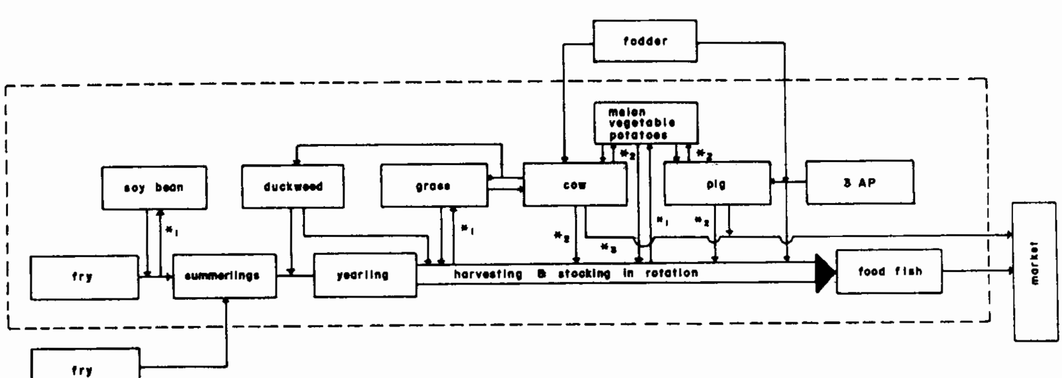


Fig. 7.15. Integrated fish farming network in Xiang Yang Aquaculture Farm, Wuxi,
Note: *1, silt; *2, cow dung, pig manure; *3 milk and meat pig; dash line means out of the unit.

Fish-Livestock-Crop and Agriculture-Industry-Commerce Web

On the basis of the parallel connection of fish-livestock-crop integration, trades develop on both the input and output ends. On the input end, feed-processing industries can be set up and food can be utilized at multiple levels. On the output end, the products of all the trades need processing and marketing. The waste of processing factories is used to raise livestock and poultry. This combination can increase the level of comprehensive utilization of natural resources, the rate of energy utilization, and the production of fish, livestock, and poultry, resulting in increased value, income, and job opportunities.

In the 1970's, this type of integration web was set up in Dong Hu Fish Farm, Siang Yin County, Hunan Province (Fig. 7.16). In recent years, the management structure and the scale of this web have developed further, e.g., Helei Fish Farm has developed into an aquaculture, industry, and commerce combination (Fig. 7.17).

On the transversal axis, they integrated fish farming with grass cultivation, pig, cow, and duck farming. On the longitudinal axis they process crops and cocoons to provide green fodder, as well as pupae wastewater for fish, livestock, and poultry at the input end. At the output end, they process the products of livestock, e.g., preserved eggs and dressed ducks. The waste of processing factories can be used as feed for fish, livestock, and poultry or as fertilizer for fish ponds. The pro-

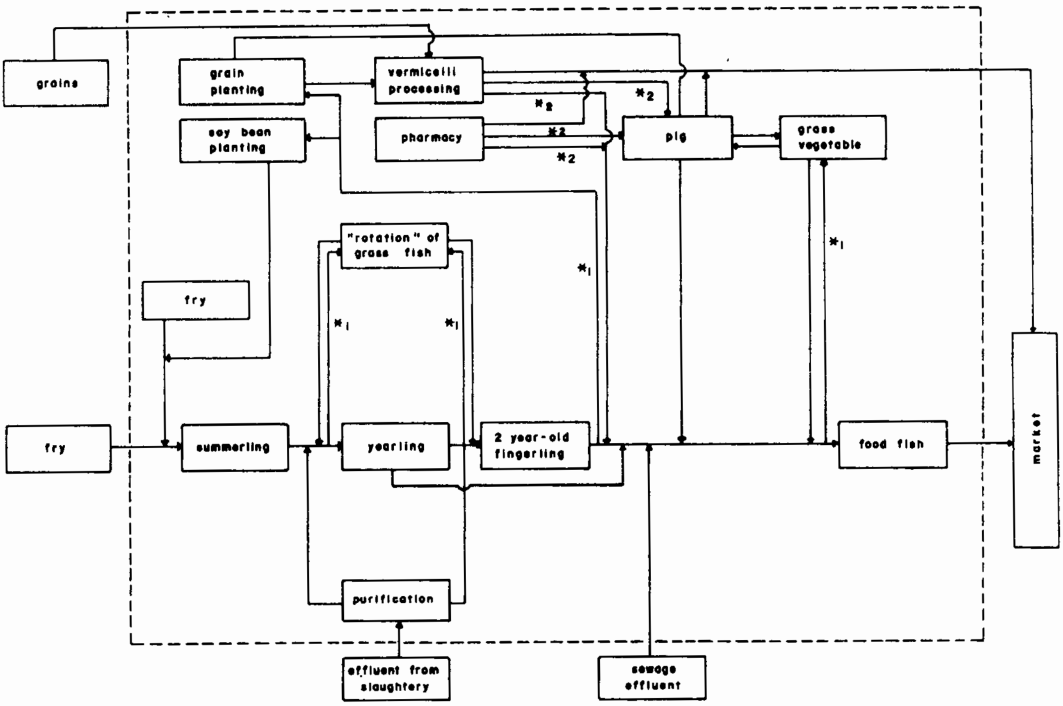


Fig. 7.16. Integrated fish farming network of Donghu Fish Farm in Xiang Country, Hunan Province.

Note: *1, silt; *2, by products and wastes; dash line means out of the unit.

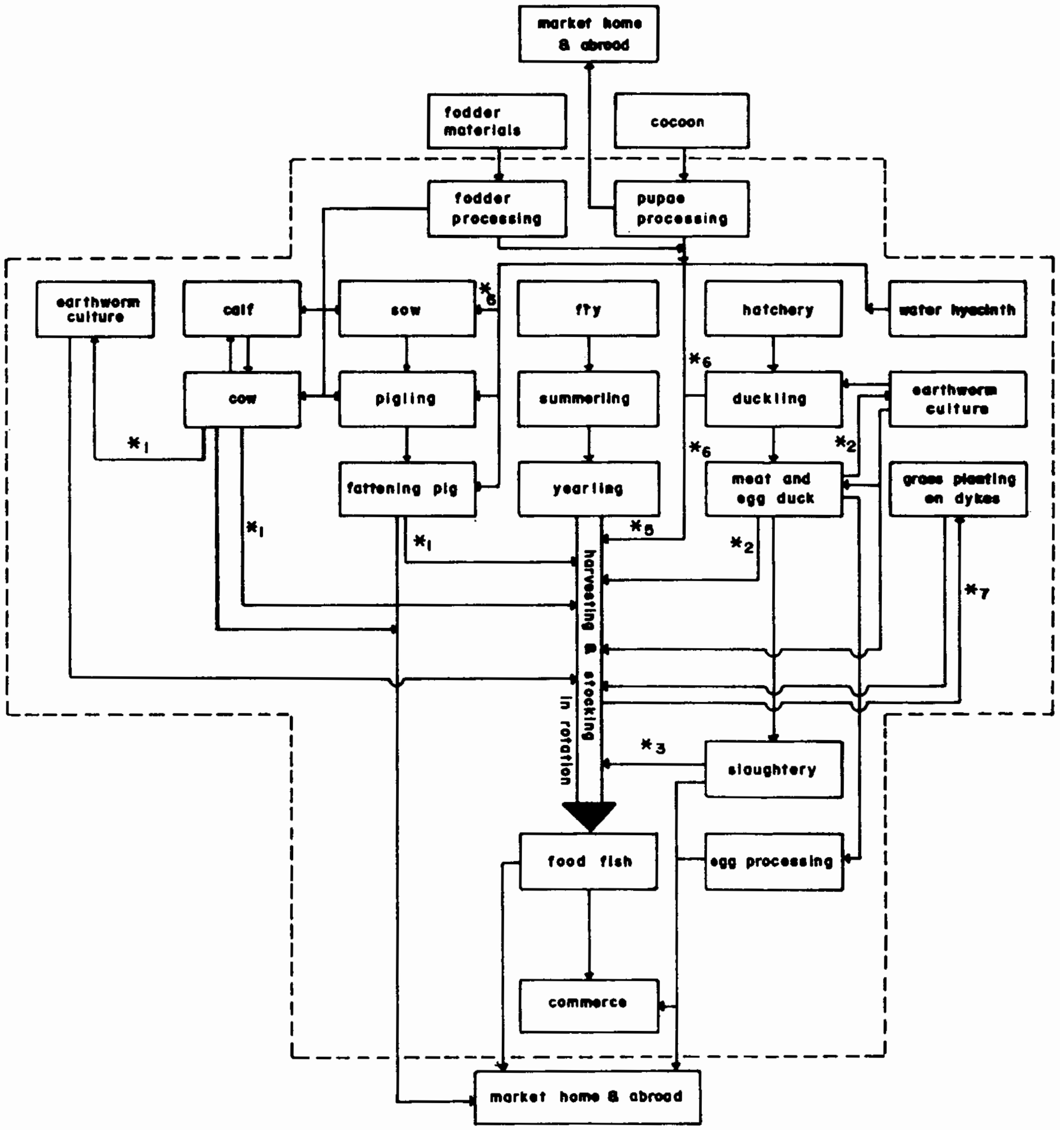


Fig. 7.17. Integrated fish farming network of Helei Fish Farm, Wuxi, China.

Notes: *1 pig and cow manure; *2, duck manure; *3, waste from duck slaughtery; *5, pupae and waste water from pupae processing; *6, silkworm pupae and water hyacinth; *7, pond stilt.

cessed products are marketed in China and abroad. Thus, the economic efficiency can be raised greatly. For example, in 1982, the average net profit was 6.78 yuan/duck. The people who were engaged in duck raising and egg processing accounted for 17 per cent of the personnel of the farm and 43 per cent the net profit.

Some Models of Integrated Fish Farming

Duck raising in fish ponds: an ancient practice in Asia and Europe.

Fish-cum-cow integration increases income of fish farm.

Fish-cum-pig integration can reduce production costs.

More labour is generated in an integrated fish farm.

Fish culture combined with pig raising is a traditional fish-farming model in China.

The Asian-Pacific Regional Research and Training Centre on Integrated Fish Farming in Wuxi, China.

Trainees on integrated fish farming in the Wuxi Centre.

Chapter 8

PLANNING MANAGEMENT ON AN INTEGRATED FISH FARM

Yang Huazhu

Necessity, Objectives and System of Planning Management

Planning is the primary function of management on an integrated fish farm. Because the target product of the farm can only be realized through planning, all production activities must be performed under the guidance of the plan. Therefore, an integrated fish farm needs strict planning management to be economically efficient.

The Necessity of Planning Management

A management plan is determined by the specific features of an integrated fish farm. An integrated fish farm is multitrade production complex. The proportional development of all trades has to be realized through planning management.

An integrated fish farm is a cell of the national economy. The products of the farm are essential to the people, and the farm expends a considerable amount of natural resources. Therefore, integrated fish farming is closely related to the national economic plan, making a proper management plan important.

Strong planning management is essential to raise the managerial level of a fish farm. Only when various managerial tasks are strictly performed to comply with the plan will the production target of the farm be fulfilled. Planning management is the most important aspect of managerial work. Raising the level of planning management raises the level of other management duties.

The Objectives

Planning management

There are three main objectives of planning management. First, the plan of the farm must mesh with the national plan and the market. Second, all production activities on the farm must be comprehensively balanced. This comprehensive balance is very important. There is a series of proportional relationships between trades, links within a certain trade, managerial departments, and the farm and the outside. The planning management of a fish farm must comprehensively balance all these proportions using quantitative economics to achieve an optimal combination. The main components of such a combination are balanced between the following aspects of integrated fish farming:

- production and marketing;
- fingerling production and the relevant fish-livestock-poultry production;
- supply and demand of fish feeds and manures;
- supply and demand of fishery instruments and their installation;
- supply and demand of labour; and
- financial revenues and expenditures.

Such a balance is not permanent, it requires much adjustment and fine tuning over time. Third, planning management aims at an overall optimal efficiency. This overall optimal efficiency includes quantitative and qualitative efficiency. However, economic efficiency is most important on an integrated fish farm.

The Planning System of Management

Long-term planning

A long-term development plan usually covers 3, 5 or 10 years and includes orientation, scale of development, main targets, and important measures. It is designed with the guidance of economic policy information and long-term market forecasts. Its content depends on production techniques, environmental conditions, managerial authority, and other social factors. The following areas may be covered by a long-term plan:

- Orientation of agricultural-produce development: i.e., development of new varieties and different of produce, sizes improvement of quality, increased quantity, improved cooperation, etc.

- Speed and the scale of production: i.e., exploitation of natural resources, increased productive capability, increased number of trades, increased or decreased real estate and its renovation, changes in the labour force, etc.

- State of the art: i.e., development trends in aquaculture, animal husbandry and agriculture, and their comprehensive utilization techniques; the extension of new species, new technology and new techniques; research work, etc.

- Principal technical economic indicators: i.e., production value, cost, profit, labour productivity, weight gain of animal, food-conversion factor, food-conversion rate, and their variations.

- Improvement of fish farm management: i.e., improved coordination between trades, rationalization of management organization, improved managerial methods, etc.

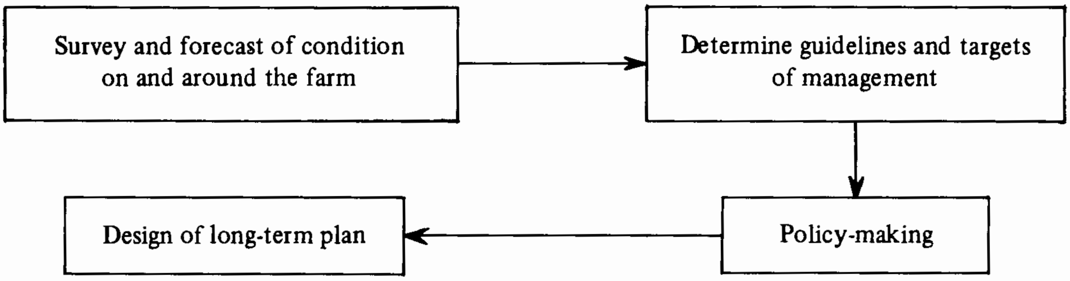


Fig. 8.1 Design of long-term plan.

- Increased employment and improved labour management: i.e., improved labour skill, coordination of the labour force, security measures, wages, social welfare, etc.

Design and adjustment – A typical design procedure is outlined in Fig. 8.1.

The long-term plan should be modified as necessary during its execution. Because of its length, the complexity of integrated fish farming, and natural factors, changing conditions may force adjustments in the management plan (Fig. 8.2).

Yearly planning

The yearly plan of an integrated fish farm defines the essential tasks involved in all the production activities of the farm. It is the basis for adjusting the long-term plan and is also the basis of the stage plan. The yearly plan is the core of the planning system.

- Sale plan: includes species of fish, livestock, and poultry, their quantities and sizes, the time of marketing, and the income from sales. This plan, including the commodity rate, should be designed by the sales department.

- Production plan: the main point of a yearly plan depends on the sale plan. It defines the species to be produced, the sizes, output, the output value, and the time of marketing. The indicators of productive capability and coordination of trades are the basis on which the other plans are designed. The aquaculture production plan is the core of the overall, yearly plan and should be designed by the technical department.

- Wage plan: defines the labour quota during the term of the plan, the productivity of all personnel, the labour size, the total allocation, and the social welfare funds. It should be designed by the payroll department on the basis of the production plan.

- Material supply plan: includes the requirements, storage, and supply of all necessities, (seeds, fry, young animals, manure, feed, drugs, diesel oil, electric power, instruments and installations, etc.). It should be designed by the material supply department on the basis of the production plan.

- Cost plan: defines all the costs of production and sales, the planned unit cost of each product, as well as the cost and inflation index of comparable products. It should be designed by the financial department.

- Financial plan: reflects the trends and the results of all the production activities on a farm in monetary terms. This plan includes the depreciation of real estate, current capital, revenues, and profits and should be designed by the financial department.

- Technical measure plan: includes new products, new techniques, scientific experimentation, maintenance and renovation of real estate etc. Besides their effects, the date of accomplishment, the person in charge, and the source of funds are also defined. This plan should be designed by the technical production department.

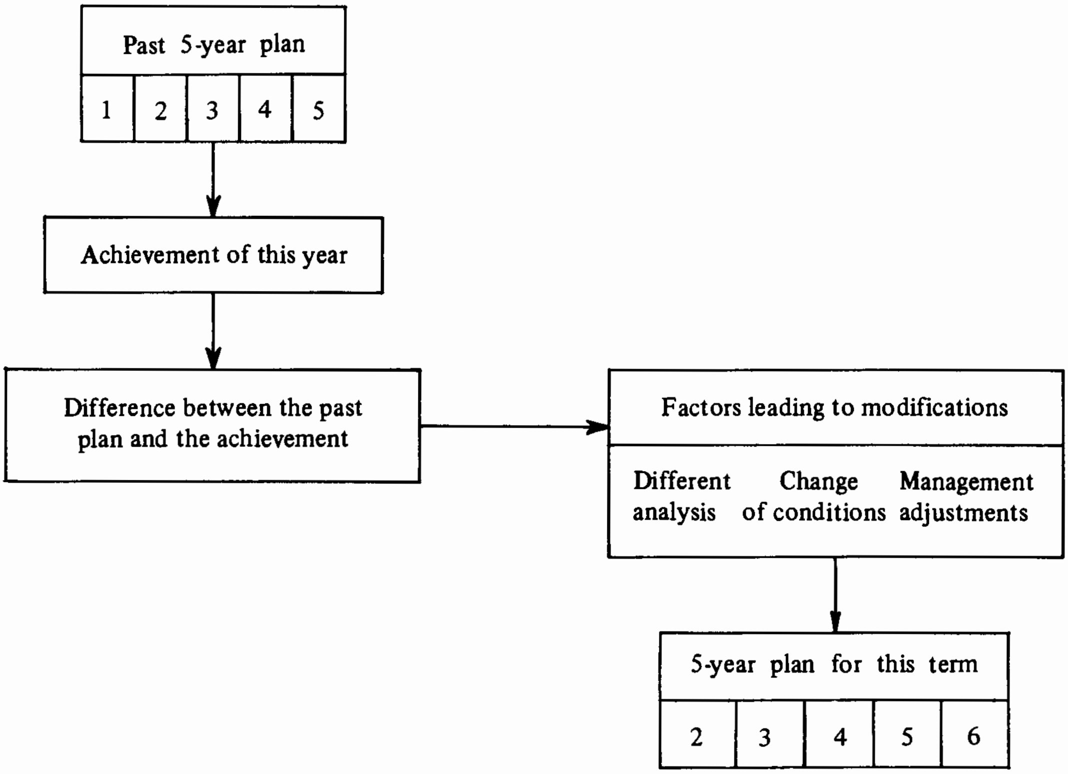


Fig. 8.2 Adjustment of long-term plan.

Design of the yearly plan – There are three stages in designing a yearly plan. First, there is the *preparatory stage*. The purpose of the preparatory work is to understand and analyze national policy and the yearly target of the long-term plan; to survey and analyze environmental conditions and natural resources; to survey and forecast market supply and demand relations; to analyze the results of the previous year's management; and to summarize these experiences and make a decision on feasible quotas. Second there is the *design stage*; there are three steps in this stage. First, on the basis of data analysis, the yearly production targets can be set: the sales target, and the targets of the production, labour, materials, costs, and finance. These targets are then sent to the department concerned and for feedback. Second, after analyzing this feedback, the draft plans of the departments are technically verified to determine the optimal plan. Third, after target balancing, the draft plan of the whole farm is formulated by the production department through comprehensive balance, modification, and adjustment. The last stage in designing a yearly plan is *obtaining authorization for the plan.*

Execution of the yearly plan – Targets should be distributed to the concerned units on a contract basis. At present, a production responsibility system is used, i.e., the farm enters into a contract with each farmer and worker as regards output, species, sizes, cost, profits, labour, wages, and tools.

Control of the yearly plan – The execution of the plan must be monitored. To examine and adjust the plans, a feedback system should be set up. Each production team of each trade must have someone responsible for keeping statistics and serving as a part-time accountant. Any feedback should immediately be reported to farm headquarters so that the plan can be modified or adjusted.

Stage plan

The yearly plan is based on several stage plans, which are developed on a seasonal, monthly, or weekly basis (Fig. 8.3). The production activities of an integrated fish farm are closely related to natural conditions. Therefore, the stage plan should be designed to ensure the accomplishment of the yearly plan.

Planning Models

Planning models of an integrated fish farm can be defined as a series of simplified formulas of basic relation between production managerial activities. The models are based on relationships between trades and a successful plan is dependent on accurate data. Because of the complexity of integrated fish farming, however (Fig. 8.4), some parameters have not been fully analyzed and some data may be inaccurate; the proportional relationship mentioned in this chapter should be adjusted during the execution a fishery programme.

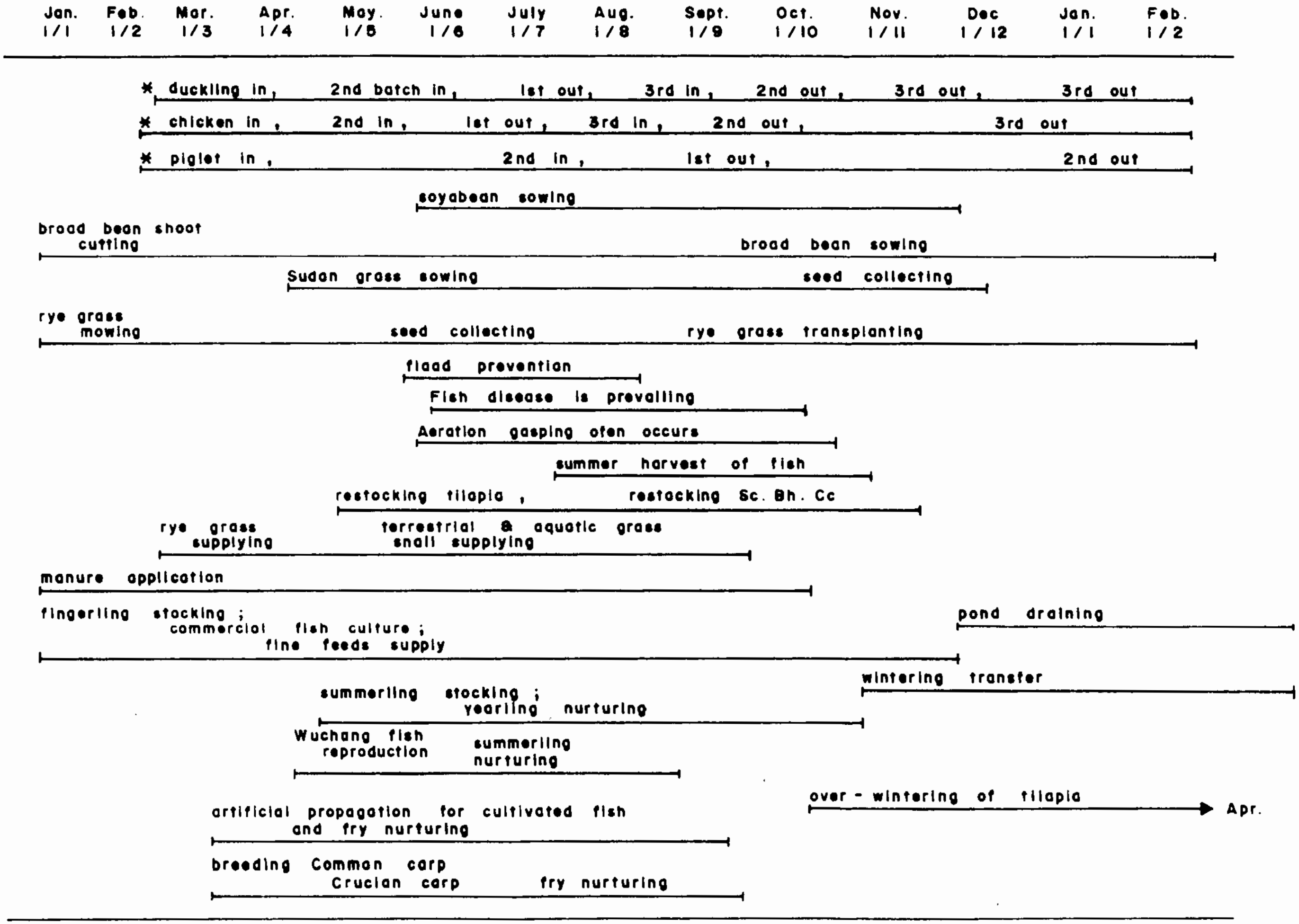


Fig. 8.3. The principal activities of integrated fish farming in The Taihu Lake Basin. (*, broilers only)

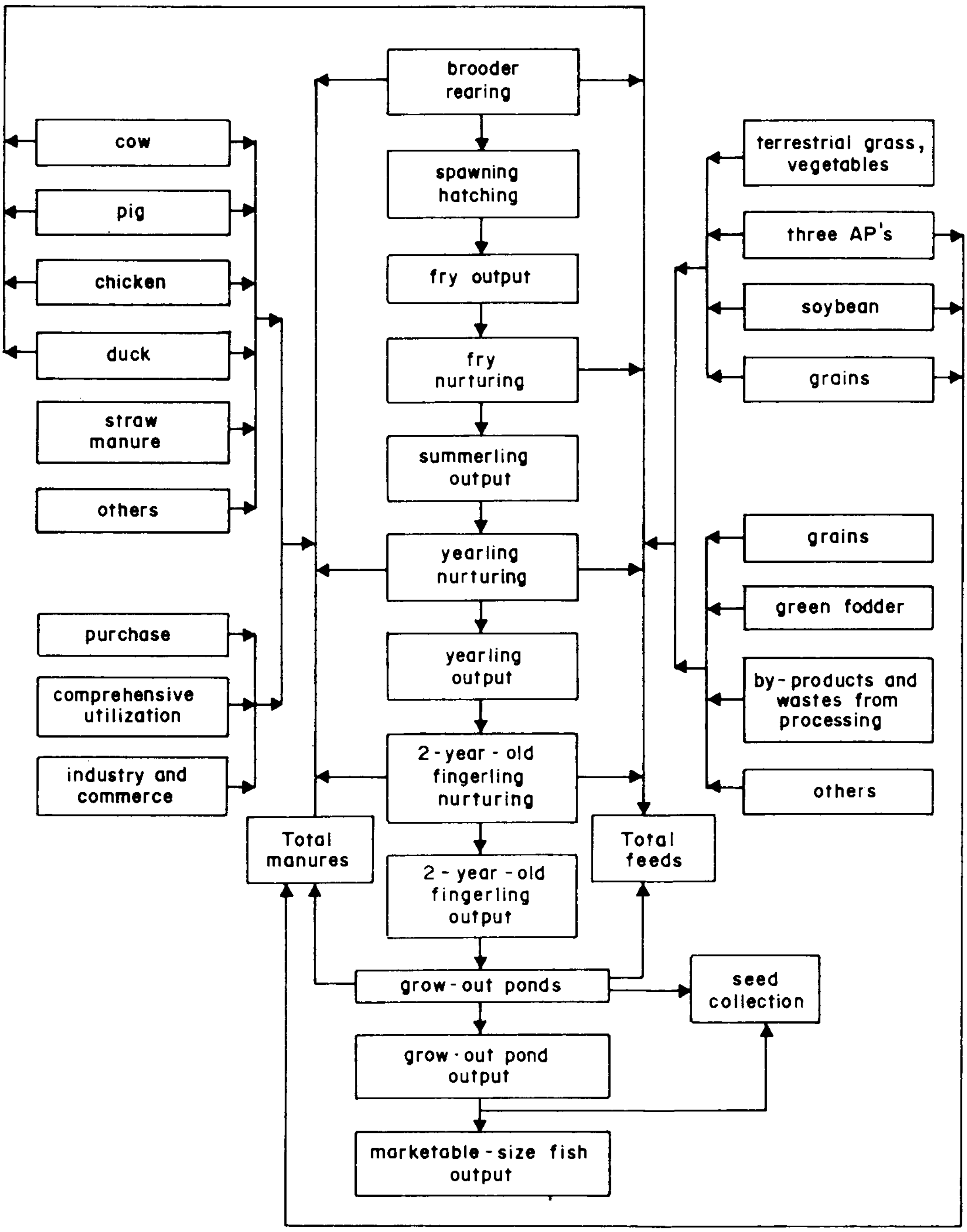


Fig. 8.4. Model block diagram of an integrated fish farming plan.

