Aquaculture in China

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Success Stories and Modern Trends

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Foreword

Aquaculture is commonly considered to have originated in China. Since the Reform and Opening of China to the Outside World for more than 30 years, the country's aquaculture industry has made remarkable achievements. In 2015, aquaculture production reached 49.38 million tonnes, amounting to about two-thirds of the world aquaculture production, with an aquaculture area of 8.47 million ha, nearly 10 million employees, and 293.77 and 533.71 billion RMB in value from marine and freshwater aquaculture, respectively. China's aquaculture not only plays an important role in meeting market supply of aquatic products, guaranteeing national food security, increasing employment opportunities and income of fish farmers, and strengthening the development of an ecologically conscious society, but also contributes significantly to the aquaculture development of the world. Innovation of aquaculture theories and technologies are important drivers for these achievements, besides market orientation and support of aquaculture policy, and enforcement of relevant laws.

At present, China's aquaculture industry is in a key transformation stage from traditional to modern aquaculture, and its sustainable development is facing many challenges, for instance, constraints both from resource limitations and environmental safeguards, limits on aquaculture space extension, aged facilities, increase of diseases and potential food safety problems, etc. These problems may also be reflected in other developing countries. The aquaculture industry must be transformed and updated, and the transformation of development methods must be accelerated in order to realize its sustainable development, including transforming the focus from increasing production to a focus on quality, and an increase in efficiency increase, transforming the focus on resource utilization to a focus on ecological and environmental protection, and transforming the focus of material input into an increased emphasis of science and technology advances and professionalism of aquaculturists.

With the support of the Chinese Academy of Sciences, the Chinese Academy of Engineering, the Chinese Academy of Fisheries Sciences, and the China Society of Fisheries, more than 100 aquaculture experts have contributed to this book, *Aquaculture in China: Success Stories and Modern Trends* after a nearly three-year effort. The book comprehensively introduces the success stories of main aquaculture species, main aquaculture practices, feed formulation and feeding techniques, genetic breeding and seed industry, disease pathology and related control technologies, and environmental protection and remediation in China, through typical cases in plain and clear language. Furthermore, the reasons and driving forces behind success are also explained. These success stories and typical cases will not only have realistic meaning and implications for the present transformation, updating and structural reform from the supply side of the Chinese aquaculture industry, but should also be able to provide help and reference for aquaculture policy making and aquaculture sustainability in other countries of the world. I am also sure that the extension and application of these successful cases will have important roles in promoting the development of aquaculture in developing countries, especially those countries of the Belt and Road Initiative, and forging forward on international collaboration in aquaculture.

Here, I would like to congratulate the editorial team led by Academician Jian-Fang Gui and Academician Qisheng Tang for their great work and hard effort, and to extend my lofty respect to them. I would also like to express my heartfelt congratulations for the publication of the book, *Aquaculture in China: Success Stories and Modern Trends*.

June 2017

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Preface

The contributions of China to science and civilization were highlighted by a seven-volume treatise, the first of which was published in 1954, by the British embryologist-cum-biochemist, Sir Joseph Needham. Needless to say, this study, that spanned over five decades, demonstrated that some of the key inventions that were previously thought to have been of Western origin were invented and in use in China literally centuries before.

In the modern era, one of the burgeoning issues confronting the global community is providing sufficient food for a growing population. Endeavors to do so in the wake of limitations of physical and biological resources, compounded by the need to maintain environmental integrity, are becoming more and more challenging. Fish has been a major component of our diet for millennia, and its consumption is increasing, whilst the supplies from traditional wild fisheries have already plateaued. In this context farmed fish supplies are likely to contribute significantly to closing the gap between supply and demand in the ensuing decades, true to the ancient Chinese proverb, "*Give a person a fish and you feed him for a day; teach a person how to grow fish and you feed him for a long time*".

Accordingly, and as much as China has contributed to modern science and civilization, it is spearheading the farming of seafood; it continues to lead global farmed food fish production, contributing to global food security and supporting millions of livelihoods. Aquaculture, or fish farming, is believed to have originated in China, many millennia ago; it has over the years, and particularly since the second half of the last century turned it from an art to a science. Aquaculture practices in China are going through many paradigm changes, aiming at maintaining production and environmental integrity leading to long-term sustainability of this primary production sector.

Chinese aquaculture is diverse. It spreads across the temperate north to the tropical south. Often, little is known in the West of the details of Chinese aquaculture practices, leading to many misconceptions. China accounts for over sixty percent of global aquaculture production, and continues to maintain its predominance in both inland and marine aquaculture. In China, over 200 species are cultured commercially. This compilation primarily attempts to apprise what is ongoing in Chinese aquaculture, often rarely recorded in Western literature. It should also be noted that in the last decade or so new policies directed at attaining environmental integrity, have resulted in many paradigm changes in aquaculture practices in China. We have endeavored to capture such major changes in this compilation. Obviously, there is an apparent bias towards freshwater aquaculture, which is the main domain of Chinese, as well as global aquaculture. As such this attempt does not claim to deal with all the diverse facets of Chinese aquaculture, but has endeavored to focus on key selected aspects that are lesser known in the public domain. Nor does the book claim to have covered all the important aspects of aquaculture developments in China, but hopefully will stimulate a freshened outlook, and a debate on Chinese aquaculture. Perhaps, a comparable follow-up compilation with a bias on marine aquaculture in China will be most apt.

Finally, compilation of this book took us nearly three years, and it is very rewarding to see it in print and in the public domain, which would have been impossible if not for the assistance of many.

Jian-Fang Gui, Qisheng Tang, Zhongjie Li, Jiashou Liu, Sena S. De Silva

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Section 1

Notable Developments in Chinese Aquaculture in the Past Few Decades

1.1

Contribution of Chinese Aquaculture to the Sector, Globally, and to Overall Food Security

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1.1.1 Evolution of Chinese Aquaculture

China is purported to be the country where world's earliest aquaculture practices took place. *Treatise on Pisciculture* by Fan Li written in 460 BCE is recognized as the earliest monograph on aquaculture in the world. It recorded the practices of pond culture of common carp at the time, covering pond conditions, breeding of fish under controlled pond conditions and stocking density. The long history of Chinese aquaculture has largely benefited from Chinese traditions in which fish are not only valued as an important food source for people, but also have cultural value, since fish are considered a sign of wealth.

Ancient Chinese aquaculture started with monoculture of common carp in ponds. It gradually evolved and diversified in form and practice through its long history, which forms the basis of modern aquaculture. In the Tang Dynasty (618–907 AC), aquaculture entered a new era in China, indicated by the transition from monoculture of common carp to polyculture of four Chinese (major) carps (grass carp (*Ctenopharyngodon idellus*), bighead carp (*Aristichthys nobilis*), silver carp – (*Hypophthalamichthys molitrix*), black carp (*Mylopharyngodon piceus*)). Paddy field clay models and ancient literature reveal that rice-fish culture started 1700–2000 years ago in China (Wang 2000). By the dawn of the Ming Dynasty (1368–1644 CE), aquaculture management practices covering pond conditions, reasonable stocking, feeding and fertilization and disease control were well established for semi-intensive culture production (Wang 2000). Various practices of integrated fish farming, such as integration of fish with livestock, and fish with sericulture and horticulture on pond dykes began in China in the seventeenth century (Dong 2011a). Extensive culture of fish in lakes and reservoirs began around 744 BCE and 1537 BCE respectively in China (Shi 1994).

Aquaculture development in China in the early days appears to have been prompted mainly by the dietary habits of Chinese people, and cultural traditions. In spite of the dependence on wild-caught seed for centuries, aquaculture continued to be an important commercial production activity for many households, mostly concentrated in the delta areas of two major rivers in the country, the Yangtze (Changjiang) and the Pearl (Zhujiang) rivers, which led to the widespread expansion and establishment of fish farming as it is seen in the country today. Despite its long history, aquaculture remained in its primitive form, and on a very limited scale in China until the late 1950s due to various limiting factors. In 1950, national aquaculture production was still below 100 000 tonnes. Until the 1950s, developments in aquaculture in China during its 2000-year history were limited to diversification in culture environments and improvements in practices. A first important technological breakthrough in aquaculture took place in China in the late 1950s and early 1960s, which was the success of induced breeding of four Chinese carps. The successfully established theory and technology for

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induced breeding of Chinese carps laid a solid foundation for later successes in induced breeding of numerous aquaculture species in China, as well as elsewhere. The technological breakthroughs overcame the most important bottleneck in aquaculture – enabling a reliable seed supply. Great efforts were made to summarize traditional aquaculture practices and experience and upgrade these to theoretical level in the 1960s in China, which formed the "Eight Character Driven Aquaculture Principle", which covered water management, seed, feed, species composition, stocking density, rotational stocking and harvesting, disease control and daily management. Another important achievement was the establishment of a large number of state-owned fish farms in counties with traditional aquaculture practices in the late 1950s and early 1960s. These had the major function of supplying seed for small fish farmers through adoption of newly developed induced-breeding technologies of Chinese carps while culturing limited amounts of fish for supplying urban areas.

From the public policy perspective, the development of the sector occurred mainly through two policy regimes: the egalitarian model under centralized state planning from 1949 to 1978, and the open market economy regime from 1978 onwards. In the first model, tight government controls at all stages of production to marketing, resulted in a lack of input from producers and consumers as well as attention to market forces. With this model development was slow. In the second and most efficient model, economic and policy reforms were encouraged to allow producers to make production and marketing decisions so that the productivity and production efficiency were improved. This led to significant benefits to all stakeholders including the state, local government, and farmers, as well as consumers.

1.1.1.1 Aquaculture for Improved Fish Supply for Food and Nutrition

For nearly two decades following the success of induced breeding of four Chinese carps, the development of aquaculture in China was not as rapid as it could have been because of government emphasis on the production of land crops. National aquaculture production was 1 800 000 tonnes in 1976 (FAO 2014), which accounted for less than a quarter of the total fisheries production.

Rapid aquaculture development started in the late 1970s in China, following the Open Door Policy and economic reforms. The Chinese government attached much greater importance to increasing the supply of animal protein for the population while assuring self-sufficiency of staple food items.

In 1979, the government started to reform fisheries production and trade systems. Fisheries became the first market-driven food production sector in China (Qi 2002). In 1985, the State Council issued the decree on Reform Policies to Accelerate Fisheries Development. This decree advocated free marketing of fisheries products and family-contract production management systems, which greatly motivated farmers to expand the scale of production and improve efficiency. In 1985, central government put forward a target to significantly improve fish supply in urban areas within a three–five year time frame. The target was achieved. To support fisheries development in China, the first fisheries law, the Fisheries Law of the People's Republic of China, was enacted in 1986 (FAO 2003).

With government support, large areas of pond aquaculture were established in peri-urban areas and traditional aquaculture regions with support from the Chinese government's 1988 "Food Basket Project". Large numbers of fishponds were constructed in waterlogged areas or enclosures of inland waters, particularly lakes and reservoirs.

There was rapid expansion of aquaculture in China between the early 1980s and mid 1990s. For instance, the area covered by inland fishponds increased from 640 000 ha in 1985 to 1 860 000 ha in 1995. At the same time, great efforts were made to increase fish production from small and medium-size lakes and reservoirs through extensive aquaculture with stocking of large, artificially propagated fish seed as the main input and management improved to ensure high survival rates and better performance. The rapid expansion of the area under aquaculture significantly improved the fish supply for urban and peri-urban populations.

Some new farming systems were introduced to China for enhancing fish production in lakes, reservoirs and rivers during the 1970–80s. In particular, cage culture was first introduced into lakes for large fish seed production in the 1970s and was later expanded to lakes, reservoirs, rivers and coastal seas for food fish culture of a range of species. Pen culture was first introduced into inland lakes in China in the early 1980s and later expanded to coastal and sheltered inshore areas. This provided an effective approach for intensive aquaculture in open water bodies in China. Experimental recirculation and running water systems also started in China from the 1980s. These have turned out to be an important aquaculture system for marine aquaculture and for the culture of some high-valued freshwater species.

Since the 1980s, the government of China has made great efforts to increase the unit production from aquaculture. One important major input was to promote the standardization of fish ponds through the modification of traditional fishponds for improved pond productivity. Another notable measure aimed at improving aquaculture productivity was to support research and technology developments of compound feeds. Since the 1980s, there has been significant emphasis on research on nutritional requirements, energy metabolism, digestive enzymes and digestion rates of feeds of traditional aquaculture species, and newly developed high-value species. The research outputs effectively supported the development of compound aqua-feeds for different cultured species, and the rapid expansion of the aquaculture feed industry in China (Liu 1999). Research on feed additives for improving animal growth performance, feed utilization, and disease resistance has further improved the quality of compound feeds for aquaculture in China. The production of aquaculture feed reached 19 000 000 tonnes in China in 2014 (Bo and Lin 2015; Han *et al.* 2016).

At the same time, research on aquaculture disease prevention, diagnosis and treatment was carried out extensively in China. A nationwide aquaculture control system was gradually established as part of the national fisheries extension service system. Aquaculture seed production systems had been well established with the support of central and local government, and were capable of meeting seed demand for all cultured species with a few exceptions, such as eel.

Between 1978 and 1990, Chinese aquaculture production achieved an average annual growth rate of 16 percent, which significantly contributed to an increase in the production of fisheries products in China. Largely due to the rapid development of aquaculture, Chinese fisheries production ranked first in the world in 1990 for the first time and has maintained that position since then (BoF 2001a).

The rapid growth of aquaculture continued in the 1990s. By 2000, total aquaculture production reached 28 460 000 tonnes in China, which accounted for 65.8 percent of the total fisheries production of 43 280 000 tonnes. Annual per capita availability of fish products reached 34 kg, which was far above the global average availability. China had generally become self-sufficient in the supply of food fish. Fish produced by 2 percent of the agricultural population comprised 1/3 of the total animal protein for the people of China in 2004 (BoF 2006). Of the total annual 67 000 000 tonnes of fisheries products, about 73.7 percent (49 400 000 tonnes) was from aquaculture (BoF 2016).

1.1.1.2 Aquaculture for Improved Rural Livelihoods

With the rapid development of aquaculture from the late 1970s, China had significantly improved the supply of fisheries products in the domestic market by the early 1990s. From the 1990s, with the overall shift of government priorities in agriculture development from ensuring overall food security to improving rural peoples' living standards through increasing income, aquaculture development started to play a more important role in increasing the income of rural households, while continuing to contribute to the supply of animal protein to the population's diet.

In order to contribute more significantly to increased income of fish farmers in China, efforts were devoted to improving the economic returns from aquaculture from the early 1990s. As part of the effort to increase production efficiency and economic returns, aquaculture has been significantly intensified through increased use of commercial compound feeds, high-quality seed and management measures such as increased stocking density and use of aerators. Intensification of aquaculture significantly improved production efficiency in China. The unit production of pond aquaculture was only 3270 kg/ha in 1990 but this had increased to 4899 kg/ha in 2000 (China Fishery Statistical Yearbook 2001).

Other changes also took place in the aquaculture industry in China. One important change was the diversification of cultured aquatic species. At the end of 1980s, aquaculture was limited to approximately 25 aquatic species. Over the next ten years, the number of important cultured species doubled. The total cultured aquatic species has further increased to over 100 currently, of which 88 species or species groups are reported and included in FAO Fisheries Statistics (FAO 2016). The new species introduced to aquaculture are mostly species of high market value, such as prawn, shrimp, marine and freshwater carnivorous finfish.

Promoting rice-fish farming was also considered by many local governments in China as an important means of increasing the income of traditional rice farmers, and obtained significant improvements. Fish production from rice-fish farming was only 130 837 tonnes in 1990 with a total area of 740 000 ha (BoF 1991). By 2000, total area of rice-fish farming increased to 1 532 381 ha in China and total fish production from rice-fish farming reached 745 770 tonnes (BoF 2001). For instance, some additional 2 billion RMB (6 RMB = 1 US$) net profit was achieved from rice-fish farming in Jiangsu Province in 2000 (BoF 2001), which has a rural population of approximately 50 million. Overall, economic returns from fish and other aquatic animals in rice-fish farming well exceeds the income from rice (Miao 2009; Xie *et al.* 2011; BoF 2012; Hu *et al.* 2015).

The pursuit of higher economic returns from aquaculture has led to changes in the sector related to markets. Since the early 1990s, Chinese aquaculture has become more diversified and specialized, with a development approach of one dominant commodity per area, which means a large number of individual farmers in one area culture selected commodities to take advantage of local geographic and climate conditions to meet the needs of certain niche markets. To facilitate the marketing for small individual farmers, a great number of aquaculture marketing centers have been established by local governments in major aquaculture producing areas to support direct trading between farmers and wholesale-buyers in China.

Rapid aquaculture development also stimulated the development in China of processing of aquaculture products for adding value. The total number of seafood processing plants reached 6922, with a total processing capacity of 9 340 000 tonnes in 2000 (BoF 2001).

By 2001, the total number of people engaged in primary aquaculture and fisheries reached 13 740 000, compared to 3 070 000 in 1979, of which about 85 percent were engaged in aquaculture. Per capita income of people engaged in fisheries production reached 4987 RMB by 2001 compared with 1151 RMB in 1990 and 93 RMB in 1978 (Qi 2002).

The development of aquaculture has not only significantly increased the income of rural populations, but has also contributed more significantly to local and national economies. Despite the relatively small number of people engaged in this sector, aquaculture has become a supporting sub-sector of agriculture. The contribution of the fisheries economy to overall agriculture GDP increased to 16.8 percent in 2015 (total agricultural GDP: 6086.3 billion RMB) in China (China Fishery Statistical Yearbook 2016; NSB 2016) from less than two percent in 1978 (Li 2002). In 2015, aquaculture contributed 49 percent of total fishery GDP (including aquaculture, capture fisheries and fishery-related manufacture, construction, logistics and services).

1.1.1.3 Sustainable Development of Aquaculture with an Emphasis on Social and Environmental Benefits

At the start of the twenty-first century, Chinese aquaculture industry entered a new stage of development. This is due to the challenges in both maintaining sustainable development of aquaculture and overall social and economic development in China, which include but are not limited to competition for natural resources, more stringent requirements on food safety and environmental impact control, and the impact of climate changes, etc. While continuing to play an important role in food and nutritional security, and rural economic development, aquaculture is expected to achieve greater ecological and social benefits.

New priorities set by the Chinese government for aquaculture development in the twenty-first century include structural improvement of the sector and improvements in quality through the establishment and implementation of a variety of standards and through effective monitoring, which will lead to strengthening environmental protection of fisheries resources and to ensuring sound ecological benefits of the aquaculture industry.

New strategies for achieving new targets of aquaculture development are identified as follows. Aquaculture development is to follow new patterns, moving towards ecological sustainability and technology-based aquaculture, requiring the application of theories and technologies of modern biology and engineering. The key to achieving sound ecological benefits and high efficiency in sustainable way in aquaculture is to effectively coordinate relationships between cultured animals and the environment. At the sector scale, aquaculture development should not compromise the ecological services of all ecosystems and environments, or the needs of other sectors. In order to achieve this goal, the current structure, scale and distribution are being adjusted (Lu 2013).

Extensive aquaculture in inland lakes and reservoirs has frequently been used as an important approach in environmental improvement and ecological rehabilitation. This has also lead to the expansion of the traditional "farming the land" to "farming the water". Innovative aquaculture practices and technologies are being tested and disseminated to minimize negative environmental impacts, and to achieve increased efficiencies in intensive aquaculture. Good examples in this regard include recirculation pond culture systems that integrated effluent treatment function into traditional intensive pond culture, and multi-trophic mariculture systems that integrated intensive farming of fed aquatic animals with filter-feeding mollusk and autotrophic seaweeds.

In order to promote the structural adjustments and functional transition of aquaculture for sustainable development and greater ecological and social benefits, the government has introduced a number of new regulations. The important regulations enacted are the Regulation on Certification of Aquaculture Rights in Inland Waters and Tidal Zones, the List of Allowed Drugs in Aquaculture and Their Use and Code of Conduct for Safety and Hygiene in Aquaculture.

Food-safety related incidences in early 2000s had a significant negative impact on public perception of aquaculture product safety. In order to ensure product safety and public health, the Chinese government has attached greater importance to improving aquaculture product safety and quality in the country. The Chinese government issued the first national food safety law in 2009. Efforts to improve the safety and quality of aquaculture products started several years before that. In September 2003, the Ministry of Agriculture (MoA) issued the Regulation on Control of Safety and Quality in Aquaculture. To support the enforcement of this regulation, great efforts have been made to encourage improvements in record keeping in aquaculture production, labeling of fish products, and recording of drug and chemical use in aquaculture. The government has provided strong support to the establishment of national and provincial centers for conducting regular monitoring of aquaculture product quality and safety, and aquaculture environment monitoring.

In addition to strengthened monitoring and regulation, various registration and certification schemes have been implemented to strengthen the control of safety and quality in aquaculture. By 2004, 957 brands of aquaculture products from 517 enterprises had been certified as a "Hazardless Product" with the total annual production of 730 000 tonnes. In the same year, 1241 aquaculture sites with a total water surface of 1 200 000 ha were registered as "Hazardless Farming Sites" (China Fishery Statistical Yearbook 2005).

Integrated functional zoning of inland and coastal waters has been undertaken as an important management tool to maintain all the important ecological services of different aquatic systems, and meet different sectoral needs. In this process, aquaculture in many open water bodies, particularly intensive culture operations, have been generally downsized or relocated for improved environmental and ecological benefits.

In the structural adjustments of aquaculture for better quality and efficiency, local governments are encouraged to establish specific commodity farming zones that offer local advantages. Such zonal developments have significantly improved the scaled benefits, facilitated public services and management, and promoted commodity centered value chain development.

Another important trend in aquaculture development is the integration of aquaculture with other social and economic activities. A good example is the rapid development of leisure fisheries, which organically combines aquaculture/fisheries with tourism, sport fishing, and restaurant business. Over 5000 leisure fisheries sites had been established by 2004 (China Fishery Statistical Yearbook 2005).

Being an integral component of overall sustainable development of China, high production efficiency with a low carbon footprint is now recognized as the major path of sustainable development of aquaculture in the future (Dong 2011b). The carbon sequestration function of some Chinese aquaculture practices has been well recognized. Aquaculture has made a positive contribution to reduced carbon emission and reduced eutrophication of inland water bodies (Tang 2012). It was estimated that in 2010 Chinese coastal mollusk culture and seaweed farming extracted 1 380 000 tonnes of carbon from coastal seas and that culture of freshwater filter feeding fish extracted more than 1 300 000 tonnes of carbon from inland water bodies. The combined contribution is the equivalent of planting more than one million ha of forest (Tang 2012). It is clear that Chinese aquaculture in the twenty-first century should have not only the function of providing high-quality food and livelihoods for the people, but should also provide ecological service functions.

In order to compensate the negative growth in marine capture fisheries, reasonable growth of aquaculture production is needed in the coming decades. The China mid- and long-term fisheries science and technology development strategy study report sets the target for aquaculture to contribute 75 percent of total fish production by 2020 (BoF 2006).

In order to achieve greater socio-economic benefits, the Chinese aquaculture industry is moving towards four different types of production systems for meeting different demands: staple fish products to meet basic demand, high-value fish products for diversified domestic markets, important internationally traded fish products for export, and leisure fisheries.

In order to achieve greater environmental and ecological benefits in aquaculture, more public and private sector efforts are needed to promote aquaculture systems and practices that can minimize negative environmental impacts, contribute to restoration of ecosystem functions and climate change mitigations, which include effluent-recycling intensive-farming systems, extensive culture of low trophic species in inland water bodies for control eutrophication, mollusk culture and seaweed farming in coastal seas for carbon sequestration and nutrient extraction.

1.1.2 Contribution of Chinese Aquaculture to Global Food Security and Nutrition

1.1.2.1 Contribution to Improved Domestic and Global Fish Supplies

Aquaculture in China produced 1 300 000 tonnes of farmed fish in 1980, which accounted for 30 percent of the country's total fish production. The 1 300 000 tonnes represented 28 percent of global farmed fish production, yet only two percent of global total (i.e. aquaculture plus capture fisheries) fish production. In 2013, farmed fish production in China reached 43 600 000 tonnes, contributing to 73 percent of the country's total fish production, 62 percent of world farmed fish production and 27 percent of world fish production (Table 1.1.1).

As indicated in Figure 1.1.1, the contribution of China's farmed fish production to its total fish production increased nearly uninterruptedly from less than ten percent in 1950 to over 70 percent in 2013. Its contribution to world fish production was below two percent before 1980, but since then has grown exponentially to 14 percent in 1995 and continued to increase steadily to 27 percent in 2013. Its contribution to world farmed fish production has been steady at 30 percent between 1960 to 1980 and started to increase rapidly after the 1980s. It reached nearly 70 percent in the mid 1990s and then declined slightly to a little over 60 percent in 2013.

Table 1.1.1 Percentage contribution of China's aquaculture to domestic and global fish supplies.

Production in million tonnes or % of global total	1980	1990	2000	2103
Farmed fish production in China	1.3	6.5	21.5	43.6
Share of China's fish production (%)	30	49	60	73
Share of China in world farmed fish production (%)	28	50	66	62
China's aquaculture in world fish production (%)	2	7	17	27

Source: FAO data on aquaculture and fisheries production (http://www.fao.org/fishery/statistics/en).

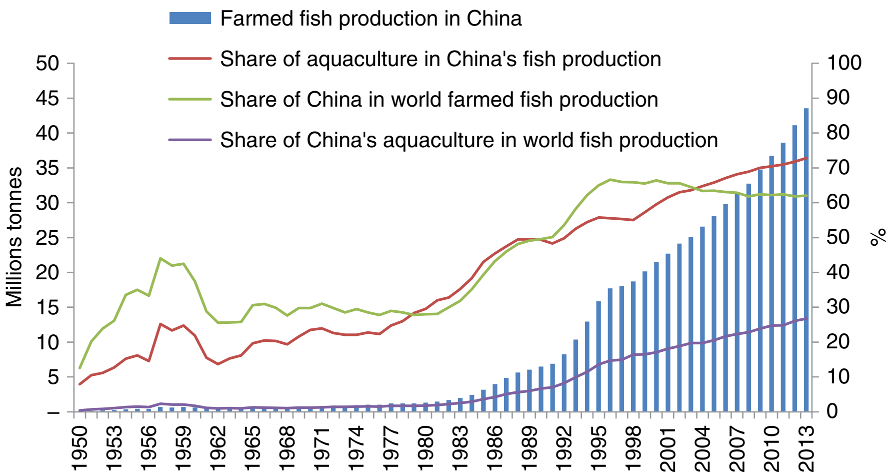

Figure 1.1.1 Contribution of China's aquaculture to fish supply domestically and globally. *Source:* FAO data on aquaculture and fisheries production (http://www.fao.org/fishery/statistics/en)

Table 1.1.2 Contribution of China's aquaculture to fish supply in 2013 by species groups.

		Share (%) of China's aquaculture production in:		
Species group	**China's aquaculture production (thousand t)**	**Global aquaculture**	**Cn: Aqua+ Fish**	**Gl: Aqua +Fish**
Fish	**43,550**	**62**	**73**	**27**
Finfishes	25,941	55	69	21
Freshwater	24,470	61	94	48
Diadromous	342	7	80	5
Marine	1,128	49	10	2
Crustaceans	3,770	56	59	28
Mollusks	12,984	84	87	58
Miscellaneous aquatic animals	855	96	78	59

Cn: Aqua + Fish = Aquaculture and capture fisheries production in China; Gl: Aqua + Fish = Aquaculture and capture fisheries production in the world.
Source: FAO data on aquaculture and fisheries production (http://www.fao.org/fishery/statistics/en)

As indicated in Table 1.1.2, in 2013 aquaculture in China contributed nearly or over half of world aquaculture production for all major species groups except diadromous fish. The low share of China's aquaculture to diadromous fish production (seven and five percent of world aquaculture and total production of diadromous fishes, respectively) mainly reflect the dearth of suitable sites in China to farm species groups such as salmonids.

In 2013, aquaculture contributed to over half of total fish production in China for all species except marine fishes (only ten percent). This reflects China's much lower aquaculture production in marine fishes (a little over 1 000 000 tonnes) compared to that in freshwater fishes (nearly 25 000 000 tonnes).

For most species groups, the contributions of China's aquaculture to global fish production are compatible with its contribution to domestic fish production, except diadromous fishes. China's aquaculture production of diadromous fishes accounted for 80 percent of the country's total production of diadromous fishes but only five percent of world production.

1.1.2.2 Contribution of Chinese Aquaculture Production to Peoples' Nutrition Domestically and Globally

Per capita fish consumption in China was 4.4 kg/person/year in 1980, less than half of the world average (11.5 kg/person/year) (Figure 1.1.2). In 2011, per capita fish consumption in China reached 33.5 kg/person/year, nearly twice as high as the world average (19.1 kg/person/year) and higher than the average levels in all continents (Figure 1.1.2).

As evident from Figure 1.1.2, the growth path of per capita fish consumption in China coincided with that of aquaculture production in the country. While the rapid increase in China's per capita fish consumption during 1980s and the first half of 1990s was contributed to by growth in both aquaculture and capture fisheries production. Growth in consumption after the mid 1990s was solely due to aquaculture (Figure 1.1.2).

World fish consumption increased to 80 000 000 tonnes from 50 000 000 tonnes in 1980 to 131 000 000 tonnes in 2011. About 46 percent of the world fish consumption increase was contributed to by the increase in China's aquaculture production by 37 000 000 tonnes, from 1 300 000 tonnes in 1980 to 39 000 000 tonnes in 2011. Indeed, growth in China's aquaculture production has made a significant contribution (over one third) to world fish consumption growth in all major species groups except marine fish (Table 1.1.3).

1.1.2.3 Contribution of Chinese Aquaculture to Global Trade of Aquatic Products

Fish exports from China increased from 90 000 tonnes in 1980 to 4 000 000 tonnes in 2011. Accordingly, China's contribution to world fish exports in terms of quantity increased from 1.3 percent in 1980 to 13 percent in 2011. In terms of value, China's fish exports increased from US$ 263 million in 1980 to US$ 17 billion in 2011 and its contribution to world fish export value increased from 1.9 percent to 14 percent (Figure 1.1.3 and Table 1.1.4). In 2011, China's contribution to world fish exports exceeded ten percent for all commodities except for dried, salted or smoked fishes (Table 1.1.4).

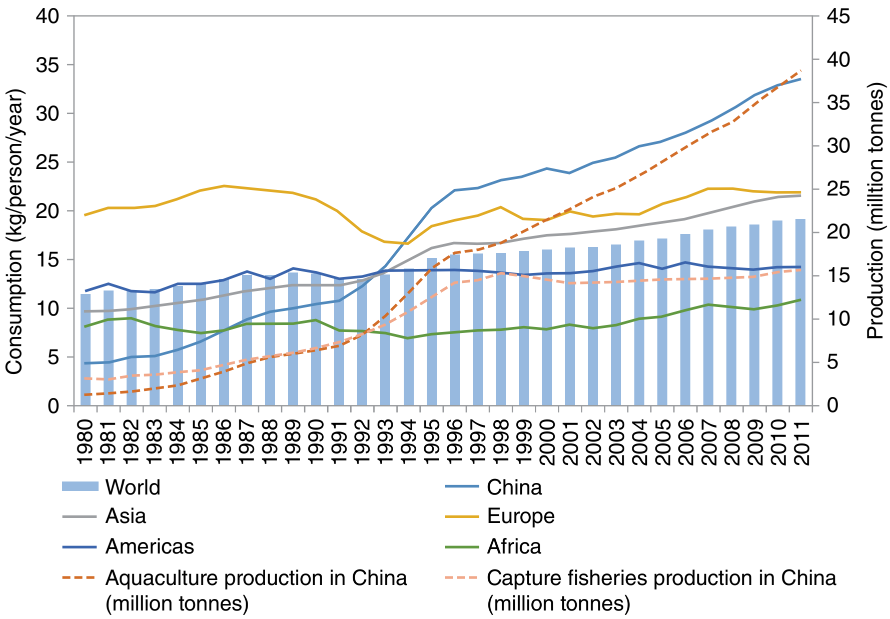

Figure 1.1.2 Per capita fish consumption: China vs. the world. *Source:* FAO data on fish consumption (http://www.fao.org/fishery/statistics/global-consumption/en)

Table 1.1.3 Contribution of China's aquaculture to world fish consumption growth (% Contribution = contribution of China's aquaculture to world fish consumption growth between 1980 and 2011).

	Aquaculture production in China (thousand t)			World fish consumption (thousand t)			
Species groups	**1980**	**2011**	**Increase**	**1980**	**2011**	**Increase**	**% Contribution**
Fish[1)]	1,316	38,621	37,305	50,492	130,985	80,492	46.3
Finfishes[2)]	906	22,818	21,912	41,313	97,270	55,957	39.2
Freshwater and diadromous fishes	902	21,850	20,949	7,841	46,560	38,719	54.1
Marine fishes	5	968	964	33,472	50,710	17,238	5.6
Crustaceans	10	3,292	3,282	3,334	12,165	8,831	37.2
Mollusks	400	11,796	11,396	5,658	20,201	14,543	78.4
Miscellaneous aquatic animals	1	716	715	188	1,348	1,161	61.6

1) Fish = finfishes + crustaceans + mollusks.
2) Finfishes = freshwater and diadromous fishes + marine fishes.
Source: FAO data on aquaculture and fisheries production (http://www.fao.org/fishery/statistics/en); FAO data on fish consumption (http://www.fao.org/fishery/statistics/global-consumption/en).

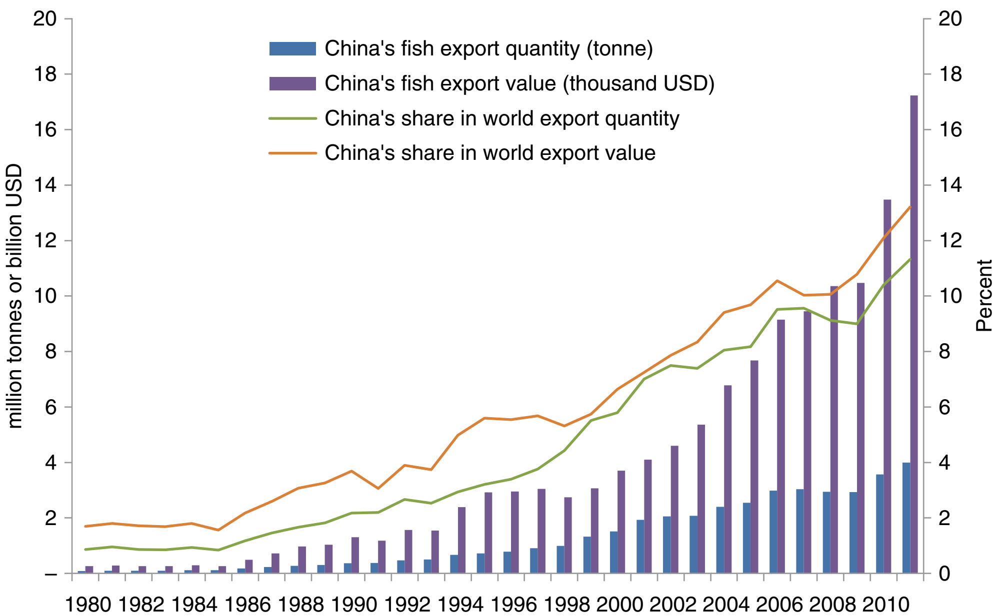

Figure 1.1.3 China's contributions to world fish exports. *Source:* FAO data on aquaculture and fisheries production (http://www.fao.org/fishery/statistics/en); FAO data on fish consumption (http://www.fao.org/fishery/statistics/global-consumption/en).