Fish Yields and Stocking Amounts

The grass yield of a grow-out pond can be calculated as follows:

$$Y = \sum_{i=1}^{n} N^{i} S_i T_i \quad = \sum^{n} \quad N_i R_i S_i \qquad [8.1]$$

Where N_i is the stocking quantity of each species at different sizes in polyculture (individuals per mu), S_i is the weight of each species at different sizes (kilograms per individual), T_i is the multiple of gross weight gain of each species at different sizes, R_i is the survival rate of each species, and S_i is the size of each species harvested. Also,

$$S' = \frac{Y}{NR} \qquad [8.2]$$

Where S' is the target size of a certain species at transference, N is the stocking quantity (individuals per mu), and R is the survival rate (per cent).

The stocking quantity of a certain species (individuals) can be estimated:

$$N = \frac{Y}{S\,T} \qquad [8.3]$$

Where S is the stocking size (kilograms per individuals) and T is the multiple of weight gain. From equation 8.1, the fingerlings size can be calculated:

$$N = \frac{Y}{S'R} \qquad [8.4]$$

$$S = \frac{Y}{N\,T} \qquad [8.5]$$

These formulae can be applied to yearling and 2-year-old fingerling ponds. To make a stocking plan or forecast yields, farmers should understand not only the relationships between items but also the interlocking part of different sizes in different stages and the general survival rate and the weight gain of fish in different sizes.

Example 1

A fish farm has 100 mu of grow-out ponds. Polyculture of various species of different sizes is practiced. The target gross yields, sizes of grass carp and silver carp, and survival rates of grass carp and silver carp are listed in Table 8.1. What are the required stocking quantities and sizes of grass carp and silver carp fingerlings?

Table 8.1 Target yields, harvest sizes, and survival rates of grass carp and silver carp.

Species	*Size (kg/fish)*	*Gross yield (kg)*	*Survival rate (%)*	*Multiple of gross weight gain*
Grass carp	1.5	60	85	4
	0.4	40	80	12
Silver carp	0.6	60	95	3.5[a]
	0.5	45	90	5

[a] Summer harvest

Solution – From equation 8.4, the total number of grass carp and silver carp can be calculated. From equation 8.5, the stocking size can be calculated. The results are shown in Table 8.2.

Table 8.2 Stocking data for grass carp and silver carp.

Species	*Sizes (kg/fish)*	*Quantity (fish/mu)*	*Weight (kg/mu)*	*Total amount of fish*	
				fish/100 mu	*kg/100 mu*
Grass carp	0.320	47	15.04	4,706	1,504
	0.027	125	3.38	12,500	338
Silver carp	0.163	105	17.12	105,000	1,712
	0.090	100	9.00	100,000	900

Yearling and summerling sizes can also be calculated using this method, the values in Table 8.2, and assuming a survival rate of 80 per cent and multiple gross weight gains of 10 and 45, respectively. There should be 5883 yearlings (4706/80), the size of each being 0.026 kg [(1504/10)/5883]. Likewise, there should be 15,625 summerlings (12,500/80), the size of each being 0.5 g [(338/15,625].

To calculate the required quantity of fry, the following equation is used:

$$N = \frac{N'}{R} \qquad [8.6]$$

Where N' is the number of summerlings (1 unit = 10,000) and R is the survival rate of summerlings from fry.

To calculate the required number of fertilized eggs;

$$N = \frac{N'}{R} \qquad [8.7]$$

Where N' is the planned number of fry (1 unit = 10,000) and R is the hatching rate. If the target spawning quantity is required, N' should be changed to the planned fertilized quantity and R should be changed to the fertilization rate.

To calculate the target body weight of female brooders (W, kilograms),

$$W = \frac{N}{n} \qquad [8.8]$$

Where N is the target spawning quantity and n is the average spawning quantity per kilogram of female brooder.

Pond Areas

The pond areas required for each stage from summerlings to grow out are calculated as follows: (target gross yields of polyculture)/(per unit gross yield of polyculture). From summerlings to yearlings, the value is calculated on the basis of individuals. Fry nurturing requires no special ponds. The brooder-rearing pond area is calculated by dividing the total weight of the brooders by the stocking amount per mu.

Fish feeds

In most cases, fish ponds in China are given whatever feeds are available. Calculating proper amounts in such a situation is complicated and inconvenient to proper scientific management. In practice, one common feeds with a stable source serves as a standard: e.g., barley in southern Jiangsu Province; pelleted feeds in other areas. For green fodder, aquatic grass serves as the standard. Then, on the basis of feed sources available and the need for cultivated species, the feed amount should be converted into the actual amount of feed according to the equivalent ratio between the actual feed and the standard feed.

Example 2

A farm expects 1000 t barley. The supply department can only provide 50 per cent of this; the balance is to consist of 20 per cent bean cake, 20 per cent bran, and 10 per cent pellets. What is the exact quantity of each substitute needed?

Solution – According to the available information, the equivalent ratio between barley and the substitutes is 3/4 for bean cake, 2/1 for brans, 1/2 for pellets. Therefore,

the quantity of bean cake is 150 t (1000 x 20 per cent x 3/4),
the quantity of bran is 400 t (1000 x 20 per cent x 2), and
the quantity of pellets is 50 t (1000 x 10 per cent x 1/2).

Fine feed requirement

The total requirement for fine feed is the total amount of fine feed needed at each stage except hatching.

$$W = \frac{\sum_{i=1}^{n}}{R} \; \frac{Y_i C_i}{} \qquad [8.9]$$

Where Y_i is the target net yield of each species at a certain stage, C_i is the food-conversion factor of a standard feed given to each species of herbivorous fish and grain feeder and R is the utilization rate of the feed (per cent). When the fine feed requirement in fry-nurturing stage is to be solved, Y and C will represent the number of fry (1 unit – 10,000) and feed given to 10,000 summerlings, respectively. If the fine feed is mixed with green fodder, the method used in example 2 is used to calculate the quantity of green fodder.

Example 3

A farm expects to gain 2000 kg of black carp, 6000 kg of herbivorous fish, and 2000 kg of common carp and crucian carp. If barley is used as the standard feed, how much is required? If only 50 per cent of the required barley can be provided, how much ryegrass and Sudan grass is required to compensate for the shortage:

Solution – The food-conversion factors of barley in rearing the above-mentioned species are 4, 3, and 3.5 respectively. Therefore, the total requirement of barley is 33,000 kg [(2000 x 4) + (6000 x 3) + (2000 x 3.5)]. If the annual output of ryegrass and Sudan grass was averaged out, the food-conversion factor for herbivorous fish is about 30 and the equivalent ratio is about 10. Therefore, the grass requirement to compensate for 50 per cent of the barley is 165,000 kg (33,000 x 50 per cent x 10).

Green fodder requirement

$$W = \frac{YC}{R} \qquad [8.10]$$

Where Y is the target net yield of the herbivorous fish at a certain stage, C is the food-conversion factor of a standard green fodder, and R is the utilization rate of this fodder; R can be omitted in production. When there is a shortage of green fodder, fine feeds are used as supplementary feeds. The deficient number should be converted into the number of fine feeds according to its equivalency ratio. For example, 1000 kg of Sudan grass is equivalent to 100 kg of barley. If it is used for the herbivorous fish, therefore, its equivalency ratio is 10.

Manure for fish culture

The total requirement for manure is the total amount of manure required at different stages. If applied manures come from different sources, a common manure from a stable source can serve as a calculation standard. The amount can be worked out according to its equivalency ratio. The target amount of manures at a certain stage (M) is

$$M = (Y_i - nY_2)C \qquad [8.11]$$

Where Y_i is the target net yield of filter-feeding fish, Y_i is the target gross yield of grain-feeding and herbivorous fish, C is the manure-conversion factor of a certain kind of manure to fish flesh, and n is the rate of net yields of the filter-feeding fish, which feed on the plankton propagated out of the excreta of herbivorous and growth-feeding fish. The rate of application varies with species, feeds, and ecological factors; generally, it ranges from 0.2 to 0.6. Factor C results from the synergism of other ecological factors and can be very specific farm. Pure livestock feces are taken as a manure standard. Livestock urine should be converted into feces using an equivalency ratio.

Example 4

A farm is expected to produce 15,000 kg of herbivorous and filter-feeding fish from its grow-out ponds. Terrestrial grass is used to feed the herbivorous fish and livestock manure is used to fertilize the pond water. There is only about 100,000 kg of pure pig excreta; how much cow dung is needed to fulfill the farm's expectations?

Solution – the conversion factors of pig excreta and cow dung are 25 and 40, respectively. Assuming 50 per cent of the filter-feeding fish can be raised on plankton propagated by the excreta of herbivorous fish, the required amount of pig excreta is 187,500 kg (15,000-0.5 x 15,000) x 25. Therefore, the required amount of cow dung is 140,000 kg (87,500 x 40/25).

Crop Production Area

The area of grass fields can be calculated according to the method mentioned in Chapter 7 (Integrated Management of Fish and Crop Farming). The planting area of grass is often calculated because the economic returns of grain crops or green manure fodder are poorer than grasses for fish farming.

Number of Animals and the Size of the Animal Shed

After the total manure requirement is calculated, the requirements for different kinds of manures can be calculated according to local conditions and, therefore, the number of different animals can also be determined.

The number of a certain animal raised in its production period is calculated using the following equation:

$$N = \frac{M}{m\,c} \qquad [8.12]$$

Where M is the requirement of a certain animal manure (kilograms), m is the amount of excreta of one animal in one production period (urine should be converted into the equivalent amount of feces), and c is the periods of animal raising in 1 year (the time can be overlapped).

To determine the construction area of animal houses, use the following equation:

$$S = \frac{N s}{C} \qquad [8.13]$$

Where N is the total number of a certain animal raised in 1 year, C is the raising periods (not overlapping) of a certain animal in 1 year (e.g., fattening take 5-6 months; therefore, there will be two periods in 1 year), and s is the average construction area for one animal. If the quantity of livestock is different in each raising period, use equation 8.13 with the following definitions: Where N is the total amount of livestock and poultry raised in 1 year; C is the number of production periods (not overlapped); s is the average area of construction that each batch of livestock or poultry occupies. If the number of batches in different periods is uneven, the formula can be simplified as S = Ns, where N is the maximum number of batches.

Appraisal of Economic Returns

Methods of Material Collection

Surveying method

In terms of scope, an investigation can be divided into general surveying, sampling, and typical surveying. In terms of form, a study may use either live coverage or a questionnaire. An investigation using various methods can get better results; nevertheless, general surveying combined with typical surveying is commonly practiced. Before the investigation, the purpose, contents, and objectives should be fixed; the design of the investigation should be developed precisely; and the outline of the investigation should be drawn up. An extensive survey can then be conducted.

Experimental method

Because of the limitations of investigation by survey, results should be verified by trial and error. On-site experimentation should be conducted before any new decision on technical measurements is adopted. To correctly appraise the situation, it is necessary to get technical and economic data that is as complete and accurate as possible.

Data analysis and processing

There are several methods of data analysis: comparative analysis, cut and try, marginal analysis, regressional analysis, linear analysis. After the appraisal (Fig. 8.5) the best plan can be selected in line with the local conditions and enterprise capabilities by using an overall, systematic analysis.

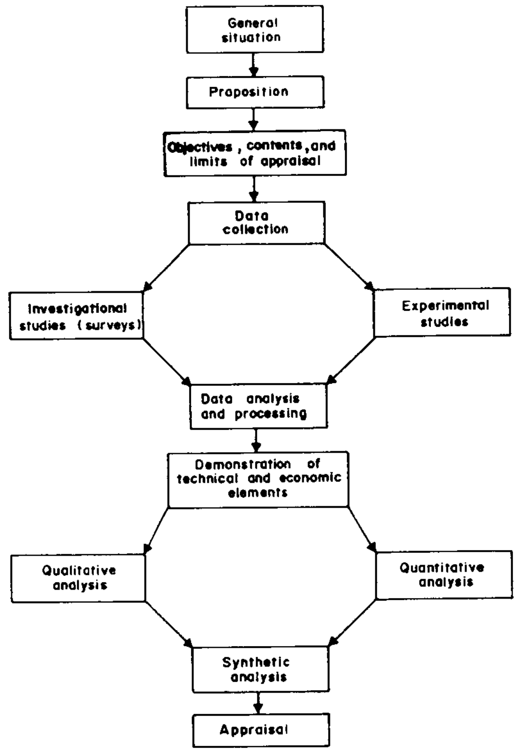


Fig. 8.5. Appraisal of the economic return of integrated fish farming techniques.

The Main Indicators of Economic Return

The indicators of economic return of integrated fish farming techniques are a measurement of farming management. Because of the complexity of integrated fish farming, any individual indicator cannot represent all farming activities. Therefore, a series of indicators must be used for analysis. The common indicators used in both research and actual production are described here.

Production indicators

Production indicators mainly reflect the productivity and the level of technical and economic management. The production indicator is also the yield indicator. On an integrated fish farm, however, there is a wide variety of produce and these products cannot simply be added together; basic production must be converted to protein production or energy output before the different productions can be totaled.

There are two kinds of production: total production and per unit yield. Total production refers to the amount of one kind of product (fish, milk, eggs, etc.) produced in 1 year. The per unit area of volume yield refers to fish and crop yields in one unit of land area or water surface area, or water body volume; the yields of husbandry and poultry, however, are based upon the number of heads. The formulae are as follows:

$$\text{Aquatic products per unit area or water body volume} = \frac{\text{aquatic products (kg)}}{\text{surface area of stocking (mu) or water body volume } (m^3)}$$

$$\text{Per unit area yield of crop} = \frac{\text{crop yields (kg)}}{\text{cultivated land area of the crop (mu or ha)}}$$

$$\text{Per unit animal output} = \frac{\text{total output of animals in one period (kg)}}{\text{average no. of head raised in same period}}$$

$$\text{Average yield of a herd of milking cows} = \frac{\text{total milk from one herd in 1 year}}{\text{average no. of adult cows raised in 1 year}}$$

The per unit area yield indicates animal production capabilities and, other factors remain unchanged, the higher the per unit area yield, the better the economic return. For the per unit area fish yield, the method of calculation varies widely from place to place. In general, the average per unit area yield is calculated as follows: the total yield is divided by the total pond area including fingerling-rearing ponds, or the yields of the grow-out pond and the fingerling pond are worked out separately for comparison. The total pond area excludes the area accepted by the pond dyke. In China, pond fish culture usually employs a polyculture system. Different techniques are practiced in different stocking models producing different species yields and, thus, different economic benefits. In an economic appraisal, therefore, it is necessary to calculate the per unit area yield of each species.

Production indicators also include commodity indicators: i.e., products entering circulation. The commodity percentage of the total yield is called the commodity rate. These two indicators represent the contributions (social efficiency or benefit) made by the labourers on an integrated fish farm.

Total yield or per unit area yield can also be divided into gross and net yield. The gross yield includes the input weight of fry or young animals and the net yield does not. Therefore, net yield indicators can accurately represent the production level.

Output value and income indicators

There are two kinds of output values: total output value of the farm and that of any specific trade. The former is the total product value of all trade. The latter is the total value of each trade such as aquaculture or livestock output. The total output value reflects the final results of farm management. The output value of a certain product equals the yield multiplied by its price. There are two kinds of prices that are used to calculate the output value: current price and fixed 1980 price, which often serves as a standard for the appraisal of economic returns on integrated fish farms.

Total income indicates the revenues that can offset expenditures and wages. Total income is different from total output value because the latter includes the weight gain of both fingerlings and young animals that are unsold, total income includes only sold products. Total output value excludes nonproductive income; total income includes the interest and rent of nonproductive income, etc. Total output value is evaluated using comparative prices; total income is calculated using actual prices.

To obtain the per unit area or per unit animal output value and income, the total output value and revenues of aquaculture, crop, and animal husbandry are divided by the stocking area, cultivated area, and the quantity of reared animals, respectively. If other factors remain unchanged, the higher these indicators, the greater the economic return.

Cost indicator

The production cost indicator of integrated fish farming is the sum of embodied labour and actual labour, i.e., the sum of total production expenses and wages: it is a synthetic indicator of labour consumption. There are two kinds of production costs: the total cost of the farm and the total cost of each trade. The total cost of aquaculture includes the costs of fingerlings and fish feed. The cost indicators are calculated according to the following formulae:

$$\text{Per unit area production cost of fish or crops} = \frac{\text{production cost of a certain product (fish or crop)}}{\text{area for aquaculture or crops (mu or ha)}}$$

$$\text{Per unit product production cost of a certain product} = \frac{\text{production cost of a certain product (fish, crop, animal)}}{\text{total yields of the product (t)}}$$

$$\text{Per unit product output value cost} = \frac{\text{production cost of a certain product (fish, crop, animal)}}{\text{total output value of the product}}$$

Per unit area, per unit product, and per unit output value cost accurately reflect farming consumption. They are important indicators in appraising the economic return of integrated fish farming: the lower the cost, the greater the economic return.

Net output value and net income indicators

The recently created net output value refers to the total output value minus all operating costs. Production results can be clearly shown from this indicator. The net output value is calculated according to a constant price.

Net income is the total initial revenue minus total production costs. For state-owned fish farms, this calculation includes taxes and profits. For collective or individual farms, the operating cost excludes labour payments; therefore, it is actually an incomplete cost. Thus, net income includes taxes and gross profits, which contain the accumulation, welfare, and bonus funds. Owing to the big difference between the collective farm and the individual farm, net income can be calculated according to the same standard or can be compared directly with gross profit.

The net output value and net income indicators are operating results that accurately reflect economic benefit. The following three indicators are often adopted to appraise the net output value and net income:

$$\text{Net output value or net income per unit area} = \frac{\text{net output value or net income}}{\text{cultured or cultivated area (mu or ha)}}$$

$$\text{Net output value of per unit product} = \frac{\text{net output value of a certain product (fish, crop, animal)}}{\text{total output}}$$

$$\text{Net output value of cost (net income)} = \frac{\text{net output value (net income)} \times 100}{\text{total sum of cost}}$$

In the equation for "net output value of cost," if the numerator and the denominator refer to the output value and production cost of the farm, a trade, or a product, respectively, the percentage shows the net output value rate of cost. If the numerator refers to the profit, the percentage will show the profit rate of cost. The three indicators defined above are important factors in appraising farm activities and accurately reflect farming consumption, production, and utilization of natural resources. The higher the value of these indicators, the better the economic benefit.

Labour productivity

Labour productivity refers to the produce and output value created by "living labour". The formula is as follows:

$$\text{Labour productivity} = \frac{\text{annual yield of integrated fish farm or output value}}{\text{labour consumption (workdays/year)}}$$

There are four indicators commonly used for comparison between living labour consumption and farming achievements: net output value created by each laborer, net income created by each laborer, profit made by each laborer, and commercial produce contributed by each laborer per annum.

$$\text{Net output value created by each laborer} = \frac{\text{total output value} - \text{value of consumption of production means}}{\text{average labour per annum}}$$

This formula can be applied to a farm, a certain trade, or a certain product. On a state-owned farm, the workforce is quite stable; on the collective or individual farms, there is a great variation in the workforce. In an actual appraisal, 300 workdays are generally considered as 1 workyear. This accurately reflects the new contribution to society by each laborer, excluding the effects of embodied labour on labour productivity. The higher the value of this indicator, the better the economic benefit.

$$\text{Net income created by each laborer} = \frac{\text{revenues} - \text{total production cost}}{\text{average labour per annum (workyear)}}$$

$$\text{Profit made by each labour} = \frac{\text{revenue} - \text{total production} - \text{taxes}}{\text{average labour per annum (workyear)}}$$

Net income created by each laborer and profit made by each laborer have the same functions as the net output value created by each laborer in the economic appraisal.

$$\text{Commercial produce contributed by each laborer per annum} = \frac{\text{products put into circulation (kg)}}{\text{average labour per annum (workyear)}}$$

As outlined earlier, an integrated fish farm produces a variety of products, but they can't be simply added together to give total production. To analyze the indicators of the whole farm, the measurement form should be uniform, e.g., protein production. This indicator reflects the social contribution of the labourers.

Investment analysis

Two indicators are commonly used for investment analysis: return on investment and coefficient of return on investment.

$$\text{Return on investment} = \frac{\text{gross investment}}{\text{average profit per annum}}$$

If the investment is used to enlarge the scale of production or to renovate old facilities, the average profit per annum should be changed to the increment of average profit.

The coefficient of return on investment, which is the reciprocal of the first indicator above, reflects the economic return per unit investment in a quota recovery period. The shorter the recovery period, the higher the coefficient, the better the economic return.

Technical analysis indicators

$$\text{Fish growth rate} = \frac{\text{total weight gain of a certain fish (g)}}{\text{no. of fingerlings and their culturing days}}$$

$$\text{Daily weight gain of an animal} = \frac{\text{total weight gain (g or kg) or a certain animal during the rearing period}}{\text{total quantity of the certain animal and their culturing days}}$$

$$\text{Multiple of weight increment} = \frac{\text{fish yield of a certain species (kg)}}{\text{stocked quantity of the fish (kg)}}$$

From gross yields and net yields, gross and net weight increment can be calculated.

$$\text{Multiple of weight gain} = \frac{\text{total fish yield of pond}}{\text{stocked quantity}}$$

These three technical indicators reflect the growth rate of fish, livestock, and fowl under different technical measures.

$$\text{Food-conversion factor} = \frac{\text{consumption of a certain feed (kg)}}{\text{gross increment of fish given this feed (kg)}}$$

$$\text{Food efficiency (\%)} = \frac{\text{total production of animal (kg)} \times 100}{\text{total consumption of feed (kg)}}$$

Food efficiency is also called food-conversion rate.

$$\text{Manure-conversion factor} = \frac{\text{consumption of a certain manure (kg)}}{\text{increment of filtering and omnivorous fish involved in this manure application (kg)}}$$

The manure-conversion factor is a new concept developed directly from integrated fish farming. This indicator varies with manure quantity, ecological conditions and technical management. Food-conversion factor, food efficiency, and manure-conversion factor all represent the relationships between the input of feed and fertilizer and the output of fish, livestock and fowl.

$$\text{Protein-or energy-utilization rate (\%)} = \frac{\text{total amount of protein or energy of produce} \times 100}{\text{total amount of protein or energy of input}}$$

The energy-utilization rate represents the relationship between inputs (feed, fertilizer) and outputs (fish, livestock, fowl) and is used in appraising the economic returns of integrated fish farming techniques.