The lack of distinction between aquaculture and capture fisheries products in trade data makes it difficult to evaluate the contribution of China's aquaculture to fish trade. The presence of re-exporting fish products processed from imported raw materials makes the estimate even more challenging. But considering the dominance of aquaculture in total fish production in China (Table 1.1.2) and China's significant contribution to world fish exports (Table 1.1.4), we can confidently say that aquaculture contributes significantly to global fish trade.

Table 1.1.4 Contribution of China to world fish exports by species group and or commodities.

	Export quantity				Export value (in US$)			
	1980		2011		1980		2011	
Species groups/ commodities	$\times 10^3$ t	% of world	$\times 10^3$ t	% of world	$\times 10^6$	% of world	$\times 10^6$	% of world
Fish	90	13	5907	12.9	263	1.9	16,867	13.7
Finfish	49	0.8	2755	11.6	101	1.3	10,206	12.5
Fresh/chilled/frozen	44	1.0	2170	11.2	95	1.7	7,176	11.7
Dried/salted/smoked	—	—	75	8.4	—	—	395	6.8
Prepared/ preserved	5	0.5	511	15.3	6	0.3	2,635	18.1
Crustaceans/mollusks	41	3.4	1152	17.6	162	3.4	6,661	16.2
Live/fresh/chilled	41	3.9	774	14.6	162	4.0	3.311	10.8
Prepared/preserved	—	—	378	30.0	—	—	3,350	31.5

Source: FAO data on fisheries commodities trade (http://www.fao.org/fishery/statistics/global-commodities-production/en).

1.1.3 China's Contribution to Global Aquaculture Development

China has a land area of 9.6 million km^2 and sea area of 3.0 million km^2, consisting of the Bohai Sea, Yellow Sea, East China Sea, and South China Sea, about 6500 islands, with a total coastline of 18 000 km.

In the two preceding sections of this Chapter, the evolution of the aquaculture sector in China and the contribution of Chinese aquaculture to global food security and nutrition were discussed. With the unprecedented development and growth in Chinese aquaculture over the last three to four decades, it was imperative that China help other countries, particularly developing countries, to contribute to the growing aquatic food needs of the world. Accordingly, China provided and continues to provide technical assistance to global aquaculture development, particularly in other developing countries through human capacity building, technology transfer, demonstration and on-site technical guidance, and share of genetic resources (Han and Lu 2010). Some of the key aspects of such Chinese involvement and the relevant institutions involved (Table 1.1.5) in global aquaculture development are presented in the following paragraphs.

Table 1.1.5 Major Chinese agencies that have conducted international training in fisheries and aquaculture.

Name	City	Operation Year	Notes
South China Sea Fishery Research Institute	Guangzhou	1975–1979	—
Pearl River Fishery Research Institute	Guangzhou	1978–1983	—
Asia–Pacific Regional research and training center for integrated fish farming	Wuxi	1981–1992	Component of FFRC since 1983
Freshwater Fisheries Research Center (FFRC) of the Chinese Academy of Fishery Sciences	Wuxi	Since 1992	—
Fujian Institute of Oceanography	Xiamen	Since 2005	—
FAO reference center for inland fishery and aquaculture research and training	Wuxi	Since 2014	Transferred to FFRC

1.1.3.1 Capacity Building

In order to share knowledge of aquaculture development with developing countries, Chinese government gave priority to human capacity building. From 1955, the Chinese government began to provide education and technical training programs in fishery and aquaculture sciences.

In 1955, the Shanghai Fisheries College received its first batch of six students from Vietnam for bachelor's degrees in marine fisheries. This was the first Human Capacity Development program in fishery and aquaculture science in the world.

In 1975, following a request by the FAO to fast track adoption of aquaculture technology and promote global aquaculture development, China conducted the first technical training course on freshwater aquaculture for 12 participants from Sri Lanka. With the success of induced breeding of carps, China started to share its knowledge and experience in induced breeding of carps. There were four courses on freshwater aquaculture conducted between 1975 and 1978, the course duration was six months, with training contents including induced breeding of carps, nursery rearing, pond fish farming, and disease prevention and treatment. It trained approximately 36 trainees from four countries. It strongly promoted and extended carp induced breeding technology to developing countries and scientists.

In 1978, a FAO technical consultative task force reported the success of freshwater integrated fish farming models in China and suggested the establishment of a research and training center in Wuxi, Jiangsu Province, and consequently the Asian-Pacific Regional Research and Training Center for Integrated Fish Farming, as an arm of the Freshwater Fisheries Research Centre (FFRC) of the Chinese Academy of Fishery Sciences, was established jointly with the FAO and the UNDP (United Nations Development Program). The Centre focused on human capacity building programs for technicians and administrators, as well as trainers / extension service officers in fisheries and aquaculture. In 1981, the curriculum was developed jointly by experts from FAO and China, and the first training program on integrated fish farming was successfully conducted in 1981 in Wuxi, China. The program received support from the IDRC, Canada (International Development Research Centre (IDRC), Canada) for ten years (Jing and Yuan 2013).

In 1992, FFRC started to organize international training and Technical Cooperation among Developing Countries (TCDC) under the China-Aid human capacity building program aimed at capacity improvement of technical staff and administrators from developing countries. In 2014, FFRC was designated as the FAO reference center for aquaculture and inland fishery research and training, in recognition of its continued and strong capacity in fisheries and aquaculture research and training expertise. Up to 2016, it has trained 2427 persons from around 127 countries (Figure 1.1.4). The main topics covered in the training included:

- integrated fish farming;
- aquaculture technology;
- inland fishery development and management;
- rice-fish farming;
- teaching methodology for fishery training;
- aquaculture industrialization;
- climate change and aquaculture.

In 2005, the Chinese government included the Fujian Institute of Oceanography, to provide training, seminars and workshops in marine resource management and mariculture. Up to 2016, it has trained 1508 trainees from 99 countries/governments, including ministers and high-level administrators. The main training fields included:

- marine management and the development of the Blue Economy;
- marine fisheries management;
- integrated coastal management (ICM);
- mariculture technology;
- maritime cities and marine emerging industries development;
- processing, logistics and trade of marine aquatic products.

In 2009, China signed an agreement with the FAO (China Trust) to set up a trust fund of US$ 30 million. The purpose of the trust fund is to improve agricultural production capacity of developing countries. Supported by the FAO and Ministry of Agriculture, FFRC organized two training programs on fish seed and fish feed production and management for participants from Central Asia and the Caucasus region. The course has trained 38 participants from Azerbaijan, Uzbekistan, Kyrgyzstan, Georgia, Turkmenistan, Armenia and Kazakhstan, and has contributed to the improvement of fisheries and aquaculture development in many countries (Zhu 2014).

1.1.3.2 Transfer of Key Aquaculture Technologies and Farming Practices

1.1.3.2.1 Induced Breeding

Under the South-South Cooperation (SSC) and the Technical Cooperation in Developing Countries (TCDC) program of the FAO, the Chinese government developed important approaches to the transfer of technology to other developing countries. The most successful case was the transfer of technology on induced breeding and mass carp seed breeding facilities. It is reported that most Asian countries have adopted the induced breeding technology and established the required basic facilities based on the principles used in China and induced breeding operation guidelines. In most cases, Chinese technicians provided technical guidance for several months to two years in each recipient country (Zhu 2014). The technology has greatly contributed to aquaculture development globally, and it is no surprise that major species of Chinese carps head the global list of cultured fish production (FAO 2016).

1.1.3.2.2 Rice-fish Farming

Supported by the MoA, China provided rice-fish farming training for Cambodia, Laos, and Myanmar. It has trained 30 participants and introduced rice-fish farming techniques to the three countries. The technology of rice-fish farming was also an important component in the course content on integrated fish farming. At the present time, rice-fish farming has become an important practice in rural areas and a means of livelihood improvement.

1.1.3.2.3 Integrated Fish Farming

In Eritrea, Nigeria, Uganda, Philippines and Thailand there are many models of integrated fish farming transferred from China. Duck-fish, chicken-fish are popular models in the rural communities. These models not only provide fish and animal proteins to families, but also improve economic returns and livelihoods, and have proved to be a good model for the rural economy.

1.1.3.2.4 Farm Design and Pond Fish Farming Business

During aquaculture technology transfer, experts also helped in providing technology in farm design, promoting rice-fish integration models, formulating pellet feed and machinery application, probiotic development and utilization. The production chain and value chain for aquatic products were also established to improve the management and production efficiency.

1.1.3.2.5 Cage and Pen Culture

Through the expertise from China, some simple cage-culture practices were adopted in Africa and Asia; the cages were fabricated with local materials and nets, most notably, the floats and cage frame were constructed with oil drums and timber, sourced locally.

1.1.3.2.6 Demonstration and On-Site Technical Guidance

Technology demonstration and on-site technical guidance were carried out through experts, SSC, agriculture technology demonstration centers and agriculture technology transfer.

Based on the request of recipient country authorities, the Chinese government has provided expertise on fishery management and aquaculture. Since the 1980s, China has sent aquaculture experts to Iran, India,

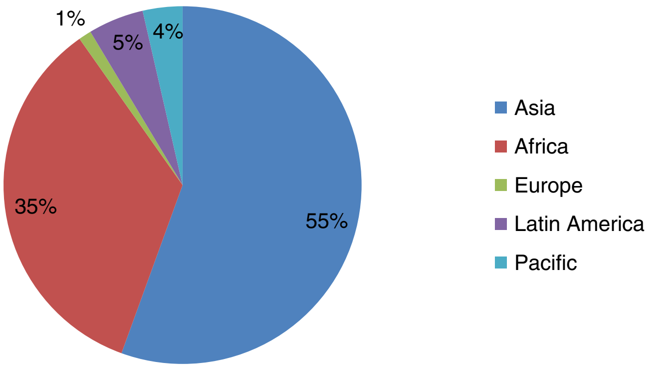

Figure 1.1.4 Distribution of trainees of FFRC (1981–2014).

Cuba, etc. to provide technical guidance. The program has received recognition of the host governments, and the results showed great efficiency in improvement of carp breeding, polyculture, pond fish farming, farm-made fish feeds, and fish disease prevention (Zhu 2014).

1.1.3.2.7 South-South Cooperation

In 1996, the Chinese government started to send agriculture experts and technicians under the FAO SSC framework. To date, China has sent 957 experts and technicians to Asia, Africa, South Pacific and the Caribbean. The projects on aquaculture development in Nigeria and Malawi, for example, have greatly improved the technology and model development in these countries, and brought benefits to local farmers and communities. Improvements in cage culture practices, rice-fish farming, pond fish farming, hatchery management, fish feed technology have been developed and brought about significant improvements in productivity (Zhu 2014).

China-Africa Agriculture Technology Demonstration Centers The Chinese government has strongly supported the principle of agriculture technical demonstration centers in developing countries, and has helped launch such centers in Asia and Africa. Of these, two were on aquaculture technology demonstration, i.e. South Africa and Uganda. Each center was funded to the tune of RMB 30 million for infrastructure, and RMB 10 million for technology demonstration and human capacity building. Cage culture, and breeding of tilapias and catfish were demonstrated, and more than 500 personnel were trained in these centers. These projects brought Chinese experts and technology to Africa, and promoted aquaculture development in local communities. This was highly praised by recipient countries, as well as international organizations (Luo *et al*. 2014).

AgriTT Programme Enhancing agricultural productivity is one of the most effective ways to alleviate rural poverty. This has been demonstrated by China's agricultural transformation since the 1980s. The aim of the AgriTT (Agricultural Technology Transfer) programme, initiated and funded by DFID, UK, was to facilitate the sharing of successful experiences in agricultural development, especially from China, with developing countries, in order to improve agricultural productivity and food security (Han and Lu 2010).

China has lifted hundreds of millions of its rural people out of poverty. Technologies and innovations to boost agriculture, allied with supportive policies and investments, have enhanced food security and increased rural incomes (Kharaz and Gertz 2010).

AgriTT adopts a whole value chain approach to innovation and technology transfer, linking producers, markets and consumers, and encouraging added-value services around new technologies. In Malawi, Chinese experts have a well-structured consultative program and established the Pilot Development Project by improving tilapia productivity. Experts worked in the Malawi National Aquaculture Centre and produced 300 000 tilapia fingerlings for the first batch, which is about ten times the production in previous years; the experts also provided technical guidance to 25 selected fish farmers in Malawi, and improved their production efficiency through teaching and guidance on stocking, feed and pond management, and so on (Jing and Yuan 2013).

1.1.3.3 Sharing of Genetic Resources

Through the "Silk Road on the Sea", officials brought Chinese carp seed to many countries of the world, and now these are called Chinese carps, i.e. Silver carp, Bighead carp, Grass carp, etc. It is recorded that Chinese carp aquaculture production played a significant role in aquaculture development in the countries on this trade route.

China is committed to natural aquatic resources conservation. China has vast fishery resources. It is recorded that there are over 1000 native freshwater species in the country (Kang *et al*. 2014; Xing *et al*. 2016). Among these are 140 species of economic importance, and most of which are warm-water species. It is reported that of the 140 economically valued species, 44 are from the Yangtze River, 22 from the Yellow River, 30 from the Pearl River, and 40 from Heiongjiang River region (Kang *et al*. 2014).

The Chinese Ministry of Agriculture has published a list of 156 breeds for farmed aquatic species, among which there are 87 finfish, 14 shrimps, 21 mollusks, as well as 21 seaweeds and 13 other aquatic animals (Table 1.1.6). Genetic improvement programs are continued under the national fish seed bank projects. This has greatly improved the natural fish germplasm bank (NCCAV 2016).

Based on the requirements of countries and governments, MoA has approved demands for renewing broodstocks from China, in particular the Chinese carps. FFRC is one of the institutes designated to providing improved carp strains to recipient countries.

Table 1.1.6 List of approved numbers of pure breeds of farmed aquatic species by MoA, China.

Year	Finfish	Shrimp	Mollusk	Seaweeds	Others
1996	27	1	3	0	2
1997	2	0	0	1	0
2000	4	0	0	0	0
2001	2	0	0	0	0
2002	2	1	0	0	0
2003	3	1	0	0	0
2004	1	0	2	2	1
2005	5	0	1	0	0
2006	3	0	2	1	0
2007	4	0	0	1	1
2008	3	2	0	0	1
2009	3	1	2	1	1
2010	8	4	0	1	0
2011	4	0	2	1	2
2012	3	1	0	2	1
2013	4	1	3	5	2
2014	9	2	6	6	2
2015	5	0	5	0	2
Total	92	14	26	21	15

Source: National Certification Committee for Aquatic Varieties (NCCAV), Ministry of Agriculture (MoA), China.

1.1.4 Future Contributions of Chinese Aquaculture to Global Food Security

The world is facing one of the biggest challenges of the twenty-first century: to feed 9 billion people by 2050 in the face of climate change, economic and financial crises, and the growing competition for natural resources that are diminishing in both quality and quantity. Food insecurity, climate change, degradation of ecosystems, and economic recession are in many ways interlinked. As such, they require an integrated response, one that should hasten the transition of the world economy towards a sustainable, inclusive and resource-efficient path. With the natural resources and technological capital in China that can be harnessed for further growth of fish production through farming of inland waters and the seas, the aquaculture industry can play a significant role in contributing to the supply of more fish and fishery products to meet the increasing demand for food and non-food by its people and the growing population of the developing world.

1.1.4.1 Sustainable Growth and Increasing Demand for Food Fish

The oceans and inland water bodies are facing threats to their health. These include overfishing, habitat degradation, and pollution due to population growth, a growing middle class, technology improvements, poor governance, institutional shortcomings and market failures. Tensions are growing between growth and conservation, between private sector interests and equitable benefits for communities, and between the Exclusive Economic Zones (EEZ) and the Areas beyond the National Jurisdiction (ABNJ) policy frameworks for effective resource management. The big question is how these various issues can be reconciled to ensure maximum contribution from sustainable Blue Growth to feed 9 billion people in 2050 (projected by the World Bank).

Population growth, urbanization, increased levels of development, and higher living standards and income are key drivers of the increase in demand for fish and seafood, and of fisheries and aquaculture development. As per capita wealth increases in populous China, the demand for fish will continue to rise. In order to maintain the current level of fish consumption (18.9 kg per capita per year), by 2050 170 000 000 tonnes of fish will be required; that is 42 000 000 tonnes, or 30 percent, more than the 132 000 000 tonnes consumed in 2013 (World Bank 2015). The estimated increase in demand would be even higher due to improvement in living standards driven by economic development. Supply will have to increase by ten million tonnes in order to maintain the current per capita consumption of 47 kg per year (Tang *et al.* 2014).

In contrast, fish production from natural ecosystems has been constrained by overfishing, with the world fishing fleet overcapitalized by about 40 percent, while the Chinese fishing fleet over-capacity is not better than that. To remove this overcapacity will require not only a large amount of money but also great efforts from all sectors of society.

The most recent FAO studies indicate that the assessed stocks fished within biologically sustainable levels have shown a decreasing trend. About 30 percent of fish stocks were estimated to be fished at a biologically unsustainable level and therefore overfished, 61.3 percent fully fished and 9.9 percent under-fished in 2011 (Figure 1.1.5).

There appears to be little scope to increase capture fisheries in the foreseeable future, but plenty of room for improvement in performance and management of production and trading systems through improved governance. On the other hand, there remains a significant potential for increasing aquaculture production notwithstanding that the sector has been growing at a rate of more than 8 percent per year for the past 20 years. To realize this potential and achieve sustained growth, aquaculture development issues will have to be addressed from the socio-economic, environmental sustainability and technical suitability points of view; this will require a multifaceted effort and an inter-disciplinary approach (Jia 2012).

Globally, aquaculture has a very promising future and will continue its growth, with a slower pace in advanced regions, but will increase in the least developed regions such as Africa, Latin America and Caribbean, as well in the Central Asia and the Pacific. Sea farming will get a bigger share while efforts to explore off-the-coast or off-shore aquaculture will grow. Cost of production could increase and profit margins decrease

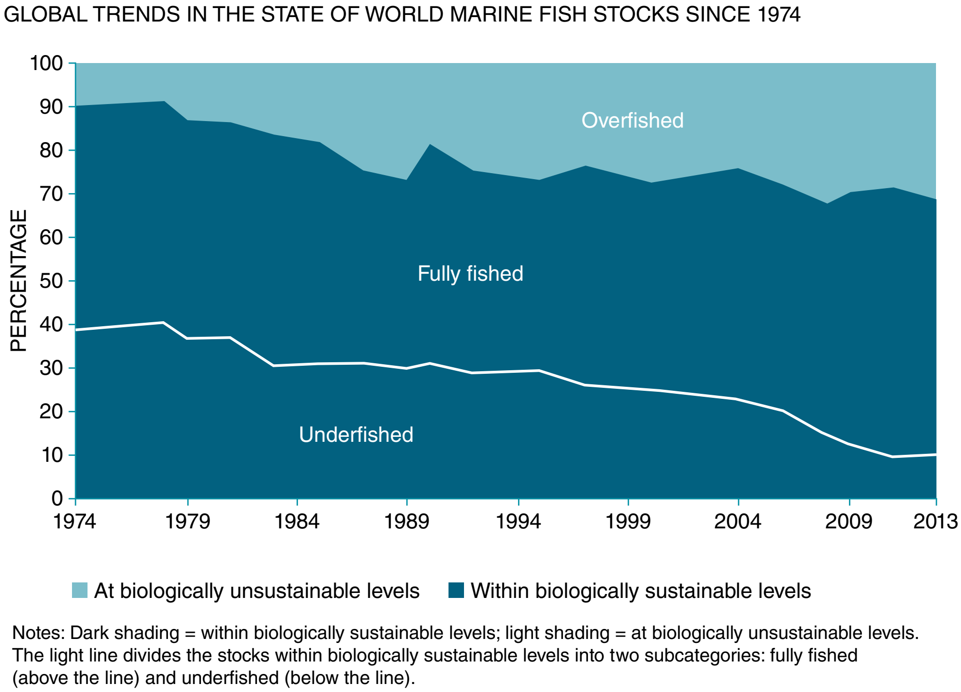

Figure 1.1.5 Global Trends in the State of World Marine Fish Stocks, 1974–2011. *Source:* FAO (2016).

unless economies of scale are attained, and production and marketing efficiencies improved. A larger volume of fish supply will bring down prices, which is beneficial to society.

In China, it is anticipated that the sector will be forced into the pathway of intensification and diversification of production systems, species and products because of scarce land and water resources. The rising costs of feeds, energy, labor, capital and other inputs would increase the cost of production, but this could be offset with the application of improved technologies for massive production and by strategies to attain an economy of scale. Considering the projected population growth over the next 35 years, i.e. an increase of 136 000 000 in 2050 in China, to meet the demand for fish supply at the current level of per capita consumption, 20 000 000 tonnes of additional output will have to be supplied by aquaculture in the face of stagnating capture fisheries landings (Tang *et al.* 2014).

1.1.4.2 Meeting the Challenges with Technological Solutions and Management Practices

Among the major constraints to China's aquaculture development are aquaculture health management, genetic improvement in view of deterioration of germplasm in cultured species and environmental sustainability (Zhang 2013). China's experiences in pushing aquaculture growth and sustaining it can offer some lessons that others might find relevant and applicable to their development efforts.

1.1.4.2.1 Environmental Impacts

The environmental impacts of aquaculture development have received a lot of attention in the past two decades. After years of public pressure, the Chinese aquaculture sector has considerably reduced its negative environmental impacts. The relevant Chinese authorities introduced policy guides to control the overall culture density, feeding regimes and strategies, as well the waste discharge from aquaculture facilities to reduce environmental impacts resulting for example in the eutrophication of water bodies. It has been recognized that aquaculture, when well-planned and well-managed, can bring about broad benefits to society without exacerbating environmental degradation. Fish farms are undertaking various forms of biological, ecological and engineering interventions to reduce environmental impacts. Certain types of aquaculture, such as algae and mollusks could make a positive contribution to the environment by reducing the negative impacts of other industries and activities. In general, the aquaculture sector needs to continue to improve environmental performance. In this context, Wang *et al.* (2017) pointed out some of the major paradigm changes that have and are occurring in the inland aquaculture sector in China.

1.1.4.2.2 Genetic Improvement and Aquatic Biodiversity

Around 200 aquatic species have been employed in Chinese aquaculture production, in the two millennia since Fan Li wrote his treatise on pisciculture. Today, many of these play an important role in aquaculture production in China, including those translocated to different geographical areas and across watersheds within the country. The expansion of farmed species groups, from less than 30 in the 1970s to nearly 200 in 2014, is recognized as one of the remarkable achievements in Chinese aquaculture development. However, the genetic management and hatchery procedures for many cultured species have generally not been adequate nor systematic, and this has apparently degraded the performance of many farmed species through inbreeding, genetic drift and uncontrolled hybridization. In contrast, managed selective breeding programs have shown continual improvements in growth and quality, such as in the cases of Jian Carp, tilapia hybrids, Yellow Sea Number One Shrimp, etc. Some alien species have become very important farmed species, either in volume or in terms of commercial value, and contributed to production and consumption nation-wide; among these are the Nile tilapia (*Oreochromis niloticus*), bay scallop (*Argopecten irradians*), vannamei shrimp (*Penaeus vannamei*), flounder or turbot (*Scophthalmus maxima*), largemouth bass (*Micropterus salmoides*) and giant freshwater prawn (*Macrobrachium rosenbergii*), crayfish (*Procambrus clarkii*) etc. These alien species have successfully found their respective ecological niches in Chinese waters and contribute significantly to the Chinese aquaculture industry (Liu and Li 2010). However, as with the role of alien species in food production elsewhere, controversy exists in this regard in China too (Lin *et al.* 2015). All in all it shows that genetically improved species and introduced species can both play an important positive role in aquaculture development if adequate scientific research is carried out and proper management and control systems are put in place. It is believed that much more work needs to be carried out in genetic improvement and aquatic biodiversity in order to improve sector performance and maintain sustainability.

1.1.4.2.3 Aquatic Animal Health Management

The sector has acquired a better understanding of aquatic animal health management. Diagnosis and veterinary medicine have been adapted for aquaculture in China, and various products and services have made remarkable improvements in their health management practices, rather than solely resorting to disease control and curing disease with drugs and medication. There are however cases of over-use of antibiotics and other chemicals. This suggests the requirement for further improvements and wider promotion of good management practices, and the strengthening of institutional, policy and regulatory frameworks, and monitoring and control systems. With intensification of production and diversification, including introduction of species into the farming systems, new pathogens have emerged and more epizootics have occurred, such as epizootic ulcerative syndrome (EUS) in freshwater species and early mortality syndrome (EMS) or acute hepato-pancreatic necrosis (AHPN) in shrimp in recent years. Therefore, there is an urgent need for much better disease surveillance, improved emergency responses and disease risk management capacities, and the “one health” concept of a healthy animal, people and ecosystem in place.

By the end of 2012, China had established a nationwide network of aquatic animal disease prevention and control centers comprising 13 at provincial level and 628 at county level. Enforcement is aided by more than 4000 monitoring and surveillance stations across the country. The stations also provided rapid disease diagnosis and advisory services; these are connected to more than 1700 internet terminals where online aquatic animal veterinary labs and trained personnel work remotely. The system has covered major areas and species groups. In the field of aquatic animal disease epidemic surveys, it has identified, isolated and purified a number of new pathogens, such as the new genetic type of shrimp yellow head virus (YHV), the second cyprinid herpesvirus (CyHV-2), oyster herpesvirus 1 μvar (OsHV-1 μvar), and from penaeid shrimp the infectious hypodermal and hematopoetic necrosis virus (IHHNV). There are two institutes that have been nominated as OIE (World Organisation for Animal Health) global reference laboratories, namely, the Yellow Sea Fisheries Institute for white spot disease and Shenzhen Quarantine Laboratory for carp viraemia disease. Other notable achievements include the success in maintaining "disease-free zone and controllable zone" for grass carp retrovirus (GCRV) disease in the vast area of the Zhujiang River delta in Guangdong Province; Hainan Province and the application of vaccination on a large production scale (Bureau of Fisheries 2012).

1.1.4.2.4 Feeds and Feeding Management

The use of pellet or compound feeds in aquaculture increased in the past 20 years from 750 000 tonnes in 1991 (Ren and Zhou 2001) to about 19 000 000 tonnes in 2011 (China Feed Industry Association 2016; Han *et al.* 2016). This was almost 50 percent of the 40 000 000 tonnes of FAO's estimated global aquaculture feed production (FAO 2010). It is not an exaggeration to state that the rapid development of Chinese aquaculture has been in part due to the ready availability of quality feed inputs in the country (Bai and Lin 2015). However, concerns persists regarding the use of fishmeal and fish oil as major feed for aquaculture production, and based on FAO studies, there are some 4 000 000 tonnes of fishmeal and 800 000 tonnes of fish oil used in aquaculture, 68 percent and 82 percent, respectively of global production. The rising price of fishmeal and oil has led to considerable investment in research to seek alternative sources of affordable, suitable and high-quality plant- and animal-based feed ingredients. The use of trash/low value fish in aquaculture, which is estimated by FAO at five to six million tonnes globally, is another important issue. More than half of this amount has been reported to be used by China and mainly for marine cage culture. The industry needs to urgently reduce its dependence on trash or low-value fish through the development of suitable dry pellet feeds. Farmers need to be convinced of the benefits of switching from low-value fish to formulated feeds. Use of on-farm feed to reduce costs and improving feed conversion ratio (FCR) are an important area of work to increase yields and improve efficiency: 45 percent of farmed fish rely on formulated pellet feed worldwide.

In spite of increased aquaculture production and accompanied increase in feed production over the last two decades, fish meal imports (= usage) in China have remained relatively steady at 1.0–1.5 tonnes per annum (Han *et al.* 2016). Han *et al.* (2016) have elaborated on the strategies that Chinese aquaculture has adopted in order not to increase its dependence on fish meal, perhaps providing a good example in the manner in which aquaculture should be developed well into the future.

1.1.4.2.5 Low Trophic and Low Input Aquaculture Systems

Seaweed and mollusk farming, as well as the culture of other valuable filter-feeding freshwater species, has great potential to raise the socio-economic status of rural communities. With its rich experience in integrated carp farming, and seaweed and mollusk farming, China could offer to other developing countries some useful lessons on these farming systems. These species groups have largely remained a marginal activity in rural communities of many developing countries because the communities lack access to alternative, higher-return economic activities.

In addition to the above, the aquaculture sector has to cope with other constraints that require resolution of technical or policy nature, for instance, access to or allocation of scarce resources, technological advancement, improvement in policy and legal frameworks, service support availability including credit and insurance coverage, stringent market and trade requirements, standards of product quality and safety including labeling and traceability issues, possible impact of climate change, global economic environment, and the public perception of the sector.

1.1.4.3 Development Policies and Enabling Environment for Sustainable Aquaculture

The most important of the many notable achievements of Chinese aquaculture in the past three decades, is its aquaculture development policies and the role of the government in creating an enabling environment for the sector to take off. It is worth noting and understanding the reasons and factors behind the rapid development of aquaculture in China, and make this knowledge available to the rest of the world, especially developing countries as they strive to develop the sector as a part of their efforts to achieve food security and economic growth.

The core of public sector policy in Chinese aquaculture development can be summarized in a few key phrases:

- full use of resources available;
- the role of markets in determining and promoting production; and
- the role of the government in guidance, safeguard and technical assistance.

Emphasis in this development policy was on full employment of productive resources, including human capital and natural resources, such as suitable waters, mudflats and waterlogged lands. The policy also promoted investment in research and technology, diversification of cultured species – indigenous and introduced – promotion of high-value species, establishment of a nationwide aquaculture extension network to grassroots level, with support from the government, as well as the establishment and constant improvement of enabling policies, legal and regulatory frameworks. With continued proactive government policies, adequate advanced planning, scientifically designed production technologies, sound management and the increasing world demand for aquaculture products, aquaculture in China can be and is likely to continue to be productively stable, sustainable and competitive, both domestically and internationally.

There are valuable lessons which can be learnt from the Chinese experiences:

- aquaculture can be developed in a sustainable manner to generate food and employment, and improve income and livelihoods of rural and urban populations, thus alleviating hunger and poverty;
- the engine for an economically resilient and sustainable aquaculture is the Government's will and determination to establish sound policies in support of the development of the sector, especially issue-specific policies such as on feeds, seed and health management, on zoning, site selection and planning as an integral part of the overall rural development plan at local level, on product quality and safety control from farm to table, with monitoring systems in place; and
- full employment of productive factors, including human resources, continuous improvements in legal and regulatory frameworks for the development of the sector, and scientific breakthroughs in production technologies that would strengthen aquaculture and ensure its sustainability, thereby making aquaculture a good contributor to the country's economic growth.

1.1.4.4 Promoting Global Aquaculture Development through South-South Cooperation

It has been noted that the growth patterns in aquaculture production are not uniform among the different regions of the world. The Sub-Committee on Aquaculture of the FAO Committee on Fisheries has called for more attention to be paid to the countries with the least developed aquaculture through technology transfer, to make the sector grow more evenly in geographical terms. This would require more support to developing countries in both technical and financial resources. Accelerating and maintaining the growth of the sector will only be possible if the sector's socio-economic benefits accrue to a larger social spectrum across the world.

In working with international and regional organizations and the governments of many developing countries, China has forged strong functional partnerships with existing research and development initiatives with similar goals. In so doing, the Chinese government has mobilized resources, based on its comparative advantages, to help improve the capacities of developing countries for sustainable aquaculture development. The mode of collaboration has been carried out through South-South cooperation (SSC), by working with partners such as FAO, in addition to bilateral arrangements. This builds synergies by recognizing the diversity, harnessing the strengths, and maximizing efficiencies among all partners.

Since 2009, the programs have covered more than 50 countries and provided technical assistance in agriculture, animal husbandry, fisheries and aquaculture development in its first phase, worth US$ 30 million. In aquaculture alone, some 100 experts from China have been fielded in 20 countries. Besides the SSC country project, the FAO–China SSC Program has supported 70 participants who attended three aquaculture capacity development events in China. Under the second phase of the Program with a replenished US$ 50 million funding support, it will continue to conduct capacity development and technology transfer in developing countries for developing aquaculture, which has been identified as one of the priority areas to be supported.

The Freshwater Fisheries Research Center (FFRC) located in Wuxi, China is one of the five agriculture centers in China that have been formally recognized by FAO as a world reference center of excellence. It has been providing support to aquaculture capacity development through training and technical assistance to developing countries. Since the early 1980s, the center has conducted a large number of international training courses on integrated fish farming and other subjects related to sustainable fisheries and aquaculture development, the details of which were provided in the previous paragraph.

The SSC mechanism is the mutual sharing and exchange of development solutions – knowledge, experience and good practice, policies, technologies and resources – between and amongst developing countries that are mostly geographically located in the global south. SSC helps developing countries benefit from innovations, lessons learned and good practice, tried and tested elsewhere in the global south. The exchange of development solutions happens through direct interaction between experts, managers and the farmers who will use the new technologies and knowledge, and through facilitating the exchange and uptake of development solutions. In consultation with experts from recipient countries in Africa, Central Asia, Latin America and the Caribbean, the Pacific and Southern Asia, SSC has identified a number of priority areas that need technical assistance. Among these are reliable and affordable production inputs, seed and feed in particular, aquaculture facilities and infrastructure, appropriate governance and regulatory frameworks, human capacity to implement the policy and legal framework, and a reliable and efficient data collection system.

Human capacity development (HCD) has been a major element of the various important international fisheries and aquaculture milestones, such as the FAO Code of Conduct for Responsible Fisheries (FAO 1995), The Bangkok Declaration adopted by the Global Conference on Aquaculture in the Third Millennium in 2000 (Anonymous 2001) and the succeeding Phuket Consensus adopted at the Global Conference on Aquaculture in 2010 (Anonymous 2012). There was also a common recognition of the importance of knowledge sharing and technology transfer through networking and international cooperation for aquaculture development at various international fora such as the FAO COFI (Committee on Fisheries) Sub-Committee on Aquaculture. To implement effective and practical transfer of technology transfer, it has been shown that better synergies could be achieved in working through collaboration, support and strengthening of the existing regional aquaculture organizations such as NACA (Network of Aquaculture Centers in Asia-Pacific), RAA (Red de Acuicultura de las Americas) in Latin America, ANAF (Aquaculture Network for Africa) in Africa, NACEE (Network of Aquaculture Centres in Central-Eastern Europe) in Central and Eastern Europe and MASA (Micronesian Association for Sustainable Aquaculture), the sub-regional intergovernmental aquaculture network being established in Micronesia. The collaboration should extend to working jointly with regional organizations such as AU (African Union), ASEAN (Association of South-East Asian Nations), CARICOM (Caribbean Community), the FORUM (Forum of Caribbean States) and ACP Group (African, Caribbean, and Pacific Group of States) in complementing bilateral and multilateral arrangements.

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1.2

Inland Aquaculture: Trends and Prospects

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1.2.1 Introduction

In spite of a millennia-old practice, aquaculture only transformed into a significant food production sector during the course of the last three to four decades, and it currently accounts for over 50 percent of the global food fish consumption (Subasinghe *et al.* 2009). Global food fish needs and changes in the food fish production sector have been dealt with previously (Delgado *et al.* 2003; De Silva 2012). Food fish production sector from capture fisheries has changed from a developed country dominance to a developing country dominance, whereas aquaculture production has been always dominated by the latter group of nations.

Globally, since aquaculture became a significant contributor to the food fish supply, inland aquaculture has played, and continues to play, a dominant role. Freshwater aquaculture accounted for 45.2 percent of the global aquaculture production of 106 004 184 tonnes in 2015, and its contribution averaged 41.1 percent over the period 1950–2015 (FAO 2017). The former percentage contribution of freshwater aquaculture to global production would be much higher if we were to not take into account seaweed production which stood at 29 273 392 tonnes in 2015, the great bulk of which is used for industrial purposes rather than as a direct human food source. China dominates global freshwater aquaculture production. Its contribution to the latter has continued to increase and currently accounts for 64.2 percent of the global total of 47 861 246 tonnes in 2015 (Figure 1.2.1). Furthermore, the contribution from China to global freshwater aquaculture production peaked in the early 1990s, and over the period 1950–2015 averaged 54.8 percent. As such, the importance of the freshwater aquaculture to global aquaculture and the predominance of the Chinese contribution to the former are evident (Figure 1.2.1).

1.2.2 Current Status

Much has been written on the freshwater aquaculture sector in China and its importance and contribution to global food security, as was highlighted in Chapter 1.1 Wang *et al.* (2015) reviewed the freshwater aquaculture sector. In this review the authors traced the development trends in inland aquaculture in China in time and space, and considered aspects of production, types and modes of culture, species cultured, and marketing. The review demonstrated that although inland aquaculture occurs in most of the 31 provinces in the country, the great majority of it occurs in the area that lies approximately between 110–120 °E and 19–35 °N, in the Yangtze and Pearl River basins. In this chapter we will not concentrate on those aspects of

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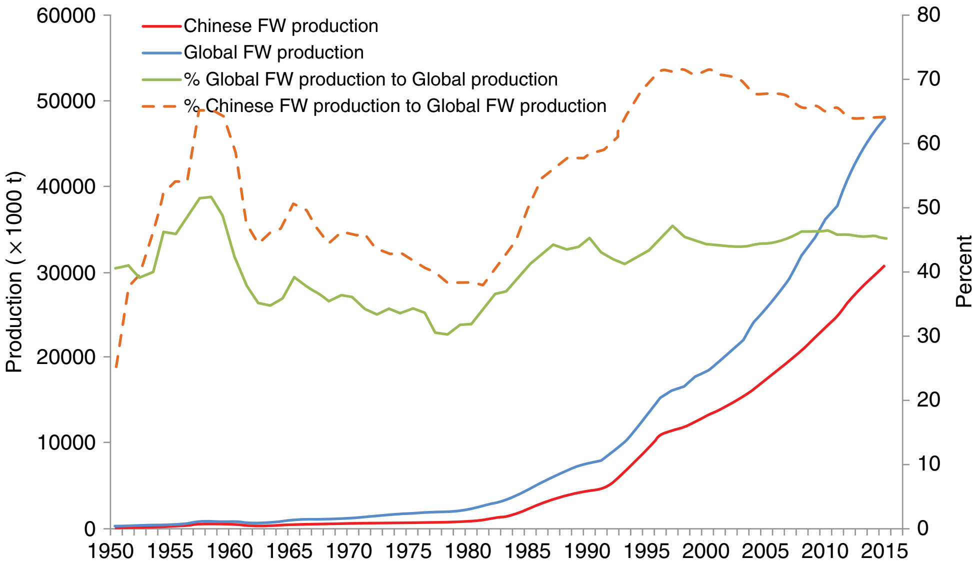

Figure 1.2.1 Trends in Chinese freshwater aquaculture production (x 1000 t), and its percentage contribution to global freshwater aquaculture production; global freshwater aquaculture production (x 1000 t) and its percentage contribution to global aquaculture production from 1950 to 2015. *Source:* Data from FAO 2017.

the freshwater aquaculture sector that were dealt in detail by Wang *et al.* (2015), but will attempt to focus on other areas and aspects that exemplify inland aquaculture in the country.

1.2.2.1 Distribution of Production

When five-year averages in freshwater aquaculture production for each province, and municipalities in the mainland of China from 2011 to 2015 are considered (data from China Fishery Statistical Yearbook 2012–2016), the ten leading freshwater aquaculture producing provinces contributed 78.7 percent of total freshwater aquaculture production in China. The top ten provinces in production over the same period were Hubei, Guangdong, Jiangsu, Hunan, Jiangxi, Anhui, Shandong, Guangxi, Sichuan and Zhejiang (Figure 1.2.2). Figure 1.2.2 shows that the provinces in the middle and lower reaches of Yangtze River basin account for 51.4 percent of the country's total freshwater production, and as such predominates inland aquaculture production in the country.

1.2.2.2 Species Cultured

The climatic regimes in China are wide ranging and together with the associated habitats the country has a relatively rich aquatic flora and fauna. For example, China is reputed to have nearly 302 genera, 920 species of freshwater finfish, of which 613 are endemic (Kang *et al.* 2014). Overall, the dominant freshwater aquaculture production in China is based on around 30 species or species groups (Wang *et al.*, 2015), which include twenty finfish, three crustaceans and one reptile.

Based on the last five-year averages of finfish, crustacean, and reptile production, the leading 15 freshwater species cultured accounted for 86.9 percent of total freshwater aquaculture production in China. The leading 15 species were grass carp (*Ctenopharyngodon idellus*), silver carp (*Hypophthalmichthys molitrix*), common carp (*Cyprinus carpio*), bighead carp (*Aristichthys nobilis*), crucian carp (*Carassius auratus*), Nile tilapia (*Oreochromis niloticus*), mitten crab (*Eriocheir sinensis*), bream (*Megalobrama amblycephala*), white-legged shrimp (*Penaeus vannamei*), crayfish (*Procambarus clarkii*), black carp *(Mylopharyngodon piceus*),

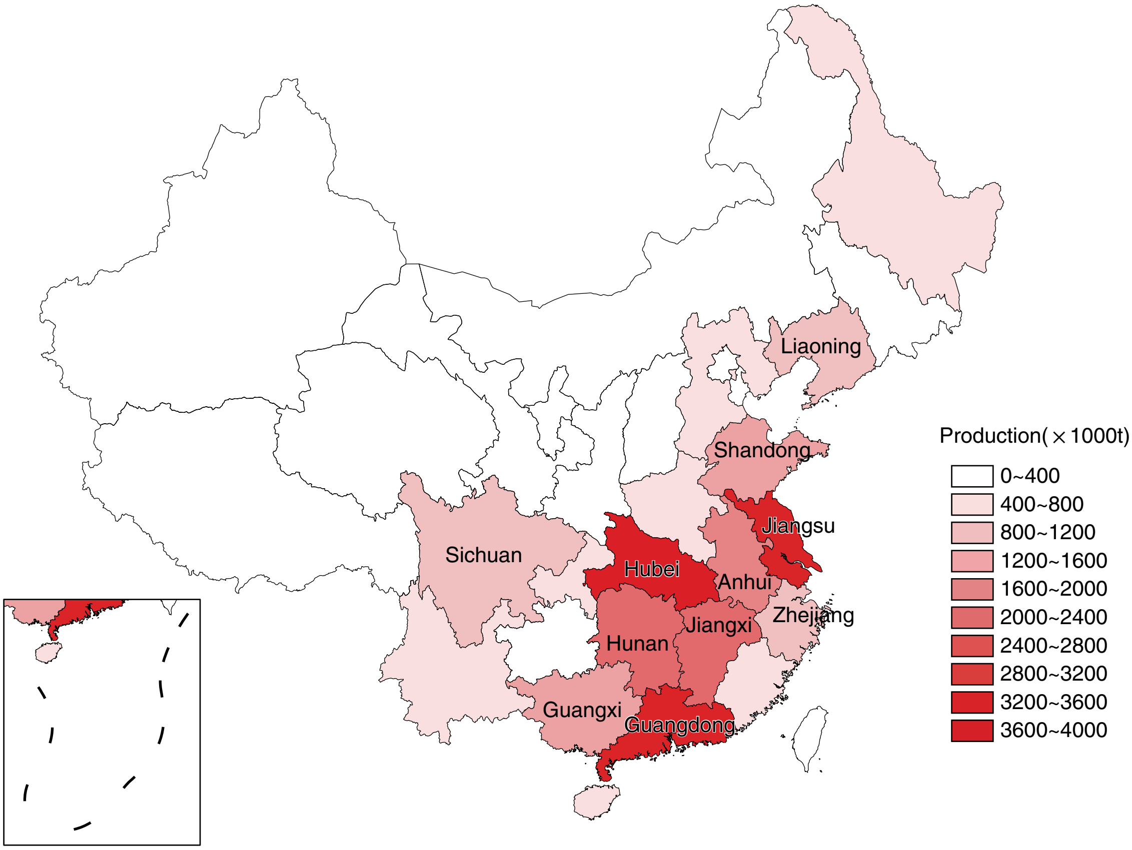

Figure 1.2.2 Average inland aquaculture production (x 1000 t) over the last five years (2011–2015) in the different provinces. *Source:* Data from *China Fishery Statistical Yearbook* 1982–2016.

snakehead (*Channa argus*), catfish (*Parasilurus asotus*), paddy eel (*Monopterus albus*), soft-shelled turtle (*Trionyx sinensis*) (Table 1.2.1).

Six major Chinese carps: bighead carp, silver carp, grass carp, black carp, common carp and crucian carp, have dominated Chinese freshwater aquaculture. Production of carp increased from 13 106 394 tonnes in 2003 to 20 256 635 tonnes in 2015 (China Fishery Statistical Yearbook 2011–2016). However, the percent contribution of cyprinids to total freshwater aquaculture production in China for this period decreased from 73.9 percent to 66.1 percent over the same period. This indicates that other cultured species were also gaining in significance over this time period. Over the same period, production of grass carp (3 492 585 to 5 676 235 tonnes) was predominant, followed by silver carp, common carp, bighead carp, crucian carp and black carp in that order (Table 1.2.1).

Apart from the cyprinids, there are a number finfish species and/or species groups that contribute (in excess of 25 000 tonnes/year) to freshwater aquaculture production in China. These include channel catfish (*Ictalurus punctatus*), yellow catfish (*Tachysurus fulvidraco*), mandarin fish (*Siniperca chuatsi*), Nile tilapia, loach (*Misgurnus anguillicaudatus*), catfish, snakehead, bass (*Lateolabrax japonicas*), paddy eel, and freshwater eel (*Anguilla japonica*). Importantly, all of these species/species groups have shown a consistent increase in production in the last decade, perhaps with the exception of the alien species channel catfish which has tended to plateau in the last few years. Notably, the above group of fishes includes mostly omnivores and strict carnivores, especially snakehead and mandarin fish. The increased production, and therefore emphasis on the culture of carnivorous species such as the mandarin fish is primarily driven by local consumer demand,

Table 1.2.1 Trends in average production (tonnes) over the last 5 years of the top 15 ranked finfish, crustaceans and reptiles cultured in inland waters in China.

Production	2011	2012	2013	2014	2015	Average	S. E.
Grass carp	4442205	4781698	5069948	5376803	5676235	5069378	484482
Silver carp	3713922	3687751	3850873	4226009	4354638	3966639	305312
Common carp	2718228	2896957	3022494	3172443	3357962	3033617	246344
Bighead carp	2668305	2851419	3015380	3202887	3359440	3019486	274224
Crucian carp	2296750	2450450	2594438	2767910	2912258	2604361	244929
Nile tilapia	1441050	1552733	1657717	1698483	1779482	1625893	131711
Mitten crab	649240	714380	729862	796535	823259	742655	69082
Bream	677877	705821	730962	783023	796830	738903	50457
Shrimp	659961	690747	617384	701423	731461	680195	43430
Crayfish	486319	554821	603520	659661	723207	605506	91603
Black carp	467736	494908	525498	557328	596102	528314	50573
Snakehead	446448	480594	509865	510340	495574	488564	26525
Catfish	392435	408750	433948	450846	450064	427209	25867
Paddy eel	292410	320966	346077	357991	367547	336998	30420
Soft-shelled turtle	285875	331424	343734	341288	341588	328782	24454

Source: Data from China Fishery Statistical Yearbook, 1982–2016.

coupled to the aspirations of the growing Chinese middle class which desires to indulge in high priced produce. On the other hand, the production of Chinese major carps, often referred to as the "common man's food" have not decreased. In spite of many changes in the socio-economic *milieu* in the past two decades, such as the growing middle class in China that generally aspires for food types perceived to be of higher quality, the production of "common man's food" has not decreased. Perhaps in spite of these socio-economic changes the basic Chinese cuisine still require the Chinese major carps as components and as such the production of these commodities is likely to keep pace with population increase.

The relative contribution of the above finfish species/species groups to the total freshwater aquaculture production in China was 18.3 percent in 2015. In contrast to the finfish species that are being cultured, only three crustacean species are of notable significance in freshwaters aquaculture in China – Chinese mitten crab, crayfish and white legged shrimp. The cumulative production of these three crustaceans increased from 715 941 tonnes in 2003 to 2 277 927 tonnes in 2015, and their corresponding contribution to freshwater aquaculture production increased from 4.0 percent to 7.4 percent (Figure 1.2.3). The other important species cultured in freshwater is the soft-shelled turtle, the production of which increased from 143 816 tonnes in 2003 to 341 588 tonnes in 2015, which is equivalent to a nearly 10.6 percentage increase in production per year. It is important to note that the aforementioned crustacean species recorded a much higher rate of production over the last ten years than most of the finfish species that have come to prominence as cultured commodities (Figure 1.2.3), perhaps reflecting the point made earlier in regard to changes in potential food habits that reflect corresponding changes in the socio-economic *milieu* of the country.

1.2.2.3 Forms of Freshwater Aquaculture

In China, all natural (rivers and lakes) and man-made water bodies such as reservoirs and ponds are used for aquaculture (Figure 1.2.4). Over the last five years, pond aquaculture has become predominant, and

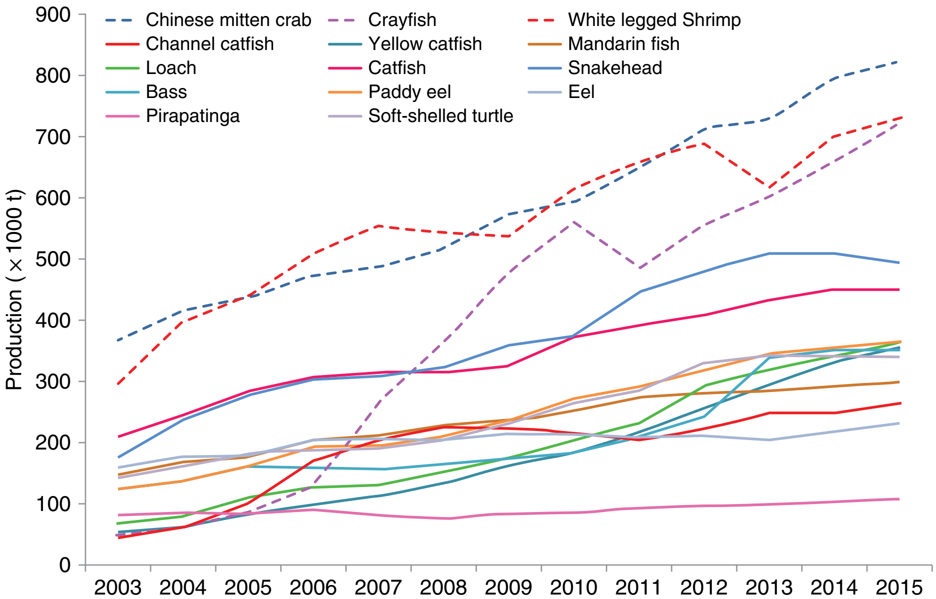

Figure 1.2.3 Trends in production of relatively high-valued freshwater aquatic species cultured. *Source:* Data from China Fishery Statistical Yearbook 1982–2016.

contributed on average 71 percent to total freshwater production, followed by production in reservoirs (12.7 percent), lakes (5.8 percent), paddy fields (5.0 percent) and rivers (3.1 percent). Wang *et al.* (2015) dealt with details on production trends in different types of water bodies in China, and it is likely that these trends will continue to persist to the foreseeable future.

1.2.3 Culture Techniques/systems

1.2.3.1 Pond Culture

In China, as indicated in the preceding section, pond aquaculture is the predominant practice, accounting for 71.7 percent of total freshwater aquaculture production and 43.9 percent of total freshwater aquaculture area in 2015, respectively (China Fishery Statistical Yearbook 2004–2016). In recent years, production from pond aquaculture increased from 12 520 000 tonnes in 2003 to 21 960 000 tonnes in 2015, and maintained an average growth rate of 5.8 percent per year, whilst the area under pond aquaculture increased from 2 400 000 ha in 2003 to 2 700 000 ha in 2015, which is equivalent to a nearly 1.0 percent increase per year. Correspondingly, the average unit production increased from 5217 kg/ha in 2003 to 8133 kg/ha in 2015; an increase of nearly 56 percent in unit area production (China Fishery Statistical Yearbook 2004–2016). In this regard perhaps the development of the polyculture systems incorporating the Chinese major carps and the gradual improvements brought about in the species combinations, and other related aspects are the major keys to success (Wang *et al.* 2015). Carp farming systems for example, are almost always carried out as a polyculture activity, where the constituent species have different food habits and preferences, and management practices ensure the utilization of all the available food resources in a pond ecosystem (Lin 1991). Similarly, in the case of mitten crab culture ponds, mandarin fish are stocked to forage on naturally recruited wild fish. As for soft-shelled turtle farming, in order to reduce the increasing risk associated with large price fluctuations of soft-shelled turtle, most turtle farming stakeholders co-culture yellow catfish in polyculture systems (Wang *et al.* 2015).

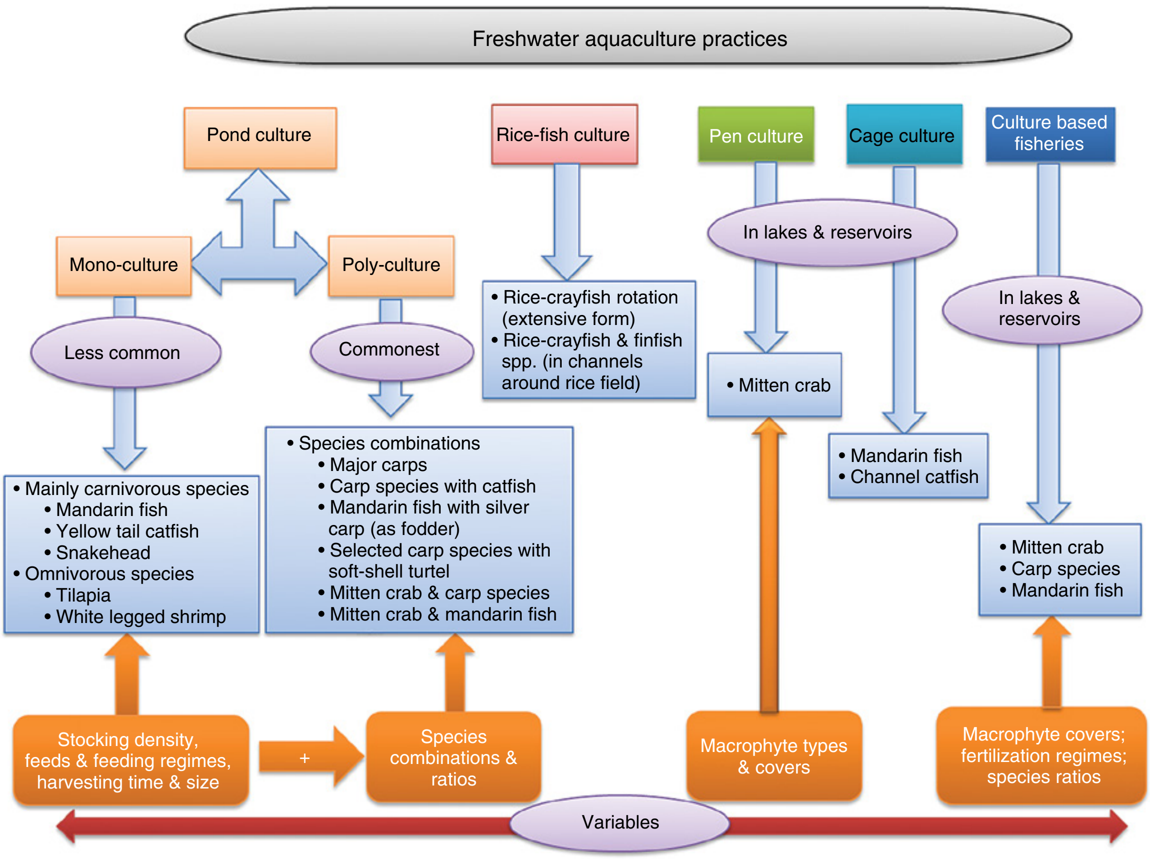

Figure 1.2.4 Schematic representation of the forms of freshwater aquaculture practices in China; the species/species groups cited in each instance are used for example only. *Source:* Modified from Wang *et al*. 2015.

Overall, farming communities are better informed of markets and as such tend to shift the emphasis to meet market demands, and thereby remain economically viable, which perhaps is a major driving force. It is in this context that there has been a gradual shift to culture more economically valuable species in polyculture systems. Pond aquaculture in China has made a concerted effort to change culture practices by popularizing selected, often high–valued, indigenous species. Accordingly, for example there has been a significant upsurge in the production of high-valued species (Figure 1.2.3).

1.2.3.1.1 Inland Saline Pond Culture

It is worth noting that China has 36 000 000 ha of saline-alkaline land, mainly distributed in the northwest, north, northeast and coastal areas of China (Wang *et al.* 2011). Amongst these are over 3 000 000 ha of saline-alkaline land suitable for aquaculture that government encouraged to be reclaimed into fish ponds (Yang *et al.* 2004b). Over the last couple of decades, shrimp (*Penaeus vannamei*; *P. stylirostris*) (Luan *et al.* 2003), common carp, grass carp, Nile tilapia, pirapitinga (*Piaractus brachypomus)*, bighead carp and silver carp were the main cultured species in intensive polyculture systems in these saline-alkaline ponds (Li *et al.* 2002, 2003). However, in recent year there has also been a prominent shift to culture high-valued species such as mitten crab, yellow catfish, mandarin fish, and soft-shelled turtle in saline-alkaline land, driven by soaring markets and improving aquaculture techniques. In practice, Chinese farmer communities in these saline-alkaline areas have synthesized environmentally friendly methods to develop workable integrated aquaculture-agriculture in specific saline-alkaline land. Farming practices such as rice-fish, reed-fish, and cattail-fish have recorded fish yields of 912 kg/ha, 3537 kg/ha and 2766 kg/ha, respectively (Yang *et al.* 2004a). On the whole, saline-alkaline land aquaculture not only produces aquatic products and increases farmers' incomes to some extent, but also improves the saline-alkali soil environment (e.g. decreases soil pH and salinity) and regional climate in China (Yang *et al.* 2004b).

1.2.3.1.2 Recent Changes in Pond Culture Farming Systems

In recent decades, with increasing emphasis on environmental integrity and sustainable development, the Chinese Bureau of Fisheries had to introduce changes to fulfill environmental demands, but also find solutions to maintain economic viability. These changes include the encouragement of environmentally friendly practices, such as use of macrophytes in pond culture, such as, for example, in Hongze Lake (Wang *et al.* 2016 a, b), which is the fourth largest freshwater lake in China. There is also an increasing emphasis on the use of aquaponics in aquaculture practices, where beds of floating plants are introduced as a tool for stripping nutrients, which also supplements the profitability (Vance 2015).

1.2.3.2 Cage Culture

Impoundment of reservoirs often leads to displacement of rural, agricultural communities. It is believed that cage culture is a plausible livelihood alternative for such displaced communities. Such a strategy is adopted elsewhere especially in developing countries (Abery *et al.* 2005). There are estimated to be 97 988 reservoirs in China, with an approximate total storage capacity of 858.1×10^9 m^3 in 2015 (NBSC 2015). Over the last decade, cage culture production in China increased from 552 965 tonnes in 2003 to 1 379 086 tonnes in 2015 (Figure 1.2.5), but has stagnated since 2013. However, the cage culture area increased from 39 363 063 m^2 in 2003 to 147 376 140 m^2 in 2015, and peaked in 2011 at 156 619 341 m^2. It is worth noting that from 2011, the scale of cage culture decreased sharply due to increasing environmental pressures on this farming system. For example, large-scale cage culture operations in Danjiangkou (110°47'27.86" – 111°42'18.22" E and 32°32'35.32" – 32°59'33.64" N) and Gaobazhou (111°8'18.54" – 111°20'42.04" E and 30°23'13.79" – 30°30'31.06" N) reservoirs both in Hubei province have been given notice by the government to be removed. The impact of

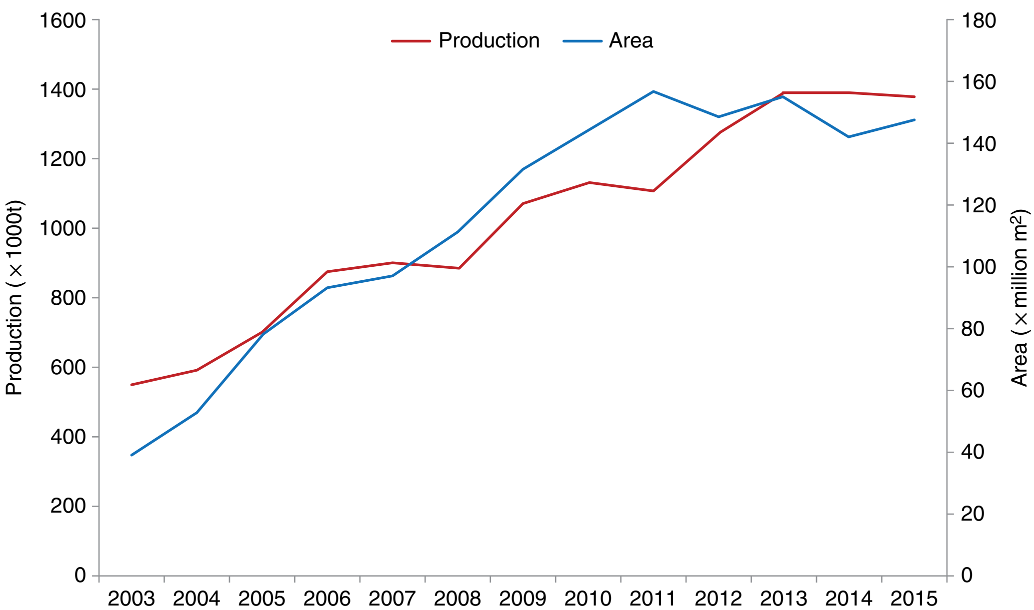

Figure 1.2.5 Trends in Chinese freshwater cage culture production (in x 1000 t) and area (in x million m^2) from 2003 to 2015. *Source:* Data from *China Fishery Statistical Yearbook* 1982–2016.

cage fish farming on the aquatic environment through the release of nutrients that affect water quality, can not only bring about conflict with multiple users, but also primarily exerts a negative feedback effect in the cage operations themselves (Guo and Li 2003).

In this context, in order to promote rational use of natural resources, new regulations have been enacted requiring that the carrying capacity for intensive cage aquaculture in a given reservoir (water body) be estimated based on limnological and farming field data. These data in turn are used to evaluate area-specific nutrient loads that can be assimilated, and to determine the scale of operation(s).

Less feed used to culture a given mass of fish means less waste released into the environment, which is more environmentally friendly. Chinese farming communities have begun to embark on multi-layered cage farming based on the principle that uneaten feed provided for the species in the inner cages are consumed by those fish in the outer cages. This improves feed utilization efficiency and reduces environmental impacts. Many design variations of multi-layered cage farming are being adopted. In general, two or three layered cages can divide the vertical water spaces into a few compartments to culture species with different feeding habits and facilitate farm management (Zhu *et al.* 2011).

The main cage cultured species (stocked in the inner cage) tend to be of higher value (e.g. sturgeon, black carp) and/or directed towards export (channel catfish). In the outer cage(s), it is common to stock species such as bighead carp, silver carp, and crucian carp to use up uneaten feed and help maintain water quality. For example, in multi-layered cage widely adopted by farmers in Geheyan Reservoir (110°21'28.43" – 111°22'55.13" E and 30°14'3.68" – 30°35'52.96" N) in Hubei Province, the feed conversion rate increased 26.1 percent compared with single layer cage culture (Table 1.2.2).

Furthermore, two- or three-layer cage culture systems can improve resistance to wind and waves, reduce the risk of escape of cultured species, improve the efficiency of feed utilization, and reduce the adverse impacts of cage farming associated with uneaten feed, feces and escape of alien cultured species (Wang *et al.* 2015).

Table 1.2.2 Details on stocking, harvest, feed used and cost–benefit analysis of a multi-layered cage culture model in Geheyan Reservoir, Hubei Province.

	Inner cage	Outer cage	
	Sturgeon	Bighead carp	Black carp
Stocking			
Mean weight (kg/ind.)	0.75	0.35	1.2
Density (ind./m^2)	12	9	0.1
Feed (kg/m^2)	31.25	0	0
Harvest			
Culture period (days)	350	350	350
Mean weight (kg/ind.)	2.8	1.1	5.2
Production (kg/m^2/cycle)	32.3	9.9	0.6
FCR of sturgeon	1.34	—	—
FCR in total		0.99	
Cost–benefit			
Total cost (RMB/m^2)		625	
Total revenue (RMB/m^2)		1314	
Net profit (RMB/m^2)		689	

Source: Modified from Zhu *et al.* 2011.

1.2.3.3 Rice-Fish Culture

Rice-fish culture, now referred to as Integrated Rice Field Aquaculture (IRFA) in China (Ma *et al.* 2016) is one of the most traditional systems of aquaculture practices, and has played an important role in producing rice and fish for local consumption, particularly in rural China (Li 1988, 1992; Miao 2010). Rice-fish culture is suggested as an effective means of rationalizing water usage, whilst increasing food production (Ahmed *et al.* 2014). In recent decades, Chinese rice-fish system has changed from small-scale traditional farming to large-scale modern farming with specialization and commercialization to ensure sustainability (Hu *et al.* 2015). The species used in rice-fish culture have changed from use of carps to high-valued species such as soft-shelled turtle, crayfish, and mitten crab (Li *et al.* 2007; Yan *et al.* 2014; Zhang *et al.* 2016). At present, China has synthesized various models to develop workable strategies for rice-fish culture in specific environments, such as for example rice-crayfish rotation, continued rice-crayfish culture, rice-mitten crab culture, rice-soft-shelled turtle culture, rice-loach culture model, etc. (Table 1.2.3). All such changes not only contribute effectively to improving environmental integrity of the farming system(s), but also ensure economic viability (see Chapter 2.6 for details).

1.2.3.4 Pen Culture

Pen culture is a product of a historical period when the country was striving to feed a growing population, and make full use of all forms of water bodies for fish production purposes. Pen culture is a common semi-intensive farming system in lakes, rivers and reservoirs that has been conducted over the last few decades, to varying intensities. During this period, pen culture was considered an effective method to control aquatic plants, and was also widely used from the 1990s in most lakes in the middle and lower reaches of Yangtze River Basin, such as Taihu Lake (119°52'32" – 120°36'10" E and 30°55'40" – 31°32'58" N), Hongze Lake (118°10'2.53" – 118°54'12.37" E and 33°37'54.07" – 32°58'16.52" N) and Honghu Lake (113°11'52.73" – 113°29'30.25" E and 29°40'33.64" – 29°58'17.45" N).

In parallel to net cage culture systems, pen culture also experienced a shift from use of low-valued species (e.g. grass carp and bream) with a unit production of 2176.7 kg per ha in the 1980s, to relatively high-valued species, such as mitten crab, with a unit production of 301.9 kg per ha from the 1990s (Cui and Li 2005). Most of the shallow macrophytic lakes in the Yangtze River basin were considered suitable for mitten crab culture in pens in the last decades, and economic interests stimulated its popularity. However, in practice, pen culture of mitten crab only achieved a relatively high production and economic returns in the first few years, which in turn was stimulated by increasing market demand and price. This is the result of a combination of reasons, amongst which are a reduction of macrophyte biomass and coverage rates, severe eutrophication, sedimentation, and so on, caused by unsustainable farming practices (e.g. overstocking and overfeeding) (Cui and Li 2005). Also, the feed conversion rates of mitten crab cultured in pen systems were relatively poor than when

Table 1.2.3 Comparison between traditional rice-fish system and modern rice-fish system.

Item	Traditional rice-fish system	Modern rice-fish system
Objectives	Increase food supplies and enhance income	Increase food supplies, enhance income, reduce negative environmental impact and improve food safety
Aquatic species cultured	Low-valued species such as carp	High-valued species such as Mitten crab, crayfish, soft-shelled turtle, mandarin fish, loach, shrimp, etc.
Farming community	Family household	Family farm, farmer cooperative, corporation
Scale	Small scale, self-sufficient	Large scale, commercial brand

Source: Modified from Hu *et al.* 2015.

cultured in ponds. This could be due to competition for feed with wild fish or other crustaceans (Wang *et al.* 2015).

In the current decade, increasingly stringent regulations (e.g. carrying capacity estimation, ban on feeding) are gradually being introduced to control pen culture in most lakes in China. For instance, before 2016 in Futou Lake (21 600 ha) (114° 8'29.82" – 114°20'33.12" E and 29°57'9.56" – 30°7'4.47" N), the third largest lake in Hubei province, more than 70 percent of its lake area was used for pen culture of various farm sizes from a few hectares to hundreds of hectares. This situation changed rapidly in the second half of 2016, when all these pens were removed by the government to ensure environmental integrity and protect water quality in the lake.

However, in some eutrophic lakes along the Yangtze River, such as Taihu Lake, a certain percentage of lake area is permitted to be used for pen culture. Farmers have planted varieties of macrophytes in pens to feed cultured species such as mitten crab, and in turn macrophytes can strip large amounts of nutrients from the lakes, and maintain better water quality with the proviso that little feed and fertilizer were used in pen culture operations.