Feed equivalent ratio

The refers to the ratio between the food-conversion factors of new feeds or substitutes and that of the standard feed. It indicates the effects of comprehensive utilization.

Chapter 9

ANIMAL RAISING AND PLANT CULTIVATION ON AN INTEGRATED FISH FARM

Chen Yaowang

Animal Raising

The purpose of raising animals on an integrated fish farm is to develop integration and fully utilize limited feedstuffs. The multi-stage utilization of feedstuffs and fertilizers makes it possible to supply the community with more produce and earn for the fish farm more revenue. Animal raising in China is practiced in line with local conditions; i.e., different natural resources and farm conditions decide the different items of management and animal raising (e.g., variety of fish-livestock-poultry integration or integrated management of aquaculture, agriculture, or a composite of animal husbandry, industry, and commerce).

Sericulture

Pond dikes, corner plots, etc., can be used to cultivate mulberry trees for sericulture on an integrated fish farm. The by-products of sericulture, dregs composed of the feces and sloughs of silkworm and mulberry residues, can be used as fertilizers for fish culture. On average, 100 kg of mulberry leaves will produce 50-60 kg of silkworm dregs. If the dregs are fed to the fish, 1000 kg silkworm dregs can be converted into 100 kg fish. By applying 5000 kg pond silt to the mulberry plots, 250 kg mulberry leaves can be produced and silkworm cocoon production will be increased. The pupa occupies 80 per cent of a silkworm cocoon by weight and 100 kg raw silk and 600 kg pupae can be obtained from every 700-800 kg of silkworm cocoon. The silkworm chrysalis is rich in protein and fat (Table 9.1) and is a feedstuff for fish, livestock, and poultry. The pupa has a strong odour, however, and feeding should be controlled.

Collection of by-products

Silkworm dregs and mulberry could be collected at an early stage of silkworm breeding, but at this time, the amount of these by-products is negligible. By-products should be collected after the dormant stage. Silkworm pupae are by-products after reeling. There are two methods of processing sericulture by-products: sun-drying and water-immersion.

Sun-drying method – This is obviously suitable only on sunny days. After the by-products are dry, they should be mixed with chicken feeds for broilers. The daily amount should not exceed 5 per cent of the total feed. This procedure must be discontinued when the chickens are 1 month old, otherwise, the quality

Table 9.1 **Nutritive composition (%) of silkworm dregs and pupae.**

	Moisture	*Crude protein*	*Crude fat*	*Crude fibre*	*Non-nitrogen extracts*	*Minerals*
Feces	12.2	15.4	2.6	19.6	36.2	
Dry pupae	0.0	46.7	32.2		4.5	4.5

of the meat is adversely affected. For pigs, the amount of pupae should not exceed 10 per cent of the pigs' compound fodder. Pupae should only be fed to sows and piglings.

Water-immersion method – Because it is difficult to dry silkworm dregs and pupae on rainy days, they are stored in large vats filled with water. The preserved by-products can only be fed to piglings. Never feed such material to the "fatteners" because of the strong odour of the wet pupae, which will adversely influence the quality of the pork.

Chicken Farming

The digestive tract of a chicken is very short, only 6 times its body length. Therefore, some of the eaten feedstuffs are excreted by the chicken before being fully digested: research has shown that about 80 per cent (by dry weight) of feed stuffs is utilized and digested by the poultry, leaving 20 per cent for use by other animals on the integrated fish farm. Chickens also peck at their food, causing 10-15 per cent of the feed to be scattered over the ground. This wasted feed can also be reclaimed. The total protein content of dry chicken excrement can be as high as 30 per cent. In general, satisfactory chicken feedstuffs have a protein content over 18 per cent.

In the past, chicken manure was used as a fertilizer for crops. More recently, however, developed countries have begun to use processed chicken manure to feed farm animals. The production of chicken manure pellets is economically important. In China, dry sawdust and pulverized, dry stalk of crops are used as bedding material for chicken coops. Bedding material and chicken excreta may be used to feed fish. Part of this material is eaten directly by the fish and the rest fertilizes the pond water. This technique, however, still does not fully utilize all the nutrients of the chicken manure. Alternatively, the excreta together with the bedding material may be fed to cattle or pigs, especially to sows and beef cattle. In this situation, the undigested and unabsorbed fine feeds in the chicken excreta are fully utilized by the hogs or the cattle.

The excreta of pigs and cattle can then be fed to the fish, which will utilize the undigested nutrients. Besides increasing the utilization rate of the feedstuffs, this technique of feeding animal manures to fish fertilizes the water, producing plankton which is a good natural fish food. If animal excreta are used to culture fish, the pond silt is enriched. This pond silt can be used as a fertilizer for mulberry plots or on the pond dyke for green fodders, and will help produce a high yield. Thus, silkworms, chickens, pigs, cows, and fish can all be reared at the same time and the utilization of the feedstuffs and fertilizers can be maximized.

Characteristics of broiler farming

Broiler farming has only existed in China for 20 years. Large-flock, high-density broiler farming is the most common method. Broilers grow very quickly; if feeding conditions are favourable, they are sent to market after 8-12 weeks. The average weight of the chicken at this point is between 1250 and 1600 g. Broilers should be fed a compound fish with all the essential nutrients. Special attention must be given to the temperature, humidity, aeration, and hygiene of the chicken house. Among other things, this will help prevent disease. Because of the large population involved in broiler farming, one small mistake can cause substantial losses. In this way, broiler farming is very different from small-scale farming.

Selection of broiler species

The most common species of broiler chicken in the world is the White Cornish White Rock, hybrid. Some companies in the world that are specifically engaged in chicken breeding, have produced purebred hybrids. The production of a hybrid broiler begins with first-generation hybrids (grandfather generation), passes through second-generation hybrids (parent generation), and ends with third-generation double hybrids (broiler chickens for commercial production) (Fig. 9.1).

The white-feather broilers bred in China are a combination of the Starbro System from Canada and the Hybro System from Holland. China has now established the National Pure Line Chicken Farm. This farm sells grandfather-generation chickens to first-grade chicken farms, which sell parent-generation chickens to second-grade chicken farms, which produce double-hybrid commercial chickens for market. However, Chinese people prefer to eat yellow-feather broiler chickens, therefore, most of the white-feather broiler chickens are frozen and exported. The live poultry supplied to the domestic and Hong Kong markets usually consists of a variety of yellow-feather chicken bred by the Institute of Husbandry, Shanghai Academy of Agriculture, the New Pudong chicken. The meat and viability of this species is better than that of the imported Starbro chicken, but their growth is a little slower: the body weight of the New Pudong reaches 1500 after 10 weeks and a hen can lay 140 eggs/year.

Equipment for chicken farming

Chicken house – For economic reasons, the open type of chicken house with natural lighting and ventilation is used on integrated fish farms. Usually, the chicken house is a one-storey building with an inverted V-shaped roof. Its length is 6-8 m, its height to the eaves is 2.2-2.5 m (3 m in warmer areas), and each room has an area of about 100 m^3, which can accomodate about 800 chickens. The

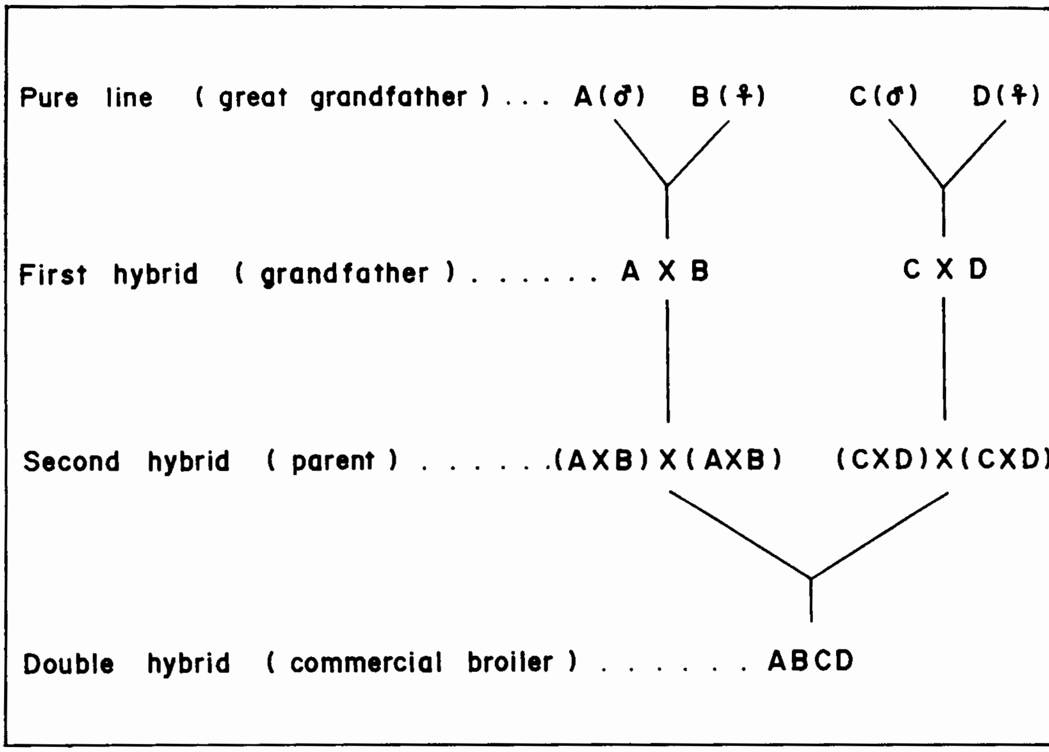


Fig. 9.1. Breeding of a double-hybrid commercial broiler.

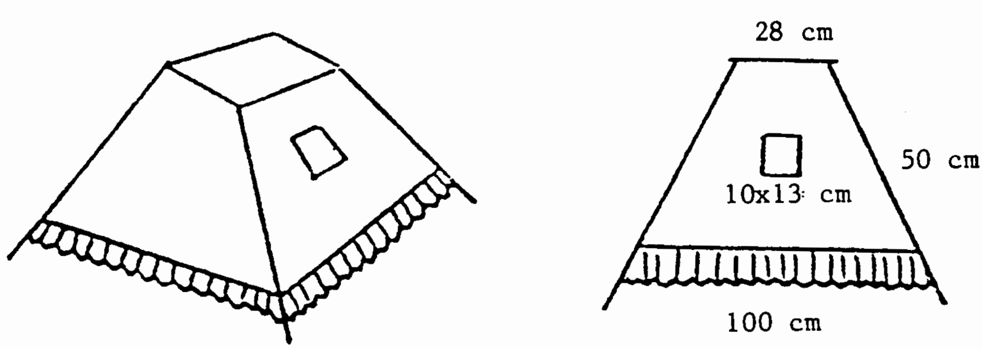


Fig. 9.2. Thermo-electric umbrella.

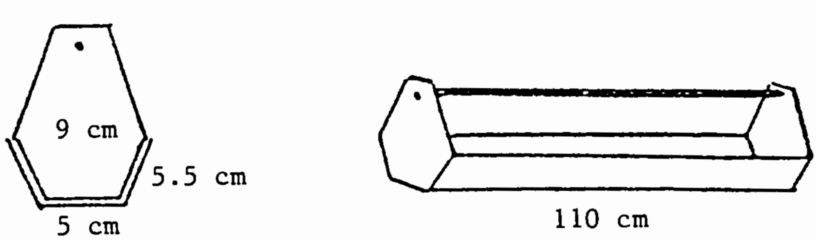


Fig. 9.3. Wooden feeding trough.

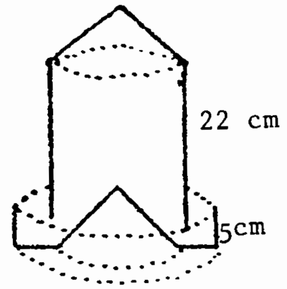


Fig. 9.4. Cylindrical feeding trough.

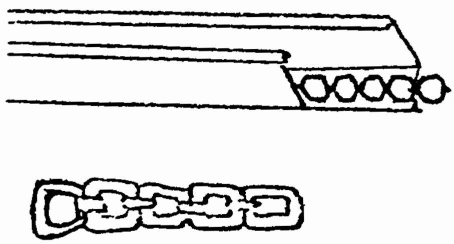


Fig. 9.5. Chain-driven feeding trough.

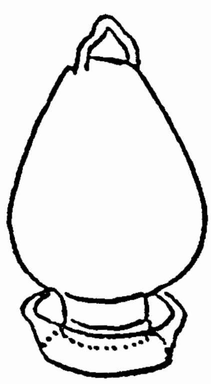


Fig. 9.6 A big-opening jar on an aluminum plate (chick waterer).

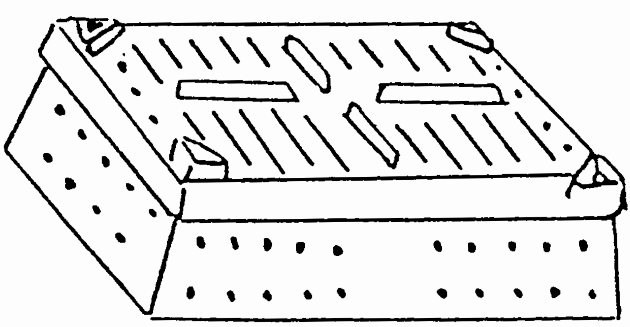


Fig. 9.7. A perforated cardboard box used for chick transportation.

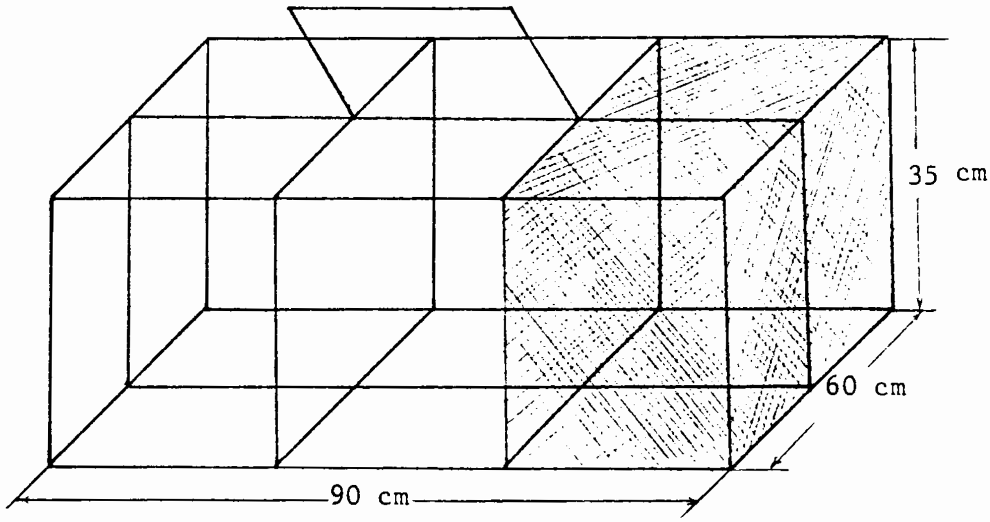


Fig. 9.8. A broiler transportation cage.

width of the house should depend on the number of chickens to be raised. Two workers can handle 3000-4000 chickens. The chicken house should face the sun and the ratio of windows to ground area should be 1:8 to 1:10. South-facing windows should be bigger and closer to the ground than north-facing windows. A concrete floor should be constructed 30 cm above ground level to facilitate drying and sterilization.

Thermo-electric umbrella – A thermo-electric umbrella is commonly used to heat the chicken house. It is 1-1.1 m square, about 0.7 m high, and has a 45° upward inclination (Fig. 9.2). Each umbrella contains 300-W thermoelectric wires and a thermostat and can keep 250-300 chickens warm. In the winter, stoves with pipes should be installed in the chicken house for additional heating.

Feeding trough – There are two types of feeding systems: manual and mechanical. The feeding troughs are either made of wood or iron. The size and height of the standard wooden feeding trough (Fig. 9.3) depend on the growth period of the chickens. There is a special rod on the trough to prevent the spillage and contamination by chicken manure. There should be enough feeding troughs in the chicken house to guarantee that all chickens are fed equally. Cylindrical (Fig. 9.4) and chain-driven feeding troughs made of sheet iron (Fig. 9.5) are also used. In the chain-driven system, a feedstuff box is attached to one end of the trough. A chain moves transversely through the trough delivering feed to the entire length of the trough. This system is easy to use and saves on labour.

Waterer – For chicks, a big-opening jar on an aluminum plate is used as a waterer (Fig. 9.6). The waterers should be installed around the thermo-umbrella for easy access by the chicks. As the chicks grow, an automatic, barrel-like, plastic waterer can be used instead of a jar. This waterer contains enough water for about 100 chickens/day. Some farms use a long trough with running water, and the results have been promising.

Table 9.2. Nutritional standards for broiler chicken feeds.

Feed component	*Age of chicken*	
	0-5 weeks	*>5 weeks*
Metabolic energy (Kcal/kg)[a]	2,800-3,000	3,000-3,200
Crude protein (%)	20-22	18-20
Protein/energy ratio (g/kcal)	72	61
Calcium (%)	0.9	0.9
Phosphate (%)	0.65	0.65
NaCl (%)	0.37	0.37
Amino acids (g/kcal)		
Methionine	2.66	2.34
Cysteine	1.24	1.04
Lysine	3.91	3.44
Tryptophan	0.72	0.63
Arginine	4.38	3.75
Leucine	5.00	4.38
Isoleucine	2.69	2.34
Phenylalanine	4.68	4.06
Tyrosine	2.18	1.88
Threonine	2.50	2.19
Valine	3.13	2.66
Histidine	1.44	1.25
Glycine or serine	3.59	3.13
Vitamins and minerals[b]		
Vitamin A, active (IU/kg)	1,500	
Vitamin D, (IU/kg)	200	
Vitamin E (mg/kg)	10	
Vitamin K_1 (mg/kg)	0.53	
Vitamin B_1 (thiamine HCL) (mg/kg)	1.8	
Vitamin B_2 (ribotlavin)	3.6	
Pantothenic acid (mg/kg)	10	
Nicotinic acid (mg/kg)	27	
Vitamin B_6 (mg/kg)	3	
Biotin (mg/kg)	0.09	
Choline (mg/kg)	1,300	
Folic acid (mg/kg)	0.55	
Vitamin B_{12} (mg/kg)	0.009	
Sodium (%)	0.15	
Potassium (%)	0.2	
Manganese (mg/kg)	55	
Iodine (mg/kg)	0.35	
Magnesium (mg/kg)	500	
Iron (mg/kg)	80	
Copper (mg/kg)	4	
Zinc (mg/kg)	50	
Selenium (mg/kg)	0.1	

[a] 1 cal = 4.19 J.

[b] For chickens 0-8 weeks old
IU, international units.

Table 9.3. Feeding standard for broiler chickens.

Age (days)	*Daily feed per chicken (g)*	*Age (days)*	*Daily feed per chicken (g)*
1-5	10.0	31-35	80.0
6-10	20.0	36-40	90.0
11-15	32.0	41-45	100.0
16-20	44.0	46-50	110.0
21-25	58.0	51-55	115.0
26-30	70.0	56-60	120.0

Chicken cage – Chick-transportation cages are made of calcium-plastic corrugated paper and can hold 100 newly hatched chicks (Fig. 9.7). For marketable chickens, an iron wire cage of 90 x 60 x 35 cm is usually used. Each cage can hold 15-20 live chickens weighing 1.5 kg each (Fig. 9.8).

Broiler chicken feeds

To fully utilize feedstuffs, cut down on feed costs, accelerate the growth, and promote the health of the broiler chicken, nutritional standards for broiler chicken feeds have been established (Tables 9.2 and 9.3). For easy feed preparation, vitamin compounds and trace element additives for broiler chickens are manufactured. These are added to the feed as needed. There are also many feedstuff companies in the world that prepare formulated feeds for broiler (e.g., Table 9.4). The requirements for metabolic energy, crude protein, amino acids, calcium, phosphates, vitamins and minerals are fulfilled by these feeds.

Feeding and management of broiler chickens

Simultaneous in-and-out systems – All chickens should begin feeding on the same day and shipped to the market on the same day. After all the chickens are sold, the poultry farm should be completely cleaned, sterilized and left dormant for 7-14 days to break any infection-diseases cycle. Thus, the next batch of chickens will have a "clean start". Because the growth rates of broilers vary, a modified simultaneous in-and-out system should be used. Chicken should be received at the same time, but sold according to body weight. Those chickens with a slower growth rate can be kept for 1 or 2 more weeks before they are sold.

It is essential that the poultry house be properly prepared for a new batch of chickens. Besides cleaning, sterilizing, and allowing the house to lie dormant for 7-14 days, a layer of clean, dry bedding should be laid down, the temperature should be kept above 80°F, the temperature under the nursing umbrella should be 90-95°F, and lamps should be installed in the umbrella to attract the chicks to the

Table 9.4 Component formulae (%) and analysis of the broiler chicken feeds produced by the Wuxi Feedstuffs Company, Wuxi, People's Republic of China.

Component	*Age of Chicken*	
	0-5 weeks	*5 weeks*
Corn	38	48
Highland barley	15	10
Soyabean cake	5	5
Bran cake	6	8
Cotton-seed cake	5	5
Wheat bran	6	5
Low-grade wheat flour	5	
Fish meal	9	9
Peptone	4	8.5
Chinese scholar tree leaf powder	4.5	5
Bone powder	1.5	1.5
Calcium carbonates	0.5	0.6
Ferrous sulphate	0.2	0.1
Table salt	0.1	0.1
Trace element additives	0.2	0.1
Multivitamin additives (g)	5	5
Metabolic energy (Cal/kg)	3,030	3,057
Crude protein (%)	21.57	20.14
Crude cellulose (%)	3.71	3.76
Calcium (%)	1.08	1.08
Phosphate (%)	0.86	0.85

warmth. A board is set up outside the umbrella to keep the chicks in the warm area. The trough and waterers should be installed around the umbrella and filled before the chicks are introduced to the poultry house, which should be done in the morning so that the chicks learn to eat and drink during the day. The lamps are left on for the first two nights only, and fresh food and water should be given daily and consumptions recorded. The temperature of the nursing umbrella should be checked nightly to avoid having the chicks huddle tightly together to create warmth. The protective board around the nursing umbrella should be extended and the temperature lowered by 1°F daily. The air should be kept fresh, the bedding of the chicken house dry, and the surrounding environment as quiet, possible.

As the chicks grow, the protective board should be removed (day 7) to avoid crowding. The trough and waterers should also be changed to larger size and the nursing umbrella is gradually raised. If feed is supplied all day, the supply should not be interrupted. For artificial feeding, the feeding time should be fixed. Weaker chickens should be separated into a group for feeding. The bedding should be changed frequently and exposed to the sun as often as possible. The chicken house should be kept warm in the winter and well ventilated and temperate in the summer. Chicks are fed a special diet during their first 5 weeks and then gradually switched to a fattening diet. Disease prevention is crucial throughout the rearing period.

When chickens reach 10 weeks of age, with a body weight of 1.5 kg, they can be sold. It is better to catch the chickens in the early morning; catching should be done carefully to avoid injuries. Each cage can hold 15 chickens in the summer and 20 in the winter. A layer of dry grass should be placed on the bottom of the cage.

Prevention and treatment of disease

The raising period of broiler chickens is short, but the population density is high. Disease prevention in this situation depends on proper nursing management, cleanliness, and hygiene. A program of disease prevention should be outlined before the raising process begins and treatment should only be carried out when prevention fails.

Common chicken diseases include pullorum disease, coccidiosis avium, infectious bronchitis, chronic respiratory diseases, variola avium, Newcastle disease, cholera avium, Marek's disease, ascariasis avium, and deficiency diseases, e.g., nutrient deficiency (vitamins, minerals). Some chicken diseases can be prevented by vaccine inoculation or by medication. Some manufacturers have produced mixed whole-value feedstuffs including vitamins, trace elements, and drugs, effectively preventing certain diseases. Some drugs produce a disease resistance after extended application, such as anti-coccidiosis medication. The most reliable way to prevent the outbreak of disease is good nursing management, cleanliness, and proper hygiene, as well as isolation and sterilization.

A preventive project – Marek's vaccine is given to chicks within 48 h of hatching. To prevent Pullorum diseases, 0.01 per cent furazolidonum is added to the drinking water for chicks 1-7 days old. Nose drops of weak toxic Newcastle disease II vaccine are given to 7-day-old chickens; at the same time, the chickens are inoculated with variola avium vaccine. To prevent coccidiosis, 30 ppm robenidine is added to the feed after 10 days and is discontinued 1 week before marketing. Beaks should be cut in the middle with a beak cutter and hemostasis is done by cauterization at 15 days to prevent bad pecking habits. The H_{120} vaccine against infectious bronchitis is administered in the drinking water to 20-day-old chickens at a dilution of 1:500 to 1:1000 (the dosage is 5-10 mL/chicken). A subcutaneous inoculation of Newcastle disease I vaccine is given at 45 days. If ascarids are found, tetrametrazol is given.