1.2.3.5 Culture-Based Fisheries (CBF)

CBF is a form of extensive to semi-intensive aquaculture practice commonly used in small water bodies that in general have inadequate natural recruitment to support even an artisanal fishery (De Silva 2003; De Silva 2016). It is a practice that has gained momentum in many developing countries in Asia, in view of the low input costs as well as the communal nature of the activity which results in income sharing and community wellbeing. CBF is practiced in most reservoirs and lakes in China, often utilizing the natural productivity and the presence of macrophytes favoring species such as grass carp, and indirectly through favoring benthos production on cultured species like mitten crab. Overall, CBF production from reservoirs has shown a regular increase through the years; 118 705 tonnes (1981) to 3 884 013 tonnes (2015) corresponding to a unit productions of 62 kg/ha and 1,930 kg/ha – a significant increase (China Fishery Statistical Yearbook 1982–2016), with an average increase of 53 kg/ha/year (Figure 1.2.6). Overall, the increase in CBF production

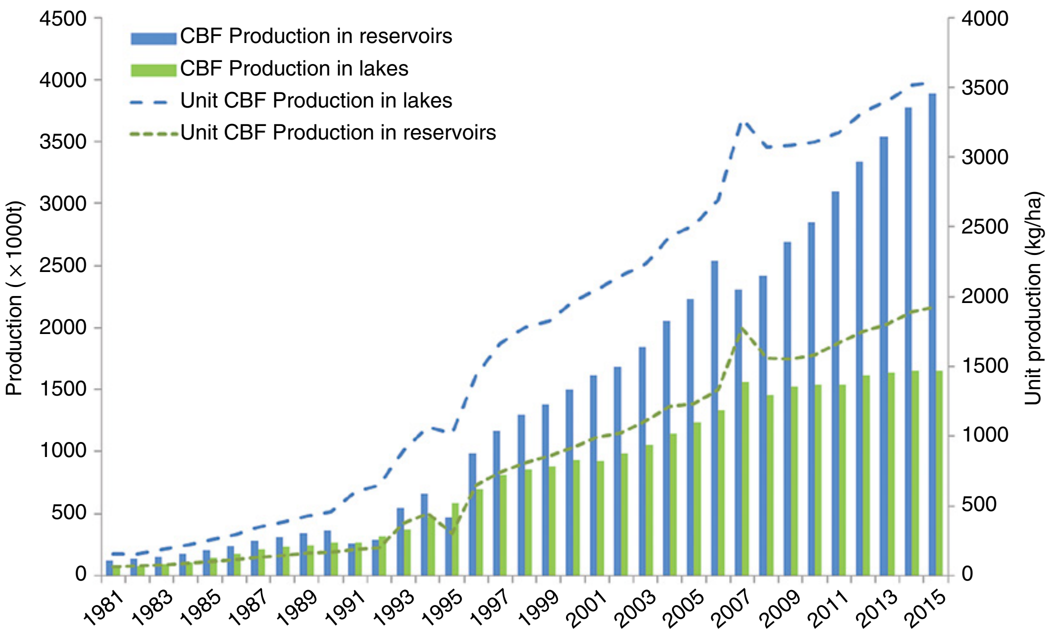

Figure 1.2.6 Trends in total CBF production and corresponding unit production in reservoirs and lakes, in China. *Source:* Data from China Fishery Statistical Yearbook 1982–2016.

has come about as a result of better management of fishery resources, such as division of individual water bodies into manageable sections, and the use of improved combinations of stocked species, as well as proper management of the ecosystem(s).

In recent decades, the water areas in small reservoirs and lakes were often subdivided, and were intensively fertilized with inorganic and organic manures. This encouraged eutrophication and associated planktonic blooms that provided food for the filter-feeding Chinese carps, together with other stocked species, and resulted in high yields (Lin *et al.* 2015; Wang *et al.* 2015). Years of such activity resulted in major environmental impacts on water quality, as well as damage to the watersheds at large (Qin *et al.* 2007). The government began to enact tighter controls on such aquaculture activities, prohibiting the sub-division of a water body either by damming or by any form of netting and fertilizing. Needless to say that it is taking time to implement these measures fully across the country. However, in the interim, the aquaculture sector has had to find alternatives; the sector had to ensure that existing practices are replaced by alternatives which may result in lower yields but continue to be economically viable by culturing relatively high-valued species. Indeed some of the high-valued species that are cultured feed low in the food chain, thereby reducing the need for external feed inputs containing fish meal for example.

In this regard, the emphasis on the culture of relatively high-valued species (e.g. mitten crab, mandarin fish, yellow catfish, soft-shelled turtle) tends to compensate for the reduction in production volume from filter-feeding carp species, and retains economic viability. Overall, and in spite of the changes in policies that have been enacted, the aims are: maintain water quality, protect biodiversity in large water bodies, offer livelihood opportunities for local communities, and maintain other ecosystem services through the adoption of a comprehensive program that includes aquatic resource monitoring, fish stocking plans, aquatic resources enhancement (e.g. snails), spawning ground protection and restoration, artificial fish habitats construction, and a rational capture strategy (see Chapter 7.4 for details).

1.2.4 Conclusions

It is important to consider the driving forces behind recent developments in the inland aquaculture sector in China. These developments are to some degree the consequences of the past growth phases of inland aquaculture, particularly in the late 1960s to 1980s when the country was striving to feed a growing population. During this time almost all primary production sectors went through a rapid phase of intensification, and indeed, in some cases, of over intensification. Little attention was paid to the environmental impacts and or consequences of such a drive.

With increasing living standards and a growing middle class in the developing world, including China, which generally has an appetite for new food varieties, one could expect a change in the species profile of cultured species. One might perhaps expect significant increase in the consumption of carnivorous species which are often purported to have a better taste, and are a relative rarity on average restaurant menus. As mentioned previously however, such production trends are not likely to occur at the expense of a decrease in production of the traditionally cultured Chinese major carps, species that still command a prime place in the Chinese cuisine of almost every household.

The major changes that are likely to occur in freshwater aquaculture in China in all probability will be associated with minimizing the environmental impact of aquaculture practices. These will necessarily include use of better feeds; feeds that result in improved utilization efficiencies, in reduced discharge of nitrogen and phosphorous into the environment, coupled with better feeding management practices, such as avoiding over feeding (see Chapter 5.1 for details).

As regards trends of inland aquaculture in China, two aspects can be expected. First, is the stricter and more controlled use of lakes, reservoirs and rivers for aquaculture. China overall is a nation with a serious water shortage, and water pollution is exacerbating this situation. Second, to compensate for aquaculture production losses from natural water bodies, more attention will be paid to the environmental control of activities in water bodies. Advanced techniques will be used for pond aquaculture to increase production with pollution control, including efficient feed use, the introduction of better aeration machinery, the use of genetically improved species and/or strains, deeper ponds, etc.

The policy changes that are gradually being introduced, mostly revolving around environmental issues, as discussed before, together with possible resource limitations, particularly related to feed ingredient availability and price, are likely to have an impact on aquaculture developments in China; these are issues that are not exclusive to Chinese aquaculture development. In spite of the above, a decline in China's global dominance of freshwater aquaculture is unlikely to occur in the foreseeable future.

Acknowledgements

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1.3

Mariculture: Developments, Present Status and Prospects

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1.3.1 Introduction

China is the world's largest developing country with a population of approximately 1.367×10^9. Chinese people have been using aquatic products as food for thousands of years, and the country has a history of more than 3000 years of freshwater fish farming (Cong *et al.* 1993). While mariculture is a relatively new development in China, globally acknowledged progress has been made in this area since 1950s. In the 1980s, aquaculture was considered by the government as an increasingly important sub-sector that provides nutrition and economic benefits to the country, and reduces the exploitation of declining natural living resources as well (Yang *et al.* 2004). Since then, reform and opening up of the economy has facilitated and accelerated the development of aquaculture nationwide.

Mariculture has a long history of development in China, from low-level to high-level, from low-tech to high-tech, from autotrophic to heterotrophic, from extensive to intensive farming, while the concept of culture also evolved from mainly exploitation combined with the preservation of living resources. The first attempt at marine shellfish farming was conducted in south-eastern China about 1000 years ago, during the Northern Song Dynasty (960–1127 CE) (Liu 2016). According to a poem written at that time, oysters were cultured on bamboo or on stone poles standing on tidal flats. To make better use of resources and increase production, coastal residents began actively developing mariculture and made significant breakthroughs during the Ming (1368–1644 CE) and Qing dynasties (1616–1911 CE). Mariculture at that time covered a wide geographical distribution and was practiced in almost all coastal provinces of China. Although the scale of production was still small, it had grown beyond the experimental stage, and achieved significant increases in the number of farmed species and in the exploited water areas (Ouyang 1998).

It is generally agreed that there have been five significant stages of development in Chinese mariculture in the past few decades, in which each stage represented by the emergence of a species/ species group: 1950–60s was the period dominated by seaweed (macroalgae) cultivation; 1960–70s shellfish farming; 1980–90s was shrimp farming; 1990–2000s saw the rapid expansion of fish farming; and after 2000, there was a surge in sea cucumber (*Apostichopus japonicas*) and abalone (*Haliotis discus hannai are*) farming.

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1.3.2 Current Status of Mariculture in China

1.3.2.1 Yield, Farming Area and Economic Value

China has been leading the world in mariculture production since the late 1980s (Qian 1994; Fang *et al.* 2001). In this chapter we focus on data on mariculture from 2000 onwards. Comparison of annual production between mariculture and marine capture fisheries from 2000 to 2014 is shown in Figure 1.3.1. Mariculture production showed an increasing trend in both production and economic value, except from 2006 to 2008, and exceeded that of capture fisheries since 2006 (China Fishery Statistical Yearbook 2001–2015). Total mariculture production reached 1.813×10^7 tonnes in 2014, increased by 71 percent compared with that in 2000 (China Fishery Statistical Yearbook 2015).

The area under mariculture grew except in 2007 and 2008 (Figure 1.3.2). The mariculture area reached 2.305×10^6 ha in 2014, an increase of 46 percent compared with 2000 (China Fishery Statistical Yearbook 2015).

The annual economic value of mariculture produce showed an increasing trend from 2003 to 2014. The value of mariculture reached 281.5×10^9 RMB (6.0 RMB = 1 US$) in 2014, increased by 284 per cent compared with that in 2003 (Figure 1.3.3). The statistics of the annual output value of mariculture before 2003 were not separated from total fishery output value, so data from 2000 to 2003 were not available in this figure.

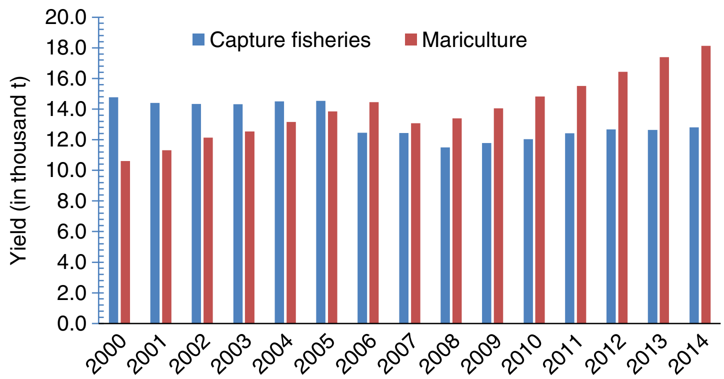


Figure 1.3.1 Comparison of trends in annual mariculture and marine capture fisheries production. *Source:* Based on data from China Fishery Statistical Yearbook 2001–2015.

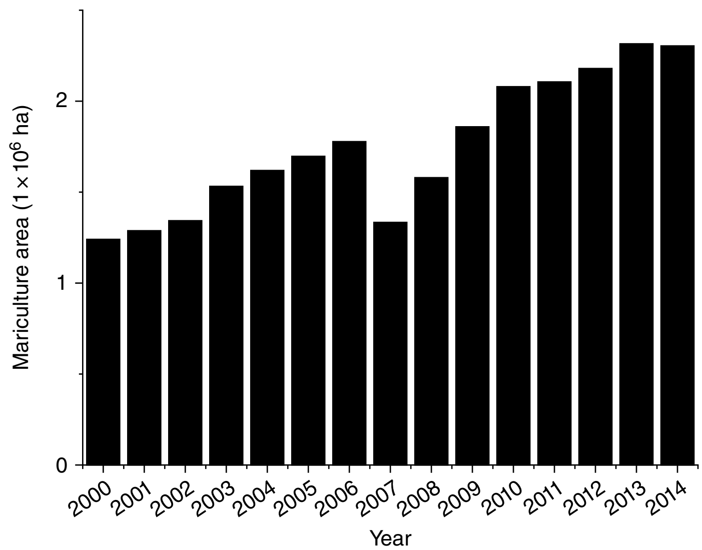


Figure 1.3.2 Mariculture area from 2000 to 2014. *Source:* Data from China Fishery Statistical Yearbook 2001–2015.

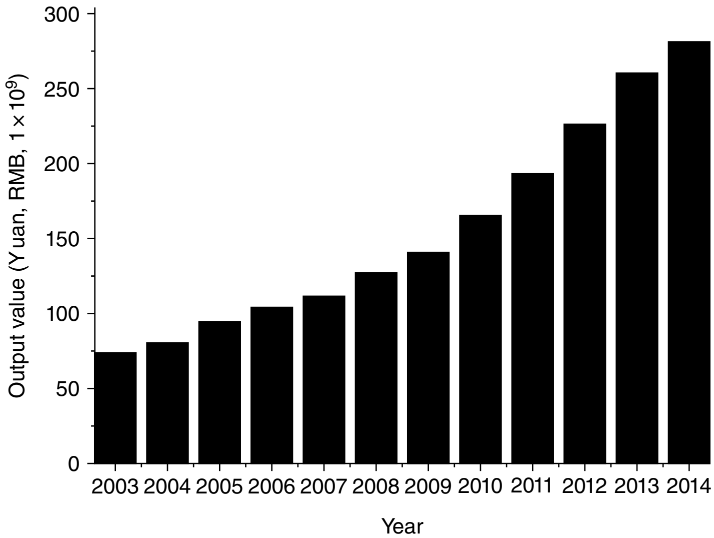


Figure 1.3.3 Annual output value of mariculture in China (2003–2014).

1.3.2.2 Species Cultured

The principal mariculture groups include shellfish, seaweed, crustaceans, finfish, echinoderms and others (Figure 1.3.4). Shellfish were the biggest contributor to the total mariculture production. Based on 2014 data, the annual production of shellfish, seaweed (dry weight) and crustaceans reached 13.17×10^6, 2.004×10^6 and 1.430×10^6 tonnes, respectively and accounted for 72.63 percent, 11.06 percent and 7.91 percent of the total output. While finfish production reached 1.189×10^6 tonnes, and accounted for 6.56 percent of total output.

Of the shellfish species of which annual production exceeded 50.0×10^3 tonnes, oyster and clam were the biggest contributors to the total, followed by scallop (*Chlamys* spp.), mussel (*Mytilus* spp.), razor clam (*Ensis* spp.), blood clam (*Anadara granosa*), conch (*Strombus* spp.) and abalone. Production of these reached 4.352×10^6, 3.966×10^6, 1.649×10^6, 805.0×10^3, 786.0×10^3, 353.0×10^3, 232.0×10^3 and 115.0×10^3 tonnes, respectively in 2014 (Figure 1.3.5).

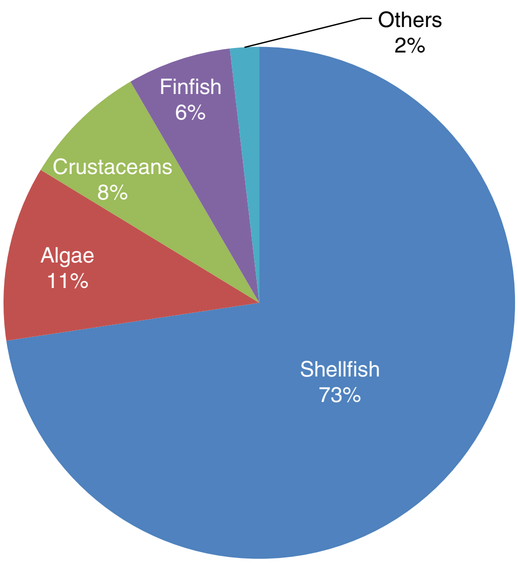
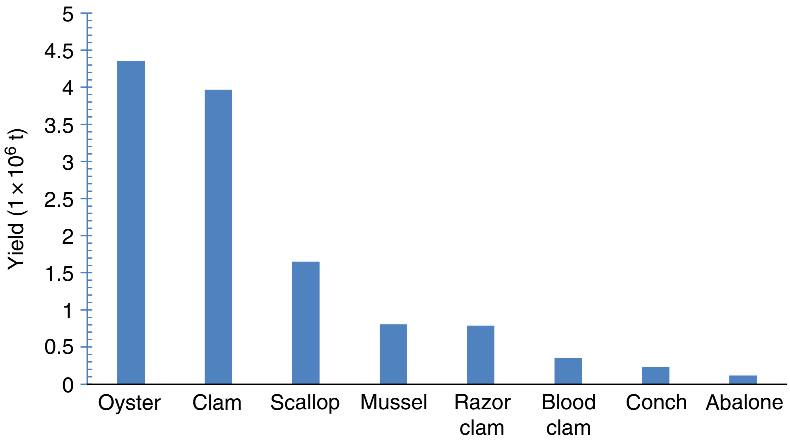


Figure 1.3.4 The proportional output (%) of the major mariculture categories in China (based on data from China Fishery Statistical Yearbook 2001–2015).

Figure 1.3.5 Output of major maricultured shellfish species in 2014.



Shellfish cultivation is one of the most important forms of mariculture in China. Shellfish are filter feeders obtaining all their nutrition from phytoplankton, microphytobenthos and different types of organic detritus. Shellfish culture is extensive and requires no external feed input. Nevertheless, the rapid growth of the industry has inevitably raised questions about carrying capacity and sustainability. Sun *et al.* (1998) reported that intensive raft culture of scallop and kelp reduced current velocity by 50 percent in farmed waters, and that the water exchange rate in these areas decreased 1.7 percent in comparison with ten years ago (early 1980s). Cultivation of scallop, oyster and other shellfish has developed so rapidly in recent years that many areas in coastal waters are densely populated with farming rafts (Figure 1.3.6). Large-scale shellfish farming can increase dissolved inorganic nutrient concentrations by increasing remineralization of particulate organic matter. The overloading of nutrients can result in negative environmental impacts such as eutrophication, oxygen depletion, biodiversity modification, and pollution of the surrounding waters (Fang *et al.* 2001; Troell *et al.* 2003).

In algal farming, kelp *Laminaria japonica* was the predominant contributor followed by *Gracilaria*, *Undaria* and laver *Porphyra* (*Pyropia*). Annual production of these commodities (by dry weight) reached 1.361×10^6, 262.0×10^3, 203.0×10^3 and 114.0×10^3 tonnes, respectively, in 2014 (Figure 1.3.7).

Seaweeds play an important role in cleaning the surrounding environment by absorbing nutrients. *Laminaria, Undaria, Porphyra* (*Pyropia*) and *Gracilaria* have been the most important species traditionally cultivated along the Chinese coast (Tseng and Fei 1987; Yang and Fei 2003). During 1950s–70s, the main mariculture algae in China were *Laminaria* and *Porphyra* (*Pyropia*). Now the trend is for farms to engage mostly in raising fish, shrimp, crab and shellfish. These multi-species culture systems provide better economic dividends to farmers. However, the ecological function of seaweed cultivation and that of economically valuable animals are quite different. Cultivated seaweeds have very high rates of productivity and grow well in water bodies with higher nitrogen and other nutrients. Seaweeds are able to absorb nitrogen, phosphorus and carbon dioxide, produce oxygen, and consequently reduce eutrophication. For example, the large-scale cultivation of kelp *L. japonica* has reduced the negative impacts of scallop cultivation in coastal waters in northern China (Fei *et al.* 1999). Another interesting example is Xiangshan Bay in Zhejiang Province. This was a fertile bay because of high-density *Laminaria* farming in 1970s, but it became seriously polluted, with numerous occurrences of red tides, after farmers switched to high-density cage culture of fish and overcrowded shellfish rafts. In 2001, mariculture production of fish, shellfish+ shrimp+crab, and seaweeds reached 9.109×10^3, 49.09×10^3 and 2.330×10^3 tonnes, respectively, in the bay. The percentage of seaweeds was only 3.9 percent of the total production (Zhang *et al.* 2003).

The productivity of cultivated seaweeds is usually much higher than that of seaweed in its natural habitats. Cultivated seaweeds are able to accumulate considerable biomass over a period of months depending on the season. When seaweeds are harvested, nutrients are removed from the water. Methods for treating effluent

Figure 1.3.6 Floating rafts used for scallop (top) and kelp (*Laminaria japonica*) farming (bottom).

from eutrophic waters with macroalgae were initiated in the mid-1970s. There has recently been renewed interest in this approach, verifying that wastewater from intensive and semi-intensive mariculture is suitable as a nutrient source for seaweed production, and that integration with seaweeds significantly reduces the loading of dissolved nutrients to the environment (Fei *et al.* 1999; Troell *et al.* 1999; Chung *et al.* 2002).

Experimental (fish and seaweed) culture systems results demonstrated that *Gracilaria lemaneaformis* can effectively remove inorganic nutrients from waters. The concentrations of NH_4-N decreased 85.53 percent and 69.45 percent and the concentrations of PO_4-P decreased 65.97 percent and 26.74 percent after *Gracilaria* was cultivated for 23 days and 40 days, respectively.

In crustacean culture, white shrimp (*Litopenaeus vannamei*) is the biggest contributor to the total production, followed by mud crab (*Scylla* spp.), swimming crab (*Portunus* spp.) and tiger shrimp (*Penaeus monodon*). The productions of these commodities in 2014 were 875.0×10^3, 140.0×10^3, 118.0×10^3 and 74.00×10^3 tonnes,

Figure 1.3.7 Production of cultured major algal species in China in 2014.

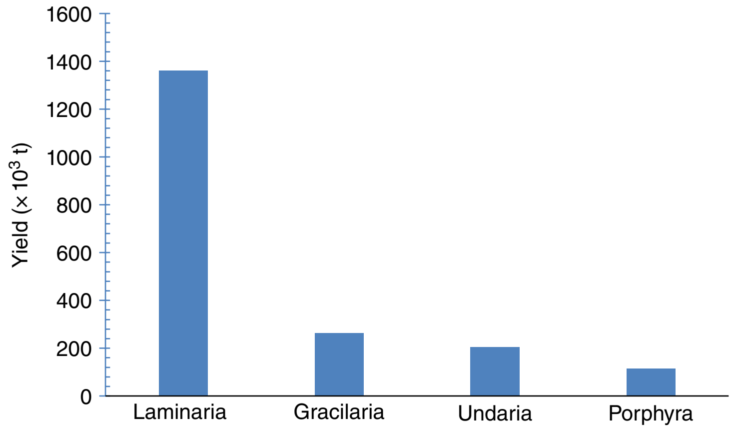
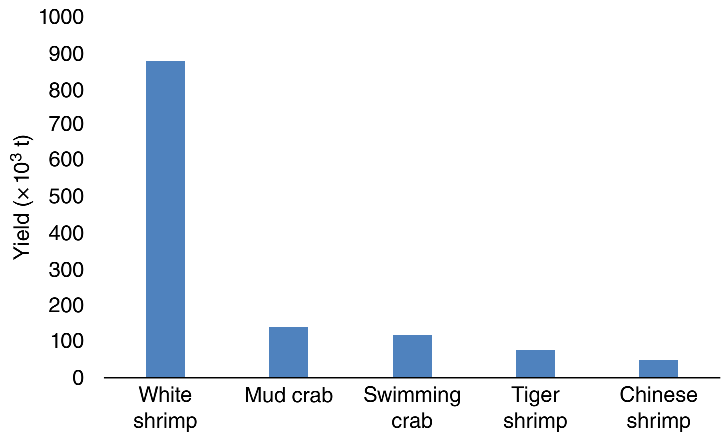


Figure 1.3.8 Production of key maricultured crustacean species in 2014.



respectively (Figure 1.3.8). While the output of Chinese shrimp (*Fenneropenaeus chinensis*), which used to be the most important farmed shrimp species in China in 1980s, was only 48.2×10^3 tonnes.

Several dozens of species of marine finfish are cultured in China. Of these, large yellow croaker (*Larimichthys* = (*Pseudosciaena*) *crocea*), flatfish (members of the family Pleuronectidae) and sea bass (*Lates calcarifer*) were the biggest contributors to the total production, followed by grouper species (members of the family Epinephalidae), red drum (*Sciaenops ocellatus*) and sea breams (*Pagrosomus major, Sparus microcephalus, S. latus, S. aurata, S.berda, Rhabdosargus sarba*). Their annual production reached 127.0×10^3, 126.0×10^3, 113.0×10^3, 88.0×10^3, 69.0×10^3 and 59.0×10^3 tonnes, respectively, in 2014 (Figure 1.3.9).

1.3.2.3 Feeds and Feeding

Pellet feeds are commonly used in marine fish farming in China, while low-valued fish (also referred to as trash fish in the past) considered to be unfit for human consumption are also used as feed in some fish farms. Studies showed that in some marine fish culture practices, higher organic and nutrient loadings are mainly generated from uneaten feed and excreta. Investigations have shown that uneaten feed and excreta were one of the most important controllable sources contributing to organic and nutrient loadings in coastal waters, and are at a higher level in cage culture systems where low-valued fish are used as feed (Wu 1995).

Fish by-catch generally consisting of low-valued small fish of 10–15 cm in body length are used as feed, and are purchased from local markets near the fish farming sites. These low-valued fish are cut into 2–3 cm pieces

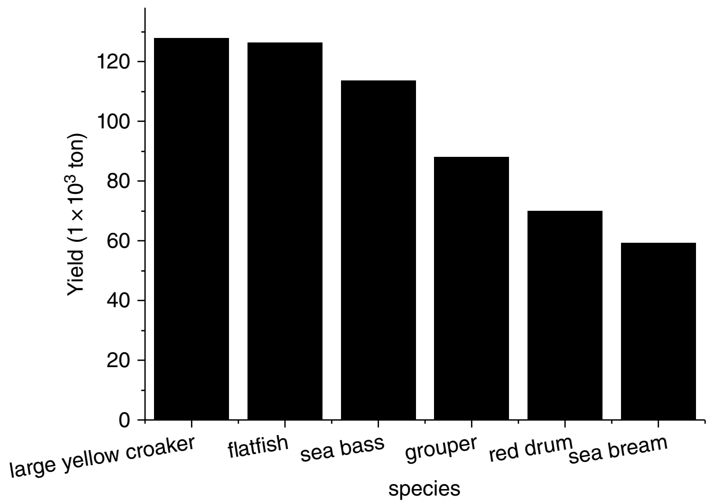


Figure 1.3.9 Production of major maricultured finfish species in 2014.

and fed to farmed fish. In general, per day, fish farmers feed 2–3 times at a rate of 2–3 kg fish fed per fish cage (3 × 3 m). Qian *et al.* (2001) found that use of minced fish resulted in higher pollution levels than that by feeding whole fish and mollusks. In general, 85 percent of phosphorus (P), 80–88 percent of carbon (C) and 52–95 percent of nitrogen (N) input into a marine fish culture system as feed may be lost into the environment through uneaten feed, excreta and respiration. High pollution loadings, 23 percent of C, 21 percent of N and 53 percent of P of feed input into a culture system are reported to be accumulated in bottom sediments. The major impact is on the sea bottom where higher sediment oxygen demand, anoxic sediments, production of toxic gases and a decrease in benthic diversity have been observed (Wu 1995).

1.3.2.4 Selective Breeding and New Varieties

In addition to progress in farming technology and feeds and nutrition, the cultivation of selected and/or genetically improved new varieties of aquatic organism play an important role in the development of mariculture in China (Wang 2013).

Chinese shrimp *Pennaeus* (*Fenneropenaeus*) *chinensis* provides a good example in this regard. In 2003, a new variety of Chinese shrimp, Huanghai No. 1 was accredited by the National Certification Committee for Aquatic Varieties (registration no. GS01-001-2003) after seven generations of selective breeding. The average body length increased by 8.40 percent, while body weight increased 26.86 percent compared to the control population. In addition, since 1998 much effort has been devoted to selecting WSSV (White Spot Syndrome virus) resistant lines of *F. chinensis*. In 2008, after 11 generations of selective breeding, Huanghai No.2, with a faster growth rate, higher pond survival rate and stronger disease resistance were certified. The harvest body weight increased by over 20 percent, WSSV resistance increased by 15.80 percent, and demonstrated a lower morbidity or slower death after infection with disease. In 2013, the Huanghai No. 3 shrimp variety was obtained after five generations of selective breeding. Farm trials showed that compared to the control, the resistance of juvenile shrimp of the new variety to ammoniacal nitrogen increased by 21.20 percent, the survival rate increased by 15.20 percent and average weight rose by 11.80 percent. Huanghai series new varieties of *F. chinensis* have been recommended by the Ministry of Agriculture of China as the main shrimp new varieties, and their culture has been promoted in Shandong, Hebei, Tianjin, Liaoning, and other coastal areas of northern China. In recent years, the annual farming area of these new varieties has exceeded 20.0×10^3 ha, and has been well received by shrimp farmers.

Up to the present, a total of 168 new varieties of aquatic organism have been authorized under the National Certification Committee for Aquatic Varieties, and popularized for aquaculture in appropriate waters in

China, of which about 70 are new varieties of marine organisms. Among these mariculture varieties, 45 were developed through selective breeding, 17 were hybrids, and the remaining 8 were introduced from other sources. These new varieties have been playing a significant role in promoting mariculture development in China.

1.3.3 Mariculture Modes and Technologies

Mariculture modes in China are currently classified into seven types based on the type of practice. They include pond farming, traditional net-cage farming, deepwater net-cage farming, long-line raft farming, lantern-net raft farming, sea-bottom ranching and land-based industrialized (indoor-tank) farming (China Fishery Statistical Yearbook 2001–2015). The output and farming area for each farming mode in 2014 are presented in Figure 1.3.10. Since production from deepwater net-cage farming is relatively small, the yields and farming areas for traditional and deepwater net-cage farming are added together in the figure.

1.3.3.1 Pond Farming

Pond mariculture is widely practiced in China. During the early stage of its development, parts of bays or inshore waters were enclosed to farm fish or other aquatic species. Large-scale pond farming commenced in the 1980s, with the surge in shrimp farming development in coastal areas of China. Pond farming techniques have been progressing over the past several decades from extensive, semi-intensive to intensive. Monoculture was the dominant method of pond farming, while polyculture became popular especially in the coastal areas of northern China. More ecological techniques are applied in pond culture, including Integrated Multi-Trophic Aquaculture (IMTA), probiotic usage and biosecurity techniques. In recent years, a new trend of Recirculating Aquaculture Systems (RAS) in ponds is becoming popular in order to reduce waste discharge and save water, and, importantly, to reduce the risk of disease outbreaks.

Total production of pond mariculture in China reached 2.295×10^6 tonnes in 2014, and the total area under pond mariculture was 456.9×10^3 ha. Guangdong and Shandong Provinces are the leading producers of pond culture in China, with records of 559.0×10^3 tonnes and 327.0×10^3 tonnes, respectively, in 2014.

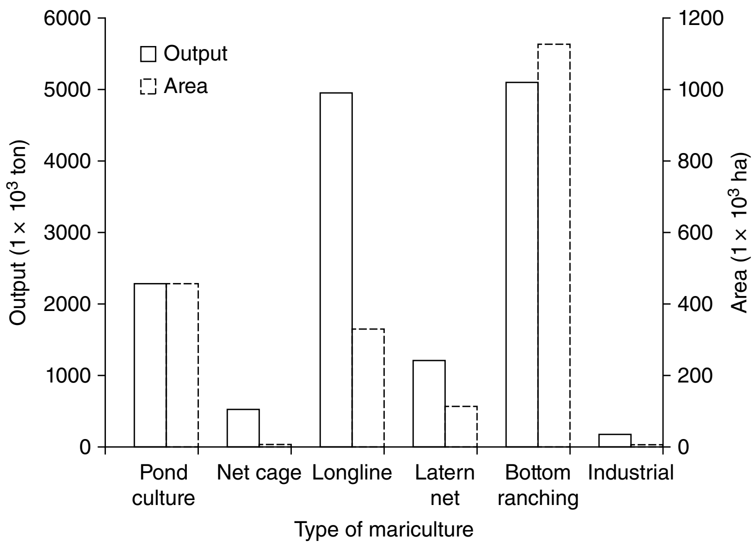


Figure 1.3.10 Outputs and farming areas of different types of mariculture in 2014. *Source:* Data from China Fishery Statistical Yearbook 2001–2015.

1.3.3.2 Net Cage Mariculture

The total harvest from net cage mariculture in China was 526.0×10^3 tonnes in 2014, with the total area of inshore traditional net cages amounting to 53.97×10^6 m^2, and the total volume of deepwater net cages of 6.055×10^6 m^3. Traditional inshore net cages are small (3 × 3 m or 5 × 5 m) and vulnerable to high waves and extreme weather conditions. As a result, these cages are usually positioned in sheltered bays and inshore areas. Thus, traditional net-cage culture often has a negative impact on the surrounding marine ecosystem, due to water pollution and habitat encroachment as the cages tended to be arranged in high densities. Fujian province is well known for its traditional net-cage culture owing to its numerous bays and gulfs protected by thousands of islands.

Deepwater net-cage farming has been developing in China since 1998 when it was first introduced from Norway. However, currently the total output from the deepwater cages is still limited (88.74×10^3 tonnes in 2014) compared to other types of mariculture. Hainan and Shandong are the provinces with the highest number of deepwater net cages. Research and technical innovation for designing and producing deepwater net cages in China is still on going, and progress is anticipated when more efforts are made to promote mariculture in offshore waters.

1.3.3.3 Raft Culture

Raft farming technology was applied for kelp *L. japonica* culture in the 1950s in China. This farming mode (see Figure 1.3.6) has been evolving since then, and has gradually developed into different forms and has benn applied to farming different species, such as long-line culture of seaweeds, lantern-net culture of scallops, and hanging culture of oysters. In inshore waters of Shandong Province, most rafts were set up within less than 20 m water depth. In recent years, however, in order to move to offshore waters to alleviate the impact of mariculture activities on the inshore environment, more rafts are installed at depths of –30 m or even deeper. The total production from raft culture was 6.170×10^6 tonnes in 2014 in China, ranking highest among all mariculture types; the total area of raft culture reached 445.0×10^3 ha. Shandong Province is the leading producer of raft culture in China. Since the main species for raft culture are seaweeds and mollusks, the Integrated Multi-Trophic Aquaculture (IMTA) approach is widely practiced in China's inshore raft culture waters.

A schematic representation of a raft applied in mariculture is shown in Figure 1.3.11. With the development of farming technology and adoption of raft mode in different waters and for different species, raft structure has been undergoing modifications based on local conditions and requirements of specific species.

1.3.3.4 Integrated Multi-Trophic Aquaculture (Imta)

The principle of IMTA was presented only about ten years ago. However, the practice of this principle in aquaculture can be traced back several hundred years in China. In mariculture practices in Shandong Peninsula this principle has been applied since the 1990s as polyculture or the integrated culture of different species with differing ecological/trophic status (Figures 1.3.12 and 1.3.13). The following is a brief introduction of IMTA of abalone-sea cucumber-kelp raft integrated farming.