Control of coccidiosis – Coccidiosis is the most serious disease of broiler chickens and usually appears after the chickens are 2 weeks old. It is mainly transmitted through manure, especially in the hot and humid season. If the bedding material is thick, the transmission will be more serious because damp bedding promotes oocyst hatching. The most effective approach to coccidiosis is to raise chicklings in cages above the ground. Thus, the chickens are isolated from their own excrement. If a thick grass bedding is used, some anti-coccidiosis medication should be given with the feedstuffs right after the initial feeding and throughout the entire growth period. For example, 125 ppm sulfadimethoxine, 30 ppm chlorophenyl quanide, or dinitolmide (zoalene) up to the concentration of 0.0125 per cent can be added to the feed. The continuous application of anti-coccidiosis drugs could result in a drug resistance and a consequent outbreak of coccidiosis. If the results of the first trial are not promising, other medications should be considered. Two kinds of medications can be applied alternatively. Besides medical control, a clean, hygienic chicken house with ground bedding is essential. The addition of vitamins A and K to the feed can also increase coccidiosis resistance.

Collection and utilization of chicken manure

The constituent breakdown of chicken manure varies with the method of chicken raising (Table 9.5). Chicken manure will ferment and decompose a few hours after excretion, producing a total smell and animals will instinctively refuse to eat chicken manure unless they are accustomed to it. Therefore, the chicken manure must be deodorized before feeding. This can be done with ferrous sulphate or by fermentation. Ferrous sulphate for industrial use ($FeSO_4 \cdot 7H_2O$, green vitriol) has a mild bactericidal function. After mixing it with chicken manure, there will be no fermentation, no decomposition, and no foul smell. The ferrous sulphate

Table 9.5 Composition (%) of chicken manure (dry) from different chicken-raising methods.

Constituent	Cage raising	Ground raising	
		Sawdust bedding	*Dry grass bedding*
Moisture	11.4	12.3	15.5
Crude protein	26.7	21.9	22.3
Crude fat	1.7	1.7	2.3
Nonnitrogenous extracts	30.6	30.0	27.1
Crude cellulose	13.0	17.2	18.7
Minerals	16.5	16.9	14.1
Calcium	7.8	1.9	2.5
Phosphate	2.2	1.3	6.4

will absorb the moisture, however, making the pulverization and spreading of the powder very difficult. The chicken manure can be mixed with chimney dust at a rate of 50 per cent and then baked dry at 60-80°C. The resulting mixture will not absorb moisture and will spread easier. Usually 7 per cent ferrous sulphate and 3.5 per cent pulverized coal dust are blended with chicken manure. After drying, the mixture is odourless and can be fed to pigs, cows, fish, and even chickens at a rate of up to 20 per cent of the feedstuff. The nutritional breakdown of the mixture is as follows: moisture, 10.35 per cent; protein, 21.90 per cent; fat, 1.25 per cent; non-nitrogenous extracts, 21.33 per cent; crude cellulose, 7.13 per cent; minerals, 30.04 per cent; energy, 2161 cal/kg (1 cal = 4.19 J).

The fermentation of chicken manure can be manipulated to produce a palatable feed. If dried, pulverized grasses are used as the bedding, a mixture of chicken manure and dried, pulverized grass (about 14 per cent) are put into a fermentation pool (2 x 2 x 0.5 m) and equal amounts of dried, pulverized grass, silage, and wheat bran are added with a small amount of table salt. The fermentation pool is then filled with water, which occupies 70 per cent of the pool.

The mixture is stacked to 15 cm in height, and allowed to ferment for 4 h in the summer. If the temperature is over 40°C the fermented material should be spread out. The material should be heaped up to 20-30 cm in the spring and fall, and allowed to ferment for about a day. In the winter, the mixture should be stacked to 40-50 cm in height and covered with a plastic sheet for 3-4 days. The fermented feed has no foul smell, a slightly wine flavor, and pigs find it very palatable.

The nutritional value of fresh manure from a chicken less than 5 weeks old is high; pigs will eat this manure without any treatment. The manure of egg-laying hens contains about 60 per cent of the crude protein from the feedstuffs. The daily excreta of an egg-laying hen contains about 4 g of digestible protein. Fresh chicken manure from cage-cultured hens can be collected and immediately mixed with the pig feed. This mixture should only be fed to sows; feeding the mixture to fatteners may influence the quality of the pork.

Chicken manure contains latent pathogens and sterilization is necessary to prevent other animals from contracting chicken diseases. One common sterilization method is to use methyl alcohol bromide to fumigate the manure and the bedding. Fumigation can be performed in the storage basement of the silage tank or in specially designed tanks. Another sterilization method involves mixing the manure with formalin at a dose of 0.5-2 per cent and allowing the mixture to air dry, before use. Fresh chicken manure accounts for no more than 30 per cent of the cow or pig feed; a 15-25 per cent manure contents gives the best results.

Goose Production

Geese are mainly for human consumption and are herbivorous animals that can utilize some of the green, coarse feeds. Unlike ducks, geese do not have to use feeds of animal origin; therefore, the feed cost for geese is much lower than that for ducks. The well-known Chinese geese has strong ability to graze, matures early, and has a high output. The ratio of feed to meat, is higher for geese than for ducks. When raising geese on a fishpond the goose droppings go directly into the pond, fertilizing the water as well as feeding the fish.

The Chinese goose is famous for its early maturity and high output. There are large and small varieties, the lionhead being the largest Chinese variety and one of the largest varieties in the world. A mature lionhead goose weighs 10-12 kg, the gosling grows quickly, and a 75 to 90-day-old meat goose can weigh 5-7.7 kg. Their ability to seek food is poor, however, and they produce only 25-35 eggs/year. The Taihu goose is famous for its small size, the mature goose weighing only 3.5 kg. This variety matures earlier than the lionhead goose and lays around 80 eggs/year; some species, in fact, can lay over 100 eggs/year. The Taihu goose has a great ability to seek food and its consumption of feed is less; therefore, the Taihu goose can be more suitable to raise than other varieties. Meat goslings can be produced by crossing the high-yield Taihu goose (maternal) and the large lionhead goose (paternal) through artificial insemination.

Grazing of meat gosling

In the spring, the temperature gradually increases and the grasses sprout. This is the best time for the growth and grazing of meat goslings. After the wheat harvest, goslings can graze on the remains of the harvest and, therefore, less feed is required. Only about 1 kg of feed is required for each gosling up to 70 days old.

Newly-born goslings are timid and dislike the cold; therefore, they should be kept warm and divided into small groups. They must be fed at least six times daily at a fixed time. A midnight feeding is essential. Feedstuffs include fragmentary rice, chopped green cabbage, or green grass. After 4 or 5 days, the goslings can begin to graze and the distance of grazing can be increased gradually. After 15 days, they can be allowed out all day but should be kept in the hut at night to prevent losses as a result of predation. During fattening, if the weather is hot, the geese should be kept in the rivers, lakes, or ponds for the night. After 70 days, or when the average weight reaches 2.5 kg, the geese can be marketed.

Management and feeding of the breed goose

A simple goose house can be built on the bank of a fish pond. The house should face south and the southern side should be open or enclosed by low walls. There should also be a dry run of at least 5 m in width for feeding and resting. The connection between the dry run and the fish pond should have slope less than 30°. The fish pond should be surrounded by hedges about 60 cm high and the bottom of the goose house should be 20 cm higher than the outside. Grass is used as a bedding to keep the house dry. Straw is stacked in one corner of the house for laying eggs. A typical goose house can hold about 4 Taihu geese/m^2 and the water area should be as large as possible.

To achieve a high fertilization rate of seed egg, there should be 15 male geese for every 100 female geese. Taihu geese can utilize green fodder, therefore, during the non-egg-laying season, raising breeder geese depends on grazing with a small amount of blighted rice as a supplementary food.

Table 9.6 Feed composition for the breeder goose.

Month(s)	*Daily feeding amount*	*Feed ingredient (%)*					*Metabolic energy (cal/kg)*[a]	*Crude protein (%)*
		Blighted rice	*Bran*	*Bran cake*	*Frag rice*	*Barnyard grass*		
June – August	150	50	50				557	3.78
Sept. – Nov.	250	50	20	15	15		842	7.34
Dec.	250	40	20	15	15	10	1,346	9.75
Jan. – Mar.	200	40		20	20	20	1,746	9.75
Apr. –	175	30		20	20	30	1,748	10.28

[a] 1 cal = 4.19 J.

The nutrients in this formula, especially the crude protein and metabolic energy, are too low. This is due to limitations in the food source and rising cost. Because Taihu geese have a propensity to graze and the ability to utilize coarse feed, however, they can adjust their intake according to energy and protein requirement. Thus, they can overcome the disadvantages in the formula in Table 9.6. If this feeding formula was improved, the egg-laying rate could increase.

Prevention and treatment of disease

Mature geese are highly disease-resistant. Goslings, however, are vulnerable to a variety of diseases. If they are kept in a large goose house with a dense population, a minor error in management could have devastating effects. The best preventive measures against goose diseases are proper rearing management, a sanitary environment, and proper vaccination.

The common infectious diseases are gosling pest, cholera avium, and yolk peritonitis. Gosling pest vaccine is now available in China. The mother goose should be inoculated with diluted (1:100) gosling pest vaccine 1 month before egg laying once a year; the goslings will be immune to the disease. Regular inoculation of cholera avium vaccine can prevent cholera in geese. It the flock is already infected, streptomycin should be injected at a dose of 100,000 IU (international units)/goose three times at 4-h intervals. Yolk peritonitis usually occurs during the egg-laying season. At present there is no vaccine for this disease. Streptomycin can be used for treatment and the whole flock should be administered furazolidonum mixed with the feeds at a dose of 25 mg/goose for 3 or 4 consecutive days. Besides medical control, sterilization, isolation and properly burying diseased carcasses should be practiced to prevent the spread of disease.

Duck Production

The Chinese have a tradition of eating duck eggs and processing them into salted or preserved eggs. Raising egg-laying ducks requires less and simpler equipment than goose raising. Ducks can produce more and larger eggs. Ducks live in groups, and graze on natural feeds. Therefore, raising egg-laying ducks is more profitable than raising egg-laying hens. On an integrated fish farm, the grow-out pond can be used to raise egg-laying ducks. Ducks are omnivorous water fowl that can use the by-products of as well as animal feeds. The nitrogen content of duck manure is twice that of goose manure. The phosphate content of duck manure is nearly three times that of goose manure.

Shaoxing duck is one of the best egg-laying species in China. It is a rather small species, a mature duck having an average weight of 1.25-1.50 kg. Its ability to seek food is strong, so it requires little artificial feed. It matures early and usually lays eggs at the age of 120 days producing 250-300 eggs/year. Highly productive ducks can lay more than 300 eggs/year. Each egg weighs about 55-65 g. Khaki-Compbell drakes from Holland have been crossed with Shaoxing female ducks. The hybrid vigor is obvious: first-generation hybrids begin to lay eggs after 102 days, producing an average of 287.7 eggs/year. Each egg weighs about 64.5 g. Therefore, one hybrid duck can produce about 18.6 kg of eggs/year. The economic benefit of this hybrid is about 50 per cent higher than that of Shaoxing duck.

Utilization of natural resources

Ducks are omnivorous water fowl. They have a great ability to seek food; therefore, they should be raised by grazing as much as possible. The natural resources of the rice fields, lakes, marshes, trenches, ditches, and river shoals can be utilized. Ducklings usually hatch in early fall and the paddy field can be used for grazing. Ducklings eat grass, snails, small fish, shrimp, and injurious insects in the paddy field. As the rice grows, the ducks can be transferred into the rivers, channels, ditches, lakes, or marshes for grazing. After the rice harvest, duck can be herded back to the rice paddy fields to graze on left-over rice, barnyard grass, snails, and mole crickets. Natural feeds are seasonally available and duck raising must take advantage of natural resources to save on artificial feeds. When grazing stops in November, the ducks begin to lay eggs.

Duck raising in fish ponds

Fish ponds can be used to raise ducks; however, ducks eat small fish and compete with black carp for snails. Therefore, ducks should be raised in grow-out ponds, which have a much bigger water area, or within an enclosed section of a large fish pond. The construction of a duck coop is similar to the construction of a goose house, but egg-laying ducks are more sensitive to the cold. Therefore, duck coops should be kept warm and there should be windows and doors on the southern wall to keep coops cool in the summer and warm in the winter.

If there are lakes, marshes, and river shoals rich in natural feeds close to the duck farm, grazing should be utilized to its utmost. Otherwise, the ducks could be bred in the coop, moving from the dry run to the wet run to the fish pond for food and rest, with all the egg-laying ducks living mainly on artificial feeds. Each Shaoxing duck must be fed 110-120 g of mixed feedstuff, including blighted rice, barnyard grass, rice bran, fragmentary rice, and 50 g of animal feeds, such as fresh fish and pupae. Besides the 100-200 g/day of green vegetables for each duck, snails and *Corbicula* spp. are often used as supplements to meet calcium needs. The green fodder should be chopped and fresh fish should be cooked and then mixed with the green fodder. Feeds are given three times daily at set times. The Shaoxing duck is rather nervous and easily disturbed, which may influence their egg-laying ability. Therefore, the environment should be kept peaceful and quiet. Although the egg-laying duck is a water fowl, they must rest on land. Thus, the duck coop should be dry and the grass bedding should be thick in the winter to keep it warm and dry.

Prevention and treatment of disease

The most common infectious diseases of the egg-laying duck are duck pest and fowl cholera. The newly developed vaccine against duck pest has shown promising results, but treatments for fowl cholera are still unsatisfactory. To treat fowl cholera, each egg-laying duck is injected intramuscularly with 50,000 IU of streptomycin three times at 4-h intervals and 0.2 g/day of sulfadimethoxinum is given orally for 3 consecutive days. Sterilization, isolation, and properly burying diseased carcasses should be practiced to prevent the spread of disease.

Pig Farming

Pigs are omnivorous. The length of its digestive tract is 14 times its body length. Feedstuffs are much better utilized by pigs than by chickens. Chinese pigs can tolerate and fully utilize coarse fodder as well as chicken excrement including the bedding. The pig has become one of the main animals in the complete fish-livestock-poultry system of integrated fish farming.

Pigsties on the pond dikes

Pigsties are usually built on the pond dike of an integrated fish farm so that the pig excrement can be directly flushed into the pond. Because the pond dike is not too wide, the pigsty is usually a single row, faces south, and has an inverted V-shaped roof. The depth of the pigsty from south to north is 4 m and the width of every house is 3 m. There should be a 1 m wide veranda on the southern side. Each house has an area of about 11 m^2 and can hold 10 fattening hogs. The height from the ground to the eaves should be 2.0-2.2 m. To reduce costs the south side should only have a fence about 1.2 m high. The cement ground should be a little higher on the northern side. This facilitates the flow of excreta directly into the fish pond through the discharge ditches. This semi-open type of pigsty is cheaper to build, well-ventilated, receives sufficient sunlight, is cool in the summer and warm in the winter. The feeding trough is installed on the southern side and pigs sleep on the northern side. This arrangement keeps the ground dry and is convenient for operation and management.

Utilization of hybrid vigour

The Taihu pig, bred in the Wuxi district of China, can copulate when it reaches 30 kg, normally at the age of 5 months. They mature earlier and produce more piglets per litter (15.5). Mature sows weigh about 125 kg. The quality of the pork is good, they use less fodder, and can tolerate coarse fodder. The growth rate for the fattening pig, however, is unsatisfactory. The Yorkshire stud pig has been crossed with the Taihu pig and the first generation hybrids have been used as fattening hogs with good results. As the standard of living in China improves, more lean meat is required. The Landrace hog for salted meat is being recommended for crossbreeding. A first-generation hybrid sow from the Yorkshire stud pig-Taihu sow cross has been crossed with Landrace stud pig. Offspring of this triple hybrid grow very rapidly. To fully utilize this good stock, artificial insemination is often used for breeding.

Pig fodders and rearing management

There are various fodders on an integrated fish farm that can be used as pig feed. However, to promote the growth and fattening of the hogs, their nutritional value should be increased. To lower the cost of pig farming, local produce and by-products of the farm should be fully utilized. The feeds should be nutritionally complete, including 55-60 per cent corn, barley, wheat bran, and rice bran; 5 per cent of soybean cake and cotton-seed cake; 15-25 per cent table salt; and 2-3 per cent bone powder and calcium carbonates. Green fodder should account for 15-30 per cent of the total fodder. Table 9.7 shows a feed formulation that could be used in an area that is rich in fodder crop.

Piglets may be produced from the sow of the same farm but are usually bought from a breeding farm. Piglet fodder should be given to the newly bought piglings, changing to pig fodder when the body weight reaches 20 kg. When the body weight reaches 30 kg, fattening fodders are maintained until the body weight is over 90 kg (Table 9.7).

Piglets must be properly trained to eat, sleep, and discharge waste at fixed positions. The feeding trough is usually placed on the southern side of the pigsty and a small amount of manure is placed near the corner of the manure exit on the southern side of the pigsty to teach the newly arrived piglets to discharge waste at that location. A clean grass bedding is stacked on the higher northern side for sleeping. Sometimes piglets discharge waste throughout the pigsty and the stockman must sweep the excreta into a fixed corner to keep the sleeping place clean. After several days, piglets develop good habits and keep their sleeping place dry and clean. The piglets are given a fixed amount of feed three times a day at a fixed time. The

Table 9.7 Component formulae (%), additives, analyses, and daily feeding amounts of artificial feeds for various sizes of pigs.

Component	*Piglet (5-20 kg)*	*Young pig (20-50 kg)*	*Fattening pig (50-90 kg)*
Corn	53	50.5	45.65
Barley	7.5	15	11
Sorghum	12	5	11
Soybean cake	15	12	7
Wheat bran	–	5	15
Fish meal	10	5	3
Chinese scholartree leaf powder	–	5	5
Bone powder	2	2	2
Table salts	0.5	0.5	0.35
Additives (g/t)			
Sodium selenite	0.15	0.15	0.15
Zinc sulphate	200	200	200
Potassium iodide	1	1	1
Multivitamins	40	40	40
Digestive energy (cal/kg)[a]	3.084	3.011	3.028
Crude protein (%)	19.3	16.41	14.32
Daily feeding amount (kg/pig)	0.32-1.2	2.1-2.2	2.2-3

[a] 1 cal = 4.19 J.

pigsty must be cleaned two or three times daily to ensure the piglets sleep and eat well.

Prevention and treatment of disease

The pig is more resistant to disease than the chicken. With proper management, a sanitary environment, and the necessary preventive measures, pigs will stay healthy. The common infectious diseases of pigs are pig pest, erysipelas, pasteurellosis, piglet paratyphoid, and pig asthema. There are vaccines for the first four diseases and a triple vaccine for the three fulminating infectious diseases: pig pest, erysipelas, and pasteurellosis. This triple vaccine is convenient to use and very effective. There is, as yet, no vaccine for pig asthema. The main preventative measures for pig asthema are quarantine and eliminating diseased pigs. Intramuscular injection of kanamycin at a dosage of 20,000-40,000 IU/kg body weight once daily for 5 consecutive days or intramuscular injection of oxytetracycline at a dosage of 20-40 mg/kg body weight once daily for 5-7 consecutive days will have certain curative effects. The sick pig should be isolated and sterilized, and dead pigs should be deeply buried or burned to prevent the spread of disease.

Milk Cow Production

A cow is a herbivorous ruminant and can efficiently utilize green forage, especially chicken manure with grass bedding. Chicken manure contains a large amount of nonprotein, nitrogenous compounds (uric acid or amide compounds) that cannot be effectively absorbed by pigs: however, milk cows can utilize these compounds. This is why milk cows are common in fish-livestock-poultry integration. The milk output of the cow is high, its economic benefit is great, and the amount of excreta produced is considerable.

Because grazing is the main method of cow raising, a large pasture is needed. In the winter, stall feeding is practiced. Because of the lack of a large pasture on an integrated fish farm, intensive stall feeding is used for milk cow raising. In front of a double-row cow barn, there is usually an enclosed playground. The cows are fed and milked in the stall and walk around in the playground. All the forages for the milk cows are supplied during stall breeding.

Black and white cows

The black and white cow is the highest milk-yielding type. Most countries of the world raise a variety of black and white milk cow which originated in the Netherlands. The Chinese black and white cow can adapt to the natural conditions of the local district and has a high milk productivity. A primiparous cow can yield 4000 kg of milk during 305 days of lactation; over 5000 kg of milk can be expected after the third pregnancy. The milk fat index is 3.203.5 per cent.

Prevention and treatment of disease

Tuberculosis and brucellosis are common infectious diseases of both humans and cows. Tuberculosis causes degeneration of the tubercle nodes on the lung and lymph nodes and brucellosis causes abortions and infertility and decreases the lactation of cows. These can infect both milk cows and humans and, therefore, quarantine measures must be practiced. Newly-bought milk cow should be isolated for three months and tuberculin tests should be performed three times by both intradermal inoculation and intraocular instillation. These cows should remain quarantined until they are proven disease-free. A similar test should be performed twice yearly for those cows without tuberculosis. If any cow develops tuberculosis, it should be isolated immediately and examined. All other cows should be examined 30-45 days after any outbreak until no positive case is found for three consecutive tests. All dairy workers should be regularly examined by X-ray. If any tuberculosis is found, the patient should be fed separately. Breeding of healthy cows should be enhanced to replace diseased cows and establish a new, healthy herd. The serum agglutination test can be used to detect brucellosis in milk cows. This test should be performed yearly. Healthy cows are given sheep type No. 5 brucellus bacillus (or pig type No. 2) attenuated vaccine for the prevention of brucellosis.

Forage and feeding of milk cows

Stall feeding is normally carried out in the dairy of an integrated fish farm and should be performed on a scientific basis. The daily feed formula and feeding plan must be set according to the nutritional content of the forage and the nutritional requirements of the animal. Feeding standards vary from country to country. Tables 9.8, 9.9 and 9.10 show the feeding and rearing standards of the United States.

The standards in Tables 9.8, 9.9 and 9.10 are minimums and 10-15 per cent could be added in practice. Because the body weight of the primiparous lactating cow is still increasing, their standards should be 20 per cent higher. If the proposed milk production is over 6000 kg, cows are usually given the feed for weaned, multiparous cow with a daily milk production of 15 kg.

The daily portion of forage for the milk cow is given according to milk production (the amount of milk produced and its fat content index). Feeding standards can be calculated according to the nutritional requirements to maintain daily milk production and the average body weight of the milk cow (600 kg). Using the nutritional requirements of the feeding standard for milk cows as reference, the total daily nutritional requirements can be determined. The physiological characteristics of different developmental stages of the milk cow should also be considered in the calculation, e.g., pregnancy. The price and palatability of the feeds are also considered. Forage for milk cows mainly consists of green and coarse feeds. In the winter or hay season, cows are fed 1 kg dry grass and crop stalks and 3-4 kg silage or 5-7 kg root tubers for every 100 kg body weight. In the grass-growing season, 8-10 kg green grass are given to the cows for every 100 kg body weight; 1 kg mixed fine forage is given for the production of every 2.5-3.0 kg milk. The fine forage mixture is 30 per cent cake-type feedstuffs (15 per cent if chicken manure is used), around 40 per cent grain feedstuffs (barley, corn, etc.) 10-15 per cent bran, 10 per cent by-products of processing, and 10 per cent minerals, salts, and fish meal. The nutritional components of different forages can be calculated from the nutrient table and amounts should be adjusted to meet the needs of the milk cow. Mixed forage production has developed very quickly in the past 20 years. Forage manufacturers use computers to calculate the needs of the milk cow and feeds are mixed automatically and a mixed whole forage is produced.

A milk cow should be fed a fixed amount three times daily at fixed times. Fine forage is usually given first, followed by fodders, and water. The forage must be fresh; iron nails and wires must be removed. Milk production can increase 10-15 per cent if the milk cow drinks a sufficient amount of water. Exercise is also essential if maximum production is to be attained. The entire cow is brushed before milking; dry brushing in the winter; washing and brushing in the summer. The cow barn and playground should be cleaned frequently; cow manure and urine being washed directly through manure ditches into the fish ponds. For sterilization of

Table 9.8 Feeding standard for milk cows (daily): oat unit standard.

Body weight (kg)	*Oat forage unit (kg)*	*Digestible crude protein (kg)*	*Ca (g)*	*P (g)*
350	3.7	210	18	9
400	4.0	230	20	10
450	4.2	240	23	12
500	4.6	260	25	13
550	4.9	280	28	14
600	5.1	300	30	15
650	5.4	310	33	17

Table 9.9 Feeding standard for milk cows (daily): milk net energy unit standard (NND).

Body weight (kg)	*Dry materials (kg)*	*NND*	*Digestible crude protein (g)*	*Ca (g)*	*P (g)*	*Carotene (g)*	*Vitamin A (IU)* [a]
350	5.04	9.17	227	21	16	37	15
400	5.57	10.13	250	24	18	42	17
450	6.09	11.07	274	27	20	48	19
500	6.58	11.97	296	30	22	53	21
550	7.08	12.88	318	33	24	53	23
600	7.55	13.73	339	36	27	64	26
650	8.02	14.59	360	38	30	69	28

[a] IU, International Units.

Table 9.10. Rearing standard (daily nutritional requirements for the production of 1 kg of milk).

Oat unit standard					*Milk net energy unit standard (NND)*				
Milk fat (%)	*Oat unit*	*Digestible crude protein (g)*	*Ca (g)*	*P (g)*	*Dry matter (kg)*	*NND*	*Digestible crude protein (g)*	*Ca (g)*	*P (g)*
3.0-3.2	0.42	42	4	3.2	0.45	0.87	44	3.9	2.8
3.3-3.4	0.44	44	4	3.2	0.47	0.90	45.5	4.1	2.9
3.5-3.7	0.46	46	4	3.2	0.48	0.93	47	4.2	3.0
3.8-4.0	0.48	48	4	3.2	0.52	1.00	50	4.5	3.2

the barn, which should be performed monthly, 5-20 per cent bleaching powder emulsion or 5 per cent cresol is used.

From 4 to 5 days after parturition, only 2 kg of milk should be taken from the breast of the high-yielding milk cow. One third of the milk can be removed at 7 days and all the milk can be removed 9 days after parturition. High-quality hay with a small amount of fine feed and juicy forage is given to the weak cow as its main food within 3 days after delivery. Milk production gradually increases for 10-15 days after delivery. Fine quality grass, fine forage, and a sufficient amount of water should be guaranteed at peak lactation. Milk production begins to decrease gradually 3 months after delivery and weaning begins 60 days before the next delivery. The amount of fine feeds, green fodder, and juicy forage and the frequency of milking should be reduced 10 days before weaning. Milking should be performed every 2-4 days and stopped when production drops to 4-5 kg.

Milking technique and storage of fresh milk

Milking can be done manually or electrically. Integrated fish farms usually do not have many milk cows, therefore, manual milking is preferred. The udder should be washed with 50°C water and thoroughly massaged. Milking is performed by massaging two nipples at the same time. The first and second runs of milk are collected in a special container and should not be mixed with the milk of other runs. When most of the milk has been removed, the udder should again be thoroughly massaged. When all the milk is removed, the udder should be given a final massage.

The milk collected by manual milking should be filtered through gauze to remove hairs, dust, fecal material, and other impurities. It should then be cooled quickly and stored in a cool place. The milk should be thoroughly sterilized, tightly sealed, and transported to the milk-collecting station as soon as possible.

Artificial Breeding and Utilization of Earthworm

Earthworms are a good food for fowl and fish. Fresh earthworms contain 8-10 per cent protein; dry earthworms 56-66 per cent. Their effective energy content is 2920 cal/kg and their nutritional value is equivalent to that of fish meal. The reproductive ability of earthworms is very strong, multiplying 200 times/year under normal conditions. With proper management, an earthworm can reproduce 1000 times/year. No special equipment or fodder are required for earthworm breeding. Fermented cow dung, pig manure, weeds, and rank grass from the integrated fish farm mixed with the proper amount of silt are good fodders for earthworms. The large-scale propagation of earthworm not only improves the soil but also improves crop productivity. Artificial breeding of earthworms is not widely advocated and practiced in China. Some integrated fish farms consider earthworm breeding as a form of animal raising. Earthworms can serve as protein feeds for poultry, pigs, and fish and the results have been promising in enhancing yields.

Plant Cultivation

Proper fertilizers and feeds are essential for high fish yields. Fertilizers are used primarily to propagate natural organisms as fish feed. Various forage grasses, beans, grains, melons, vegetables, and aquatic plants are also good fish foods. Crop production on an integrated fish farm uses the pond dikes, river banks, corner areas, and forage field. The cultivation of grains, beans, pasture grasses, melons and vegetables, and fruit and mulberries should be rationally practiced according to the needs of the fish and the growing seasons of the different crops. Furthermore, the water surface at the edges of the rivers and lakes in the vicinity of the fish farm can be utilized to cultivate aquatic plants; this ensures the availability of high-quality forage throughout the year. This forage and silage can be used not only for rearing fish but also for raising domestic fowl and animals or to fertilize the water for plankton growth.

Pasture Grasses

Perennial ryegrass

Perennial ryegrass (*Lolium perenne*) belongs to the Gramineae family. It grows rapidly, has a high yield, is nutritionally rich, easy to cultivate, inexpensive, and very adaptable. Ryegrass may yield 5-10 t/mu per year and is a good food for grass carp, chinese bream, and wuchang fish. The cultivation of ryegrass provides a fresh fish food in the early spring, enabling the fish to break their fast early in the year.

Seeding and transplanting – Ryegrass is a late-season plant that can grow in the shade and prefers moist conditions. Seeding is usually performed at the end of September. The land should be prepared by applying 1000-1250 kg/mu of night soil or a layer of silt as the base manure, turning the soil by deep tilling, and pulverizing and smoothing the soil. The amount of seed for broadcast sowing is 2-2.5 kg/mu. If the weather is dry after sowing, the plot should be watered until the complete emergence of the seedlings. After seedling emergence, another dressing of night soil (same amount as the first application) should be spread over the soil. When seedlings reach a height of 12-15 cm, they are transplanted to a field that has already been tilled and covered with a layer of pond silt as the base fertilizer. Transplanting usually occurs at the end of October or in early November. The leaves of the seedlings should be cut in half to ensure quick establishment and the seedling should be spaced at 18 x 18 cm or 21 x 21 cm, with six or seven seedlings per bunch. After transplanting, a 1:3 dilution of night soil is applied.

Field management – To enhance the growth of the transplants, all weeds must be removed. Weeding should be done before, during and after transplanting. Seedling plots and transplant fields should be kept moist and must be watered during a prolonged period of dry weather. One application of nitrogenous fertilizer is usually given before initial cropping. Organic manure should subsequently be applied at a rate of 250-300 kg/mu after every harvest. Results are better if the soil is loosened before fertilizer application. Some inorganic fertilizers can also be used.

Harvesting – At the height of 30-60 cm, the ryegrass should be cut near the ground. At this stage, the grass is tender and all of it will be consumed by the fish, thus, the utilization rate of the feed is high. In addition, ryegrass grows fast and has a high tillering activity after cutting. In general, when the air temperature is low from October to February, the growth of ryegrass is retarded and only one or two cuttings can be done. From March to May, harvesting can be made approximately once every 20 days. The second and third cuttings must be close to the ground, leaving 2-3 cm "stubbles". This increases tillering, yield, and promotes quality.

Production of seeds – Ryegrass begins to shoot, bear ears, and flower in April; seeds can be collected in early June. Seeds do not ripen at the same time and will fall to the ground easily; therefore, when the ears turn yellow, seeds should be collected. The seed yield is about 50 kg/mu. Plots reserved for seed production should not be cropped as green fodder.

Sudan grass

Sudan grass (*Sorghum sudanese*) is an annual plant of the Gramineae family. It thrives in soils of different fertilities, preferring fertile, clayey soils. Sudan grass yields about 10 t/mu, withstands dryness and soil fertility, shows rapid regeneration, high reproductivity, strong adaptability, and superior quality. It is easy to cultivate, a high-yielding crop in the summer and the autumn and therefore suitable for integrated cultivation with ryegrass to provide high-quality fresh food (Table 9.11) to grass carp, Chinese bream, and Wuchang fish from spring through autumn.

Table 9.11. Utilization by fish of Sudan grass at different development stages.

Development stage	*Yield (Kg/mu)*	*Amount utilized (Kg/mu)*	*Utilization rate (%)*	*Component used*		
				Coarse protein (Kg)	*Coarse fat (Kg)*	*Coarse fibre (Kg)*
Seedling	9,171	9,171	100	278.8	70.6	278.8
Nutrition I	10,138	9,631	95	176.3	60.7	274.0
Nutrition II	13,007	11,055	85	162.5	47.5	362.6
Ear bearing	12,839	8,987	70	178.8	62.9	412.5

Seeding and transplanting – Sudan grass prefers a damp environment and is vulnerable to frost. Seeding is usually done when the soil temperature is above 10°C. The optimum temperature range for germination is 20-30°C. Strip drilling is suitable for Sudan grass, which is primarily cut for green fodder. The row spacing is 20-30 cm, the depth of seeding is 3-4 cm and the seeded plot should be mulched with a 1-cm layer of plant ash. For dense drilling, about 2 kg seeds/mu is used. Dibbling (nursery seeding) can also be practised. Plant spacing in the nursery is 18 cm and each bunch takes about 10 seeds. When seedlings are 12 cm high, they are ready for transplanting. Before tilling and sowing, a layer of pond silt is applied to the field as base fertilizer and the soil is turned, levelled, and smoothed. When transplanting, plants are spaced at about 18 x 18 cm with four or five seedlings per bunch.

Field management – Seedling emergence is completed 7-8 days after seeding, budding takes place in 70-80 days, and flowering occurs in 80-90 days. The growth period is 100-120 days. Weeding should be done regularly. In prolonged dry weather, the plot should be watered, especially during the seedling period. The soil should be loosened and fertilized after every cutting. The method of dressing and the amount of fertilizer are the same as for rye grass.

Harvesting – When Sudan grass grows to a height of 60 cm, harvesting is feasible. The remaining stubble should be about 10 cm high, otherwise, tillering, regeneration, and yield will be adversely affected. From mid-May to August, harvesting can be done about every 15 days. The growth of Sudan grass slows around September and death occurs with the first frost.

Bunch grass

Bunch grass (*Symphytum peregroimum*) is a perennial plant belonging to the Borraginaceae family and originated in the Iran-Transcaucasia region. It is usually planted in early spring and yields 7-9 t/mu in its 1st year, 10-12 t/mu in its 2nd year, and may reach 15 t/mu. The stems and leaves of this grass are tender, juicy, and nutritious, with a high protein content. On a dry-matter basis, it contains 22-25 per cent crude protein, 4-6 per cent crude fat, 7-13 per cent crude fibre, and 38-40 per cent non-nitrogenous extracts. Therefore, it is an excellent green fodder (Table 9.12).

Table 9.12. Nutritional analysis of dry and fresh bunch grass.

Development stage	*Moisture (%)*		*Coarse protein (%)*		*Coarse fat (%)*		*Coarse fibre (%)*	
	Dry	*Fresh*	*Dry*	*Fresh*	*Dry*	*Fresh*	*Dry*	*Fresh*
Seedling	8.42	88.40	30.29	3.84	1.23	0.15	13.31	1.69
Flower	7.46	88.43	25.66	3.26	1.19	0.13	13.86	1.73

Bunch grass has a well-developed root system with vigorous growth, and is adaptable to environmental conditions. It is susceptible to few pests, easy to grow and propagate, and has a high survival rate. The underground portion of bunch grass can withstand temperatures ranging from -40 to 37.8°C. It is also resistant to drought and disease.

Seedling cultivation and setting – Both aboveground (leaves, pedicles, and rhizome buds) and belowground organs (rhizomes and roots) of bunch grass can be used for seedling culture and propagation. Propagation methods include sucker division, root cutting, longitudinal cutting of root necks, setting buds divided from root, and setting of stalk cuttings. Nursery bed breeding lasts 30-40 days. When the seedlings reach a height of 10-15 cm, they can be transplanted at a spacing of 45 x 45 cm with 2500-2600 plants/mu. In poor soils, the plant density should be increased to about 3000 plants/mu. For dibbling, the plant should be buried up to the neck of the root and thoroughly watered. Bunch grass is tolerant of a wide range of soil conditions, but a thick layer of sandy soil with good drainage is considered to be the most suitable. Plants can be cultivated on spare land around a pigsty or on pond dike slopes. The land should be deeply tilled, well fertilized, harrowed, smoothed, and leveled before setting the plants. In plots with poor drainage, a system of broad, grooved ridges that cross each other must be established so that any excess water will drain away.

Field management – The bunch grass plot should be fertilized once before the grass turns green in the early spring. Roughly 2500 kg/mu of pig manure should be applied. For new seedlings, the soil must be loosened and weeded. After seedling establishment, a second layer of fertilizer will invigorate the settings and promote root development. The soil should be fertilized after each harvest and before overwintering; this final application will ensure that hardy plants survive the cold months. When the weather is dry and hot, the plot should be watered; in the rainy season, proper drainage is crucial (water logging will cause root rot). Bunch grass is very pest resistant; however, cutworms usually attack seedlings and control measures should be practiced.

Harvesting – When bunch grass begins to bud and flower in early May, harvesting can start. The remaining stubble should be about 6 cm. Harvesting is done at about 35-day intervals, giving five or six cuttings every year. The proper time for harvesting depends on the amount and colour of the foliage. In general, one planting will last 8-10 years. When autumn arrives, the grass will no longer bud or flower, and usually, cropping stops in late October to retain the year's final coat of leaves for overwintering. Bunch grass is resistant to cold but vulnerable to frost. The roots however can survive temperatures as low as -40°C. To make full use of the land, other fodder crops can be intercropped after autumn.

Beans

Soybean

Soybean (*Glycine max*) is an annual plant belonging to the Leguminousae family (subfamily Papilinaceae) and is a native plant of China. The yield of soybean is generally 80-130 kg/mu and the soybean seed contains 30-40 per cent protein, 20-24 per cent fat, about 30 per cent carbohydrate, and several kind of minerals and vitamins, giving it a high nutritive value. When ground, it makes an excellent fish food.

From seeding to maturity, soybean passes through various growth stages (e.g., germination – seedling stage, third true-leaf stage); the entire growing period is 120-140 days. The time from germination to blossoming varies with variety: early ripening varieties, 34-43 days; intermediate varieties, 40-60 days; late varieties, 50-60 days; very late varieties, 63-84 days. Soybean is tolerant of a wide range of soil conditions, but soils that are thick and rich in calcium and humus with good drainage are more suitable. Soils with a pH ranging from 5 to 8 are preferred; soybean will not grow in soils with a pH value above 9.6 or below 3.9.

Seeding – When the soybean seed absorbs water (100-150 per cent of its own dry weight), and if air temperature is 10-20°C and there is sufficicent oxygen, germination will occur. With a sufficiently moist soil, the seed will absorb enough water to germinate 1 day. Seedlings grow rapidly when the air temperature averages 20-25°C in the day and, at the least, 15-17°C at night. Seeding time for spring and summer soybeans is from late March to early April and from 1 to 20 June, respectively; 6-7.5 kg/mu of seeds is required. Seeds should be selected by winnowing and screening. The cotyledon emergence of the soybean is relatively difficult; therefore, the soil must be loose. In addition, the germination of soybean requires ample moisture; therefore, the soil should be turned and smoothed to preserve soil moisture and fertilizer. Dibbling is the common method of seeding. Plants are spaced at 15 x 18 cm or 18 x 18 cm, there are 15000 to 20000 dibbles/mu, and each dibble has two or three seeds. After seeding, thin mulch of plant ash or fine soil is applied to facilitate emergence.

Field management – For every 50 kg soybean produced, it is necessary to apply 2.8 kg nitrogen, 5 kg phosphoric acid, and 6.5 kg potassium oxide. Initially, when nodules have not yet formed on the root portion of the seedling or the action of the root nodules is weak, growth is slow. To increase soybean production, the appropriate amount of nitrogenous fertilizer and large amounts of phosphorus and potassium must be applied. In addition to base manure, a little seed-mulching manure may also be used, i.e., high-quality fertilizer like decomposed barnyard manure, high-quality compost mixed with plant ash, or superphosphate to mulch the seedlings. Depending on growth conditions, ammonium sulphate should be applied at a rate of 2.5-5 kg/mu during the seedling stage and 7.5-10 kg/mu during the flowering stage. When soybean seedlings have uniformly emerged, they should be examined. Dibbles without seedling must be replanted. To enable seedlings to grow stoutly and evenly, thinning should be performed after a pair of true leaves appears.

After the seedlings are established, weeding and thinning should be continued. From flowering to pod swelling, soybean requires much water. A rational irrigation scheme will appreciably increase production. When the pods are ripening, a complete weeding will improve interplant ventilation and sunlight penetration, quickening the ripening process and ensure a good yield. The prevention of soybean pests such as soybean aphids, pod borers, and bean hawkmoths, as well as the weed, dodder (*Cuscuta*), is important.

Harvesting – The spring soybean crop reaches maturity in late or mid July; the summer soybean crop, in early or mid-October. Harvesting should be done when two-thirds of the foliage has turned yellow and fallen, when the majority of the stems and pods appear dark brown with the seeds separated from the inner walls of the pods, when the beans are half-dried, quite hard, or when the pods rattle when shaken. The crop should be harvested within one week and thoroughly dried in the sun for a few days. After removing all impurities, the crop can be stored. In the storage area, the moisture level should be below 13.5 per cent; if moisture level is below 12 per cent, the crop can be stored a little longer.

Grains

Barley

Barley is an annual plant belonging to the genus *Hordeum* of the Gramineae family. Barley yields 200-300 kg/mu and, apart from being a food grain, it is important in brewing beer, producing alcohol, and making maltose and straw is appropriate for weaving straw hats. The growth period of barley is about 190 days. Its lowest germination temperature is 1-2°C and its optimum temperature for growth is around 20°C. Barley bears ears in early and mid-April with a milk stage of about 10 days normally followed by a waxy ripe stage of 6 or 7 days.

Seeding – Seeding of barley is generally done in late October to mid-November at a rate of 15-18 kg seeds/mu by broadcast or strip drilling. Most of the root system is distributed within 15-18 cm of the cultivated surface layer; therefore, secondary tillage should be done carefully with the "three-ditch" pattern of drainage. Seeding should be shallow and even. For every 50 kg barley production, it is necessary to fertilize the soil with 1.5 kg nitrogen, 0.62 kg phosphorus, and 1.15 kg potassium. A base manure of grass and decomposed pond silt (6000-7500 kg/mu) or pigsty manure (2500-3000 kg/mu) is also applied. For the intermediate soil layer, 15-20 kg/mu ammonium sulphate and 25 kg/mu calcium superphosphate should be used with 3000-4000 kg/mu seed-mulching manure.

Field management – If seeding is followed by dry spell, the total even emergence of seeds should be ensured by applying fertilizer at the first-leaf stage: 500 kg/mu night soil diluted with 3000-3500 kg/mu water or 10-12.5 kg/mu ammonium sulphate diluted with water. Alternatively, 5000 kg/mu diluted silt mixed with 30-40 kg/mu dissolved ammonia or 1500 kg/mu pigsty waste followed by a layer of river silt 5000 kg/mu could be applied. Inter-row cultivation may be done two or three times. Cholraluron may be used for weeding in barley fields. In early February, 7.5-10 kg/mu ammonium sulphate, 20 kg/mu diluted ammonia, or 1000 kg/mu night soil should be applied to revive the seedlings. Ditches must be cleared to ensure proper drainage. Toward the end of February, 12.5 kg/mu ammonium sulphate should be applied to promote growth and the bearing of ears. In the late stages of growth, disease prevention and pest control is important. Spray 90 per cent trichlorfon (1:1000 dilution) to control army worms, 40 per cent dimethoate emulsion (1:2000 to 1:3000) for aphids, and 0.2-0.3 kg carbendazol diluted with 75-100 kg water for red mold and powdery mildew.

Harvesting – Barley ripens in late or mid-May. Harvesting should be performed at the waxy ripe stage.

Corn

Corn (*Zea mays*) is an annual plant of the Gramineae family. It is a good fodder with a high nutritional value, and has a high yield, 250-300 kg/mu. Its grain contains 8.5 per cent protein, 4.3 per cent fat, and 73 per cent carbohydrate. Therefore, 50 kg corn is nutritionally equivalent to 67.5 kg oats, 60 kg sorghum, or 65 kg barley. The nutritional value of the corn stalk is generally more than double that of the stalks or stems of other crops. The fresh stems and leaves harvested after the shooting of the phalanxes or before the waxy ripe stage are green and juicy. Their nutritional value is very high and they are excellent substitutes for fine feeds. The successful cultivation of corn is important in developing livestock farming.

Corn thrives in warm climates (the lowest temperature at which germination occurs is 10-12°C) but requires only a short photoperiod. At the seedling stage, 22.7 per cent of the total water requirement is needed; at the middle stage, 44.5 per cent; at the late stage, 32.8 per cent. The soil should be rich in organic matter and well drained; a sandy loam soil is also appropriate. For every 50 kg corn grain production, the crop removes 1.24-1.95 kg nitrogen, 0.68-0.91 kg phosphorus, and 1.96-2.07 kg potassium from the soil. Corn varieties can be classified according to growth period (early, 80-95 days; intermediate, 96-115 days; late, 116-150 days) and sowing season (spring, summer, autumn, and winter corn).

Seeding – Before seeding, seeds must be carefully selected. To achieve full germination and even, vigorous growth, the seed should be prepared by sunning and by immersing and mixing with certain chemicals. Seeds of spring corn can be sown when the soil temperature is above 10°C. To maximize the growth period, seeds should be sown as early as possible. Seeds of summer and autumn corn should be sown as soon as the preceding crop is harvested. Seeding is usually done by drilling or dibbling. The seeding rate for drilling is 2.5-4 kg/mu; for dibbling, 2-3 kg/mu. The seeding depth is 3-5 cm. The seeding density for late varieties is 2000-3000 plants/mu; for intermediate varieties, 2500-4000 plants/mu; for early varieties, 3000-5000 plants/mu. When the corn is to be cultivated for fodder (silage or fresh), the planting density may be 20 per cent more than those given. There are many ways of planting corn. The tilling depth should be 21-24 cm and ample organic manure should be applied before the land is tilled. For ridge cultivation, it is important to ensure sufficient moisture in the top soil. In waterlogged or poorly drained areas, bedding cultivating should be adopted. The base manure is the principal source of nutrition for the corn. Barnyard manure, livestock manure, and compost prepared from decomposed stems and stalks which are rich in nitrogen, phosphorus, and potassium, are the best base fertilizers for corn.

Field management – After seedling emergence, thinning should be done. Weak seedlings should be removed, leaving the strong seedlings and ensuring even growth and vitality. Quick-acting-fertilizers such as night soil, ammonium sulphate, urea, potassium sulphate, and plant ash are applied as a top dressing to promote growth during the following three stages: shooting up of stalks, impregnation of ears, and phalanxing.

Harvesting – After pollination, the corn will be fully ripe in 50-65 days. The higher the air temperature, the faster the corn will ripen. The leaves on the stem turn yellow, the cob wrappers dry up and wither, and the grains appear bright when the corn is fully ripe. At this time harvesting should be done.

Sweet Potato

Sweet potato (*Ipomoea batatas*) is a trailing plant of the Convovulaceae family that originated in tropical America and the Caribbean. It yields 1500-2000 kg/mu and the tuber contains 20-27 per cent starch, 2.3 per cent protein, 0.2 per cent fat, and multivitamins. Besides being used for human consumption, it is also a fine, high-yielding forage crop. The tubers, vines, and residues from processing can all be used as fodder. Its tender, juicy vines and leaves are a good fresh fodder and the value of sweet potato as a feed is higher than that of ordinary forage grasses. In addition, its vines and leaves can be cut during July and August, yielding 1000-1500 kg fresh vines that can be used as fresh fish feed. From setting to harvesting, the growth period of sweet potato is 110-160 days. Early tuber-bearing varieties can give a harvest in 80-90 days. The plant is very sensitive to cold weather. Growth stops at 15°C and stored tubers will be damaged at 9°C. It is, however, a relatively drought-resistant crop and will thrive in regions with an annual precipitation of 400 mm.

Seeding and transplanting – In sweet potato production, most farmers use the tuber-vine-cutting method of propagation. The final yield is directly dependent on the time of transplanting (the earlier, the better). Spring cuttings should be set from late April to mid-May; summer cuttings, in June. The density of settings should be determined by climate, soil, amount of fertilizer applied, characteristics of the sweet potato variety, length of the growing season, and method of cultivation. Because sweet potato is a tuber crop, it requires a deep, loose soil layer. Therefore, the land should be ploughed to a depth of 12-15 cm and banked in ridges for setting the cuttings. For every 500 kg production, the vines must absorb 2 kg nitrogen, 0.5 kg phosphorus, and 3.1 kg potassium. The most suitable fertilizer for this crop is a compound, N-P-K fertilizer such as barnyard manure and compost. Manures that have more potassium (e.g., plant ash) will increase the yield.

Field management – When the roots of the sweet potato cuttings are established, missing settings should be replanted. Inter-row cultivation and weeding should be performed as needed. After dressing and spraying with fertilizer, tilling and weeding are necessary. Inter-row cultivation should not damage the root system of the plant. Earth banking is a helpful management technique for sweet potato cultivation. It helps to preserve soil moisture and prevent the tuber from being exposed. It also helps to drain excess water as the grooves or furrows are deepened in the process of ridge banking, which is usually done twice during the growth of the vines.