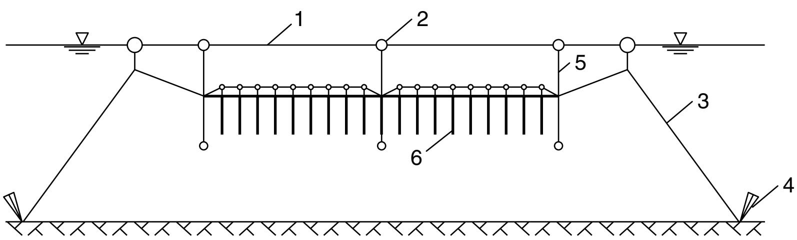


Figure 1.3.11 Schematic diagram of a mariculture raft. Note: 1. floating raft rope; 2. float/buoy at sea level; 3. anchor rope; 4. anchor/stake; 5. hanging rope; 6. cultured kelp in long-line/scallop in lantern net.

Figure 1.3.12 Integrated Multi-Trophic Aquaculture (IMTA) practiced in Sungo Bay, China.

Figure 1.3.13 Farmers working on IMTA system.

Kelp, *L. japonica* and abalone are important species in inshore raft farming in China. Bioaccumulation of abalone and seaweed fragments on the sea bottom were one of the main sources of pollutants in culture areas. Sea cucumber is one of the rare economic marine animal species that scavenge. In the integrated farming of abalone–sea cucumber–kelp, depending on the relationship between food and wastes, the cultured seaweed can be a high-quality food for abalone, while the feed waste, feces and other particulate organic matter produced by the abalone settle on the sea bottom and become a food source for the sea cucumber. Abalone and

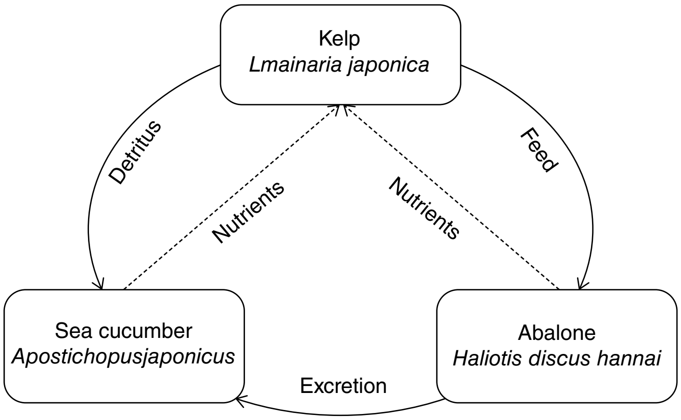


Figure 1.3.14 A simplified schematic diagram showing relationship in abalone–sea cucumber–kelp integrated farming system.

sea cucumber respiration and excretory products, i.e. inorganic nitrogen and phosphorus and CO_2, can be readily utilized by macroalgae for photosynthesis (Figure 1.3.14).

It has been suggested that the IMTA technology which includes the production of seaweed (kelp), mollusks (abalone), bivalves (bay scallop [*Argopecten arradians*]), and echinoderms (sea cucumber) should be used to help close the food fish protein gap, while capture fisheries recover to sustainable levels (Sherman and McGovern 2012). Preliminary results suggest that the IMTA pilots should be extended throughout the Yellow Sea Large Marine Ecosystem (YSLME), and into other Asian large marine ecosystems, where application could provide job opportunities and food security. Pilot IMTA projects have proven to be highly energy efficient, and optimized the carrying capacity of coastal embankments while improving water quality, increasing protein yields, and, through carbon capture, contributing to mitigation the effects of climate change (Sherman and McGovern 2012).

1.3.3.5 Sea Bottom Ranching

Generally, this form of mariculture refers to intertidal zone bottom, inshore bottom and deep water bottom culture. Main species for bottom culture are bivalves, abalone and sea cucumber etc. Shandong and Liaoning in northern China are the leading provinces in sea bottom ranching. The total harvest of aquatic products from sea bottom ranching was 5.100×10^6 tonnes in 2014, and the area utilized for sea bottom ranching was 1.130×10^6 ha. Sea bottom ranching is relatively easy to implement, is a labor-intensive practice, and relies highly on a favorable natural environment. In the last two decades, Zhangzidao Fishery Group Co., Ltd (now Zoneco Group), located in the Northern Yellow Sea, has been focusing on stock enhancement and sea ranching in waters around its islands with a sea area of around 2000 km^2. Natural conditions in the Zhangzidao area are characterized by less influence from the mainland, unobstructed currents, optimal water temperature, stable salinity, muddy and sandy bottom, and relatively high primary productivity, conditions that are ideal for stock enhancement and sea ranching. Artificially propagated seed stocks of scallop *P. yessoensis*, sea cucumber *A. japonicus,* abalone *H. discus hannai*, ark shell *Sapharca broughtonii* and other native species were released into waters annually for stock enhancement and sea ranching.

Another example is from Shandong peninsula. Chudao Island located at the south point of Sungo Bay, where integrated farming is practiced in eelgrass (*Zostera* spp.) beds. Within this farming practice, the seagrass ecosystem, consisting of members of the genera *Phyllospadix* and *Zostera*, provides food for sea urchins (*Paracentrotus* spp.) and abalone, and habitats for other benthic organisms or swimming creatures. Mollusk feces and naturally occurring organic deposits may provide feed for abalone and sea cucumber, while the ammoniacal nitrogen these animals produce can be absorbed by eelgrass and phytoplankton, and phytoplankton may provide food for mollusks. Another important point is that seagrass and phytoplankton may

Table 1.3.1 Annual economic return from eelgrass beds in Chu Island, Shandong Province (2013).

Species ranched	Seeds/spats ranched annually (no. of ind.)	Annual yield (kg)	Economic value (RMB/kg)	Total economic return (RMB)
Sea Cucumber *Holothuria* spp.	500 000	20 000	160	3 200 000
Abalone *H. discus hannai*	50 000	1500	400	600 000
Sea urchin *S. nudus*	Natural spat	2500	56	140 000
Clam *R. philippinarum*	Natural spat	200 000	7	1400 000
Sea conch *R. venosa*	Natural spat	20 000	10	200 000
Seaweed *Gracilaria spp*	Natural seedling	80 000	6	480 000
Pacific oyster *C. gigas*	Natural spat	300 000	0.5	150 000
Clam *S. purpuratus*	Natural spat	80 000	6	480 000
Total		704 000		6 650 000

provide dissolved oxygen for the system. In recent years, through implementation of seagrass seedling transplanting and integrated farming, eelgrass resources in the area are expanding, the harvest of economically valuable species such as clam, conch, sea urchin, sea cucumber, abalone, and other products from the waters are also increasing. The average annual economic return from the Chudao marine ranch in recent years is around 7 million RMB (Table 1.3.1), and even higher output from these waters by the local farming communities is expected.

1.3.3.6 Land-Based (Indoor Tank) Industrial Mariculture

Land-based industrial mariculture usually refers to indoor-tank farming including flow-through and recirculating aquaculture systems (RAS). The total production of land-based industrial mariculture in China was 1.70×10^6 tonnes in 2014, and the total farming water volume was 25.64×10^6 m^3. Shandong and Fujian provinces rank high above others in industrialized mariculture production. The main species involved in this type of culture include flatfish, shrimp, and abalone. Although flow-through systems are usually applied in industrial indoor-tank farming in China, recirculating systems are becoming popular especially in Shandong, Tianjin, and Liaoning provinces in northern China. In winter time, recirculation of water through treatment systems may efficiently increase the re-use of heat, and reduce the cost of operations. Industrial mariculture makes efficient use of water resources, effectively controls wastewater and solids discharge, increases output of unit farming area per hectare, and reduces land costs, and also labor costs because these systems are not labor intensive.

1.3.3.7 Challenges and Way Forward

Mariculture-related environmental problems, such as water pollution and eutrophication, are prevalent in some mariculture areas in China, while disease problems and concerns about the food safety/quality of aquatic products occur in over-intensive practices. In Sungo Bay, located on the east coast of Shandong peninsular, the growth rate of the scallop *Chlamys farreri* had decreased from that a decade ago. Related investigations indicate that the current scale of farming has exceeded the carrying capacity of the bay (Sun *et al.* 1998; Fang *et al.* 2001). In the Xiamen sea area of Fujian Province, the culture area of Japanese seabass (*Lateolabrax japonicas*) and Hooded oyster (*Saccostrea cucullata*) has a high density of *Enterobacter* (Ke *et al.* 2002). In Zhelin Bay, in Guangdong province, the culture of *Sparus macrocepalus*, *Pagrosomus major*, *Plectorhynchus cinctus* and *Mugil cephalus* were associated with lower DO (dissolved oxygen), higher COD (chemical oxygen demand), higher concentrations of PO_4-P and NO_2-N, and higher concentrations of sulphide and PO_4-P in sediments.

In recent years, the public has become increasingly aware of the dynamic nature of mariculture ecosystems. The systems include not only the cultured species and their environment, but also people and their associated social and economic institutions and communities. Some reports have emphasized the challenges to biological, economic, and social sustainability of mariculture systems: complexity, variability, measurement errors and so on. These characteristics lead to uncertainties, which in turn create risks – biological risks for aquatic ecosystems, economic risks for industry, and social risks for coastal communities (Campbell 1994; Caddy, 1999; Peterman *et al.* 1999; Liu and Liu 2001).

Mariculture can be a sustainable development provided that the pollution loadings generated by fish and other cultured animals are kept well below the carrying capacity of the water body. Negative impacts of mariculture can be significantly reduced by careful site selection, maintaining long-term health of coastal environments, control of stocked species and densities, improved feed formulation and integrated culture with macroalgae, filter-feeders and deposit-feeders (Wu 1995; McVey *et al.* 2002).

1.3.4 Coastal Environment Management

The coastal environment is an important resource. Pollution created by human activities on land should be controlled, thereby decreasing impacts from terrestrial origin. For near-shore resources, governments and related stakeholders should incorporate ecosystem considerations, including environmental fluctuations and socioeconomic factors. Coastal communities should use resources in sustainable ways. High priority should be given to the management of marine resources, including rebuilding depleted resources, restoring habitats, and maintaining genetic and ecological diversity (Caddy 1999). While environmental impact assessment (EIA) tends to be a standard requirement for major developmental projects, so far the application of EIA to aquaculture licensing in China is less common. Indeed, EIA helps to prevent conflict between coastal users, protects sensitive habitats, and is important for the sustainable development of the mariculture industry. Since nitrogen and organic wastes are major concerns, the susceptibility of sites to changes in DO and nitrogen pollution should be given special attention in any EIA of mariculture zones (Wu 1995).

1.3.4.1 Controlling Species and Stocking Densities (Degree of Intensity)

Many studies have demonstrated that environmental impacts of mariculture vary considerably between sites and are highly dependent upon water circulation, species, stocking density, farming practices and feed types (Wu *et al.* 1994, Fei *et al.* 1999; McVey *et al.* 2002). At one site in Hong Kong with good flushing and low stocking density, benthos (even corals) could be found underneath fish cages (Wu 1995). These results clearly indicate that mariculture can be a sustainable industry provided that stocking species and density do not exceed the carrying capacity of the waters.

1.3.4.2 Promotion of Integrated Mariculture

Ongoing attempts to optimize traditional integrated mariculture and adopt environmentally friendly practices have also helped to sustain and increase farmed production. Some cultivated seaweeds have high productivity and can absorb N, P and CO_2, produce O_2, and have excellent effects on decreasing eutrophication. *G. lemaneiformis* and *P. haitanensis* are two important commercial seaweeds cultured in inshore waters of south-eastern China. The yields may reach 40–80 t/ha/yr and 30–60 t/ha/yr, respectively. Investigation showed that the yield of *G. lemaneaformis* reached 50 t/ha/yr in the Nanao Sea area of Guangdong Province in 2002. Fifty tonnes of seaweed can fix 1250 kg C and 125 kg N, indicating that seaweeds effectively absorb nutrients from the surrounding waters. In addition, seaweeds can be widely used for human consumption, fodder, a raw material for chemical products, and as an organic fertilizer. Large-scale seaweed cultivation will benefit both the environment and local economies. It could be a powerful method for removing large amounts of nutrients and for bioremediation in marine animal farming areas (Fei *et al.* 1999).

Seaweeds can absorb N and P, just as filter feeders (e.g. bivalves) can remove particulate organic matter and phytoplankton from the surrounding water. Clearing of nutrients generated by marine fish farming by seaweeds and filter feeders would be an attractive option, since this would alleviate nutrient overloading on the one hand, and increase productivity on the other (Wu 1995; Yang and Fei 2003). Culturing shellfish to remove N and plankton derived from fish farms appears to be a viable and a practical option, and should be adopted in net-cage culture systems. However, caution must be exercised to avoid bacterial contamination of shellfish from fish farms (Wu 1995).

Filter feeders can remove and benefit from nutrients in fish farms in two important ways. First, they consume organic particulates, and prevent further release of nutrients from bacterial degradation of organic matter. Second, they also feed on bacteria and phytoplankton that use inorganic nutrients for growth. Cultivating filter-feeding bivalves, such as scallops and mussels, therefore, is recommended for integrated culture systems because they consume organic particulates originating from fish feed and cultured species' excretion, and directly lower the extent of organic pollution. Moreover, they remove dissolved inorganic pollutants through consumption of phytoplankton, and thus reduce the fouling rates in fish cages and nets (Qian *et al.* 2001).

Traditional polyculture may include combinations of shellfish, finfish and macroalgae, which are considered more sustainable than monoculture due to the reutilization of waste products of one species by the other. Sustainable development will need to recognize the diversity of mariculture practices, as well as the social, economic and environmental conditions in which they take place (Chopin and Yarish 1999; McVey *et al.* 2002).

1.3.5 Mariculture Management

The enforcement of management measures to mitigate deterioration of the quality of coastal waters, and diminish the environmental impacts of mariculture development have now become urgent in mariculture zone management in China. Mariculture is a land/water-use activity, just as in agriculture or forestry. Though it may seem strange to talk about the production of aquatic products as being a land/water-use like the production of sheep or trees, the coastal waters in which marine organisms live are intimately affected by the nature of the adjacent land and events that happen on that land (Campbell 1994).

The production of high-quality aquatic products requires good water quality. Fish-cage farming has been regarded as a source of organic pollution. Therefore, integrated management is necessary. Development of integrated mariculture (e.g. fish + seaweeds) may help the mariculture industry avoid noncompliance, and gain both direct and indirect benefits from improving water quality and coastal ecosystem health (Troell *et al.* 2003).

The human component is an often neglected aspect of mariculture management. The elements of farmed species are relatively easy to handle. However, the needs and demands of the farming communities are considerably less predictable and meeting their needs is not easy to handle. The latter is particularly so in respect of quality of mariculture operations, and the environmental impacts of the practices and the willingness to incur any costs to improve the latter aspects.

Primary objectives for mariculture management in relation to eutrophication in coastal waters are to reduce growth of microalgae, increase water clarity, and re-establish biodiversity richness. The key to improving and maintaining the long-term health of mariculture ecosystems lies in instituting management practices over the whole watershed. A control plus management strategy should be implemented as a whole in mariculture zones, and some measures are suggested to achieve such objectives:

a) Control stocking density and number of labor involved in both fisheries and mariculture, and restrict the total number of fish net-cages in all fish-culture zones, based on the carrying capacity of the waters.

b) Periodic shifting of net-cages and/or a fallow period (suspending fish-culture activities) to be implemented to facilitate the recovery of water quality and the benthic communities.
c) Develop submersible net-cages to undertake fish-culture operations in deeper and well flushed waters. Support and encourage offshore mariculture.
d) Encourage and promote the use of formulated pellet feeds, and eliminate the use of low-valued fish as feed.
e) Increase seaweed cultivation to reduce eutrophication and remediate coastal waters, especially in waters of marine animal culture with high stocking rates.
f) Collect, analyze, and openly communicate data and information. Clearly define the roles, rights, and responsibilities of stakeholders to align their interests with the overall objectives of sustainability.

Successful management of the mariculture industry depends upon establishing partnerships and fostering interactions between experts from different but related disciplines and stakeholders. Mariculture definitely has the potential to develop sustainably provided the industry is properly managed.

1.3.6 Conclusions

Mariculture has been developing rapidly in China since the 1950s and is considered as an important strategy to meet the increasing demand for seafood internationally and domestically. Currently, seafood from mariculture are well received by consumers, and mariculture is playing a critical role in the economic development of coastal areas. It is estimated that more than 100 species of marine organism, including finfish, crustacean, shellfish, sea weeds, echinoderms, and other species of commercial significance, are exploited and cultured on a range of scales in China. Various farming modes have been developed, based on local socio-economic and environmental conditions, and technical progress is promoting the advance of mariculture nationwide.

It should be pointed out that in discussions about the development of mariculture, more attention has been paid to seafood production and its economic benefits, while its ecological impacts have usually been ignored. Recent studies show that through the mariculture of shellfish and seaweeds, with an annual production of >10 million tonnes in China, $3.79 \pm 0.37 \times 10^6$ t C yr^{-1} are being sequestered, and $1.20 \pm 0.11 \times 10^6$ t C yr^{-1} are being removed from the coastal ecosystem through harvesting. Cultivated shellfish and seaweed can indirectly and directly take up a significant volume of coastal ocean carbon – shellfish accomplish this by removal of phytoplankton and particulate organic matter through filter feeding, and seaweeds through photosynthesis. Thus, cultivation of seaweed and shellfish plays an important role in carbon fixation, and therefore contributes to improve the capacity of coastal ecosystems to absorb atmospheric CO_2 (Tang *et al.* 2011).

Mariculture undoubtedly has a promising future, even though some constraints and challenges need to be properly addressed. The authors of this volume believe that in coming years, more attention should be paid to reform the structure, improve the quality, and raise the efficiency of practices of the mariculture industry. Some suggestions are presented in this volume to promote and facilitate mariculture development, including new theories and ideas to be introduced and/or innovated on new farming techniques, and new types of farming. Breeding new varieties with faster growth rate, and better performance and disease resistance should be enhanced, and disease diagnosis, prevention and control techniques be strengthened and improved. Feed quality and feeding schemes should also be improved. What should be emphasized is that, the authors believe, mariculturists and related stakeholders must enhance their understanding on the interactions of mariculture activities with the ecosystem, and practice ecosystem-based approaches for mariculture so as to maximize profits while minimizing the impacts of farming activities on the ecosystems.

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1.4

Chinese Aquaculture: Its Contribution to Rural Development and the Economy

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1.4.1 Introduction

China is the most highly populated country in the world. Its current population is 1.3 billion and is predicted to rise to 1.6 billion by 2030. Due to rapid growth of its population, per capita agricultural land has steadily decreased from 0.19 ha in 1949 to 0.076 ha in 2005 (Liu 2008). The acknowledgement of depletion of wild fish stocks has focused Chinese fishery development policies on expanding inland, brackish and, in particular, marine aquaculture as a key strategy for meeting changing national demand and consumer patterns.

As was apparent from the previous chapters, China is the largest fish producer in the world, with a very long history of aquaculture. The earliest aquaculture practices started some 2500–3000 years ago (See Chapter 1.1). Chinese aquaculture production has accounted for about 70 percent of the world total due to fast and steady development in the past decades (Mai 2012). Since 1988, Chinese aquaculture has surpassed capture fisheries in output and become a dominant subsector in Chinese fisheries (Yang 2000).

Aquaculture has been providing a very important source of animal protein for Chinese people, estimated at 25 kg per capita of aquatic products, equivalent to 20 percent of the animal protein intake for the Chinese people (Miao 2010). Moreover, aquaculture plays a significant role in rural livelihoods and economic development. Compared with other agricultural subsectors aquaculture has been a dynamic food production subsector in China, particularly over the last three decades. It is characterized by diverse farming systems and practices, and by the wide range of organisms that are cultured. The sector has changed and restructured to adapt to changes in socioeconomic and environmental conditions in China during the last three decades. Some aquaculture systems and practices are effective in adapting to such changes, and still continue to play an important role in improving rural livelihoods and contribute to food security.

This Chapter aims to review and evaluate the successful development of Chinese aquaculture in the past decades and provides valuable experiences and lessons for comparable developments elsewhere.

1.4.2 Significance of Chinese Aquaculture Industry in 2014

For purposes of clarity in this Chapter the industry status in the year 2014 is taken as a base.

1.4.2.1 Outputs and Values

In 2014, the total output of fisheries in China was 64 615 200 tonnes, of which aquaculture accounted for 47 480 000 tonnes and capture fisheries 17 130 000 tonnes (Figure 1.4.1). The production ratio of aquaculture

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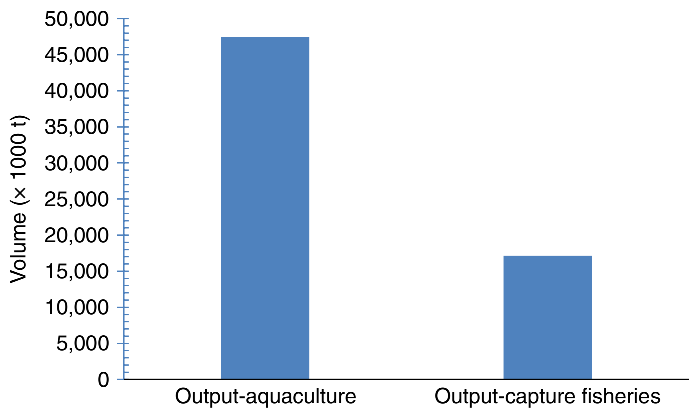

Figure 1.4.1 Production output of aquaculture and capture fisheries in 2014. *Source:* China Fishery Statistical Yearbook (2014).

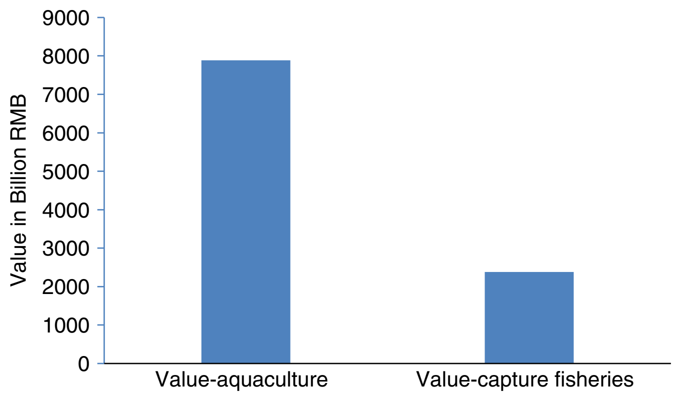

Figure 1.4.2 Value of aquaculture and capture fisheries in 2014. *Source:* China Fishery Statistical Yearbook (2014) (6 RMB= I US$).

to capture fisheries was 73:27. The total value of production was 1.086 trillion RMB (6 RMB = I US$), of which aquaculture accounted for 788.805 billion RMB, and capture fisheries 237.628 billion RMB (Figure 1.4.2), and fingerlings 59.687 million RMB. The value ratio of aquaculture to capture fisheries was 77:23 (China Fishery Statistical Yearbook 2014).

1.4.2.2 Types of Aquaculture

The total aquaculture area in China in 2014 was about 8 386 000 ha. Among these, the area under mariculture was about 2 305 000 ha, and the area under inland aquaculture was about 6 081 000 ha (Figure 1.4.3). The proportion of marine to inland water was 27 to 73.

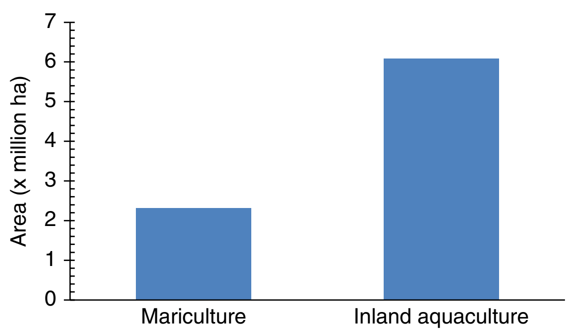

Figure 1.4.3 Inland and marine aquaculture areas in 2014. *Source:* China Fishery Statistical Yearbook (2014).

For inland aquaculture, the respective percentages of ponds, lakes, reservoirs, rivers, and other type of systems were 44 percent, 17 percent, 33 percent, 4 percent and 2 percent (Figure 1.4.4).

In mariculture (also see Chang and Chen, 2008) the percentage area devoted to the culture of finfish was 4 percent, crustaceans 13 percent, shellfish 66 percent, algae 13 percent and others 66 percent (Figure 1.4.5).

In terms of culture commodities, finfish were dominant in inland aquaculture, with a production of 26 030 000 tonnes in 2014, while mollusks are the major cultured organism in mariculture, with a production of 13 170 000 tonnes (Figure 1.4.6).

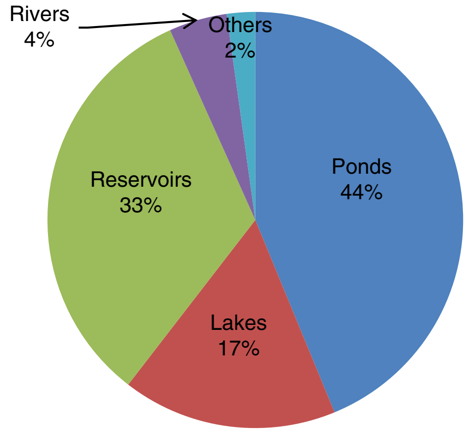

Figure 1.4.4 Share of inland aquaculture areas based on systems. *Source:* China Fishery Statistical Yearbook (2014).

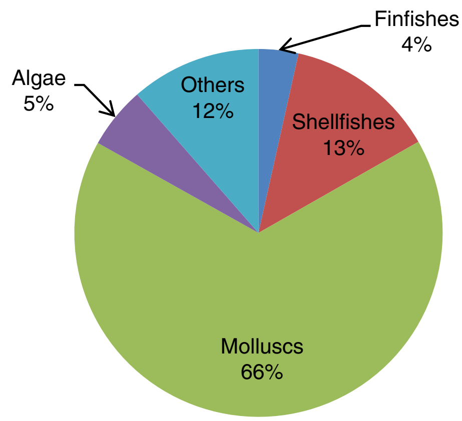

Figure 1.4.5 The proportionate share (%) of areas used in mariculture of different species groups. *Source:* China Fishery Statistical Yearbook (2014).

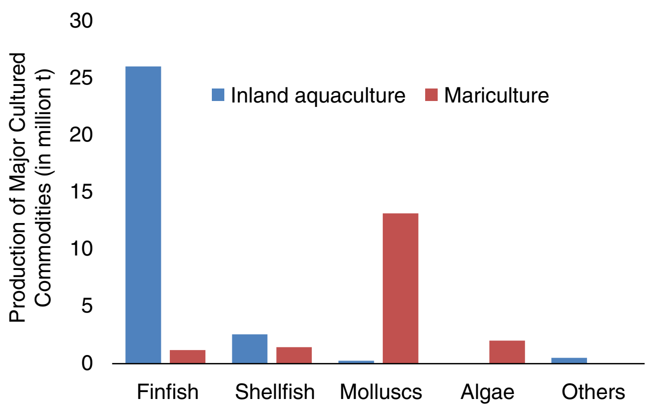

Figure 1.4.6 Production of the major species groups in inland and marine aquaculture in 2014. *Source:* China Fishery Statistical Yearbook (2014).

1.4.2.3 Net Income of Fishers

According to a survey of 10 000 fishery worker families, the per capita net income in 2014 was 14 426.26 RMB, an increase of 10.64 percent over the previous year.

1.4.2.4 Per Capita Availability of Aquatic Products

In 2014, per capita availability of aquatic products in China was 47.24 kg, an increase of 4.17 percent over the previous year.

1.4.2.5 Fishery Workers

In 2014, the total number of people working in the fishery sector in China was 20 350 400, a decrease of 0.56 percent over the previous year (National Bureau of Statistics of China 2014). Among them, traditional fishery workers were 6 864 000, a decrease of 3.66 percent from the previous year, and fishery workers were 14 290 200, a decrease of by 0.97 percent in comparison to the previous year. The proportion of full-time workers engaged in aquaculture was 66 percent, capture fisheries 23 percent and other activities 11 percent (Figure 1.4.7).

1.4.2.6 Aquatic Product Exports

1.4.2.6.1 Export Products

In 2014, 4 160 000 tonnes of aquatic products were exported, which was 5.16 percent higher than in the previous year. The products ranged from squid, shrimp, mollusks, tilapia (*Oreochromis* spp.), eel (*Anguilla* spp.), crabs, crawfish, large yellow croaker, etc., accounting for 34.66 percent of all exported aquatic products (Figure 1.4.8).

The export value reached US$ 21.698 billion, 7.08 percent higher than the previous year, and accounted for 30.15 percent of total agriculture exports (Figure 1.4.9).

1.4.2.6.2 Export Markets

Japan and the United States are listed at the top of China's fishery export markets, followed by Southeast Asia, Hong Kong China, the European Union, Korea and Taiwan China (Figures 1.4.10 and 1.4.11).

1.4.3 Experiences Gained from the Past Decades

The rapid development of the aquaculture industry in China has not only greatly increased the fish supply and improved the civilian dietary profile, but it has also led to the expansion and consolidation of related industry chains such as fish feed manufacture, fish processing, marketing, and import and export. The sector has

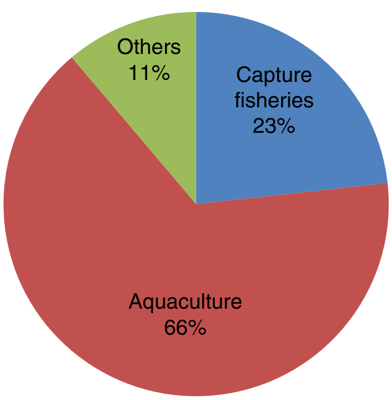

Figure 1.4.7 The percent distribution of full-time fishery workers in the different sectors. *Source:* China Fishery Statistical Yearbook (2014).

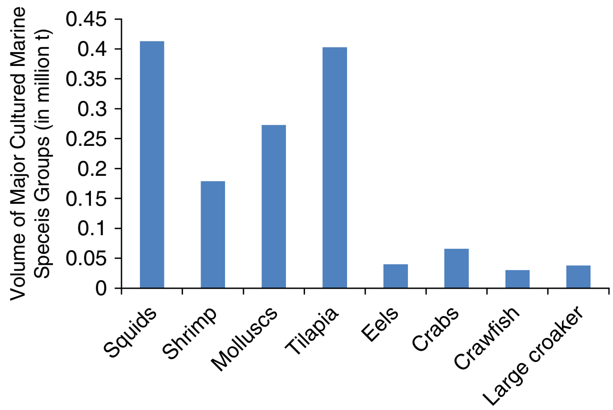

Figure 1.4.8 Major export fishery products by quantity. *Source:* Yearbook of China Fisheries Import and Export (2014).

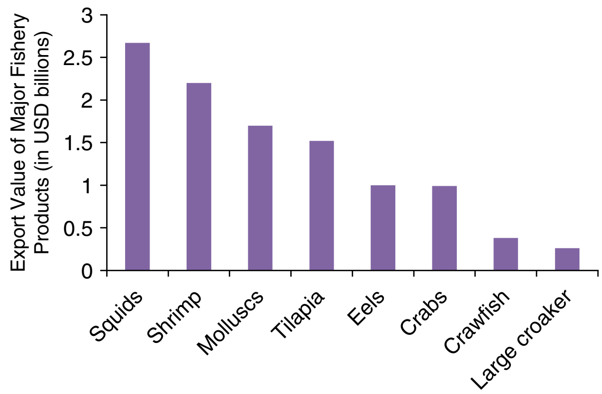

Figure 1.4.9 The value of major exported fishery products. (*Source:* Yearbook of China Fisheries Import and Export 2014).

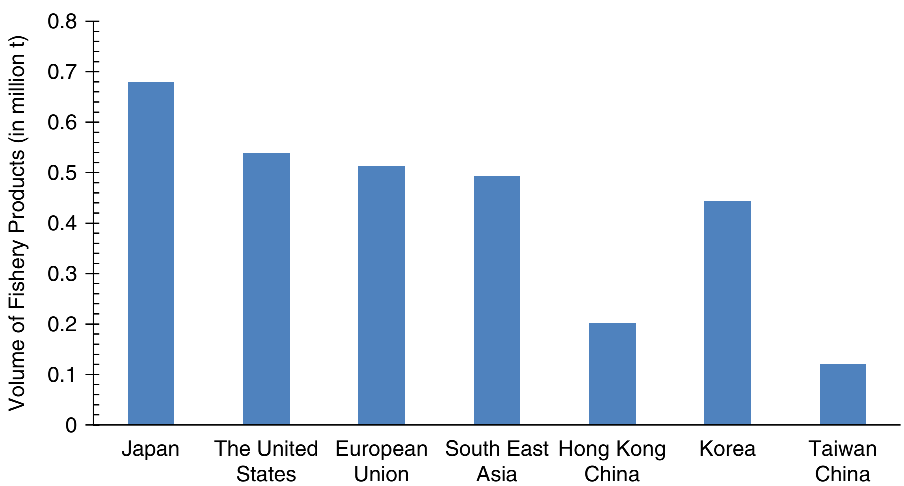

Figure 1.4.10 The main export markets, based on quantity, for fishery products of China. *Source:* Yearbook of China Fisheries Import and Export (2014).

grown from a rural sideline in the past into a significant industry at present, and has therefore contributed to adjustments in the structure of agriculture in China, the transfer of millions of surplus labor in the rural workforce, the enhancement of farmers' annual incomes, and the easing of pressures on wild fishery resources. Looking back at the development of Chinese aquaculture in the past decades the primary drivers for the success of the sector can be considered to be as follows.

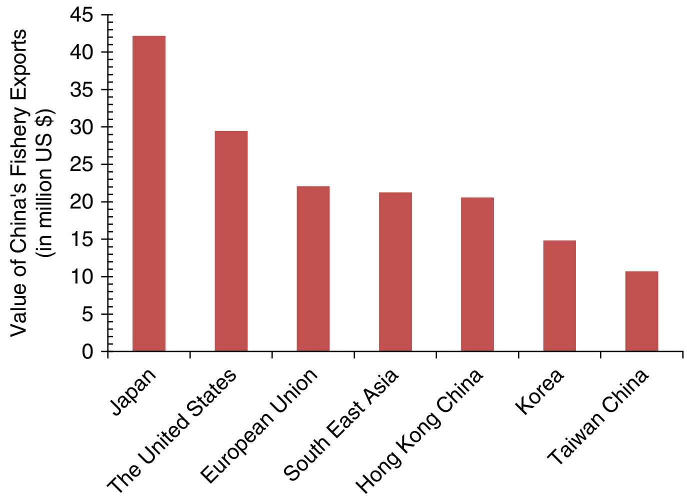

Figure 1.4.11 The main markets for export of fishery products based on value. *Source:* Yearbook of China Fisheries Import And Export (2014).

1.4.3.1 Government Policies

After the reforms and opening up of the economy during the early 1980s, the Chinese government introduced a series of policies to promote aquaculture development. The growth of Chinese aquaculture can be broadly divided into four phases: an initial phase, rapid growth phase, transition phase, and the current consolidation phase.