Harvesting – Harvesting should be done when the temperature begins to drop in the autumn, when leaves near the stock have fallen and others are turning yellow and when the tubers are sufficiently swollen and their water content is reduced. Spring-set crops are harvested from late September to early October; summer-set crops are harvested in late or mid-October.

Cabbage and Melons

Chinese cabbage

Chinese cabbage is a biennial vegetable belonging to the genus *Brassica* of the Cruciferae family. It is a native plant of China. The nutritional value of Chinese cabbage is very high; the deeper the leaf colour, the higher the nutritional value is. Each 0.5 kg of Chinese cabbage contains 5.5 g protein, 0.5 g fat, 10 g sugar, 2 g crude fibre, 4 g inorganic salt, and vitamins, carotenes, and mineral salts. In general, Chinese cabbage yields 1500-2500 kg/mu. It is a high-quality fresh food for herbivorous fish as well as domestic animals and fowl.

The optimal temperature range for Chinese cabbage growth is 15-20°C. For seed germination, the optimum temperature range is 20-25°C. When the seedlings are young, nutritional requirements are not so much; in the intermediate stage when growth is vigorous, the demand for nutrients increases. Nitrogen is the major required nutrient. The soil should be fertile with good moisture retention.

Seeding and transplanting – For spring seeding, sowing and transplanting are conducted from the beginning of February to the end of May. The seeds of Chinese cabbage are directly sown, usually in early February. For summer seeding, sowing and transplanting are conducted from early June to the end of August. For autumn seeding, cultivation lasts from early September to the end of October. For winter seeding, cultivation lasts from early November to the end of January. Seeding rates depend on seeding time: early spring 3.5-5 kg/mu; spring, 1.5-2.5 kg/mu; summer (Pakchoi, *Brassica chinensis*), 2.5-3 kg/mu; summer (direct seeding), 0.5-0.75 kg/mu; autumn (sown and transplanted), 0.75-1.0 kg/mu; winter (nursery bed cultivated), 2.5-3 kg/mu. Chinese cabbage seeds are sown by broadcast. Thinning, weeding, manuring, spraying, and pest control should be done after seedling emergence. Field setting is also known as transplanting. Different cultivation seasons have different requirements for setting. Seedlings for transplantation before August are usually about 25 days old; those transplanted in September, 28-30 days old; those transplanted in October, 32-35 days old; those for transplanting in November, 35-40 days old.

Field management – Field management work includes top dressing, watering, and disease and insect control.

Harvesting – The harvesting period for Chinese cabbage depends on the cultivation method. Yound Pakchoi seeedlings directly planted in the summer can be harvested in 20 days; those cultivated in the winter, in 80-90 days; those transplanted from mid-September to the end of the month, in 25-30 days; those transplanted in October, in 40 days; those transplanted from mid-October to early November, in 45 days.

Wild cabbage

Wild cabbage (*Brassica aleracea* cv. Capitata) is a biennial plant belonging to the Cruciferae family and is a native of southern Europe. The variety commonly cultivated in China is the ordinary cabbage. The yield of this variety is 2000-4000 kg/mu and it is rich in nutrients (having proteins, carbohydrates, mineral salts, and vitamin C). Wild cabbage is suitable for human consumption and is a fine fodder for livestock. Because wild cabbage is biennial, only the edible globular top develops in the 1st year. In the following spring, when the air temperature is still as low as 2-6°C, flowering buds form and the plant blossoms and bears seeds. Wild cabbage will adapt to cold weather, although the optimum temperature for growth is 14-20°C. It grows well in a fertile soil that can effectively retain moisture, has proper drainage, and is easily irrigated. During the formation of the globular top, ample fertilizer and water are required. The nutrient most required by wild cabbage is nitrogen; a considerable amount of phosphorus and potassium is also required. The resistance of wild cabbage to disease is good.

Seeding and transplanting – Cabbage can be planted year round. According to harvesting season and cultivation method, there are three varieties of cabbage: spring, summer, and autumn-winter cabbage.

Field management – Spring cabbage usually requires several applications of top dressing at the end of the year. Night soil is applied in 1:2 dilution at a rate of 1500 kg/mu 1 week after the setting of the seedling. The second dressing should be given before January 19 to enhance sprouting in the early spring. The concentration and application rate are the same as for the first dressing. The third dressing should be applied 1 month later: concentration, 1:1; application rate, 2000 kg/mu. The fourth dressing depends on the stage of growth, i.e., when the spring cabbage is forming its globular top in March to early April. The rate of diluted night soil applied is 1500-2000 kg/mu. This dressing solidifies and accelerates the growth of the globular top. Drainage grooves must be dug in the early spring. From the setting of the plants to the closing of ridges by their foliage, tilling is conducted in combination with weeding three or four times. Summer cabbage (*Brassica broccoli*) usually requires three fertilizer dressings per month. Each dressing calls for 1500 kg/mu of night soil. The first dressing is given in a 1:3 dilution after the set transplants have been established. The second dressing is applied 10 days later in a 1:1 dilution. Before the formation of the globular top, the third dressing is applied in a 2:1 dilution. Fertilization must be stopped when the globular top begins to form, otherwise rotting may occur. Chemical fertilizers can also be applied throughout growth, e.g., aqueous ammonia (1:100 dilution) four or five times at a rate of 25 kg/mu. The soil is generally loosened two or three times. Autumn cabbage generally gets three or four dressings of 15,000 kg/mu of night soil in different concentrations. The first dressing is given in a 1:3 dilution, 3-4 days after the transplants have been established. After 2 weeks, the second dressing is given in 1:1 dilution 2 weeks later. The third dressing is applied in a 2:1 dilution before the formation of the globular top. Cabbage for overwintering should be fertilized lightly in the second and third dressings. In the middle of November, to aid in the formation of the globular top, a dressing of night soil (2:1 dilution) is applied at a rate of 2000 kg/mu.

Harvesting – Spring-grown cabbage are harvested in batches from mid-April to early June, depending on variety. The yield is 2000-5000 kg/mu. The summer varieties are sown in early March and harvested in July or August with yields of 1500-3000 kg/mu. Those seeds sown in early May are gathered in August or September with a yield of 1500-2000 kg/mu. Seeds sowed in early June are collected in September or October with a yield of about 23000 kg/mu.

Squash

Squash (*Cucurbita maschata, C. maxima,* and *C. Melopepo*) is an annual plant belonging to the Cucurbitaceae family and is native of the tropics. It is a high-yielding, juicy fodder rich in nutrients, containing a lot of carotene, vitamin C, and glucose. Its stems and leaves can be processed into stalk sugar fodder after drying. Yield generally ranges from 1000-2000 kg/mu. The optimum temperature for the germination of squash seeds is 25-30°C; the most suitable temperature for the development of the fruit is 25-27°C. It requires only a short photoperiod and thrives in dry, hot environment with a soil moisture of about 50 per cent. A fertile, neutral, or slightly acid sandy loam soil is preferable.

Seeding and transplanting – The nursery bed seeding period usually falls between mid-March and early April. Two kinds of seeding are practiced; bunch planting and "broadcast" sowing. In bunch planting, the size of the planting holes is usually 7.5-9 cm^2 and 9-12 cm deep. Each hole takes an average of two or three seeds. The plot is then evenly mulched with a layer of nutritive fine soil, to ensure that the seeds are not exposed to the air. A thin covering of straw should be placed over the bed to serve as shading and to preserve moisture. Alternatively, a few short bamboo sticks should be used to support a plastic sheet that would act as a cover. Finally, mud is used to seal the edges of the covering. At night, straw mats are used as blankets to prevent the loss of heat and accelerate germination. The other method, "broadcast" sowing, is also known as two-stage breeding. Over the surface of a dressed bed, a layer of plant ash is spread. Seeds are then evenly cast. A fine-nozzle sprayer should then be used to sprinkle fine droplets of water over the plot. The seeds are then mulched with a 2 cm layer of nutritive soil. Finally, a layer of straw or a plastic sheet is spread over the bed and the nursery bed is sealed. At night, straw mats are used as blankets to preserve heat to enhance germination. It is also necessary to maintain proper ventilation, sufficient sunlight, and to control pests in the nursery. When squash seedlings have grown to a height of 9-12 cm with two or three true leaves, they can be transplanted. Seedlings are usually set in late April and are intercropped with other vegetable crops.

Field management – After transplantation, missing transplants must be identified and seedlings reset, holes must be dug to properly orient the plant, vines must be hilled as necessary, and diseases and pests controlled.

Harvesting – Early set squash can be collected 10-15 days after the pistillate flowers have withered. Harvesting in batches at regular intervals begins at the end of July and mass harvesting occurs in early and mid-August.

Aquatic Plants

Water peanut

The water peanut (*Alternanthera philoxeroides*) is a perennial plant native to Latin America and introduced into China more than 30 years ago. This plant is a high-yielding, easily cultivated aquatic crop that overwinters easily and is very adaptable. The surface of lakes, river bends, ditches, and ponds can all be used for float cultivation. The annual yield of fresh grass can reach 15-25 t/mu, enough to provide 10-15 pigs with silage all year. The stalks and leaves of water peanut contain 2.49 per cent non-nitrogenous extracts, 2.18 per cent crude protein, 0.18 per cent crude fat, 1.19 per cent crude fibre, 1.25 per cent ash content, 0.23 per cent calcium, and 0.03 per cent phosphorus. It can be served either fresh or cooked, and also can be prepared as fermented fodder or dried and ground as fodder for use throughout the year.

Water peanut prefers a warm, humid climate with a long photoperiod. They can grow in a wide range of water depth and grow well in rivers, ditches, and ponds that have slow running or stagnant, fertile water at a depth of 1-1.5 m. Water peanut reproduces asexually through their stalks and vines. As seedlings can germinate and grow on each node, they propagate very fast.

Time for breeding and propagation – The growth and reproduction of water peanut is very fast. Except in mid-summer when it is too hot and in winter when it is bitter cold, the rest of the year is appropriate for cutting, transferring and propagating the stalks. However, if it is to be introduced from another region to a locality for cultivation, the best time is early April when the old stalks are just beginning to germinate. Upon arrival in a locality the introduced cuttings should be placed on the water surface where they are to be propagated within one or two days to promote their early germination. Shelter the cuttings from wind and sunlight to prevent their drying up. Seedlings are best cut for cultivation when new stalks grow to a length of 15 to 30 cm; cuttings can float better this way and are more resistant to wave action.

Method of planting – Two methods are practiced: laying ropes and using lattice frames. Where the current is swift and the water deep, the method of laying ropes is used to prevent seedlings from being scattered by the water and wind; in stagnant water bodies, lattice frames are preferred.

Management

Fertilizer treatment – Water peanut is seldom fertilized. If the water is sheer and seedlings turn yellow, it is necessary to give a top dressing of fertile silt mixed with barnyard manure, or to spray diluted nitrogenous fertilizer in order to sustain a normal growth.

Weeding – This should be done before planting or after cultivation if moss and weeds are observed. Moss can be eradicated manually. If the results are not so good, it is better to spread plant ash or copper sulphate. The application is done in two ways: (1) use 0.2-0.5 per cent copper sulphate solution to directly kill the moss, or (2) crush copper sulphate into small pieces and put them in a small bag hanging on water surfaces densely aggregated by moss. With the gradual dissolution of copper sulphate in surrounding water, moss will be gradually eliminated.

Pest control – Three-spotted plusia occurs in July to September, crawling over and devouring water peanut plants. To control them, use 90 per cent crystalline trichlorfon at 12 ppt for spraying. Allow 3 to 5 days for the chemical to lose its toxicity before harvesting and feeding thet stalks to livestock. Another method is to disperse the plant so that the affected stalks will bend over drowning the pests.

Harvesting – After 30-40 days from planting when stalks and leaves rear 20-30 cm above the water surface, harvesting can be done. Leave 6 cm of stalk above water and retain 3-4 leaves on them. Cuttings can be made about every 10 days. In July and August when the weather gradually becomes hot with abundant rainfall, the water is enriched and growth is fast. Harvesting interval becomes shorter. After every cropping, use a hoe to loosen and separate the seedlings, which will help restore the growth through better spacing. The last harvest is done by the end of October.

Seedling reservation and overwintering – Water peanut reserved for seed should be densely cultivated on sunny leeward ponds. Choice should be made of plants whose stalks and leaves are luxuriant and healthy. Reserves should not be cut after a frost. Stalks and leaves of such seedlings should remain 50 cm above the water surface.

Water Lettuce

Water lettuce (*Pistia stratiotes*) is a wild aquatic plant belonging to Araceae family. The roots look like a bundle of cotton threads suspended in the water. The stalk is very short and leaves grow in clusters. Each plant has 6-10 leaves arranged in a ring shape. Leaf blades are oval. Its flowers are yellow in colour and the stamens, without pedicels, grow in symphysis but look protruded, while the pistile are like solitary bulbs of oval with single ovary in which are found several ovules. The fruit is a berry.

Water lettuce contains 1.07 per cent crude protein, 0.26 per cent fat, 1.63 per cent carbohydrates and a considerable amount of crude fibre. It can be used as fresh or cooked fodder for pigs. It grows and reproduces very rapidly and yields 10-20 tons/mu. The cultivation of water lettuce is characterized by less labour input lower cost, and easy management. Water lettuce floats, all the water surfaces of rivers, lakes and ponds, etc. can be used for propagation. It grows well in places where the water is fertile and stagnant. On running water, its growth is relatively poor. The suitable water depth for cultivation is 0.7-1.5 m, and the optimum pH value, 6.5-7.5. This plant prefers warm weather, and its resistance to cold is poorer than water peanut and water hyacinth, but its endurance to heat is better. Although it can grow in a wide temperature range between 15-40°C, it grows faster at 22-35°C. If water, fertilizer and sunlight conditions are favourable, each plant can reproduce 50-60 plants in a month. When temperature is above 35°C or below 18°C, it is unable to divide, or divides only a few times. When it is below 10-15°C, it will just maintain its life activities, and when it falls below 50°C, it dies. It demands an ample supply of nitrogenous fertilizer if it is to grow well. If water quality is poor and no fertilizer is applied, it will not thrive well.

Small pond planting in spring

When air temperature rises above 15°C around mid April, small ponds can be used to plant seedling removed from the nursery beds for the first propagation in order to have enough seedlings for extensive planting in summer. When seedlings are transferred to ponds, be sure that they are crowded together at one corner of the pond so that they will mutually give support to each other and are not able to move about. Every measure has to be taken to prevent filamentous green algae from entangling the seedlings. A fertile, warm, damp and quiet conditions should be ensured to promote their propagation so that cultivation may commence ahead of season.

Large-scale planting in summer

When the temperature of the water surface has risen to about 23°C in mid-May, the growth and reproduction of water lettuce increases conspicuously. It is the right reason to expand the cultivation of this crop. The stocking amount of seedlings is 10-20 kg/mu. When planting, it is necessary to use reed stalks, bamboo poles or straw ropes to form an enclosure for the growing plants so that they may thrive and grow in groups. As the population increases, the enclosure should be enlarged gradually to provide more space for growth, and when the seedlings cover half of the pond surface, the ropes should be removed for free propagation. Later, they can be transferred to other places for production.

Water surface management

Fertilizer treatment – Fertilizer is applied 5-7 days after planting. After that, the dressing is done weekly, each time at a rate of 250-300 kg of night soil per mu or pigsty manure diluted 4- to 5-fold to be splashed onto the leaf surface in the evening.

Prevention and control of weeds – On the initial stage of planting, it is necessary to eradicate all weeds on the water surface. If filamentous green algae is present, the effective method is to plant ash or spray 1 per cent lime water or 0.5 per cent copper sulphate.

Pest control – Use 0.5 per cent 666 powder to spray on the leaves of water lettuce to control aphids early in the morning when the leaf surface is still wet, or use 40 per cent dimethoate emulsion in about 1:2000 dilution for spraying. At the initial stage of the occurrence of yellow wilt, use the Bordeaux mixture containing 160- to 200-fold water for spraying to control it. Crop can be harvested for fodder one week after applying chemicals to avoid poisoning of livestock.

Sprinkling water on leaf surface – In the summer season when the day is hot and dry, it is necessary to sprinkle clear water on the plant leaves 2-3 times at noon to increase humidity and lower air temperature, thereby promoting growth.

Harvesting

Cropping usually commences from mid or late June. First, divide the crop into several square blocks and then scoop up the plants block by block. The harvest amount depends on growth conditions and it should be done gently. After harvesting, the seedlings should be set apart so that they are distributed evenly on the water surface to enhance their propagation.

Seedling protection and overwintering

From late October to early or mid-April, protection of seedlings from the cold should not stop until it is entirely frost-free. The work is done on the nursery beds. Temperature must be constantly maintained at the proper level which is above 15°C. In addition, more sunlight and better ventilation will help the crop to overwinter safely.

Water Hyacinth

Water hyacinth (*Eichhornia crassipes*) is a perennial aquatic plant belonging to the Pontederiaceae family. The plant floats on the water, growing out creeping branches from its roots to form new branches. The leaves grow straight and are either oval or round in shape varying from 2.5-5.0 cm in width. They are smooth and shiny. The pedicel bulges out on the lower half like a gall bladder, a spongy interior filled with air. The flower is monopedicel with a sheath in the middle portion. It has six petals blossoming on the top in violet and blue. There is a bright yellow spot at the centre of the top petal.

The yield of water hyacinth is very high, reaching 10-16 t/mu. It is also rich in nutrients. Analysis shows that fresh crops contain 1.9 per cent crude protein, 0.25 per cent fat, 1.11 per cent fibre, 2.21 per cent non-nitrogenous extracts, 1.33 per cent ash content and inorganic salts like calcium and phosphorus. The planting of water hyacinth is a good way of providing green forage requirement of pigs. This crop likes warm and damp climate and still or slowly running water. The optimum water depth is 0.3-1 m, but the water has to be fertile. Its adaptability is better than water lettuce; its endurance to poor fertility is higher. It is more cold-resistant than water lettuce; as long as temperature remains at 7-10°C, it can overwinter safely. The river bends and ponds that are not fit for planting water lettuce can be used for cultivating water hyacinth.

Planting time – Water hyacinth is cultivated along the Changjiang River Basin in early or mid-April. When air temperature rises above 13°C and frost is over, the old seedlings that have overwintered start to germinate and sprout. New leaves burst forth with vigour. This indicates that it is the right time to plant water hyacinth.

Method of planting – Small stagnant ponds of less than 1 cm can be directly seeded with water hyacinth seedlings which float and grow freely. In large ones or in slightly running water, planting should be done with the help of bamboo frames or by setting up supports and tying straw ropes to them to enclose an area of the water surface in which the seedlings can be planted. When the enclosure is densely occupied by the plants, it should be gradually enlarged and eventually removed. In this way, the crop will not be dispersed by winds and water current, and so it is advantageous to its growth and reproduction. One mu of water surface needs about 4-6 kg of seedling.

Management

Fertilizer treatment – In fertile ponds, no fertilizer is required, but it is necessary to stir the fertile silt at the bottom to enable nutrients to dissolve in the water. If water quality is poor, the plants will be weak and slender, and leaf blades yellow. In this case, night soil or animal manure need to be applied. The dressing is usually done in the best growing season weekly or biweekly.

Weeding – During the initial stage, weeds can easily interfere with the growth of water hyacinth. It is necessary to eradicate the aquatic weeds and filamentous green algae. Weeding should be stopped only when the growth of water hyacinth is vigorous and when seedlings cover the entire water surface.

Cropping – Water hyacinth begins to grow luxuriantly and reproduce rapidly after 1 or 2 months by which time harvesting can commence. The amount to be harvested is limited to about one-fourth of the whole crop or one third at most. After cropping, it is necessary to set the seedlings apart for speedy reproduction. In summer, it is possible to harvest once every week, but this interval of cropping depends on the fertility of the water, the growth condition of the crop and air temperature. In Changjiang River Basin, the growth of this plant ceases by the end of October when temperature drops below 10°C and leaves begin to turn yellow. At this point, seedlings that are of medium size, look more seasoned and healthy, and free from diseases and pests, are usually chosen as seeds for overwintering. The method involves placing a layer of fertile pond silt at the bottom of large vessels or wooden tubs and filled with water to a depth of 9 cm. Place the selected seedlings into it and place the containers in a nursery. Maintain the temperature inside above 7-10°C. The seedlings should be frequently exposed to sunlight. They can be placed together with water lettuce seedlings in the same nursery for overwintering.

Chapter 10

DESIGN AND CONSTRUCTION OF AN INTEGRATED FISH FARM

Jiang Guizhen

In China, there is a great variety of integrated fish farms involved in lake, reservoir, and pond fish culture. This chapter deals with the design and construction of an integrated fish farm that combines pond fish culture with crop, livestock, and poultry farming as well as sideline occupations.

Site Selection and Preparation

An integrated fish farm is a production base. The design and quality of construction directly affects the investment and the deployment of labour in construction and, more importantly in fish, livestock, and poultry production. The following requirements should be emphasized in calculation and design. All information should be gathered for detailed analysis and comparison, providing a reliable scientific basis for site selection.

Water Source

Water quality

The most important requirement in constructing an integrated fish farm is the water supply. Irrespective of its origin, water can be used provided it is of desirable quality. However, if the water source is near a factory or mine sewage, the water quality must be examined for possible toxicity to fish. For example, the effluent from metallurgical factories contains lead; instrument plants or table salt electrolyzing plants produce mercury; the effluent from coking plants or petroleum and gas industries contains phenols. All of these materials either kill a fish directly or accumulate within the body and harm the consumer. Such water sources should be avoided.

The waste water from food-processing mills such as slaughterhouses, breweries, and beancurd works is rich in organic materials. This water can be beneficial to fish farming by way of fermentation, sedimentation, or controlled introduction.

Underground water often contains an excess of carbon dioxide and lacks oxygen. Also, its temperature is too low for warm-water fish. Underground water should be completely exposed to the air before it is used. The underground water flowing out of coal or sulphur mines is too acidic for fish culture.

The acidity or alkalinity of water represents its hydrochemical quality. In general, the optimum pH for pond fish culture is between 6.5 and 8.5. Beyond this range, fish yield is affected and high mortality could occur.

Many cultured fish species, such as tilapia, mullet, red-eye mullet, milkfish, and common carp, have a strong salinity tolerance. A salinity of 5°/00 will not harm common carp; however, at 11.5°/00 the fish will die (Soller et al. 1965). To determine whether the water source is fit for fish farming, the growth of the fish native to the water should be examined. A more reliable method, however, is to rear fish in that kind of water in a small container for a period of time as well as to physiochemically analyze the water.

When investigating water quality, it must be remembered that in the flood season the water may be less toxic than in the dry season, when, because of evaporation, the concentration of toxic elements will increase. If such a water source is used, the reserve water supply should be used in the dry season. Only when the water to be used has been established as non-toxic and suitable for fish farming, can any other problems be considered.

Water amount

The water supply should be abundant and relatively stable, able to meet the needs of the fish ponds at any time. Therefore, it is important to gather first-hand information on the seasonal fluctuation of the water level, the agricultural irrigation requirements for crop farming, and the water requirements of the fish ponds. These are the primary factors in designing the fish pond area because a deficiency of water will prevent production potentials from being achieved. Therefore, the relevant information on hydrology, meteorology, topographical features, and edaphic condition should be collected in detail and this data, in conjunction with the water depth needed per unit area of fish pond (based on the volume of flow in different seasons) can be used to determine the adequacy of water supply both for fish ponds and fields. If a farm is constructed along a lake, river, or reservoir, information on the highest and lowest water levels in the past must be obtained and the areas with the most stable water levels should be selected. Thus, draught through leakage in the dry season and overflow in flood seasons can be avoided. Flood-prevention measures should be taken as in small-scale irrigation works: it will not be offended by flood within 25 years. The farm should be kept above the safety line. Water-logged areas and depressions with too much rainfall should not be selected for a fish farm.

Soil Quality

Soil characteristics greatly affect the quality of pond construction and influence fish and crop yields. Therefore, soil quality should be carefully determined. In determining soil quality, it is insufficient to just examine the topsoil. Enough samples must be taken from various representative spots. The sampling depth should exceed the depth of the pond by 1 m. The soil should ensure that pond dikes will not leak or collapse. This is especially important for manured ponds.

Loam conserves water and fertilizer and is well-aerated. Therefore, it is the best soil for dike construction. Sandy loam also conserves water; however, it has a weak coagulation and, therefore, is unsuitable for dike construction. Clay conserves water well. It can be used on the pond bottom; however, because it cracks when dry, it is unsuitable for dike construction. If sandy loam or clay are used for dikes, the crown should be widened and the gradient of the slope decreased. Gritty soil, sandy soil, and silty soil are very porous and poor in the retention of water and fertilizer. They are poor materials for dike construction; however, if needed, sand could be used with clay.

Attention should also be given to the contents of the soil that influence fish growth. If the iron content is too high, colloidal ferric hydroxide will form in the water and settle on the pond bottom. This rusty sediment often adheres to fish gills and hinders respiration, especially during egg hatching and fry rearing. An iron-rich soil is russet brown or green and is relatively easy to identify.

Soils with an excess of decaying matter have lower water and fertilizer-retention power. This material collapses easily if used in the pond dike. In tidal areas and swamps, pond construction is more difficult because the ground water level is high. The operating cost may be much higher. These areas are too low to allow complete drainage and water temperature raising as required for proper management.