1.4.3.1.1 The Initial Phase (1978–1984)

Faced with an inadequate supply of fish over a long period, the government of China started to promote fishery development by implementing reforms in the way fish markets operate, and in price and supply, which used to be under tight government control. The government introduced a "double-track" price system, which is a combination of government control and prevailing market forces. Under this system, most aquatic products were allowed to be traded freely in the markets except those staple fish products in that time such as shrimp, hairtail fish (*Trichiurus lepturus*), etc. The previous collective production system of aquaculture management was gradually discontinued, and Household Responsibility System was introduced to encourage farmers to engage in aquaculture. These changes were enthusiastically adopted, and aquaculture became one of the most important sources of income for farmers in rural areas. In addition, to further stimulate the development of aquaculture, the government issued permits for the use of tidal flats. Since then, mariculture has become increasingly popular. In 1984, China's fishery output reached 7 080 000 tonnes, of which aquaculture production was 2 920 000 tonnes. As a result of these developments, the fish supply for urban and rural residents began to improve.

1.4.3.1.2 Rapid Growth Phase (1985–1994)

On the basis of the encouraging outcomes of the initial development stage, the government reinforced its fisheries policies, particularly as regards the Household Responsibility System and operating market forces impacting on fish prices. In 1986, the Fishery Act of the People's Republic of China was enacted. This Act clearly specified that the Chinese fishery sector should simultaneously develop aquaculture, capture fisheries and fish-processing industries, with an emphasis on aquaculture. These initiatives drove the sector into rapid growth, and brought considerable social and economic benefits. Within a decade, Chinese fishery output increased to 25 160 000 tonnes in 1994, from 8 020 000 tonnes in 1985, of which aquaculture accounted for 55 percent. The number of fishery workers increased from 5 950 000 to 10 840 000 and fishery workers per capita net income rose from 626 RMB to 2936 RMB – about 3.7 times that of the previous decade.

1.4.3.1.3 Transition Phase (1995–2001)

With its rapid development, the fisheries sector faced further challenges. The most significant of these being the decline in natural resources and problems of environmental pollution. In 1996, in order to resolve these issues the government put forward guidance on “two fundamental shifts”, that is a shift in the structure of economic development, and in the mode of economic growth. This guidance pointed out that in fisheries development attention should be paid not only to growth of production volume, but also equally to the protection of the environment and wild fishery resources. Since then, the government has emphasized the conservation of fishery resources. In order to rationalize use of limited fishery resources, the sector was authorized to control fishing in inshore and inland waters, and encouraged to explore fishery resources in distant waters. China developed international collaboration in fishery explorations with a number of countries, and expanded its fishing fleets to operate in international waters. In 1999, China implemented a zero growth plan in marine capture fishery, strictly limiting inshore fishing. On the other hand, the government advocated the development of aquaculture, particularly mariculture (Chang and Chen 2008). In 2001, China’s aquaculture production reached 37 960 000 tonnes, accounting for 62 percent of the country’s total fishery output. The export of aquatic products was valued at US$ 3.83 billion, ranking top amongst agricultural export commodities.

1.4.3.1.4 Consolidation Phase (2002 to Present)

After 2002, under the guidance of the Scientific Outlook on Development raised in the Sixteenth National Congress of the Communist Party of China, the nation entered a new period of economic development. In this period, China recognized that economic developments need to harmonize with resource utilization and environmental protection in order to achieve sustainable development. The central government has further strengthened political and economic support for agriculture development in rural areas, and for improving farmer livelihoods. The fishery sector benefited from this political environment. First, the sector received 14.235 billion RMB in financial support from the central government between 2002 and 2007 to help it overcome the difficulties of development transition. Second, the improvement of fishery worker livelihoods have been placed in the government agenda. Since 2002, most agriculture taxes in China, including aquaculture, have gradually been eliminated, thereby significantly easing the tax burden on farmers. In 2007, the new National Property Law stipulated the rights of fishery workers in using the waters and tidal flats for aquaculture. This fundamentally pushed forward the rate of development of Chinese aquaculture industry. Third, the fishery administrations in China began attaching great importance to overall planning, and carried out the Strategy on Developing Competitive Aquaculture Zones for Export. This initiative accelerated the process of Chinese aquaculture in terms of standardization, scale of production, and industrialization. In 2014, Chinese exports of aquatic products amounted to US$ 21.7 billion, ranking top in the country’s agricultural exports for 15 consecutive years. Since then Chinese aquaculture has begun to develop along a healthier and more sustainable path.

Some aspects of the above changes and trends are depicted in Figures 1.4.12, 1.4.13, and 1.4.14. These Figures essentially show the development of Chinese fisheries and aquaculture in the past three decades.

1.4.3.2 Advance of Science and Technologies: Key Drivers

The fast development of Chinese aquaculture has relied largely, in addition to the principles and policies of the government, on scientific and technical advances, especially on technical breakthroughs in hatchery, nursery and grow-out technologies.

The first significant and historical achievement was the success of seaweed culture during the 1950s, which was the result of technical breakthroughs in the artificial propagation of kelp (also see Chapter 1.3). By the end of the 1970s, annual seaweed production in China had reached 250 000 tonnes in dry weight (approximately 1 500 000 tonnes fresh equivalent).

The second prominent achievement was the success of artificial propagation of the four major Chinese carp species in the 1960s which led to a rapid development of inland water fish culture in China. Currently, the output of inland aquaculture is about three-fifths of the total output of Chinese aquaculture.

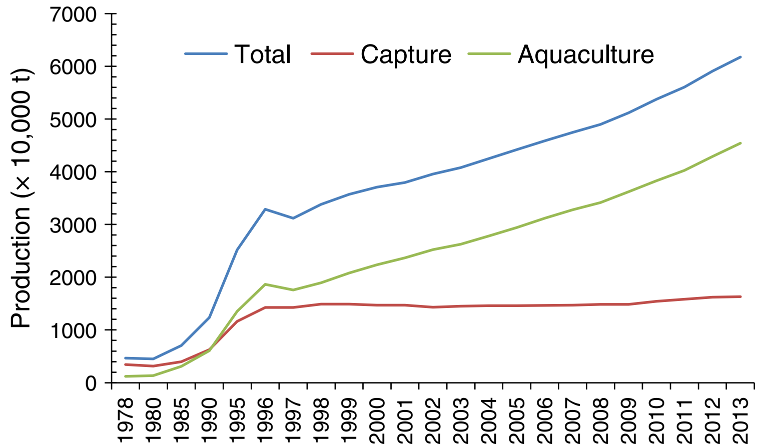

Figure 1.4.12 Trends in capture fisheries and aquaculture production. *Source:* China Statistical Abstract (2014).

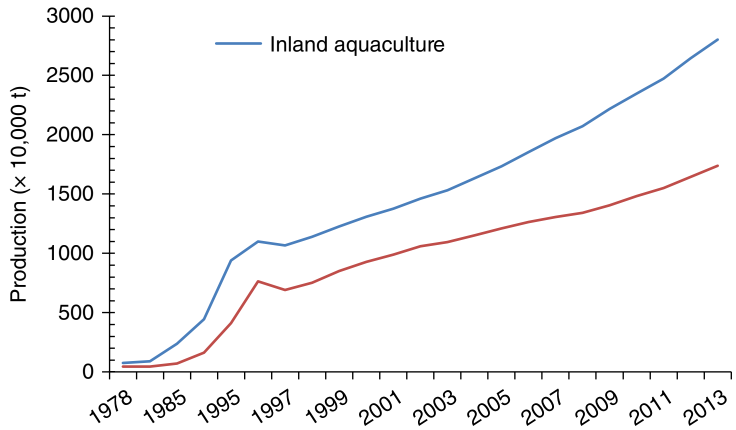

Figure 1.4.13 Trends in inland aquaculture and mariculture production. *Source:* China Statistical Abstract (2014).

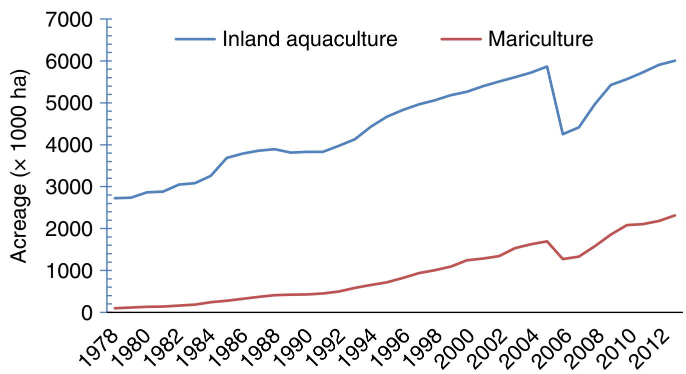

Figure 1.4.14 Trends in the acreage used for inland aquaculture and mariculture. *Source:* China Rural Statistical Yearbook (2014).

The third remarkable technological breakthrough was the artificial propagation of scallop in the 1970s which enabled the rapid development of Chinese mollusk production. Since then, China has expanded mollusk culture beyond the four traditional species (oyster, cockle, razor clam and ruditapes clam (*Ruditapes philippinarum*)). Mussel culture was the first new industry to emerge, followed by scallop culture in the 1980s. Abalone culture has become a major industry since the 1990s. Traditional oyster and clam culture have also advanced and expanded in recent years. Now more than 30 species of marine mollusk are cultured commercially in China. Due of its rapid development in recent years, mollusk culture has become the largest industry of Chinese mariculture, accounting for 81 percent of the total production by weight.

The fourth contribution was the breakthrough in shrimp hatchery technology in the 1980s. This important achievement has enabled the shrimp industry to become a very important export market. Annual shrimp production reached 210 000 tonnes in 1992, though this reduced in subsequent years due to disease outbreaks. Freshwater crab culture also began to contribute to the development of aquaculture in the 1980s, due to technical progress in hatchery and nursery technologies in seawater and brackish water.

The fifth technical achievement was the introduction of European eel (*Anguilla anguilla*) farming in 1990s. The successful technology enabled large-scale eel farming in China changed the overall pattern of the Asian eel farming industry, and brought China to a dominant position in the global eel export markets.

The above five significant technical advances in Chinese aquaculture, occurring approximately once every ten years, are known as the "five waves of Chinese aquaculture development". Each technical breakthrough has lifted Chinese aquaculture to a new level (Chinese Academy of Engineering 2013).

Entering into the 21st century, Chinese aquaculture is still driven by advances of sciences and technologies. More and more research projects have been prioritized in fields such as seed production, disease control, feed technology, the development of improved strains and varieties, improvements to aquaculture facilities, and fish processing. Concurrently, the extension services have been improved in recent years in order to enhance the efficacy of transfer of technologies to fish farmers. It is reported that contribution by the advance of science and technologies to Chinese fishery production is about 55 percent, out of all the driving factors (Chinese Academy of Engineering 2013).

1.4.3.3 Diversification of Aquaculture

1.4.3.3.1 Diversification of Culture Practices

After more than 30 years, China has developed a number of aquaculture approaches to make full use of various culture environments such as shallow sea areas, tidal flats, ponds, rivers, lakes, reservoirs, paddy fields and saline wasteland. Table 1.4.1 shows the various culture species with different culture practices.

In inland waters, pond fish culture is the most popular, followed by aquaculture in reservoirs, lakes, paddy fields, rivers and other types of waters (Figure 1.4.15). In mariculture, shallow sea culture is the primary production approach which includes hanging, floating net, long-line and net-cage culture. Tidal flat aquaculture plays an important role in mollusk culture including scallops, mussels, oysters, clams and abalone. Mariculture in land-based facilities has been developed very fast in recent years. It includes fish ponds and household fish

Table 1.4.1 Aquaculture methods used in China.

Commodity	Culture methods
Finfish	Land based tank culture; pond culture; cage culture; other methods
Crustaceans	Pond culture
Shell fish	Hanging culture (scallop, oyster, abalone, mussel, etc.); Bottom culture (clam, oyster, abalone etc.); Land- based tank culture (abalone)
Seaweeds	Floating net method; longline methods; others
Others	Pond culture
Sea cucumber	Pond culture
Polychaetes	Pond culture
Jelly fish	Bottom culture
Sea urchin	

Source: Liu (2008).

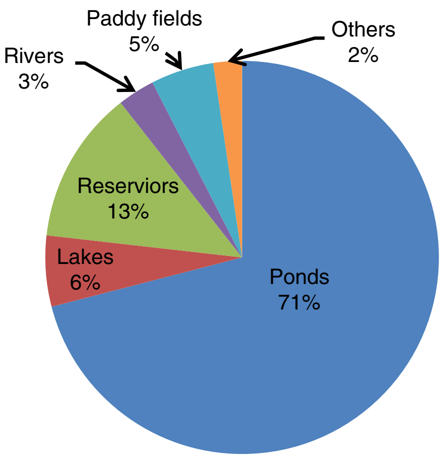

Figure 1.4.15 The relative percentage contribution in production of different culture systems to inland aquaculture in 2014. *Source:* China Fishery Statistical Yearbook (2014).

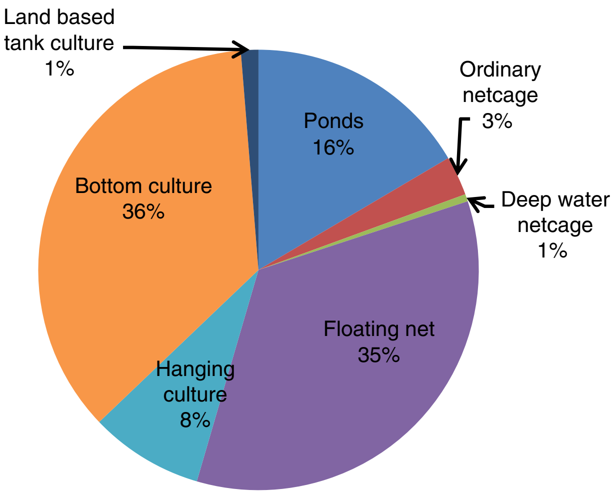

Figure 1.4.16 The relative percentage contribution in production of different culture systems to mariculture in 2014. *Source:* China Fishery Statistical Yearbook (2014).

tanks, which are widely used for rearing valuable commodities for exports such as shrimp, sea cucumber and high-valued finfish (Figure 1.4.16).

1.4.3.3.2 Diversification of Organisms Cultured

Diversification of the types of organism cultured has not only promoted the development of Chinese aquaculture but has also met market needs. It has been reported that organisms currently cultured in China exceed 200, and include finfish, shrimp, crab, mollusk, algae, echinoderms and amphibians (Chinese Academy of Engineering 2013).

In freshwater aquaculture more than 120 organisms are utilized. The major organisms are grass carp, silver carp, big head carp, common carp, crucian carp (*Carassius auratus*)and tilapia, and the annual output of each of these exceeds 1 000 000 tonnes (Chinese Academy of Engineering 2013). Mariculture has also expanded comprehensively in the number of cultured organisms. At present about 60 kinds of finfish are cultivated achieving a total annual output 600 000 tonnes. *Penaeus vannamei*, the introduced shrimp species, has been successfully cultivated in China and contributes 50 percent to Chinese shrimp production per annum (Liu 2008). Table 1.4.2 shows the major cultured species in northern China.

Table 1.4.2 Marine species cultured in northern China. *Source:* Liu (2008).

Marine species cultured in northern China			
Molluscs	*Crassostrea gigas, C. plicatula, C. rivularis, C. talienwhensis, Chlamys farreri, Argopecten irradians, Patinopecten yessoensis, Mytilus edulis, Ruditapes philippinarum, Meretrix meretrix, Cyclina sinensis, Mercenaria mercenaria, Mactra antiquata, M. veneriformis, Saxidomus purpuratus, Tegillarca granosa, Scapharca subcrenata, S. broughtonii, Sinonovacula constricta, Haliotis discus hannai, H. gigantea, Rapana venosa, Bullacta exarata*		
Marine fish	*Pagrus major, Lateolabrax japonicus, Fugu* sp., *Paralichthys olivaceus, Scophthalmus maximus, Cynoglossus semilaevis, C. trigrammus, Kareius bicoloratus, Verasper variegates, Sebastodes fuscescens, Mugil cephalus, Liza tade, Hexagrammos otakii, Seriola lalandi*		
Crustaceans	*Fenneropenaeus chinensis, Penaeus monodon, P. japonicus, P. merguinsis, Litopenaeus vannamei, Eriocheir sinensis, Callinectes sapidus, Scylla serrata*		
Seaweeds	*Laminaria japonica, Undaria pinnatifida, Porphyra yezoensis*		
Echinoderms	*Apostichopus japonicus, Strongylocentrotus intermedius, S. nudus*		
Major mariculture species and production (tonnes) in 2014, for selected spaces			
Finfish	Bastard halibut *(Paralichthys olivaceus)*		57 270
	Blackfin seabass *(Lateolabrax latus)*		80 625
	Convict grouper *(Epinephelus septemfascitus)*		33 033
	Black porgy *(Acanthopagrus schlegelii)*		46 248
	Parrotfish *(Oplegnathus fasciatus)*		—
	Red seatream *(Pagrus major)*		—
	Other seabreams		—
	Brown croaker *(Miichthys miiuy)*		—
	Red drum *(Sciaenops ocellatus)*		43 506
	Yellowtail *(Seriola quinqueradiata)*		12 572
	Puffers		14 861
	Korean rockfish *(Sebastes schlegeli)*		—
	Other rockfishes		—
	Mullets *(Mugil spp.)*		—
	Okhostk atka mackerel *(Pleurogrammus azonus)*		—
	Konoshiro gizzard shad *(Konosirus punctatus)*		—
	File fishes *(Stephanolepis* sp., *Thamnaconus* sp.*)*		—
	Other finfish		—
		Subtotal	**582 566**
Crustaceans	*Fenneropenaeus chinensis*		54 380
	Penaeus japonicus		45 173
		Subtotal	**722 172**
Shellfish	*Crassostrea gigas*		3 750 910
	Rapana venosa		202 452
	Haliotis discush hannai		—
	Chlamys Farreri nipponensis		—

(Continued)

Table 1.4.2 (Continued)

Major mariculture species and production (tonnes) in 2014, for selected spaces			
	Cyclina sinensis		2 799 004
	Mactra chinensis		—
	Scapharca subcrenata		323 225
	Solen spp.		676 391
	Ruditapes philippinarum		—
	Meretrix lusoria		—
	Atrina pectinata		—
	Scapharca broughtonii		—
	Mactra veneriformis		—
	Mytilus coruscus		717 368
	Other shellfish		—
		Subtotal	**10 247 151**
Seaweeds	*Porphyra* spp.		81 017
	Laminaria japonica		801 128
	Undaria pinnatifida		219 607
	Gelidium amansii		115
	Gigartina spp.		—
	Codium fragile		—
	Hijika fusiforme		—
	Enteromorpha spp.		—
	Other seaweeds		—
		Subtotal	**1 467 545**

1.4.4 Potential of Chinese Aquaculture

Human population and income growth, together with urbanization and dietary diversification, are expected to create additional demands for animal products, including fish, in China. International market demands will also play an important role in the expansion of the Chinese aquaculture industry.

1.4.4.1 Population Growth and Increasing Demand for Aquatic Products

In a world where more than 800 million people continue to suffer from chronic malnourishment, and where the global population is expected to grow by another 2 billion to reach 9.6 billion people by 2050, the world is faced with more challenges than ever before. It is predicted that global food fish availability will continue to outpace world population growth, and aquaculture remains one of the fastest-growing food producing sectors (FAO 2014). In 2012, aquaculture set another all-time production high, and now provides almost half of all fish for human food, a significant change from a hunted to a farmed supply dominance, as with all our other staples (De Silva 2012). This share is projected to rise to 62 percent by 2030 (FAO 2014). The significant role that aquaculture has played in eliminating hunger, promoting health and reducing poverty has to be acknowledged. Never before have people consumed so much fish or depended so greatly on the sector for their well-being. It has been predicted that by 2030 global aquaculture production will need to increase by two and half times to prevent the present global per capita fish supply from

Table 1.4.3 Prediction of the domestic fish demand 2020–2030 in China.

Year	2000	2010	2020	2030
Population (x 100 million)	12.7	13.4	14.6	15
Percentage of urbanization (%)	36.2	47.5	60	70
Fish availability per capita (kg)	29.4	40	45	50
Total fishery production (10 000 t)	3706	5373	6570	7500

Source: Chinese Academy of Engineering (2013).

falling. If responsibly developed and practiced, aquaculture can generate lasting benefits for global food security and economic growth.

China is the most populated country in the world with more than 1.3 billion population now and is predicted to rise to 1.6 billion by 2030. If the current 50 kg per capita fish availability (Chinese Academy of Engineering 2013) is to be maintained China will need a total 75 000 000 tonnes of fish, about 20 000 000 tonnes above the present production (Table 1.4.3). This additional production has to be contributed through aquaculture as China has inadequate natural fishery resources to exploit, and let alone safeguarding natural resources for future generations.

1.4.4.2 Economic and Social Development to Boost the Demand for Aquatic Products

Fish play an important role in food and nutrition security, poverty alleviation and general well-being. According to the Committee on World Food Security (CFS 2014), food security exists when, 'all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life'. Consumption of fish provides energy, protein, and a range of essential nutrients. In many cases, there may be no alternative affordable food sources for many of these essential nutrients. Fish accounts for about 17 percent of the global population's intake of animal protein (CFS 2014).

In recent decades, average per capita apparent food consumption has also been growing, and global dietary patterns have become more homogeneous and globalized. Such changes have been the result of several factors, including rising living standards, population growth, rapid urbanization, and opportunities for trade and transformations in food distribution. These patterns of change have fueled growing demand for protein food products, in particular meat, fish (Figure 1.4.17), milk, eggs, as well as vegetables, with a reduction in the share of staples such as roots and tubers in the diet (FAO 2014). In addition, growing urbanization is a major

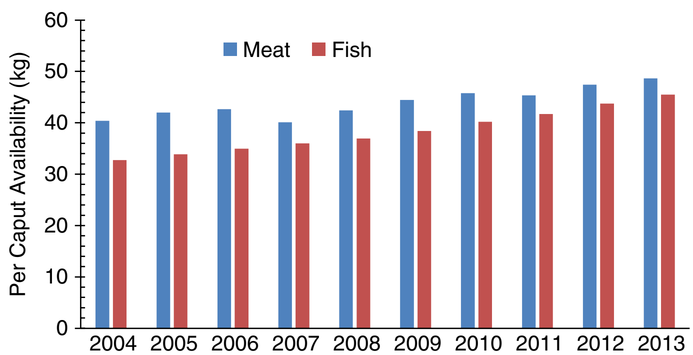

Figure 1.4.17 Comparative changes in the per capita availability of meat and fish. *Source:* China Statistical Yearbook (2014).

driving force influencing food consumption patterns, with an impact also on the demand for fishery products. City dwellers tend to devote a higher proportion of their income to food purchased than do rural populations on lower incomes. In addition, the former groups generally eat out of the home more frequently, and purchase larger quantities of fast and convenience foods.

Despite the overall increase in the availability of fish to most Chinese consumers, growth patterns of per capita apparent fish consumption have been uneven. The supply of animal protein continues to remain significantly higher in urban areas than in rural areas. Fish consumption in urban areas (57 percent of the national population; www.wapbaike.baidu.com) accounts for 70 percent of the country's total (Chinese Academy of Engineering 2013). Along with increasing urbanization in China, the urban population will increase rapidly, and the consumption demand for aquatic products will also increase substantially in the future.

1.4.4.3 International Trade and Growth

Fish remains the most traded food commodity worldwide. The fish trade is especially important for developing nations, in some cases accounting for more than half of the total value of traded commodities. In 2012, it represented about ten percent of total global agricultural exports and 1 percent of world merchandise trade in value terms. The share of total fishery products exported in different forms for human consumption or non-edible purposes grew from 25 percent in 1976 to 37 percent in 2012 (FAO 2014).

The European Union is the largest market for imported fish and fishery products, and its dependence on imports is growing. An important change in trade patterns is the increased share of developing countries in fishery trade. Exports from developing countries have increased significantly in recent decades driven by a lowering of tariffs. This trend follows the expanding membership of the World Trade Organization (WTO), the entry into it facilitates bilateral and multilateral trade agreements, and rising disposable incomes in emerging economies. Developing economies saw their share rise to 54 percent of total fishery exports by value in 2012 and more than 60 percent by quantity (FAO 2014).

China is, by far, the largest exporter of fish and fishery products, and since 2011, it has become the world's third-largest importing country. At present, about 40 percent of world fish products are traded in the international markets. However, only ten percent of Chinese fish products are exported. There is great potential for China to gain a bigger share of the international fish trade. As global fish consumption continues to grow and the decline of the world fishery resources also continues, growing market demands will mainly rely on aquaculture to make up the deficit in the supplies. This will obviously provide an opportunity for China to increase its fish export to the international markets.

1.4.5 Conclusions

Aquaculture is a vital source of income, nutritious food and economic opportunities, and has a key role to play in meeting one of the world's greatest challenges: feeding a population set to rise to 9.6 billion by 2050. Employment in the sector has grown faster than the world's population. It provides jobs to tens of millions, and supports the livelihoods of hundreds of millions.

China, as the largest fish producer and most populated country in the world, would inevitably meet the rising demand from a growing population by continuing its aquaculture growth in both quantity and quality. However, we also need to look beyond the economics and ensure that environmental well-being is compatible with human well-being, in order to make long-term sustainable prosperity a reality for all. To this end, promoting responsible and sustainable aquaculture is central to our work and purpose. That is, we need to increase aquaculture production sustainably in a context of climate change, greater competition for natural resources, and conflicting interests. Improved science, technology and governance should be all combined to create an overall strategy to help meet the goals of responsible and sustainable use of aquatic resources in order to secure valuable resources for the benefit of present and future generations.

To meet these rising demands, China needs to formulate and refine its aquaculture development policies, targeting specific national, provincial and farm-level issues aimed at transforming the aquaculture sector from traditional, extensive governance to modernized intensive governance.

To address key issues such as pollution, the government needs to introduce legislation to control water quality in order to ensure healthy aquaculture development.

To promote sustained aquaculture development, the Chinese government needs to continue to improve technology transfer, and reduce some of the investment risks. There are more tasks facing China, including:

- restructuring of the entire aquaculture sector to improve quality and increase income (not only increase production) to add value to the sector;
- provide opportunities for preferential loans, improve fiscal conditions, and improve technical support to operators;
- extend the use of manufactured feeds to reduce eutrophication;
- support the transformation of aquaculture into a professional industry with producer associations;
- upgrading of the national technological base; and
- strengthening of scientific research, education and training to improve research capability and preparedness for emergencies.

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1.5

Species Composition in Chinese Aquaculture with Reference to Trophic Level of Cultured Species

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1.5.1 Introduction

China is considered the 'Home of Aquaculture'. The country is recognized not only for having a long history in aquaculture, but also for its important role in the development of aquaculture in modern times, and its contributions to global food security. In the mid-to-late twentieth century, after nearly 30 years of debate, discussion, and improved practices, China advocated a "culture-oriented" development policy in fisheries in 1986 (SNPC 1986), thus contributing to the rapid development of aquaculture. Aquaculture production increased from less than 100 000 tonnes in 1950 to 3 630 000 tonnes in 1985, and to 49 380 000 tonnes in 2015, resulting in an increased proportion of aquaculture in fisheries from 8 percent to 45 percent and then to 74 percent, respectively, with nearly four-fold production enhancement in the last 30 years (China Fishery Statistical Yearbook 2004–2016; TFCA 2013). Aquaculture has become one of the fastest-growing industries in the large-scale agricultural development of China. An analysis of the reasons for the rapid growth of Chinese aquaculture revealed that, in addition to being driven by decision-making and technological advances, an undeniable reason for the sector's growth is that external feed inputs (non-fed) were not required for a considerable proportion of aquaculture species (TFCA 2013; Tang *et al*. 2014). Non-fed means:

- lower production costs and investments that favor industry development;
- cultured aquaculture species occupy a low trophic level in the food chain, exhibiting characteristics of high food conversion efficiency and a large output; and
- less fishmeal demand for aquaculture, thus reducing the pressure on wild fishery resources.

Therefore, the fact that a considerable proportion of aquaculture is non-fed species is an important characteristics of Chinese aquaculture, which is determined by a unique species composition and the trophic levels of these species.

A recent critique on Chinese aquaculture and the world's wild fisheries (Cao *et al.* 2015) has been controversial and consequently initiated much discussion. On the one hand, the media hype surrounding this

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critique further amplified the conclusions of the article, namely that “China’s aquaculture is destined to cut the resource of the world’s wild fisheries”, claiming “China’s aquaculture is ‘dangerous’ to wild fisheries”,[1] while on the other hand, many experts in the field did not agree with the conclusions thereof and believed that the development of Chinese aquaculture is not necessarily related to changes in the world’s fisheries resources. Aquaculture could provide food for China and the world and reduce the demand for wild fisheries resources; that is, China uses only approximately 25 percent of the world’s fishmeal, but accounts for more than 60 percent of global aquaculture production (Han *et al*. 2015; Shan *et al.* 2015; Han *et al*. 2016). Many reasons exist for the different views, but the technical reason is the a lack of a comprehensive in-depth understanding of the unique way in which aquaculture has been developed in China, and a lack of understanding of the basic status of species composition, of the use of species that are not provided with an external feed input (non-fed species), and of the trophic levels occupied by many species that are predominant in Chinese aquaculture.

Therefore, based on Tang *et al.* (2016a), the basic characteristics and changes in the species composition, the percentage of non-fed species, and the general trophic levels of predominant species in Chinese aquaculture are analyzed in this Chapter, and the future development trends and the likely patterns of Chinese aquaculture are discussed.

1.5.2 Species Composition of Chinese Aquaculture

The initial stage of modern Chinese aquaculture development began in the 1950s with only dozens of species. With the development of artificial propagation technology for the four major cultured carp species, viz. black carp (*Mylopharyngodon piceus*), grass carp (*Ctenopharynogodon idellus*), silver carp (*Hypophthalmichthys molitrix*), and bighead carp (*Aristichthuy nobilis*), as well as for marine mollusks, seaweeds, and other species, up to one hundred aquatic species became available for culture in the 1980s (Ding 1989; Lei 2005; China Fishery Statistical Yearbook 2004–2016; TFCA 2013; FAO 1950–2013). In the twenty-first century, due to the continuous progress and improvements in artificial propagation and farming technologies, the number of cultured species increased significantly. As given in Tables 1.5.1 and 1.5.2, currently, there are 296 species (including 25 introduced species) and 143 varieties (including 138 newly bred varieties and 5 introduced varieties) in Chinese aquaculture, amounting to 439 farmed species and varieties.

Among the five categories of introduced species are 189, 54, 21, 15 and 17 fish, mollusks, algae, crustaceans, and miscellaneous species, respectively. Each of these account for 63.9 percent, 18.2 percent, 7.1 percent, 5.1 percent and 5.7 percent of the overall number of species cultured in China. Figure 1.5.1a and b shows the changes in the proportion of the production for the five major categories from 1950 to 2014. Fish showed the highest proportion of change from 86.8–55.3 percent, followed by mollusks, algae, crustaceans and other species, which accounted for 12.5–36.1 percent, 0.1–9.3 percent, 0.1–8.4 percent and 0.1–2.0 percent, respectively, with relatively large annual variations. Over the past decade, however, development has stabilized, with smaller annual variations, and the proportions of production of the five categories in 2003–2014 were 57.3–55.3 percent, 28.3–33.1 percent, 5.7–8.4 percent, 4.0–4.6 percent, 1.3–1.9 percent of fish, mollusks, crustaceans, algae and other species, respectively. In 2014, aquaculture production was 47 484 000 tonnes, and the proportions of the production for the five categories were 57.3 percent, 28.3 percent, 8.4 percent, 4.2 percent and 1.8 percent for fish, mollusks, crustaceans, algae and other species, respectively with a relatively large increase in crustaceans compared with the previous data.

Due to the different culture environments, the species composition of Chinese aquaculture showed significant regional differences, with fish dominating freshwater culture, and mollusks and algae dominating marine culture.

1 Researchers: China aquaculture ‘dangerous’ to wild fisheries. http://www.seafoodsource.com/news/environment-sustainability/27496-researchers-china-aquaculture-dangerous-to-wild-fisheries#sthash.iQYKgFMR.dpuf. 2015

Table 1.5.1 Species and varieties used in Chinese freshwater aquaculture.

Categories	Reported by China Fishery Statistical Yearbooks[1)]	Not reported by China Fishery Statistical Yearbooks[2)]
Fish	*Mylopharyngodon piceus, Ctenopharyngodon idellus,* silver carp (*Hypophthalmichthys molitrix,* Changfeng silver carp[3)], Jin silver carp[3)]), *Hypophthalmichthys nobilis,* carp (*Cyprinus carpio, C. carpio yuankiang, C. carpio rubrofuscus, C. carpio heamatopterus, C. carpio Xiangjiangnensis, C. carpio chilia, C. carpio* var. Jian[3)], Germany mirror carp[5)], Scatter scale mirror carp[5)], Ukraine scaly carp[5)], German mirror carp selection[3)], *C. carpio* Triploid[3)], *C. carpio var. singuonensis*[3)], *C. carpio var. wuyuanensis*[3)], The strain of fight lucius of red common carp[3)], *C. carpio var. wananensis*[3)], Songpu carp[3)], Songpu mirror carp[3)], Songpuhong mirror carp[3)], Molong carp[3)], Yuxuan huanghe carp[3)], Songhe carp[3)], Jinxin carp[3)], Yibu common carp[3)], FFRC strain common carp[3)], *C. carpio var. color* "Longshen No. 1"[3)], Ying carp[3)], Feng carp[3)], Yuanhe hybrid carp[3)], Yue carp[3)], Hybrid common carp[3)], Furong carp[3)], Carp "Jinxin No.2"[3)]), crucian carp (*Carassius auratus, C. auratus gibelio, C. aumtus gibelio*[3)], *C. aumtus gibelio* "Cas III"[3)], *C. aumtus var.* Xiangyun[3)], *C. aumtus var.* Xiangyun "No. 2"[3)], *C. aumtus var.* Pengze[3)], *C. aumtus gibelio* Songpu[3)], *C. aumtus var. Pingxiangnensis*[3)], *C. aumtus* hongbaichangwei[3)], *C. aumtus* baijinfengchan[3)], *C. aumtus* lanhuachangwei[3)], Huangjin crucian carp[3)], *C. aumtus* jinxinwu[3)], Hybrid crucian carp[3)], *C. aumtus* ganchangli[3)], *C. aumtus var.* Changfeng[3)]), *Megalobrama* (*Parabramis pekinensis, Abramis brama orientalis, Megalobrama amblycephala, M. terminalis,* Hybrid bream[3)], *M. amblycephala* "Pujiang No. 1"[3)]), loach (*Cobitis taenia, Paramisgurnus dabryanus*), *Ictalurus* (*Ictalurus nebulosus, I. punctatus*[4)], *I. punctatus* "Jiangfeng No.1"[3)]), *Silurus* (*Pangasius sutchi, Silurus soldatovi meridionalis, S. soldatovi, Clarias gariepinus*[4)]), *Pseudobagrus* (*Pseudobagrus fulvidraco, P. fulvidraco* "Quanxiong No.1"[3)]), *Piaractus brachypomus*[4)], *Monopterus albus, Siniperca* (*Siniperca scherzeri, S. chuatsi, S. kneri,* Qiupu hybrid *S. scherzeri*[3)], *S. chuatsi* "Huakang No.1"[3)]), bass (*Perca fluviatilis, Lucioperca lucioperca, Micropterus salmonoids*[4)], *M. salmonoids* "Youlu No.1"[3)]), *Ophicephalus argus,* tilapia (*Oreochromis niloticus*[4)], *O. aureus*[4)], *O. niloticus* "Luxiong No. 1"[3)], GIFT train Nile tilapia[5)], Jifu tilapia "Zhongwei No. 1"[3)], Jifu new tilapia[3)], *O. aureus* "Xiaao No. 1"[3)], Aoni tilapia[3)], Fushou tilapia[3)], Jiao tilapia[3)], Jili tilapia[3)], Mohe tilapia "Guangfu No. 1"[3)]), *Anguilla* (*Anguilla japonica, A. rostrate*), sturgeon (*Acipenser baeri, A. schrenckii, A. gueldenstaedti, A. ruthenus*[4)], *Huso dauricus, H. huso, Polyodon spathula*[4)], *A. stellatus,* Hybrid sturgeon), trout (*Salmo gairdneri*[4)], *Oncorhynchus donaldsons*[4)], *O. mykiss, O. masou masou,* steelhead trout, *S. trutta fario, O. mykiss*[3)]), *Hypomesus olidus,* icefish (*Prolosalanx hylocranius, Neosalanx reganius*), *Leioeasis longirostris, Fugu* (*Takifugu obscurus, T. ocellatus*), salmon (*Hucho taimen, Brachymystaxc lenok, Salvelinus fontinalis, Oncorhynchus kisutch, Salmo salar, S. leucomaenis, S. alpinus, S. malma, S. leucomaenis, Coregouns peled*[4)], *O. keta*)	*Elopichthys bambusa, Odontobutis sinensis, Channa asiatica, Perccottus glenii, Channa* "Hangli No.1"[3)], Wuban *Channa*[3)], *Spinibarbus sinensis, Puntius goniontus,* culter (*Erythroculter ilishaeforrmis, E. mongolicus, E. dabryi, Culter* "Xianfeng No.1"[3)], *Lutaifang Culter*[3)]), *Xenocypris* (*Xenocypris microlepis, X. argentea, X. davidi,* hybrid *Xenocypris*[3)]), *Myxocyprinus asiaticus, Zctiobus cyprinellus*[4)], *Hemibarbus labeo, H. maculates, Phoxinus lagowskii, Chalcalburnus chalcoides aralensis, Squaliobarbus curriculus, Escox lucius, Macrura reeuesii, Leuciscus waleckii, Labeo rohita*[4)], *Plecoglossus altivelis, P. altivelis* "Zhemin No.1"[3)], *Opsariichthys bidens, Lota iota, Zacco platypus, Onychostoma sima, Coreius heterodon, Schizothorax* (*Gymnocypris przewalskii przewalskii, Schizothorax prenanti, S. yunnanensis, S. wangchiachii, S. kozlovi, S. parvus*), *Aspiorhynchus laticeps, Scortum barcoo, Trachidermus fasciatus, Oxyeleotris marmoratus, Tinca tinca, Cichlasoma managuense, Mystus macropterus, Pangasius sutchi*[4)], *Xiphophorus helleri* RP-B strain[3)]

Crustaceans	*Macrobrachium rosenbergii*[4)], *M. rosenbergii* "Nantaihu No.2"[3)], *M. nipponense*, Hybrid *M. nipponense* "Taihu No.1"[3)], *Procambarus clarkia*, *Litopenaeus vannamei*, *Eriocheir sinensis*, *E. sinensis* "Guanghe No.1"[3)], *E. sinensis* "Changjiang No.1"[3)], *E. sinensis* "Changjiang No. 2"[3)], *E. sinensis* "Jianghai No.1"[3)]	*Metapenaeus ensis*, *Cherax quadricarinatus*
Mollusks	Unionidae (*Hyriopsis cumingii*, *Cristaria plicata*, *Anodonta woodiana*, *H. schlegelii*[4)], Kangle *H. cumingii*[3)]), Gastropod, Corbiculid	
Algae	*Spirulina*	
Others	Turtle (*Chinemys reevesii*, *Macrochelys temminckii*[4)]), soft-shelled turtle (*Pelodiscus sinensis*, *Apalone ferox*, *P. sinensis* "Zhexinhuabie"[3)], *P. sinensis* "Qingxiwubie"[3)], *P. sinensis* Japanese strain[5)]), *Rana* (*Rana catesbeiana*[4)], *R. giglio*[4)])	*Whitmania pigra*, *Andrias davidianus*

Note:

1) Aquaculture species were reported by China Fishery Statistical Yearbooks from 2003 to 2015. The statistical data of some species are carried out with category, and their aquaculture species and bred species (cultivated varieties) listed in parentheses.
2) Data in the table were from Ding (1989) and expert consultation.
3) Varieties (bred species).
4) Introduced species.
5) Introduced bred species (NCAV 2016).

Table 1.5.2 Species and varieties used in Chinese mariculture.

Categories	**Reported by China Fishery Statistical Yearbooks**[1)]	**Not reported by China Fishery Statistical Yearbooks** [2)]
Mollusks	oyster (*Crassostrea gigas*[4)], *C. rivularis, C. plicatula, Ostrea denselamellosa, C. angulate, C. gigas* "Haida No.1"[3)], *O. gigas thunberg*" Huanan No.1"[3)]), abalone (*Haliotis discus hannai, H. diversicolor, H. asinine, H. ovina*, Hybrid abalone "Dalian No.1"[3)], Xipan abalone[3)], Abalone "Dongyou No.1"[3)]), conch (*Bullacta exarata, Turritella terebra*, Nassariidae, *Rapana venosa, Neptunea cumingi, Thais luteostoma, Nevertia didyma, Babylonia areolata, Hemifusus tuba*), cockle (*Scapharca subcrenata, S. broughtonii, Tegillarca granosa, T. granosa* "Leqingwan No.1"[3)]), mussel (*Mytilus edulis, M. crassitesta, Perna viridis*), *Atrina pectinate*, scallop (*Chlamys farreri, Patinopecten yessoensis*[4)], *Argopecten irradians*[4)], *C. nobilis, Pinctada martensii, Pteria penguin, P. maxima, C. farreri* "Penglaihong"[3)], *C. farreri* "Penglaihong No.2"[3)], *C. farreri* "Bohaihong"[3)], *P. yessoensis* "Haida Jin Bei"[3)], *P. yessoensis* "Zhangzidaohong"[3)], *A. irradians* "Zhongkehong"[3)], *A. irradians* "Zhongke No.2"[3)], *Mimachlamys nobilis* "Nanao JinBei"[3)], *P. martensi* "Haiyou No.1"[3)], *P. martensi* "Haixuan No.1"[3)], *P. martensi* "Nanzhen No.1"[3)], *P. martensi* "Nanke No.1"[3)]), clam (*Meretrix meretrix, Venerupis philippinarum, V. variegate, Mactra veneriformis, M. chinensis, Mercenaria mercenaria, Paphia undulate, Saxidomus purpuratus, Cyclina sinensis, Dosinia, M. meretrix* "Kezhe No.1"[3)], *M. meretrix* "Wanlihong"[3)], *V. philippinarum* "Banmage"[3)]), razor clam (*Sinonovacula constricta, Solen grandis, Cultelles*)	*Panopea generosa, Sepia esculenta, Octopus variabilis*
Algae	kelp (*Saccharina japonica*, Kelp "Ronghai"[3)], hybrid kelp "Dongfang No.2"[3)], hybrid kelp "Dongfang No.3"[3)], Kelp "Dongfang No.6"[3)], Kelp "Dongfang No.7"[3)], Kelp "901"[3)], Kelp "Sanhai"[3)], Kelp "Ailunwan"[3)], Kelp "Huangguan No.1"[3)], Kelp "205"[3)]), sea mustard (*Undaria pinnatifida, U. pinnatifida* "Haibao No.1"[3)], *U. pinnatifida* "Haibao No.2"[3)]), laver (*Porphyra yezoensis, P. haitanensis, P. yezoensis* "Sutong No.1"[3)], *P. yezoensis* "Sutong No.2"[3)], *P. haitanensis* "Shenfu No.1"[3)], *P. haitanensis* "Minfeng No.1"[3)], *P. haitanensis* "Shenfu No.2"[3)], *P. haitanensis* "Zhedong No.1"[3)]), *Gracilaria* (*Gracilaria lemaneaformis, G. tenuistipitata, G. chouae, G. lichenoides, G. lemaneaformis* "Lulong No.1"[3)], *G. lemaneaformis* "981"[3)], *G. lemaneaformis* "2007"[3)]), *Eucheuma, Gelidium amansii, Sargassum fusiforme, Ulva lactuca, Enteromorpha clathrata, E. intestinalis, E. linza, E. prolifera*	*Sargassum, S. thunbergii, Gelidiella aceyosa, Grateloupia filicina*
Crustaceans	*Penaeus vannamei* (*P. vannamei*[4)], *P. vannamei* "Kehai No.1"[3)], *P. vannamei* "Zhongke No.1"[3)], *P. vannamei* "Zhong No.1"[3)], *P. vannamei* "Guihai No.1"[3)], *P. vannamei* "Renhai No.1"[3)]), *Penaeus monodon* (*P. monodon, P. monodon* "Nanhai No.1"[3)]), *Fenneropenaeus chinensis* (*F. chinensis, F. chinensis* "Huanghai No.1"[3)], *F. chinensis* "Huanghai No.2"[3)], *F. chinensis* "Huanghai No.3"[3)]), *P. japonicus, Portunus* (*Portunus trituberculata, P. trituberculata* "Huangxuan No.1"[3)], *P. trituberculata* "Keyong No.1"[3)]), *Scylla serrata*	*Exopalaemon carinicauda, P. merguiensis, P. penicillatus, Marsupenaeus japonicus* "Minhai No.1"[3)]

Fish	*Lateolabrax japonicus*, lefteyed flounders (*Scophthalmus maximus*[4], *S. maximus* "Duobao No.1"[3], *S. maximus* "Danfaping"[3], *Paralichthys olivaceus*, *P. olivaceus* "Pingyou No.1"[3], *P. olivaceus* "Beiping No.1"[3], *P. olivaceus* "Beiping No.2"[3], *P. dentatus*, *P. lethostigma*[4]), large yellow croaker (*Larimichthys crocea*, *L. crocea* "Minyou No.1"[3], *L. crocea* "Donghai No.1"[3]), *Rachycentron canadum*, *Seriola (Seriola dumerili, S. quinqueradiata, S. aureovittata*), sea bream (*Pagrosomus major, Sparus microcephalus, S. latus, S. aurata, S.berda, Rhabdosargus sarba*), *Sciaenops ocellatus*, *Fugu* (*Fugu rubripes, F. pseudommus, F. obscurus, F. bimaculatus, F. xanthopterus*), *Epinephelus* (*Epinephelus lanceolatus, E. awoara, E. akaara, E. fario, E. malabaricus, E. tauvina, Cromileptes altivelis*), righteyed flounders (*Kareius bicoloratus, Verasper variegates, V. moseri, Hippoglossus hipoglossus, Pseudopleurnectes yokohamae*)	*Cynoscion nebulosus, Nibea albiflora, N. miichthioides, N. coibor, Miichthys miiuy, Megalonibea fusca, Trachinotus ovatus, T. blochii, Plectorhynchus cinctus, Hapalogenys nitens, Pomadasy hasta, Parapristipoma trilineatus, Lutjanus russelli, L. erythropterus, L. argentimaculatus, L. bohar, Mugil cephalus, M. macrolepis, Liza haematocheila, Sebastes schlegeli, Sebastiscus marmoratus, Inimicus japonicus, Hippocampus trimaculatus, H. ramulosus, H. japonicus, Solea solea, S. senegalensis, Oreochromis niloticus, O. aureus, Anguilla japonica, A. Anguilla, Sigauns fuscesens, S. oramin, Oplegnathus fasciatus, Bostrichthys sinensis, Boleophthalmus pectinirostris, Hexagrammos otakii, Clupanodon punctatus, Morone saxatilis, Coryphaena hippurus, Acipenser sinensis, Chilocsyllium plagiosum, Cynoglossus semilaevis, Lates calcarifer, Muraenesox cinereius, Chanos Chanos*
Others	sea cucumber (*Apostichopus japonicus, A. japonicus* "Kongdongdao No.1"[3], *A. japonicus* "Shuiyuan No.1"[3]), sea urchin (*Strongylocentrotus intermedius, Anthocidaris crassispina, S. intermedius* "Dajin"[3]), *Rhopilema*	*Urechis unicinctus, Nereis diversicolor, Sipunculus nudus, Tachypleus tridentatus, Pyrosomella verticilliata*

Note:

1) Species were reported by China Fishery Statistical Yearbooks from 2003 to 2015. The statistical data of some species are carried out with categories, and their aquaculture species listed in parentheses.
2) Data in the table were from Lei (2005), Xie (2014) and expert consultation.
3) Varieties (bred species).
4) Introduced species.
5) Introduced bred species (NCAV 2016).

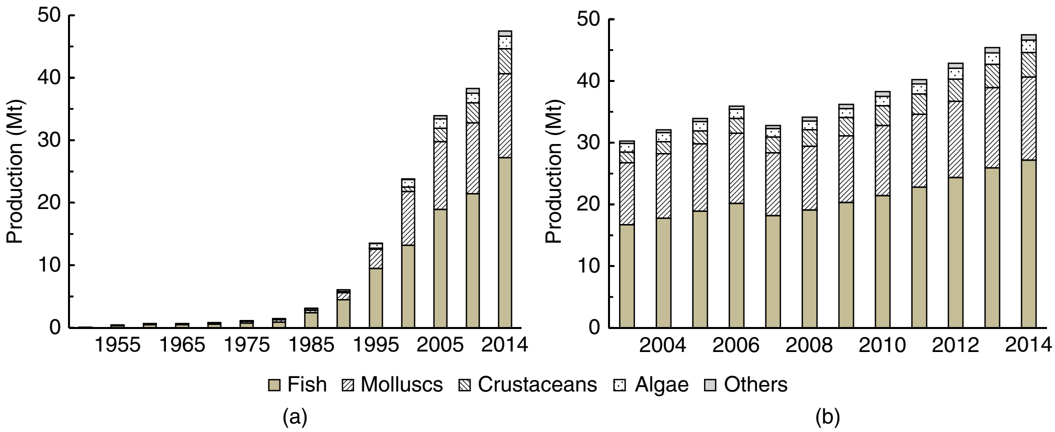


Figure 1.5.1 Decadal (a) and annual (b) changes in Chinese aquaculture production by species groups. Data *source:* China Fishery Statistical Yearbook (2004–2016); FAO (1950–2013).

1.5.2.1 Species Used in Freshwater Aquaculture

There are 135 aquaculture species (including 19 introduced species, and five species cultured in both freshwater and marine water) and 79 varieties (74 newly bred varieties and five introduced varieties), resulting in a total of 214 species and varieties utilized in freshwater aquaculture. In freshwater aquaculture 113, 7, 6, 1, and 8 species of fish, crustaceans, mollusks, algae, and others, respectively are utilized. Each accounts for 83.7 percent, 5.2 percent, 4.5 percent, 0.7 percent and 5.9 percent of the total species that are cultured in China (1.5.1.). Figure 1.5.2a and b shows the change in the proportion of the production of the five categories. In 1950–2014, fish had the highest proportion, accounting for 100–88.7 percent, followed by crustaceans accounting for 0–8.7 percent, mollusks 0–0.9 percent, algae 0.0 percent and other species 0–1.7 percent. In 2003–2014, the proportions of the production of the five categories were 91.4–88.0 percent for fish, 6.0–9.1 percent for crustaceans, 0.9–1.1 percent for mollusks, 0.02–0.04 percent for algae, and 1.5–1.8 percent for other species. In 2014, freshwater aquaculture production was 29 358 000 tonnes, and the proportionate contribution of fish was 88.7 percent, crustaceans 8.7 percent, mollusks 0.9 percent, algae

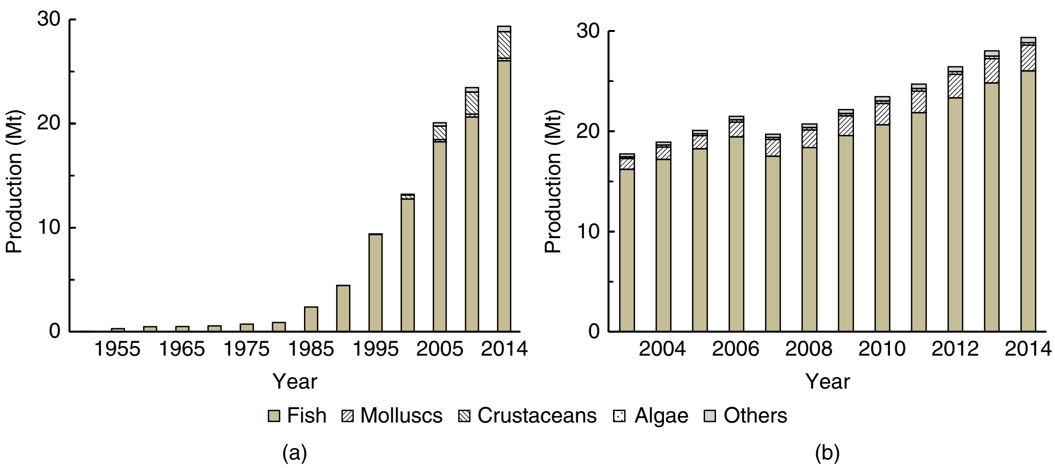


Figure 1.5.2 Decadal (a) and annual (b) changes in Chinese freshwater aquaculture production by species groups. Data *source:* China Fishery Statistical Yearbook (2004–2016); FAO (1950–2013).

0.02 percent, and other species 1.7 percent. Species with a production higher than 1 000 000 tonnes included grass carp, silver carp, bighead carp, common carp, crucian carp (*Carassius carassius*), and tilapia, which are filter feeding, herbivorous and omnivorous species, and accounted for 69.6 percent of the freshwater aquaculture production. Species with a production of 0.5–1 million tonnes included Chinese mitten crab (*Eriocheir sinensis*), blunt snout bream (*Megalobrama* spp.), white legged shrimp (*Litopenaeus vannamei)*, freshwater crayfish (*Procambarus clarkii*), black carp, and the snakehead (*Channa argus*), which are omnivorous and carnivorous species, accounting for 13.7 percent of the freshwater aquaculture production. The species with a production of 0.1–0.5 million tonnes include catfish (*Silurus* spp.), Asian swamp eel (*Monopterus albus*), bass, loach (*Misgurnus* spp.), soft-shelled turtle (*Pseudobagrus)*, Mandarin fish (*Siniperca*), mantis shrimp (*Squilla spp.*), catfish (*Ictalurus* spp.), eel (*Anguilla* spp.), giant freshwater prawn (*Macrobrachium rosenbergii*), gastropods, and pirapitinga (*Piaractus brachypomus*), which are mostly carnivorous species, accounting for 12.1 percent of freshwater aquaculture production. The total production of the above 25 species accounted for 95.4 percent of the freshwater aquaculture production (the production of the top 12 species accounted for 83.3 percent).

1.5.2.2 Species Used in Mariculture

There are 166 species (including six introduced species, and five species for both freshwater and marine water) and 64 new varieties, resulting in a total of 230 species and varieties used in mariculture. The five categories composing marine aquaculture include 80, 48, 9, 20 and 9 species of fish, mollusks, crustaceans, algae, and other species, respectively and each group accounted in order for 48.2 percent, 28.9 percent, 5.4 percent and 12.1 percent of the total number of species used in mariculture (Table 1.5.2). Figure 1.5.3a and b shows the changes in the production of the five categories during 1950–2014. Mollusks showed the greatest changes, accounting for 100–54.1 percent during that period, followed by algae 0–37.8 percent, crustaceans 0–11.6 percent, fish 0–6.6 percent, and other species 0–1.8 percent. In 1950–1980, cultured algae and mollusks accounted for more than 97 percent of mariculture production, followed by an increased annual production of other species; the proportion of the production for the last decade gradually stabilized, with smaller annual variations. During 2003–2014, the proportion of the production for the five categories was 72.6–78.6 % for mollusks, 10.3–11.1 percent for algae, 5.3–7.9 percent for crustaceans, 4.1–6.6 percent for fish, and 0.9–2.2 percent for other species. In 2014, the total mariculture production was 18 126 000 tonnes, and the proportion of the production of the five major categories was 72.6 percent

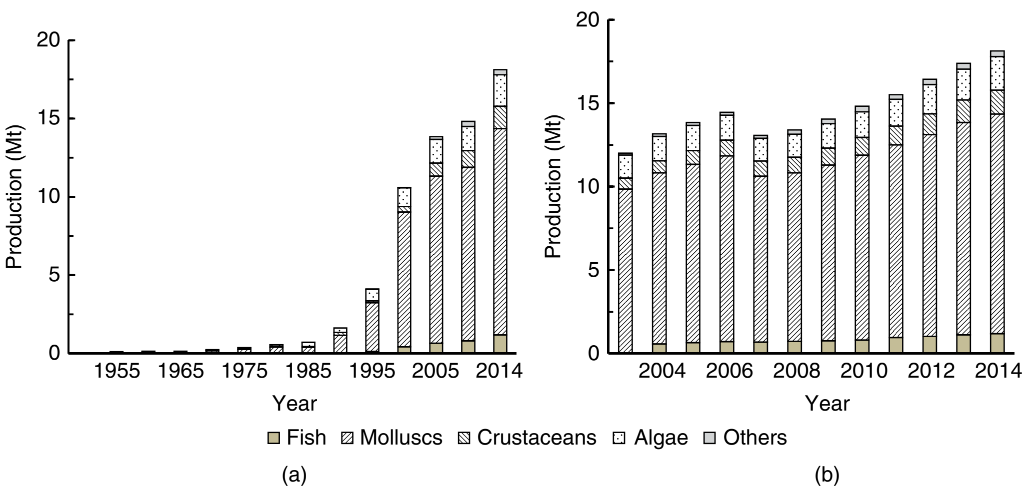


Figure 1.5.3 Decadal (a) and annual (b) changes in Chinese mariculture production by species group. Data *source:* China Fishery Statistical Yearbook (2004–2016); FAO (1950–2013).

for mollusks, 11.1 percent for algae, 7.9 percent for crustaceans, 6.6 percent for fish, and 1.8 percent for other species. Productions of more than 1 000 000 tonnes were filter feeding and autotrophic species such as oysters, clams, scallops and kelp, which together contributed 62.5 percent of the total mariculture production. The species with productions between 0.5–1 million tonnes included *L. vannamei*, mussels, and razor clams, which are either omnivorous or filter-feeding species, and together accounted for 13.6 percent of total mariculture production. Species the productions of which was between 0.1–0.5 million tonnes include cockle, *Gracilaria*, conch, *Undaria pinnatifida*, sea cucumber, *Scylla serrata*, *Larimichthys crocea*, left-eyed flounder, *Arnoglossus* spp. *Trachinotus ovatus*, *Portunus trituberculärus*, *Haliotis spp.*, *Porphyra spp.*, and sea bass, which are filter feeding, autotrophic, carnivorous, and omnivorous species, and account for 12.3 percent of total mariculture production. The total production of the above 20 species accounted for 88.4 percent of total mariculture production (the production of the top seven species accounted for 76.1 percent).

1.5.3 Diversity of Cultured Species

The estimation of the biodiversity index (FAO 1950–2013) showed that, compared with other leading aquaculture-producing nations (14 countries), and regional representative aquaculture-producing countries (seven countries) species cultured in China have a higher diversity, richness, and evenness, with a relatively low dominance of individual species (Table 1.5.3). Cluster analysis results of the diversity index (H') show that China is unique, representing an independent group largely different from the other countries (Figure 1.5.4). European countries (and Australia, but excluding Russia) are clustered together, with Norway being different from the other four European countries, with lower diversity, richness, and evenness. The remaining 16 countries are clustered into one group, which is then divided into three subgroups. Bangladesh alone is a subgroup with a relatively high diversity index; Korea, the USA, Japan, Vietnam, and Thailand form another subgroup; and all other countries belong to the third subgroup. Figure 1.5.5 shows the changes in the species diversity index H' in the major aquaculture-producing countries for the period 1950–2013. These changes can be divided into two stages: the H' index of most countries showed a rising trend before 1995; only China showed a sharp increase after 1980. The H' of most countries barely changed or even declined after 1995; whereas China, Vietnam, Spain, and the USA exhibited a trend of continuous increase. These characteristics of diversity indicate that the species structure of Chinese aquaculture has significant high diversity, with a trend towards good development. High biological diversity is important for the protection of genetic diversity of species, the stability and sustainability of aquaculture ecosystems, and achieves high efficiency of biomass output.

1.5.4 Cultured Species that are Independent of an External Feed Inputs

The contribution of species that are not dependent on an external feed input in Chinese aquaculture varied greatly in different periods, and shows a significant downward trend. Before 1990, aquaculture of most species was based on food produced naturally, with a high non-fed rate of 96.7–100 percent. Thereafter, the contribution of non-fed species was largely reduced from 90.5 percent in 1995 to 59.2 percent in 2010 and has remained stable for the last three years, showing a smaller decline (53.4–54.2 percent) (Figure 1.5.6a and b). However, compared with the world average of culture of non-fed species (33.3 percent, 2010) (FAO 2012), the current non-fed rate of Chinese aquaculture remains relatively high.

Among the five categories (Figure 1.5.6a and b), the non-fed numbers for farmed fish has dropped greatly. Before 1990, aquaculture in natural waters was mainly for filter feeding and herbivorous, non-fed species. After that, due to the availability and use of compound feeds, attempts to improve production efficiency and to increase the contributions from omnivorous and carnivorous fish species, numbers and contributions of non-fed species decreased from 87.6 percent in 1995 to 41.8 percent in 2010, becoming stable during

Table 1.5.3 Biodiversity indices of cultured species.

Country	Production[1]	Species	*H′*	*dM*	*J′*	*D*	Region
China[2]	57 113 175	92	3.438	5.095	0.760	0.047	East Asia
Korea[2]	1 533 446	61	1.905	4.213	0.463	0.201	East Asia
Japan[2]	1 027 185	44	2.070	3.106	0.547	0.176	East Asia
Indonesia[2]	13 147 297	47	1.533	2.806	0.398	0.417	Southeast Asia
Vietnam[2]	3 294 480	26	2.005	1.666	0.615	0.195	Southeast Asia
Bangladesh[2]	1 859 808	30	2.554	2.009	0.751	0.099	Southeast Asia
Thailand[2]	1 056 944	41	2.143	2.884	0.577	0.167	Southeast Asia
Myanmar[2]	930 780	25	1.476	1.746	0.459	0.443	Southeast Asia
India[2]	4 554 109	28	1.565	1.761	0.47	0.34	South Asia
Philippines[2]	2 373 386	35	1.463	2.316	0.412	0.395	South Asia
Egypt[2]	1 097 544	25	1.567	1.726	0.487	0.34	Africa
USA[2]	441 098	45	1.938	3.385	0.509	0.215	North America
Canada[3]	174 343	17	1.714	1.326	0.605	0.252	North America
Chile[2]	1 045 718	23	1.520	1.587	0.485	0.289	South America
Brazil[2]	474 159	44	1.580	3.290	0.532	0.162	South America
Norway[2]	1 247 865	15	0.473	0.936	0.175	0.142	Northern Europe
Spain[3]	223 698	49	1.060	3.897	0.272	0.542	Southern Europe
Italy[3]	162 596	46	1.482	3.750	0.387	0.318	Southern Europe
France[3]	202 178	57	1.076	4.584	0.412	0.271	Western Europe
UK[3]	194 632	34	0.697	2.710	0.198	0.649	Western Europe
Australia[3]	68 761	22	1.254	1.885	0.406	0.429	Oceanica
Russia[3]	155 540	22	1.862	1.757	0.603	0.206	Eurasia

1) Aquaculture species and production cited from FAO statistics data in 2013.
2) Farmed food fish production by top 15 producers.
3) Regionally representative producers from different continents.

2013–2016 (33.7–34.7 percent), and reaching 34.5 percent in 2014. Crustacean culture is based on fed species; with a very low number of non-fed species, 5.0–-8.5 percent from 1985–1995. After that time, due to some changes in aquaculture, the non-fed rate fluctuated at approximately 20 percent, reaching 22.2 percent in 2014. Mollusks usually do not require external feed, and almost 98–100 percent of the species cultured are non-fed, whereas algae depend solely on sunlight and nutrients in the water. For other species, in order to increase output efficiency, the non-fed rate declined from 80.0 percent in 1995 to 13.9 percent in 2014. The large proportion of finfish culture output is related to a concurrent decrease in non-fed species in China in recent years (as shown in Figure 1.5.6).

1.5.4.1 Non-Fed Species in Freshwater Aquaculture

The contribution of non-fed species in aquaculture has decreased greatly. From 1950 to 1990, freshwater aquaculture species dependent on naturally available food was dominant. After that, extensive aquaculture methods relying on natural food types were slowly replaced with fed-aquaculture, and the non-fed numbers declined from 87.3 percent in 1995 to 42.5 percent in 2010, becoming stable during 2011–2014 (34.8–35.8 percent) and reaching 35.7 percent in 2014 (Figure 1.5.7a and b).

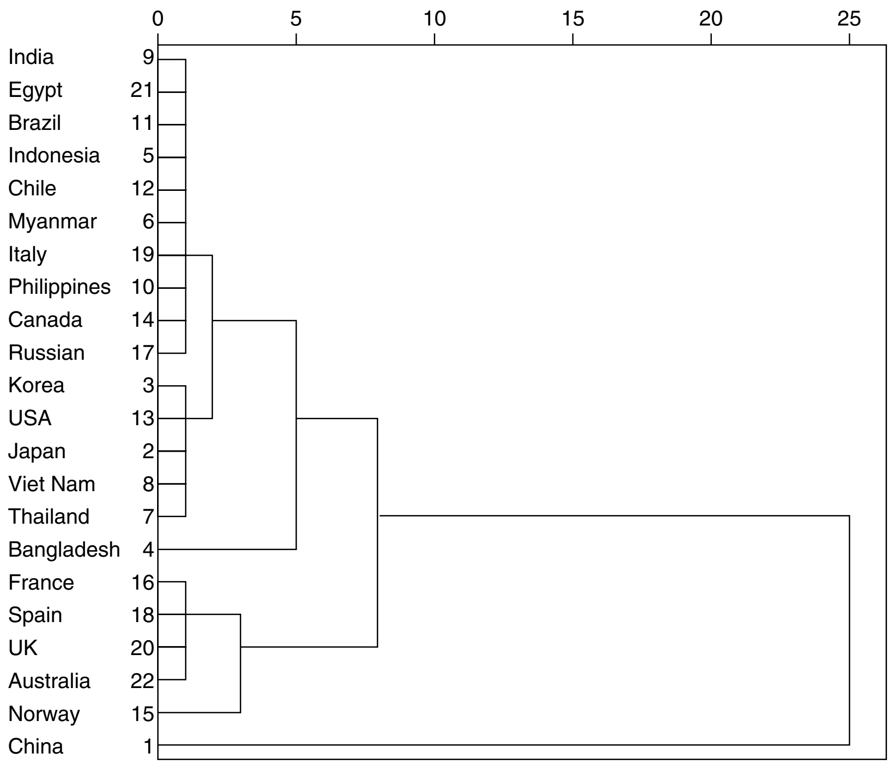
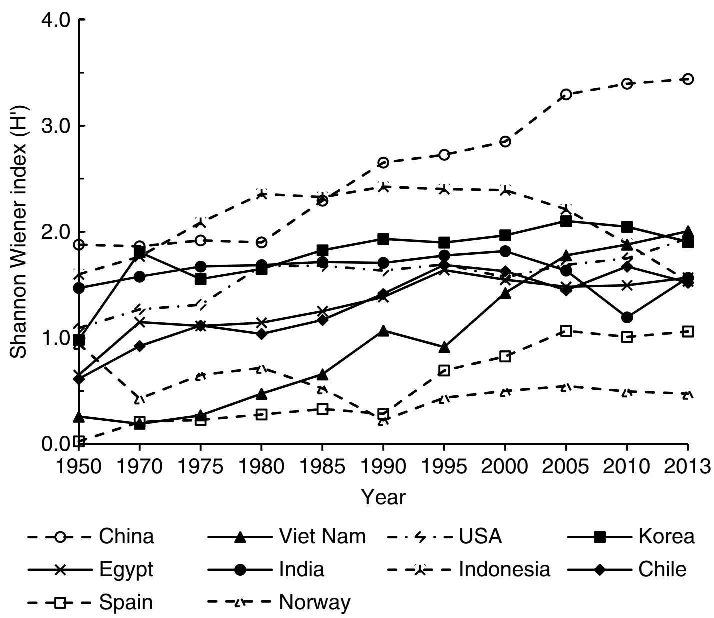


Figure 1.5.4 Cluster analysis of Shannon–Wiener index (H') of the main aquaculture producers in the world. Data *source:* FAO (1950–2013).

Figure 1.5.5 Changes in Shannon–Wiener index (H') of the main aquaculture producers in the world. Data *source:* FAO (1950–2013).



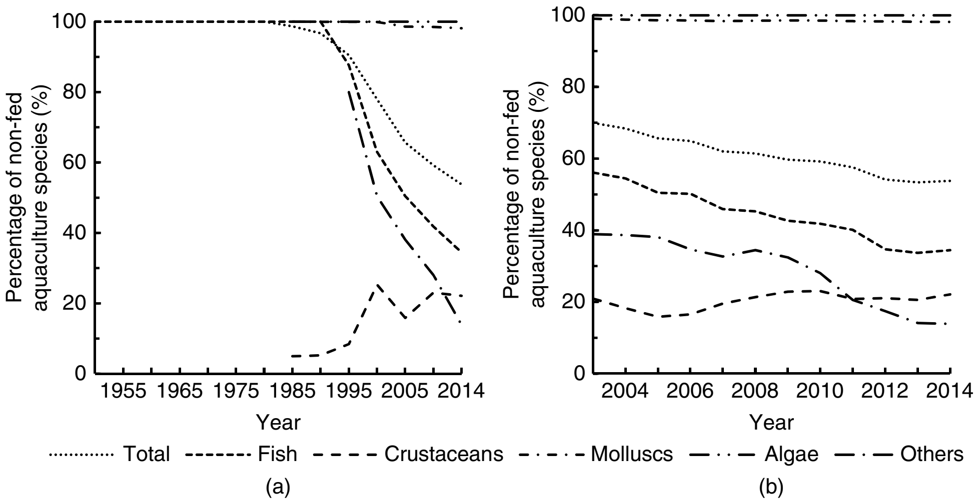


Figure 1.5.6 Decadal (a) and annual (b) changes in the use of non-fed species in Chinese aquaculture. Data *source:* Tang *et al.* (2016a, App. 1–2).