Topographical Features

Because of the variety of integration on an integrated fish farm, the productivity of the land can always be fully utilized. Nevertheless, it is desirable to construct a fish farm on flat land. Generally, there is no problem in setting up a farm in a hilly district because the slopes are appropriate for afforestation, fodder cultivation, and livestock production. In designing fish ponds, gravitational flow can be exploited to reduce soil excavation and energy consumption.

Infertile land, hilly districts, valleys, or lake bay areas are preferable for pond construction; however, these topographies require greater investments and farm construction is more time-consuming. Nevertheless, the fish pond would not occupy fertile cropland; the development and utilization of wasteland is of great significance to any developing country.

Transportation and Energy

A large amount of fresh produce and processed food will be sent to the market and fishery, animal husbandry, and agricultural necessities will be purchased from the market. Therefore, the farm should be easily accessible. For example, Helei Fish Farm is located in the suburbs of Wuxi. Water or land transportation facilitates the development of the farm.

If possible, the farm site should have access to an area rich in natural food (e.g., snails, *Corbicula* spp., and aquatic grasses) so that, besides the self-supplied feeds and fertilizers, there is a sufficient supply of food for the fish year-round. Electricity is the primary energy source on a fish farm so that the farm site should have easy access to a power plant. Water, road, and electricity must be within reach before beginning construction.

Overall Layout of the Farm

To develop an overall design for a farm, land area and elevation measurements are necessary. Draw up a ground plan (ichnography) with a scale of 1:500 to 1:1000 before starting any earthwork calculation or pond construction. The management items and their scale of diversification are determined by the natural conditions of the site, investment, and consumer preference. In the overall farm layout, the various departments and their facilities should be rationally arranged (Fig. 10.1). This not only involves construction and investment but also affects future operations. The farm layout must fulfill the following criteria:

- Facilitate management and increase production and economic returns;
- Minimize labour intensity, heighten efficiency, and protect the workers' health; and
- Economize on capital construction investment and reduce material consumption.

The layout of an integrated fish farm should not only be geared to the present but also to the future. There should be room enough to implement a practical long-range program in stages according to the funds and labour force available.

The other occupations on an integrated fish farm serve fish production. The scale of crop and animal production depends upon the needs of aquaculture. Therefore, the locations and areas of the fish ponds should take priority; this is followed by the location and areas of livestock pens, crop fields, processing plants and other structures.

Aquaculture Facility Arrangements

Fish ponds are the main structures on a fish farm. They are generally outdoor earthen ponds. Fish seeds, if possible, should be produced on the farm to reduce operating costs and ensure a supply of properly sized fingerlings. This will bring out the full potential of the fish ponds and avoid the invasion of infectious fish diseases from outside.

Farms with herbivorous and grain-feeding fish as the major cultivated species need large fingerlings. The nursery ponds generally account for 25-30 per cent; grow-out ponds, 70-75 per cent. If plankton-feeding fish are the major species,

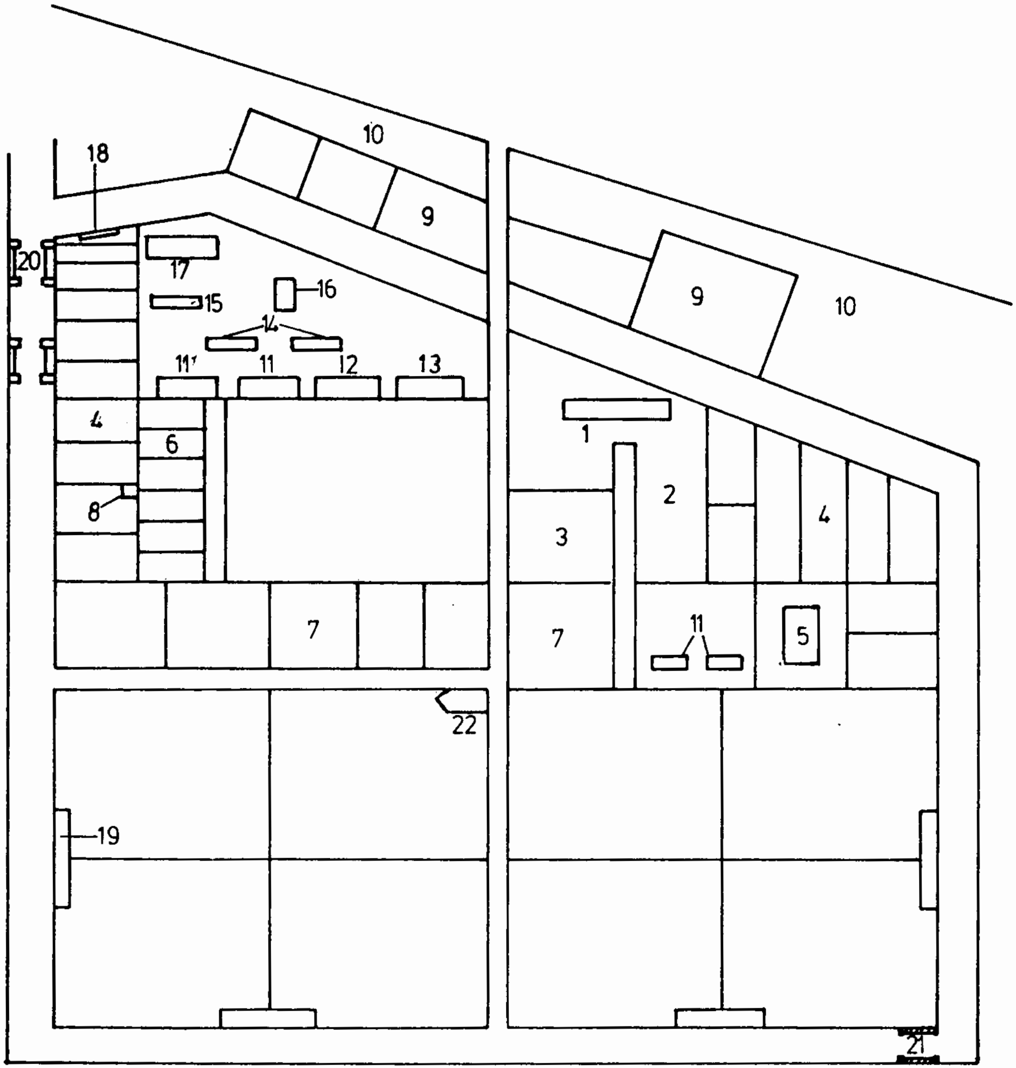


Fig. 10.1. Schematic Diagram of Xi Nan Fish Farm

1 Headquarters
2 Vegetable plotes
3 Green plotes
4 Yearling ponds
5 Cow shed
6 Experimental ponds
7 2-year-old fingering ponds
8 Fodder grinding
9 Grow out ponds
10 Fodder crop field
11 Sow pigty
12 Chicken house
13 Office of livestock poultry farming
14 Duck pens
15 Over wintering ponds for ilapia
16 Brew house
17 Office of aquaculture brigade
18 Tool house
19 Pigsties
20 Locks
21 Locks for flooding drainage
22 Administration house

the nursery ponds should account for 15 per cent and the grow-out ponds, 85 per cent. If the production scale is large and the farm intends to breed its own fry and fingerlings, spawning ponds and hatcheries must be built. The ratio of the areas of brooder ponds to fry ponds to fingerling ponds depends on the quantity of fry and fingerlings needed for farm use and sale. In general, the ratio is about 5:10:85. The ratio of the water surface to the total farm area depends on soil quality and integrated management requirements. Generally speaking, the water area occupies about 60-70 per cent. In the Wuxi area, water area accounts for 68 per cent; pond dikes, 21 per cent; inlet and outlet channels, 11 per cent. Various fish ponds are arranged on the basis of water demands and operational convenience for the purpose of increasing the survival rate of fish. The brooder ponds, spawning ponds, and hatcheries should be close to the hatching facilities. Spawning ponds and hatcheries should be built in the vicinity of the brooder ponds to facilitate brooder transportation. Fingerling-rearing ponds should be next to the fry-nurturing ponds and the food fish ponds. In other words, the fish ponds should be arranged in such a way that the various operations of aquaculture, such as fry stocking and fingerling transfer, can be carried out in the shortest possible time with the minimum amount of labour.

Arrangements for Other Occupations

Pigsty location

To lead the pig excreta into the fish ponds, the pigsties are generally built on pond dikes or on highlands close to the fish pond. A small farm may centralize the pigsties; a big farm should disperse the pigsties. Pigsties built on pond dikes can be easily reached by canal or road. The pig excreta is channeled into septic tanks for fermentation before it is used. This shortens the distance of transportation.

Cow shed location

Cows need both a shed and a playground. These will occupy more area than pigsties on pond dikes. Generally, intensive cow farming is practiced. The cow shed should be built near the fish pond for the easy transportation of the wastes, feeds, and milk.

Location of duck and goose pens

Duck and goose pens are built separately along the pond dikes.

Chicken house location

Chicken houses are open with good ventilation. They are almost always built on dry ground on the highlands. To prevent the outbreak of chicken diseases, the chicken house should be located away from other domestic animal houses. For the sake of transportation, however, they should be near the roads.

Fodder crop fields

Aside from the dike and slope for crop cultivation, an integrated fish farm should have special plots for fodder crop. The area of the plots depends on the fodder requirement and the land available. If the fine feeds are provided mainly by the market, less land for fodder crops is required. Wasted plots, hilly areas, and the water surface should be put into full use. Some farms even grow crop in the fingerling-rearing ponds in the off season or in lake bays and river bends.

Farm Administration Building

The farm administration building is the headquarters of those responsible for the organization and leadership of the farm. The headquarters should be located centrally in the farm for easy access.

Industry and Sideline Occupations

For the sake of marketing, convenience of transportation, comprehensive utilization of farm produce, and enhancement of employment, a big farm should establish a slaughterhouse, brewery, fish gear repair shop, and simple processing workshops for fish, duck eggs, milk, and beans. These workshops should be arranged near the source of the produce. (See Fig. 10.1).

Fish Pond Design

After determining the location and area of fish ponds, the position of ponds and pond dikes and the direction, shape and size of inflow and outflow channels must be established.

Fish Pond Size

The size of a fish pond depends on the environmental requirements of fish in different stages of growth and the requirements of operational management. In general, grow-out ponds range from 5 to 10 mu with a depth of 3-3.5 m (water depth, 2.5-3); fingerling ponds, 2-5 mu with a depth of 2-2.5 m (water depth, 1.5-2 m); nursery ponds 1-2 mu with a depth of 1.5-2 m (water depth, 1-1.5 m). The brooder ponds have the same size as the grow-out pond.

It may be necessary to construct ponds for water storage, settlement, filtering, or sun exposure. A fish pond is often rectangular, being broadest from east to west. This kind of fish pond gets more solar radiation which benefits the photosynthesis of aquatic plants, enabling them to produce more oxygen. This in turn, promotes the growth of fish and natural food organisms. The ratio of pond length to width should be 2:1 or 3:2. The length of a large pond should be increased. The width of the same types of ponds should be uniform; this requires less fishing gear and saves labour time.

Pond Structure

All the fish ponds have the same structure with little differences in size and depth.

Embankment

The embankment includes the pond dike, the partitional dike, the marginal dike, the transportation dike, and the cofferdam. The soil quality and the various uses of the dike are the main factors in deciding the width of the crown and the gradient of the slope. The dike can be narrower if the soil quality is better, the food supply is sufficient, or the land area is inadequate. Pond banks range in width from 2 to 5 m. A large pond needs a wider crown than a small pond. The width of the dikes between fish ponds and inflow and outflow canals should be kept within 5 m; the width of the dikes for pigsties, cow sheds piping, or traffic should range from 5 to 10 m. If the outflow canal is too narrow for boat traffic, the dike should be wide enough for land traffic, at least on one side of the pond.

With loamy soil, the dike slope gradient should be 1:1 to 1:1.5. With poor soil or on a grow-out pond dike, the slope gradient should be 1:2.5 to 1:3 under the water surface and 1:1 to 1:1.5 above the water surface. In a grow-out pond, a path about 0.5-1 m wide along the inner slopes should be provided for the sake of pulling nets and avoiding erosion by waves (Fig. 10.2).

A cofferdam is a structure that prevents a fish farm from flooding. It must be built 0.5 m higher than the historical peak water level. The crown width of a cofferdam is 4-6 m or even 10 m as required for the stretch against the wind and waves and the slope gradient should be large. The leeward slope should be 1:1.5 to 1:2.5; the windward slope, 1:2.5 to 1:3.5. If the slopes are well protected with grass and stone, the gradients may be reduced to 1:2. A slope several metres wide out of the dike foot should be left as a buffer zone where the aquatic plants can be planted, lessening wave attacks. If the soil is poor, an edaphic core made of soil with good coagulation should be built (Fig. 10.3).

Pond bottom

The pond bottom is flat and it should slope from the inlet toward the outlet with a gradient of about 3°/00 for a large pond and about 5°/00 for a small one. A slight slope from the dyke foot to the central area of the pond aids drainage and harvest (Fig. 10.2).

Water Intake and Drainage Systems

Water intake and drainage systems maintain the water level and adjust the water quality, preventing draught and flood and the spread of fish diseases. These systems are very important and every effort must be made to ensure proper design and construction, otherwise, future operations may be endangered. An independent water intake and drainage system is required for each pond. The system

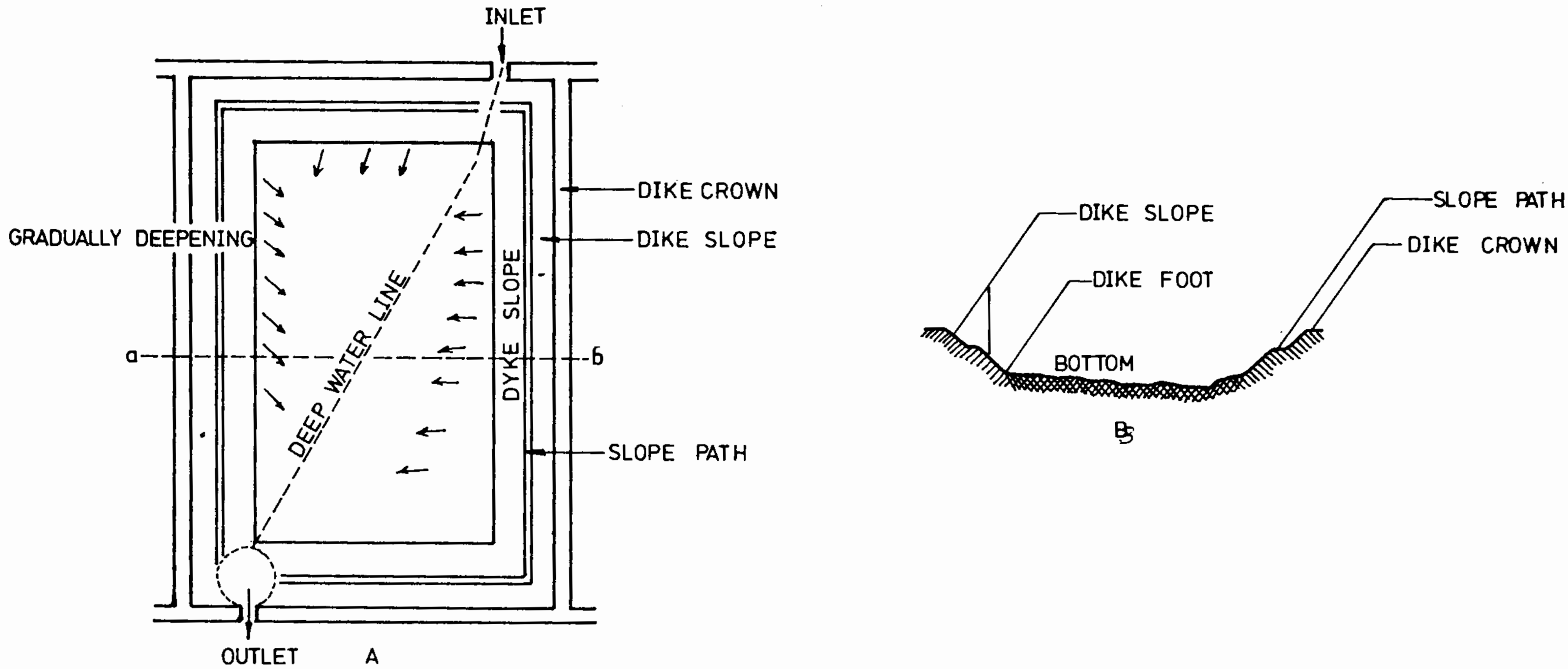


Fig. 10.2. Sketch of pond structure
(A) plane figure
(B) sectional view along line a-b

Source: Chinese freshwater fish culture editorial board, 1982.

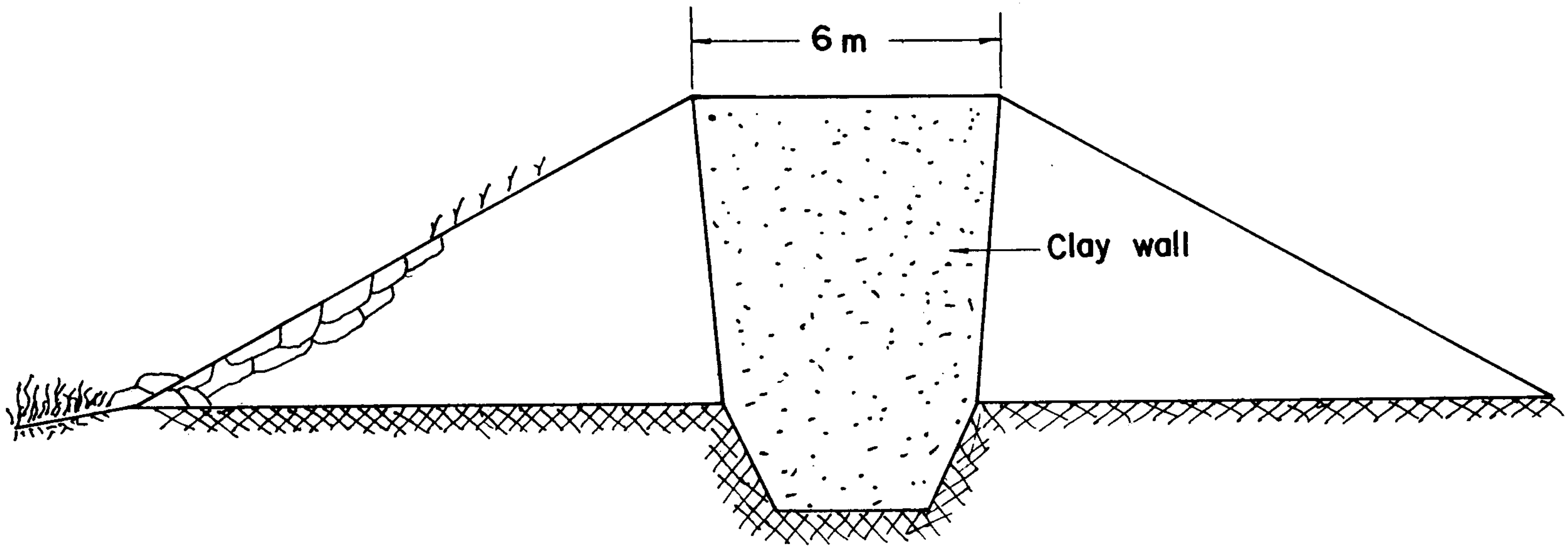


Fig. 10.3. Sectional view of flood control dikes.

Source: Chinese freshwater fish culture editorial board, 1982.

includes inlet and outlet canals and other bypass channels such as aqueducts, culverts, drop basins, sluice gates, etc.

Inlet canal

There are three types of inlet canals: general canal, branch canal, and bypass channel. The flow of water should satisfy the demand for water supply at any given time. The bottom of the inflow canal should be higher than the peak water level of the fish ponds. It should be kept dry when there is no irrigation. The sectional size of a canal is dependent upon the flowing amount of water. In cross-section, the earth dyke is trapezium-shaped with slope gradients of 1:1 to 1:1.5 on both sides. If protected with bricks and stones, it often appears to be rectangular. The slanting ratio of a canal will influence the flow speed of the water. In a field construction, the slant should be based on the slope of the land. If the slope of the land is too steep, several drop basins can be built. In constructing the canals, the following slanting ratio should be adopted: bypass channel, 1:300 to 1:750; branch canal, 1:750 to 1:1500; general canal, 1:1500 to 1:3000.

The distance of water conveyance should not be too great; otherwise, land is wasted and there are bad effects on the water supply. A general canal should supply water for 150-200 mu of fish ponds.

The inlet water locks are generally the culvert type, using underground pipes made of bricks, stones, and cement. The size of the head gate depends on the pond size, ensuring the ponds will have sufficient water at any given time. The area between the gate and the pond bottom must be cemented with stones to prevent bank erosion (Fig. 10.4).

Outflow canal

The design of the outflow canal is almost similar to that of the inflow canals, except that the bottom of the outflow canal should be 0.3 m lower than the pond bottom. If the canal is used for drainage in the flood season, it should be large enough to drain the water in a limited time. Outlet water locks are often the trough type; however, it is difficult to close the gate tightly because of the strong water pressure. It is also inconvenient to lift it up; hence because of its easier operation, the terraced type of outflow sluice is used. The sluice gate should be big enough to drain all the water in a limited time (Fig. 10.5).

The inflow and outflow canals should be arranged alternately: one side for irrigation and the other for drainage. This will not only prevent the spread of fish diseases but also assist the rearing of brooders and flood control (Fig. 10.6).

Open ditch versus hidden culvert

Inflow and outflow canals may not only be an open ditch but may also be a hidden culvert or a combination of the two. The ditch has many advantages: e.g., simple construction, less labour and material, easy maintenance. However, it

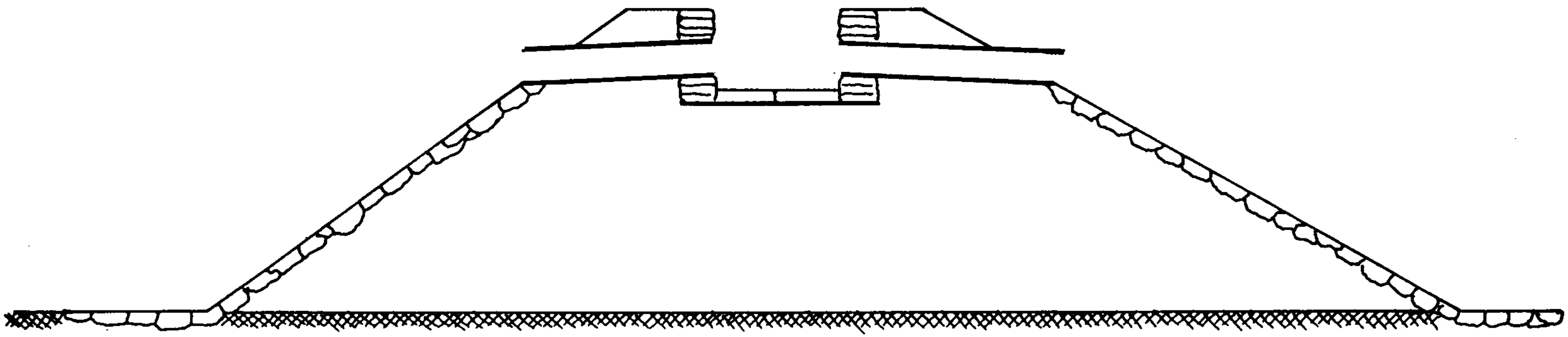


Fig. 10.4. Sectional view of an inlet lock.

Source: Chinese freshwater fish culture editorial board, 1982.

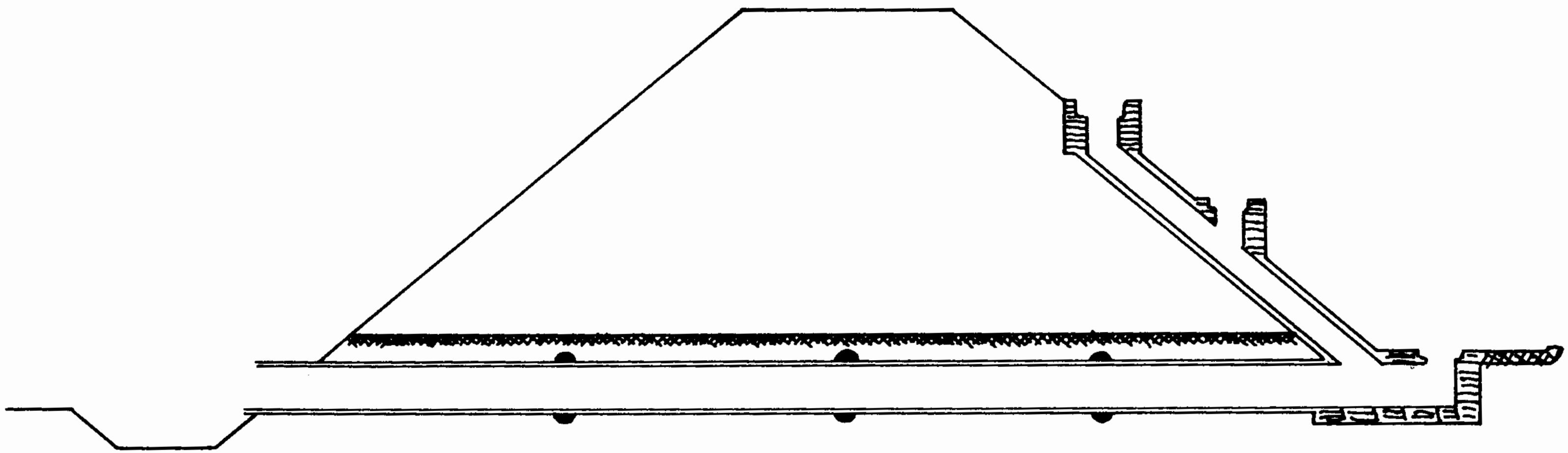


Fig. 10.5. Sectional view of an outlet lock.

Source: Chinese freshwater fish culture editorial board, 1982.

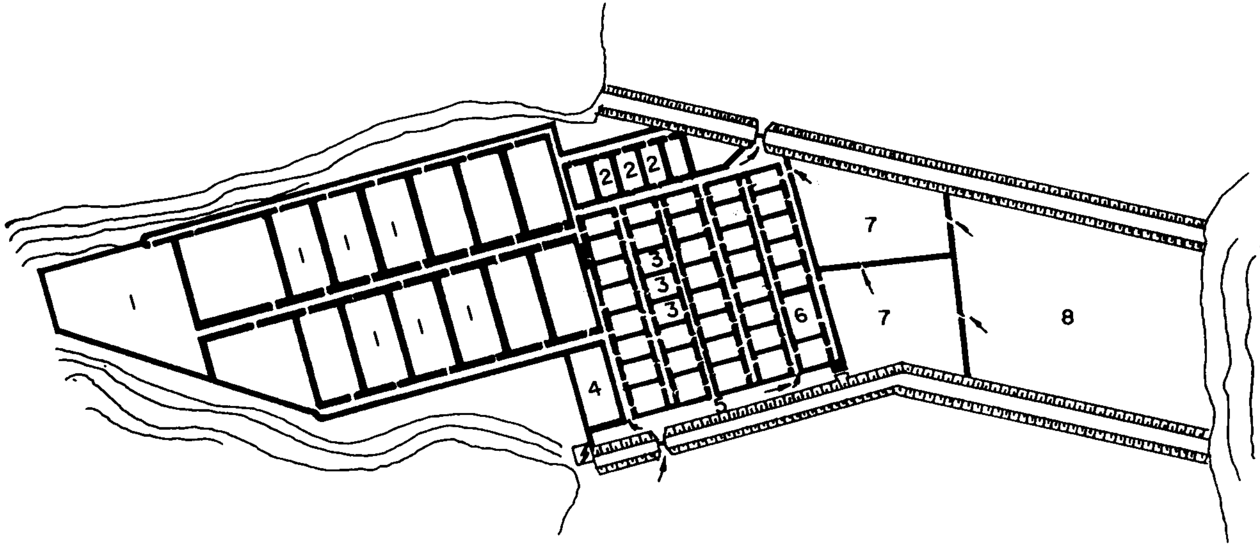


Fig. 10.6. Plane figure showing opposite inlet and outlet type ponds.

1 Figerling-nurturing pond
2 Experiment pond
3 Fry-nurturing pond
4 Feed storage
5 Reservoir
6 Spawning and hatching pond
7 Brooder pond
8 Overwintering pond

Legend
Power
Weir
Sluice
Pond dyke
Inlet and outlet canals
Inlet and outlet

occupies a large area of land, obstructs traffic, and loses a large amount of water. The hidden culvert also has many advantages: e.g., it occupies a small area of land, does not obstruct traffic, and loses only small amount of water; however, its construction requires a large financial investment. For the sake of convenience, several maintenance wells should be built at intervals along the channel to avoid the accumulation of silt.

Earthwork Calculation

Based on the level measurement, the area of fish ponds, and the depth of excavation, the volume of earthwork can be calculated. The amount of excavation should be approximately equal to the amount of filling. The excavated soil should be piled as near as possible to the fill site. This will shorten transportation time and save labour. Therefore, the excavation and filling work should be well coordinated. In balancing the earthwork, if the soil excavated is more than the required fill, it is appropriate to decrease the size or depth of the fish ponds or to increase the stocking area or the height of the weir.

Leakage Control and Soil Improvement

Leakage Control

Before implementing any corrective measures, the reason for the leakage must be determined. If the pond bottom or dike contains sand or grit soil, which may cause pond leakage, spread clay soil on the pond bottom; it will be evenly distributed by the inlet water. The clay particles will enter the cracks on the pond bottom during the leakage, plugging the cracks. In certain countries, about 10 m^3/ ha of cow dung is spread on the pond bottom a few times; this greatly controls leakage by blocking the soil pores. If the leakage is due to poor construction of the pond dike, compacting of the soil may stop the leaking. If the leaking persists, spread heavy clay soil or turn over the dike for rebuilding until the leakage stops.

Improvement of Acid Soil

Acid soils are common in many parts of the world, e.g., lateritic soil in the tropics, humic soils in the temperate zone, and acid sulphate soils in Southeast Asia ("coastal mangrove soil," $pH < 3$). In the Philippines, there are about 100,000 ha of fish ponds on acidic soil; the fish yields are very low. Acidic soil can be regulated with quicklime ($Ca(OH)_2$) or limestone ($CaCO_3$). However, the feasibility of this method depends on the local economic conditions. According to Swingle (1961), practical experience has shown that soils of pH 5 require approximately 2 t/ha of limestone; those with pH 4, 4-6 t/ha.

Heavy Metals

Newly dug fish pond often contain heavy metals that could harm fish growth and cause "body-curved disease" of fry. Therefore, in the first 2 years, it is better to farm 2-year-old fingerlings and adult fish. If the new ponds are to be used to nurture fry, the water should be changed before stocking the fry to wash away the elements that are harmful to the fry.

Fieldwork Guides

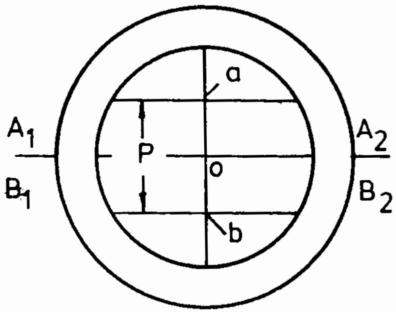
I. Ichnographical Drawing with a Theodolite

Objectives

Within a given area designed for a fish farm, set several points where a theodolite is used for making measurements of horizontal angles and sight distances. Draw an ichnography and calculate the land area.

Method

1. Selected land area: 25-30 mu.
2. Based on the shape of the area, set several points as point 1, 2, 3, . . . n with numbered stakes as indicators.
3. Place the theodolite at point 1, put the horizontal level at 0°, and point the axis of the telescope toward true north. Record the readings and run the telescope clockwise towards point 2; record the reading and calculate the magnetic bearing of point 2.
4. Set a leveling rod at point 2 and theodolite at point 2. Write down the reading of the lower and upper stadia hairs. Calculate the distance between points 1 and 2. See Figures 10.7, 10.8 (Shanghai Fisheries College, 1961).
5. Turn the telescope clockwise toward point n and record the reading to calculate the azimuth of angle 1.
6. Set the leveling staff at point n and use the same method as in step 4 to calculate the distance between points n and n-1.
7. Move the theodolite to point 2, level and centre it and repeat steps 4, 5, and 6 to calculate the distance between points 2 and 3 and between points 1 and 2 and the azimuth of angle 2, etc. See Fig. 10.9.
8. An example is shown in Table 10.1.



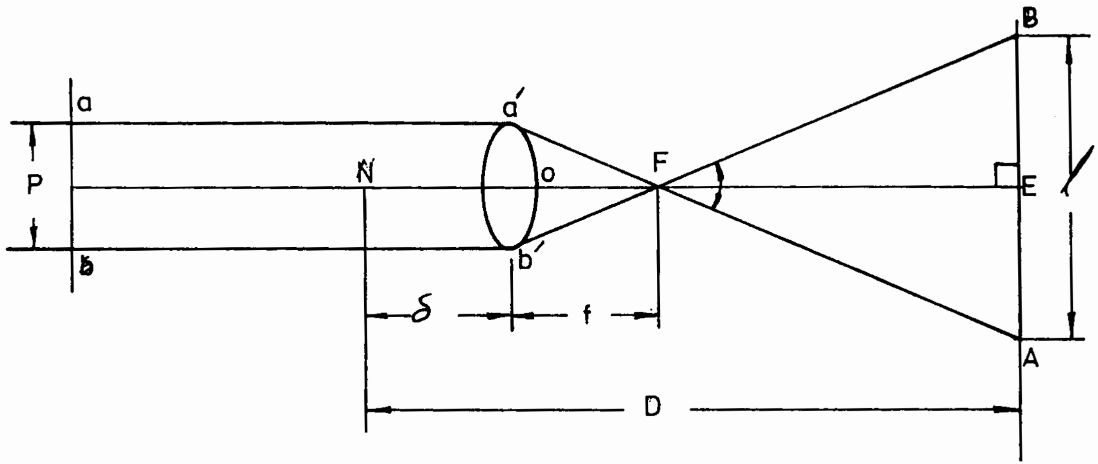


Fig. 10.7.	A_1 A_2	upper stadia hair
	B_1 B_2	lower stadia hair
	P	scale distance between point a and point b

Fig. 10.8.	l	sight distance between point A and point B
	F	focal point
	N	centre of the instrument
	D	distance between N and the rod

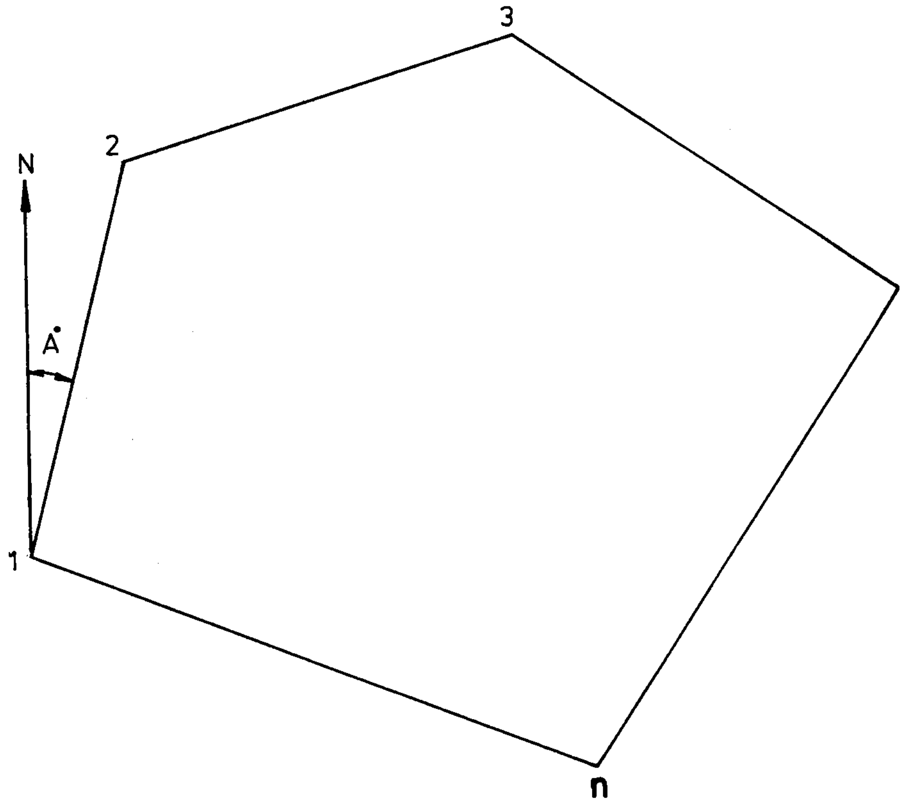


Fig. 10.9. Magneic azimuth.

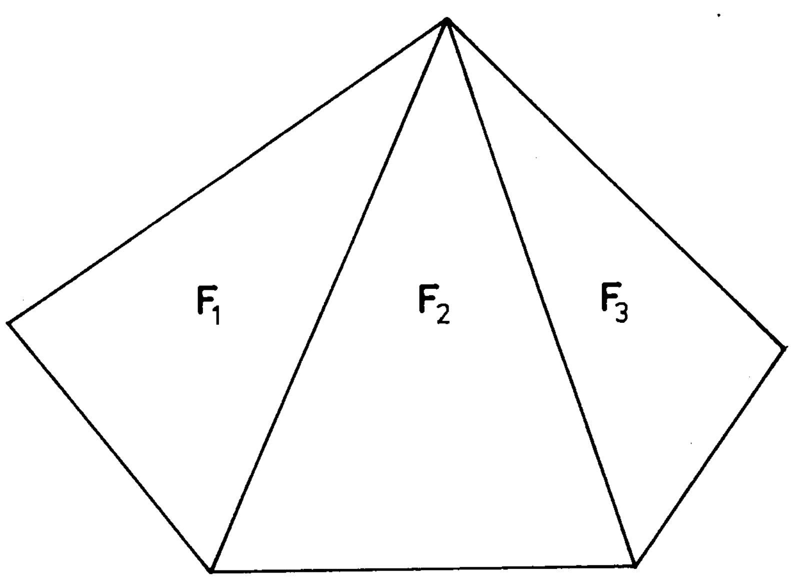


Fig. 10.10. Area calculation.

Table 10.1. Measurement record form.

Point of origin	*Measured point*	*Compass reading*	*Horizontal azimuth*	*Sight distance reading*
· 1	2	00340		Lower stadia hair, 2.044 upper stadia hair, 0.963 sight distance, 1.081 Horizontal distance, 108.1 (m)
			1793110	
1	n	1793450		Lower stadia hair, 2.143 upper stadia hair, 0.429 sight distance, 1.714 Horizontal distance 171.4 (m)

Calculation and correction of angle deviation

In theory, the total amount of interior angles of a polygon should be as follows:

$$\Sigma\beta\hat{t} = (n - 2)\ 180°$$

When n represents the number of interior angle in a polygon or within a closed line and β represents the interior angle. In practice, however, the sum of the interior angles measured $\Sigma\beta\hat{m}$, is often not equal to the sum, $\Sigma\beta\hat{t}$, because of errors in measurement. The difference between the two is called the closed difference of the angles;

$$f\hat{\beta} = \Sigma\beta\hat{m} - \Sigma\beta\hat{t}$$

First, we must calculate whether $f\hat{\beta}$ is within the range of allowable error, which is different in different instruments. If a theodolite is within 6' or 15', the allowable closed error of the angles is $\pm\ 25\sqrt{n}$ or $45\sqrt{n}$. If the error is beyond the allowable range, the reason must be found. If $f\hat{\beta}$ is less than the allowable range, adjustment is made: the error with the opposite sign, is added to each interior angle. In theory, the total corrected angles should be almost the same as $\Sigma\beta t$.

Land area calculation

The ichonograph that is drawn can be divided into a number of triangles, squares, or trapezoids (Fig. 10.10). The side parameters are measured with a tape measure.

II. Elevation Measurement with Leveling Instrument

Objectives

Based on the ichnographical measurements, typical points are selected for elevation measurements for design and calculation of fish ponds and earthwork.

Method

At the practical site, several points are selected according to topographical features. Elevation should be measured on the basis of the closest national standard sea level point. If there is none, a hypothetical point can be set as a standard to establish an independent system. Then, from this hypothetical point of origin, the elevation of each point can be measured.

Direction is set with a theodolite and a tape measure is used to calculate distance. In general, there is a survey point every 20 m. These points are marked with numbered stakes and are called elevation control points. The number of these points can be changed in designing and constructing the fish ponds based on the topographical features.

The leveling instrument is placed in a wide sighted view. The leveling staff is set on each control point (Fig. 10.11) and the elevation of each point is calculated (Table 10.2).

Table 10.2. Elevation measurement with leveling instrument.

Control point	*Reading on leveling staff no.*	*High (+)*	*Low (−)*	*Elevation*	*Remarks*
BM	1.732			3.0505	Elevation known
1	1.571	0.161		3.211	
2	1.920		0.188	2.862	
3	2.002		0.279	2.780	
4	1.642	0.090		3.140	

III. Design and Layout of an Integrated Fish Farm

Objectives

Based on the practical work done with Fieldwork Guides I and II and the instructor's lecture, an integrated fish farm can be designed.

Topics

Choose one:

1. Design an integrated first-livestock-crop farm with herbivorous fish as its major species (60 per cent fish yield).

2. Design an integrated fish farm with a plankton-feeding fish as its dominant species (60 per cent fish yield).

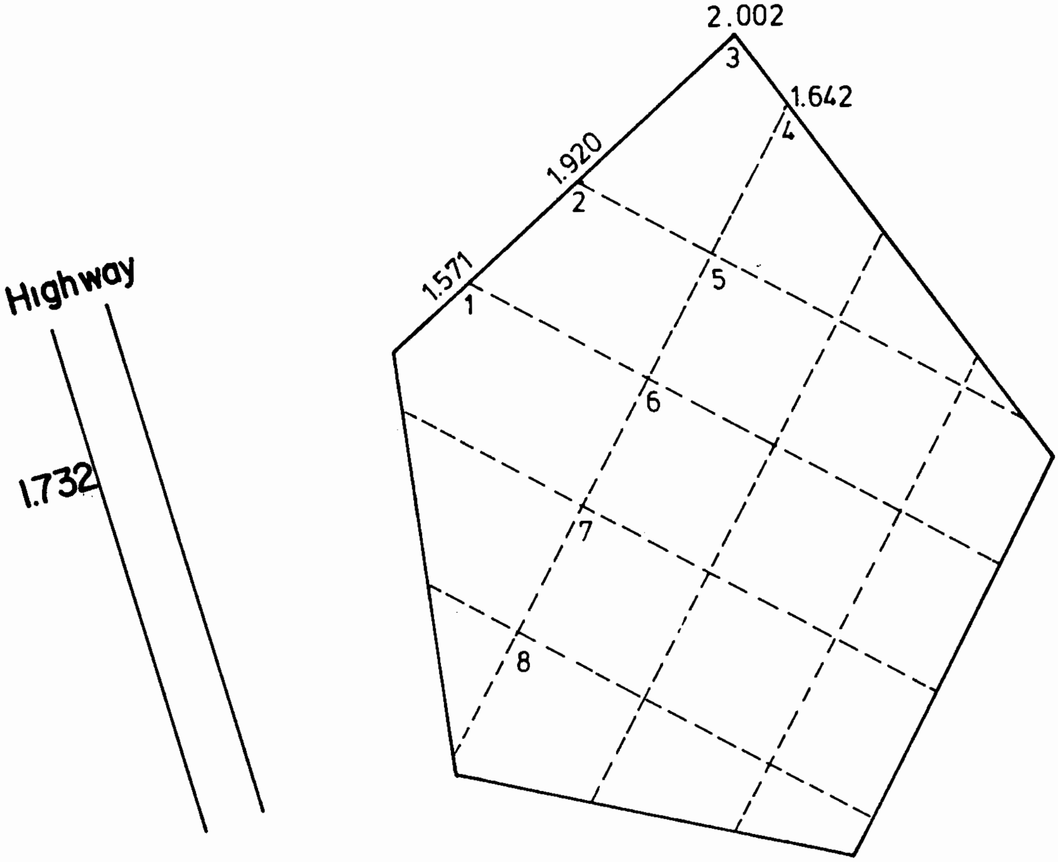


Fig. 10.11. Elevation measurement.

Note the following:

1. Net yield is about 200 kg/mu.

2. The fine feeds needed by the livestock are provided by the market.

3. Fry are provided by the market and fingerlings are nurtured by the farm.

Task

Calculate the area of the fish ponds, the width of the dike crown, the position and structure of the inflow and outflow canals, the amount of soil to be excavated and to be filled, the area of the fodder crop land (including dike crown and slopes). Determine the positions and number of livestock and poultry houses on the farm.

REFERENCES

Aerator Research Group, 1976: The Preliminary Investigation of the Utilization of Aerator and the Variation of Water Quality. The Journal of Freshwater Fisheries Science and Technology (4).

Balfour Hepher, Yoel Pruginin, 1981: Commercial Fish Farming, A Wiley-Interscience Publication.

Beijing Agriculture University, 1979: The Manual of Manures. Agro Publisher.

Cao Faren, 1984: The Operational Techniques of Pond Fish Culture. Published by Wuxi Suburban Society of Fisheries.

Changli Agriculture School, 1981: Measurement and Layout. Agricultural Publisher.

Chinese Freshwater Fish Culture Editorial Board, 1982: Science of the Culture of Freshwater Fish Species in China. IDRC TS 16E.

China Society of Fisheries, 1985: The High-yield Techniques of Freshwater Fish Farming. Universal Science Publisher.

Chung Ling, 1965: The Biology and Artificial Propagation of Farm Fishes. The Science Publishing Association, Beijing, China.

Fang Yingxue et al., 1984: Studies on the Performance of Different Livestock Manures in Relation to Fish Production. The 4th Advisory Committee Meeting of the Network of Aquaculture Centres in Asia, 3-5 December Bhubaneswar, India.

Fish Pathology of Department of Hydrobio Research Institute, 1979: Handbook of Fish Disease Investigation. Shanghai Science and Technology Publisher. 119-239.

Fish Pathology of Department of Hydrobio Research Institute, 1975: Handbook of Fish Disease Control. The Science Publishing Association, Beijing, 26-281.

He Zhihui and Li Yonghan, 1983: Studies on the Water Quality of the High-yield Fish Ponds in Heleikou, Wuxi: II. Plankton. Journal of Fisheries of China 7 (4), 287-299.

Huang Chiyian, Tang Silian, Zhang Jianyin and Hua Kouding, 1983: Fish Pathology. Agriculture Publisher. 24-104.

Hu Baotong, 1983a: Integrated Fish Farming and the Comprehensive Management of Fisheries, Animal Husbandry and Agriculture. Journal of Agricultural Modernization Research (1).

Hu Baotong, 1983b: The Ecological Basis of Polyculture in Manured ponds. Journal of Ecology (3). 31-33.

Hu Baotong et al, 1984: Characteristics of Integrated Fish Farming in China. Sixth Session of the IPFC working Party, 19-25 Jan 1984, New Delhi.

Hu Baotong and Yang Huazhu, 1985: An Artificial Ecosystem of Mulberry-Silkworm-Fish. Rural Eco-environment. No 2 pp 37-40.

Hu Baotong, 1985-1986: Lectures on Integrated Fish Farming Techniques (1-4). Rural Science (11) (12) 1985; (1) (2) 1986.

Japanese Society of Fisheries, 1982: The Maturity and Ovulation of Fish (Chinese version). Agricultural Publisher.

Larcher W., 1975: Physiological Plant Ecology. Chinese version. 1980.

Lei Huisen, et al., 1981: Pond Pisiculture. Shanghai Science and Technology Publisher.

Lei Yanzhi et al., 1983: Studies on the Water Quality of the High-yield Fish Ponds in Heleikou, Wuxi: I. Chemistry of Fish Pond Water and Primary Productivity. Journal of Fisheries on China. 7(3) 185-200.

Li Yuanshan, 1983: The Preliminary Research of Fish Pond Ecosystem and the Role of Silver carp. Freshwater Fisheries 113 (3) 8-11.

Marcel Huet, 1972: Textbook of Fish Culture p6-17. Printed in Great Britain by Page Bros (Norwich) ltd. Norwich.

Shandong Provincial Fisheries College, 1980; Freshwater Pisiculture. Agricultural Publisher.

Shanghai Fisheries College, 1961: Aquaculture Civil Engineering. Agricultural Publisher.

Shanghai Fisheries College, 1981: Histology and Embryology. Agricultural Publisher.

Shanghai Fisheries College, 1982: Pisiculture and Marinefish Culture Agricultural Publisher.

Shi Hongfang et al, 1984: Freshwater Aquaculture. Ahejiang Science and Technology Publisher.

Shi Quanfang, 1964: Study on the Annual Variation on the Gonad Development of Silver carp. Hydrobio 5 (1).

Wang Zuxiong et al., 1964: Study on the Biochemical Composition of Pond Cultured Silver carp Ovary in Reproduction Cycle. Hydrobio 5 (1).

Wu Xianwen, 1982: Taxonomy of Chinese carps. Shanghai Science and Technology Publisher.

Wu Xianwen, 1982: Taxonomy of Animals of Economic Value. Shanghai Science and Technology Publisher.

SUGGESTED READINGS

S.V. Pullin and Ziad H. Shehadeh, 1979: Integrated Agriculture-Aquaculture Farming Systems. ICLARM.

S.V. Pullin and R. H. Lowe-McConnell, 1982: The Biology and Culture of Tilapias. ICLARM.

Yung C. Shang, 1981: Aquaculture Economics, Basic Concepts and methods of Analysis. Westview Press, Inc.

Brian Moss, 1980: Ecology of freshwaters. Blackwell Scientific Publications Oxford London.

Emberlin, 1983: Introduction to Ecology. M & E Handbooks.

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