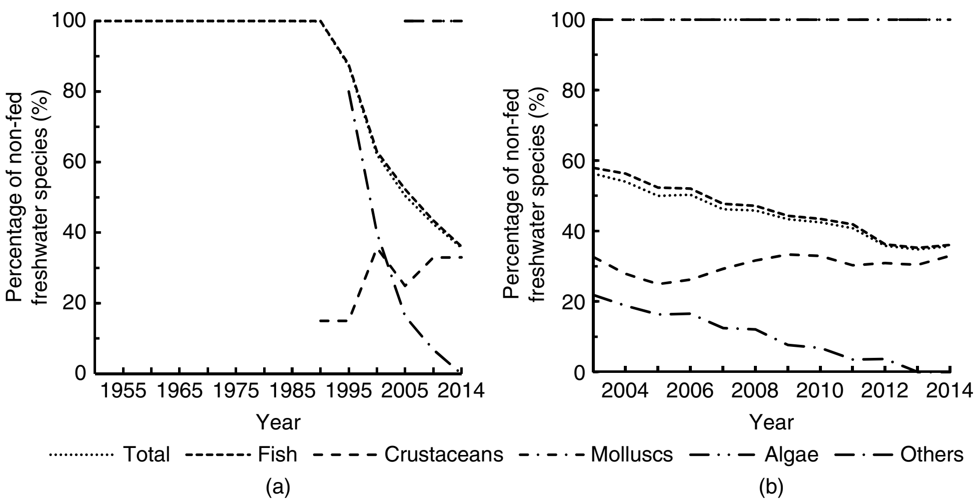


Figure 1.5.7 Decadal (a) and annual (b) changes in the percentage of non-fed species in Chinese freshwater aquaculture. Data *source:* Tang *et al*. (2016a, App. 1).

As shown in Figure 1.5.7, among the five categories, non-fed species in freshwater aquaculture declined greatly. After 1990, when compound feeds began to be used for fish such as black carp, grass carp, common carp and crucian carp, and the proportion of production of fed species increased rapidly. By 2014, the proportion of fed fish reached 85 percent of total fish culture production. Previously, no feed was provided for culture of silver carp and bighead carp, which mainly relied on natural food in the water. After 2012, 5 percent of silver carp and bighead carp culture used external feeds, however, the proportion of silver carp and bighead carp production in the total freshwater aquaculture production continued to decrease, from 65 percent in 1950 down to 25 percent in 2014. These changes greatly contributed to the decrease of non-fed species in freshwater aquaculture. Artificial feeds are used in all cultured *Siniperca* and bass. The farming of other fish, including sturgeon (*Acipenser* spp.), trout (*Salmo trutta*), pond smelt (*Hypomesus* spp.), long-snout catfish (*Leiocassis longirostris*), *Fugu*, and salmon (*Salmo salar*), are based on formulated feeds. Therefore, the contribution of non-fed species to freshwater aquaculture declined from 87.6 percent in 1995 to 43.5 percent in 2010, becoming stable in 2011–2014 (35.2–36.3 percent) and reaching 36.1 percent in 2014. In 1985–1995, cultured crustaceans were fed fresh fish, and the non-fed rate was as low as 0.0–15.0 percent. After 2000, a big change was made when the proportion of *M. rosenbergii* production based on formulated feed increased gradually, and based entirely on external diets in 2013. For cultured *Squilla,* an 80 percent feeding rate was achieved. Before 2009, the aquaculture of *P. clarkii* was based on the *Potamogeton malaianus*, black algae, and other large aquatic plants, without the use of compound feeds. Since 2010, 5–10 percent of the production of *P. clarkii* is on formulated feeds. In recent years, large-sized crabs were raised by feeding on gastropods farmed on planted grass; therefore, the proportion of crab culture based on compound feeds gradually declined. Thus, since 2000, the percentage of non-fed species has fluctuated between 24.9 percent and 35.7 percent, reaching 33.0 percent in 2014. As regards the culture of the soft-shelled turtle (*Trionyx sinensis*), other turtles, and *Rana* spp. the proportion based on compound feeds increased after 2000, accounting for 60 percent of production, and nutritionally wholesome diets began to be used by 2013.

1.5.4.2 Non-Fed Species in Mariculture

Non-fed species used in mariculture has remained at a high level. From 1950 to 1980, mariculture relied on natural foods, with non-fed species being nearly 100 percent. From 1985–2000, the proportion of non-fed species fluctuated between 88.1 percent and 97.8 percent, and then gradually dropped slightly from 89.1 percent in 2003, becoming stable during 2011–2013 (83.0–83.7 percent), reaching 83.0 percent in 2014 (Figure 1.5.8).

The situations of the five categories are shown in Figure 1.5.8. All mollusks cultured prior to 1995 were non fed. There are a few mollusk species that are fed, which reduced the non-fed proportion to 99.9–98.1 percent from 2000–2014. The number of non-fed crustaceans was relatively low. Although the non-fed proportion of some species (such as *Penaeus japonicus*) has increased to 20 percent since 2009, the overall impact is minor due to the small overall proportion produced. The non-fed proportion of crustaceans was 5.0 percent from 1985–2000 and 0.5–1.3 percent from 2003–2014; mariculture for fish is based on feeding. The recent increase in fish farming is also the main factor affecting the decrease in the proportion of non-fed species in mariculture. For other species, sea urchin culture was partially based on cage feeding with kelp and wakame

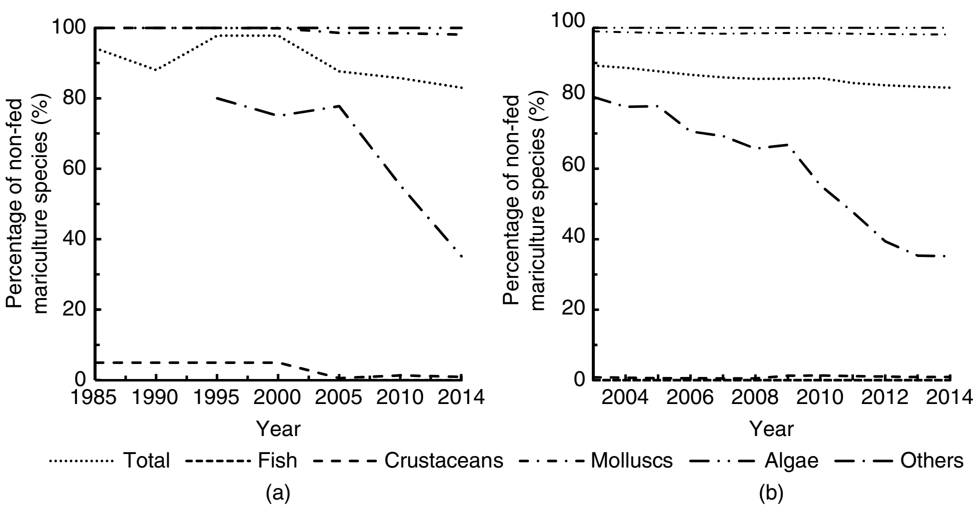


Figure 1.5.8 Decadal (a) and annual (b) changes in non-fed species of Chinese mariculture. Data *source:* Tang *et al.* (2016a, App. 2).

(*U. pinnatifida*); the overall non-fed proportion of sea urchin reached 70–80 percent. The use of compound formulated feed in *Rhopilema* culture gradually increased from 3 percent in 2003 to 30 percent in 2014, and other aquaculture feeds included copepods and other zooplankton, with a non-fed proportion of 97–70 percent. In the last 10 years, the proportion of compound feeds (main components are algae and sea mud) used in sea cucumber culture has increased, with the non-fed proportion decreasing from 80 percent in 1995 to 2 percent in 2014.

1.5.5 Trophic Levels of Cultured Species

The trophic level of species used in Chinese aquaculture is low and relatively stable, with a slight decline in recent years. As shown in Figure 1.5.9a and b, although the trophic levels fluctuated in different periods of development due to the changes in species composition (mainly the exploration and development of marine aquaculture), the extent of the change was small (2.12–2.33). The changes over many years can be divided into three stages:

- from 1950–1980, the trophic level dropped to 2.12 from 2.33;
- 1985–2005, the trophic level showed an increase-decrease-increase pattern between 2.17–2.32;
- 2006–2014, due to the widespread application of compound feeds, and a decrease in the use of fishmeal and fish oil (Tang *et al.* 2016a, App. 3–4; Han *et al.* 2016), the trophic level dropped to 2.25 from 2.32.

During 2011–2013, the variation in the trophic levels was small (2.25–2.27), reaching 2.25 in 2014. The trophic level of Chinese aquaculture is not only lower than that in the developed countries (such as European countries), but also lower than that of other developing countries (e.g. Southeast Asia) (Tacon *et al.* 2010; Olsen 2011).

The annual changes in the trophic level pyramid structure shown in Figure 1.5.10a (1985–2014) further demonstrates that the trophic level pyramid for Chinese aquaculture sits on a sturdy base of trophic level 2, accounting for 62.8–71.3 percent of production, followed by trophic level 3 at 20.7–27.7 percent, while trophic levels 1 and 4 showed very low proportions of 4.2–8.9 percent and 0.8–3.4 percent, respectively. The foundation for the trophic level pyramid of global aquaculture, however, is trophic level 3 (Tacon *et al.* 2010), indicating that Chinese aquaculture ecosystems have more biomass output.

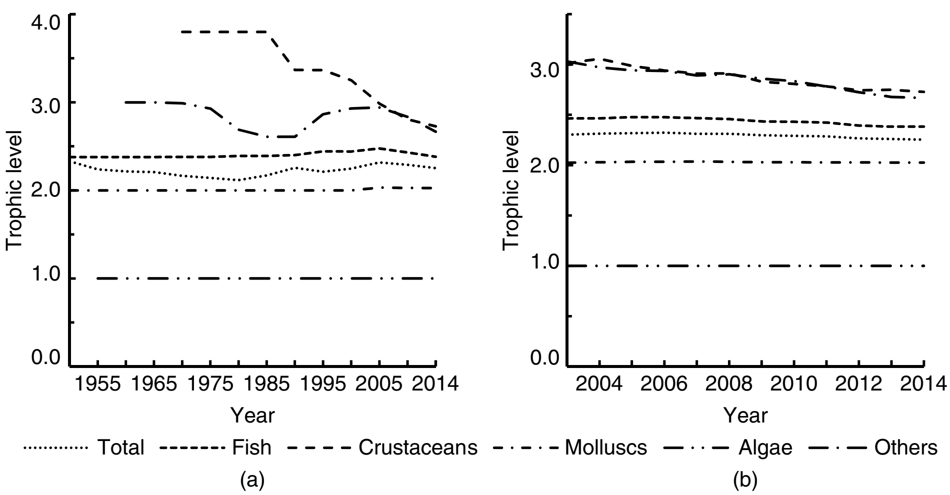


Figure 1.5.9 Decadal (a) and annual (b) changes in mean trophic level of species used in Chinese aquaculture. Data *source:* Tang *et al.* (2016a, App. 5–6).

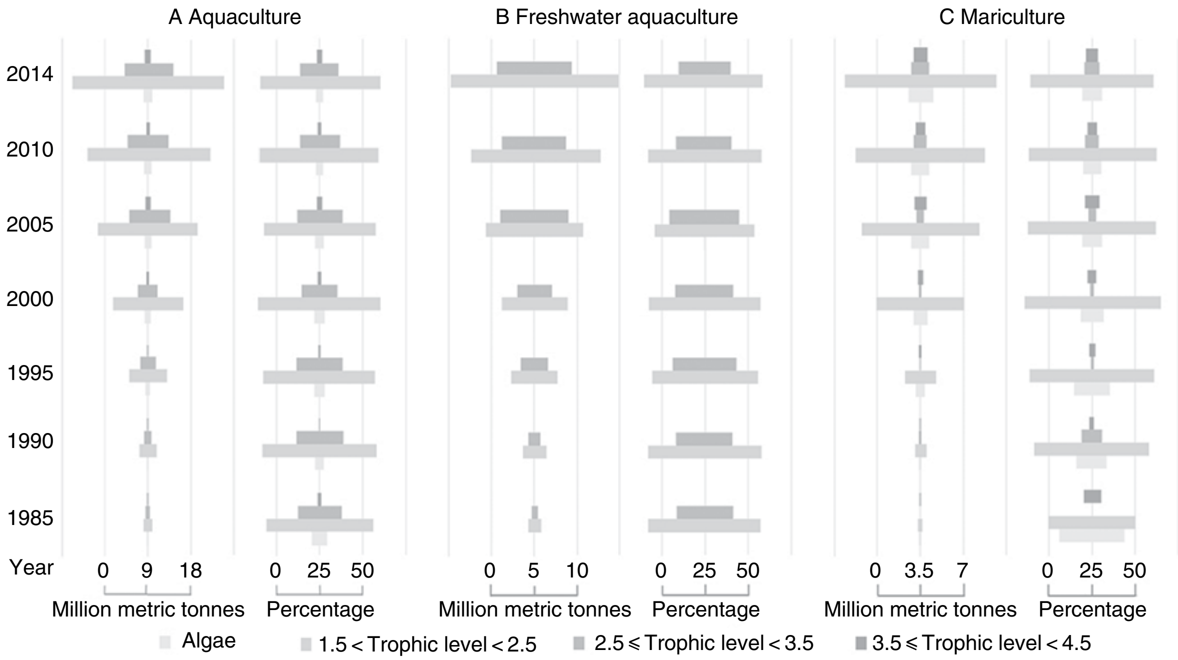


Figure 1.5.10 Changes in trophic pyramid structure of Chinese aquaculture, and aquaculture, freshwater aquaculture and mariculture production by calculated weighted mean trophic level, the percentage based on the proportional contribution to the total production, total species production taken from *China Fishery Statistical Yearbook* (2004–2016) and FAO (1950–2013), and trophic levels for individual species taken from App. 5–6 of Tang *et al*. (2016a).

For the five categories (Figure 1.5.9a and b), the trophic level for finfish culture changed slightly, varying from 2.38–2.48 over the years, with a trophic level of 2.38–2.40 for 1950–1990 and a slight increase during 1995–2005 (2.44–2.48), attributable primarily to the development of marine finfish with species at higher trophic levels. After 2006, the trophic level for finfish culture showed a downward trend, and in recent years the trophic level has stabilized (2.38–2.39), and was at 2.38 in 2014. Although the fluctuations in the trophic level of finfish were relatively small, due to the relatively large proportion of finfish in aquaculture production, its impact on the overall trophic level of aquaculture is high. The trophic level of mollusks after 2003 increased slightly (by 0.02–0.04), stabilizing at 2. The trophic level of algae is 1. The continuous development of aquaculture for species occupying low trophic levels, such as marine algae and mollusks, had an important effect on the decline of the total aquaculture trophic level from 1950–1980, as well as on subsequent fluctuations. The changes in the trophic levels for crustaceans and other species were relatively large. These levels declined gradually from 3.80 in 1970 for crustaceans, and fluctuated between 2.84 and 3.03 from 1960–2010 for other species, becoming stable during 2011–2013, with trophic levels of 2.73 and 2.67 in 2014, respectively. Although the total amount of aquaculture production of these two categories was small, the changes were relatively large, showing a certain influence on the overall trophic level.

1.5.5.1 Trophic Levels in Freshwater Aquaculture

The trophic levels for species and categories, as well as the respective annual changes are listed in Table 1.5.4. The trophic level for freshwater aquaculture showed minor fluctuations, in the range of 2.35–2.45. The changes in this level over many years were as follows: the trophic level from 1950–1990 stabilized at 2.38; in 1995–2006, the trophic level increased to 2.40–2.45; and after 2006, it gradually decreased, showing little change in the last three years (2.35–2.37), reaching 2.35 in 2014. In 2014, species at this level accounted for

Table 1.5.4 Trophic level of Chinese freshwater aquaculture by species and species groups from 1950 to 2014.

Species	1950–1985	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Fish	2.38	2.38	2.41	2.37	2.40	2.40	2.41	2.41	2.40	2.39	2.37	2.37	2.36	2.33	2.32	2.32
Ctenopharyngodon idellus	2.00	2.00	2.03	2.06	2.07	2.07	2.07	2.07	2.06	2.05	2.03	2.03	2.03	2.03	2.00	2.03
Hypophthalmichthys molitrix	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.19	2.19	2.19
common carp	2.92	2.92	2.82	2.57	2.54	2.54	2.51	2.48	2.44	2.40	2.34	2.34	2.33	2.24	2.24	2.24
Hypophthalmichthys nobilis	2.77	2.77	2.77	2.77	2.77	2.77	2.77	2.77	2.77	2.77	2.77	2.77	2.77	2.73	2.73	2.73
Carassius carassius	2.28	2.28	2.31	2.31	2.31	2.31	2.32	2.29	2.28	2.27	2.23	2.23	2.20	2.18	2.18	2.18
Tilapia	2.60	2.60	2.54	2.37	2.35	2.33	2.33	2.32	2.29	2.29	2.25	2.25	2.23	2.17	2.17	2.17
Megalobrama	2.00	2.00	2.06	2.13	2.14	2.14	2.15	2.15	2.15	2.14	2.13	2.13	2.13	2.10	2.10	2.10
Mylopharyngodon piceus	3.33	3.33	3.19	2.89	2.80	2.80	2.75	2.75	2.68	2.67	2.57	2.57	2.53	2.46	2.37	2.37
Ophicephalus argus		—	—	—	3.44	3.36	3.33	3.33	3.29	3.27	3.23	3.21	3.19	3.09	2.98	2.90
Silurus		—	—	—	3.28	3.20	3.17	3.16	3.12	3.07	3.05	3.00	2.87	2.83	2.75	2.71
Monopterus albus		—	—	—	3.43	3.42	3.40	3.38	3.33	3.31	3.24	3.22	3.22	3.17	3.17	3.17
Bass		—	—	—	3.33	3.33	3.31	3.31	3.31	3.31	3.31	3.30	3.29	3.27	3.26	3.25
Loach		—	—	—	3.06	2.95	2.86	2.86	2.79	2.74	2.72	2.67	2.61	2.51	2.43	2.37
Pseudobagrus			—	—	3.12	3.02	2.99	2.92	2.88	2.80	2.77	2.77	2.64	2.60	2.54	2.54
Siniperca		—	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34
Ictalurus			—	—	2.47	2.40	2.39	2.39	2.34	2.33	2.31	2.31	2.26	2.22	2.16	2.16
Anguilla		3.33	3.32	3.32	3.31	3.31	3.31	3.31	3.25	3.25	3.21	3.21	3.17	3.11	3.10	3.10
Piaractus brachypomus		—	—	—	2.46	2.33	2.32	2.32	2.28	2.26	2.26	2.23	2.17	2.13	2.10	2.10
Icefish		—	—	—	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10
Other fish		—	—	—	2.50	2.48	2.46	2.45	2.44	2.43	2.42	2.41	2.40	2.40	2.40	2.40
Crustaceans	—	3.33	3.33	3.08	3.03	2.94	2.88	2.86	2.82	2.79	2.74	2.73	2.70	2.66	2.67	2.64
Macrobrachium rosenbergii		—	—	3.08	3.03	2.98	2.93	2.93	2.91	2.82	2.79	2.79	2.67	2.61	2.56	2.56
Squilla		—	—	3.15	3.09	3.03	2.96	2.96	2.90	2.87	2.80	2.76	2.72	2.68	2.60	2.60
Procambarus clarkii			—	—	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.59	2.58	2.58	2.56	2.56
Litopenaeus vannamei			—	—	3.06	2.94	2.91	2.88	2.84	2.82	2.73	2.73	2.63	2.57	2.56	2.56
Eriocheir sinensis	—	3.33	3.33	3.05	2.98	2.91	2.84	2.84	2.81	2.85	2.81	2.81	2.85	2.79	2.78	2.78
Mollusks		—	—	—	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25

(Continued)

Table 1.5.4 (Continued)

Species	1950–1985	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Unionid			—	—	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
Gastropod		—	—	—	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
Corbiculid			—	—	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
Algae			—	—	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Spirulina			—	—	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Others		—	3.28	3.11	3.17	3.16	3.15	3.15	3.10	3.10	3.04	3.05	3.02	2.95	2.90	2.90
soft-shelled turtle		—	—	—	3.23	3.22	3.22	3.22	3.18	3.19	3.12	3.12	3.11	3.05	3.00	3.00
Rana		—	—	—	3.06	3.05	3.03	3.03	2.96	2.93	2.87	2.85	2.75	2.65	2.64	2.64
Turtle		—	3.28	3.11	3.07	3.05	3.03	2.99	2.96	2.93	2.90	2.90	2.78	2.68	2.64	2.64
Freshwater culture	2.38	2.38	2.41	2.40	2.45	2.45	2.45	2.45	2.44	2.43	2.41	2.41	2.40	2.37	2.36	2.35

Note: Trophic level of culture species calculated by 1+ (percentage fed compound aquafeed * trophic level of compound aquafeed+ percentage fed non-compound aquafeed * trophic level of the other diets+ percentage non-fed * trophic level of the species in natural waters) Year 1950–1990 represents year 1950, 1955, 1960, 1965, 1970, 1975, 1980 and 1985, respectively. "—" indicates that the species has been cultured but there is no data from China Fishery Statistical Yearbook. Blank space in the table means no culture for the species. The method of trophic level calculation was found in Tang *et al.* 2016a.

69.6 percent of freshwater aquaculture production. The weighted trophic level of six species with an individual annual production of more than 1 000 000 tonnes was 2.24. Of these, five species (grass carp, silver carp, common carp, crucian carp, and tilapia) showed a trophic level of less than 2.25, whereas bighead carp, which depends on natural food showed a slightly higher trophic level (2.73), indicating that low-trophic-level fish dominated Chinese freshwater aquaculture. Figure 1.5.10b shows that in the trophic level pyramid structure of freshwater aquaculture, level 2 accounted for approximately 65 percent, and trophic level 3 accounted for approximately 35 percent.

For the five categories (Table 1.5.4), the trophic level of finfish in freshwater aquaculture fluctuated slightly in the range of 2.32–2.41 and changed over many years. The trophic level of finfish was 2.38 in 1950–1990. In 1995–2006, due to the aquaculture development of carnivorous fish, including the snake head (*C. argus*), catfish (*M. albus*), bass, Mandarin fish (*Siniperca chuasti*), eel (*Anguilla* spp.), icefish (*Neosalanx* spp.), and *Silurus spp.*, the trophic level increased slightly, reaching 2.40–2.41. After 2006, due to the widespread use of compound feeds, the trophic level showed a decreasing trend, becoming stable in recent years (2.32–2.33), and was at 2.32 in 2014. For crustaceans and other species, respectively, due to the popularization of compound feeds, the trophic levels decreased from 3.33 and 3.28 in 1995, to 2.64 and 2.90 in 2014. The trophic levels of mollusks and algae remained at 2.25 and 1.00, respectively.

1.5.5.2 Trophic Levels in Mariculture

Mariculture is mostly mollusks and algae which are at low trophic levels, resulting in a significantly lower overall trophic level than that of freshwater aquaculture (Table 1.5.5). Changes also occurred in the trophic level in mariculture over many years. Mariculture before 1985 was mostly of mollusks and algae, with a trophic level of 1.71–2.00. In 1990–2008, due the development of crustacean and finfish aquaculture, the trophic level increased to 1.95–2.13. After 2009, due to the widespread application of compound feeds, the trophic level decreased to 2.12–2.10, reaching 2.10 in 2014. Crustacean and finfish aquaculture production accounted for 62.5 percent of mariculture production in 2014. The species with an individual production of more than 1 000 000 tonnes included oysters, clams, scallops, and kelp, with a weighted overall trophic level of 1.88, accounting for 13.6 percent of mariculture production. The species with an individual production of 0.5–1 million tonnes included *L. vannamei*, mussels, and razor clams, with a weighted overall trophic level of 2.19, of which the trophic level of *L. vannamei* was slightly higher (2.54). The trophic levels of the other two species were both 2.00, indicating that species with low trophic levels are the main features of Chinese mariculture. Figure 1.5.10c. clearly demonstrates this characteristic, with annual variations in the trophic level pyramid structure for mariculture.

For the five categories (Table 1.5.5), due to the aquaculture development of carnivorous gastropods, the trophic level of mollusks increased slightly from 2.02–2.04. The trophic level of algae is 1.00, and the trophic level of crustaceans varies widely. Due to the increase in the proportion of species receiving compound feeds, and the corresponding reduction in the culture of freshwater low-valued fish and mollusks, and feeding of fresh low-valued fish/mollusks feeding, the trophic level declined from 3.50 in 1985 to 2.89 in 2014. For the same reason, the trophic level of finfish decreased from 4.50 in 1985 to 3.77 in 2014, and the trophic level of other species dropped from 3.00 in 1985 to 2.31 in 2014.

1.5.6 Concluding Remarks

The results presented in this Chapter show that the structure (trophic) of Chinese aquaculture is relatively stable, with small variations occurring over the years. It is characterized by a large number of species, rich diversity, multi-trophic levels, lower overall trophic level, higher eco-efficiency, and higher biomass output. These characteristics are driven by many factors, including cultural traits and developing demand; the four major freshwater aquaculture species that include black carp, grass carp, silver carp, and bighead carp, all have a long aquaculture history. Except black carp, these species are either filter feeding or herbivorous. The culture of

Table 1.5.5 Trophic level of Chinese mariculture by species and species groups from 1985 to 2014.

Species	1950–1980	1985	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Mollusks	2.00	2.00	2.00	2.00	2.00	2.02	2.03	2.03	2.03	2.04	2.03	2.03	2.03	2.03	2.03	2.02	2.03
Haliotis			2.00	2.00	2.00	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01	2.01
Conch		—	—	—	—	3.50	3.50	3.50	3.50	3.48	3.48	3.48	3.48	3.48	3.46	3.46	3.46
Oyster	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Cockle	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Mussel	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Atrina pectinata						2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Scallop		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Clam		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Razor clam	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Algae	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Crustaceans	—	3.50	3.37	3.38	3.32	2.98	3.25	3.15	3.07	3.07	3.14	3.00	2.96	2.95	2.90	2.89	2.89
Penaeus vannamei		—	—	—	—	3.04	2.91	2.78	2.70	2.70	2.70	2.64	2.60	2.60	2.56	2.54	2.54
Penaeus monodon		—	—	—	—	3.02	2.97	2.87	2.87	2.86	3.79	2.70	2.64	2.60	2.60	2.60	2.60
Fenneropenaeus chinesis	—	3.50	3.37	3.33	3.25	3.10	2.95	2.95	2.95	2.91	2.91	2.86	2.86	2.82	2.82	2.82	2.82
Penaeus japonicas		—	—	—	—	3.37	3.37	3.37	3.33	3.33	3.31	3.21	3.20	3.20	3.20	3.20	3.20
Portunus trituberculatus.		—	—	—	—	4.01	4.01	4.01	4.01	3.99	3.98	3.93	3.91	3.91	3.85	3.85	3.85
Scylla serrate		—	—	—	—	4.01	4.01	4.01	4.01	4.01	3.98	3.98	3.98	3.97	3.97	3.97	3.97
Fish	—	4.59	4.56	4.53	4.50	4.46	4.42	4.33	4.29	4.19	4.13	4.07	4.02	3.87	3.84	3.76	3.77
Lateolabrax japonicus		—	—	—	—	4.29	4.13	3.78	3.78	3.42	3.42	3.41	3.38	3.14	3.11	2.93	2.93
Lefteyed flounders			—	—	—	4.33	4.32	4.03	3.99	3.95	3.95	3.98	3.83	3.80	3.80	3.64	3.64

Larimichthys crocea				—	—	4.52	4.52	4.52	4.52	4.49	4.48	4.43	4.43	4.35	4.35	4.25	4.25
Rachycentron canadum					—	4.56	4.56	4.52	4.52	4.51	4.51	4.51	4.43	4.43	4.42	4.42	4.42
Seriola						4.53	4.53	4.52	4.52	4.52	4.43	4.43	4.43	4.42	4.25	4.25	4.25
Sea bream			—	—	—	4.44	4.44	4.44	4.29	4.27	4.26	4.08	4.08	3.91	3.91	3.75	3.75
Sciaenops ocellatus					—	4.46	4.45	4.38	4.37	4.29	4.27	4.27	4.25	4.25	4.07	4.05	4.05
Fugu			—	—	—	4.44	4.44	4.44	4.43	4.43	4.43	4.43	4.42	4.25	4.24	4.24	4.24
Epinephelus			—	—	—	4.56	4.56	4.52	4.52	4.52	4.52	4.45	4.44	4.44	4.28	4.35	4.35
Righteyed flounders					—	4.33	4.31	4.31	4.16	4.16	4.02	3.99	3.85	3.70	3.48	3.24	3.24
Trachinotus ovatus				—	—	4.08	4.08	4.08	3.91	3.75	3.34	3.34	3.16	3.08	2.89	2.89	2.79
Other fishes	—	—	—	—	—	4.52	4.52	4.52	4.43	4.43	4.27	4.27	4.27	4.08	4.08	3.91	3.91
Others	—	3.00	3.00	2.99	2.93	2.69	2.61	2.57	2.51	2.52	2.63	2.61	2.56	2.40	2.36	2.35	2.31
Sea cucumber		—	—	2.32	2.30	2.28	2.26	2.26	2.25	2.23	2.21	2.21	2.18	2.13	2.10	2.10	2.10
Sea urchin		—	—	—	—	1.98	1.98	2.28	2.28	2.28	2.3	2.3	2.31	2.31	2.31	2.32	2.32
Rhopilema		—	—	—	—	2.50	2.50	2.51	2.5	2.5	2.5	2.5	2.48	2.48	2.48	2.47	2.47
Mariculture	1.71–2.0	1.77	2.06	1.95	2.03	2.07	2.09	2.10	2.11	2.12	2.13	2.12	2.11	2.11	2.10	2.10	2.10

Note: Same as Table 1.5.4.

mollusks and algae, which either directly prey on phytoplankton by filter feeding or absorb nutrients in the water through photosynthesis, has been developing rapidly since its early stages in order to resolve the problems of an insufficient seafood supply. The common feature of these species is low trophic level and high production, and relatively low technical requirements in culture, which enabled a rapid expansion and commercialization. We are well aware of the varying food habits of different ethnic groups: for example, the Japanese are accustomed to eating raw fish and surimi, Westerners prefer to eat fish fillets, while Chinese prefer fresh and live seafood. Chinese people enjoy a variety of aquaculture products, and sometimes prefer new dishes to routine ones. These preferences have significantly affected the selection of aquaculture species, as well as the production structure, and the amount of production, thereby promoting the development and the diversification of cultured species. Through long-term development, the structural characteristics of Chinese aquaculture have been effective, and have been in accordance with the needs and norms of modern development, with high production levels achieved as shown earlier. Aquaculture can not only solve the problem of the lack of seafood resources, increase the income of fish farmers, provide high-quality protein, and contribute significantly to adjustments in the fisheries structure (TFCA 2013), but it can also play an active role in reducing the release of CO_2 and alleviating eutrophication in waters (Tang *et al.* 2007, 2011; De Silva and Soto 2009; Xie *et al.* 2013).

Based on the above analysis, the future development of Chinese aquaculture should follow green, sustainable, and environmentally friendly development concepts, aim at aquaculture with higher efficiency, higher quality, better ecology, health and safety. Therefore, Chinese aquaculture should explore new production models for appropriate developments, with different characteristics, including effective aquaculture models, ecological favorable farming models, Integrated Multi-Trophic Aquaculture (IMTA) models, recirculating aquaculture system (RAS) models, and integrated rice-fish farming models; develop an ecosystem-based approach for aquaculture (EAA) based on carrying capacity to enable the construction of environmentally friendly aquaculture (Tang *et al.* 2009, 2014, 2015, 2016b; Tacon *et al.* 2010; Chopin *et al.* 2012; Nebri and Nobre 2012; Tang and Fang 2012). Such development patterns can better highlight the functions of food supply and ecological services of aquaculture, thereby meeting the needs of China's social development, the demands of modern aquaculture development, and the balance of human needs and ecological benefits. In turn, Chinese aquaculture development patterns can thereby make a greater contribution to the protection of national food safety, and the construction of an ecologically conscious civilization.

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Section 2

Traditionally Farmed Species/Species Groups and Farming Practices

2.1

Grass Carp: The Fish that Feeds Half of China

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2.1.1 Introduction

Grass carp (*Ctenopharyngodon idellus*) (Cypriniformes, Cyprinidae, Leuciscinae), also known as white carp, grass-roots fish, and thick fish, is the most important freshwater fish species cultured in China (Figure 2.1.1). Grass carp, silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), and black carp (*Mylopharyngodon piceus*) are the four major Chinese carp species. Grass carp are dark olive in color, shading to brownish-yellow on the sides, with a white belly and large, slightly outlined scales. They have elongated, chubby, torpedo-shaped bodies, a terminal, slightly oblique mouth with non-fleshy, firm lips, and no barbels. The pharyngeal teeth are blunt with transverse grooves, and are arranged in two rows. They have no hard spines on the dorsal and anal fins. Grass carp generally occur in lakes, ponds, pools, and backwaters of large rivers, preferring large, slow-flowing or standing-water bodies with vegetation. They swim quickly, often foraging in groups. The fry feed on zooplankton and the juvenile fish feed on insects, worms, algae, and duckweed. Once they reach about 10 cm, grass carp feed exclusively on aquatic plants, especially gramineous plants. Grass carp display lacustrine migratory behavior, and sexually mature individuals spawn in rivers, reservoirs, and other large bodies of water. The parent fish and larvae then swim into tributaries and lakes after spawning, and usually grow in flooded shallow regions of rivers and subsidiary water bodies, and overwinter in the deep parts of rivers or lakes.

China started to farm grass carp more than 1700 years ago. People began polyculture of grass carp, black carp, silver carp, and bighead carp early as the Tang Dynasty (618–907 CE). However, wild fry had been caught in the Yangtze and Pearl rivers, and cultured in ponds for eating or selling prior to that. In 1958, Chinese scientists developed artificial reproduction technology for grass carp, and established a solid foundation for the large-scale cultivation of grass carp in China. Developments in fisheries science since then have meant that grass carp aquaculture production now ranks top in the world's freshwater aquaculture. Grass carp are an important component of aquatic products. They are the most popular cultured fish species in China and are cultivated over the widest area. The aquaculture production of grass carp in 2013 was 5 070 000 tonnes, accounting for 18.1 percent of the total freshwater aquaculture production (China Fishery Statistical Yearbook 2014).

Aquaculture in China: Success Stories and Modern Trends, First Edition.
Edited by Jian-Fang Gui, Qisheng Tang, Zhongjie Li, Jiashou Liu, and Sena S. De Silva.

Figure 2.1.1 Grass carp, *Ctenopharyngodon idellus*. *Source:* Photo by Dapeng Li.

2.1.2 Regions and Yields of Cultured Grass Carp

Geographical differences mean that the yields of grass carp differ significantly among different regions of China (Figure 2.1.2). Eastern and Central China are the two top producing areas, with yields of 1 644 070 tonnes and 1 610 165 tonnes, respectively per year. Southern China offers conducive conditions for culturing grass carp, with average water temperature exceeding 20°C throughout the year, providing a long period for growth. A rich supply of water resources, good transport facilities, and burgeoning markets for aquaculture products, all contribute to promote the grass carp culture industry. In

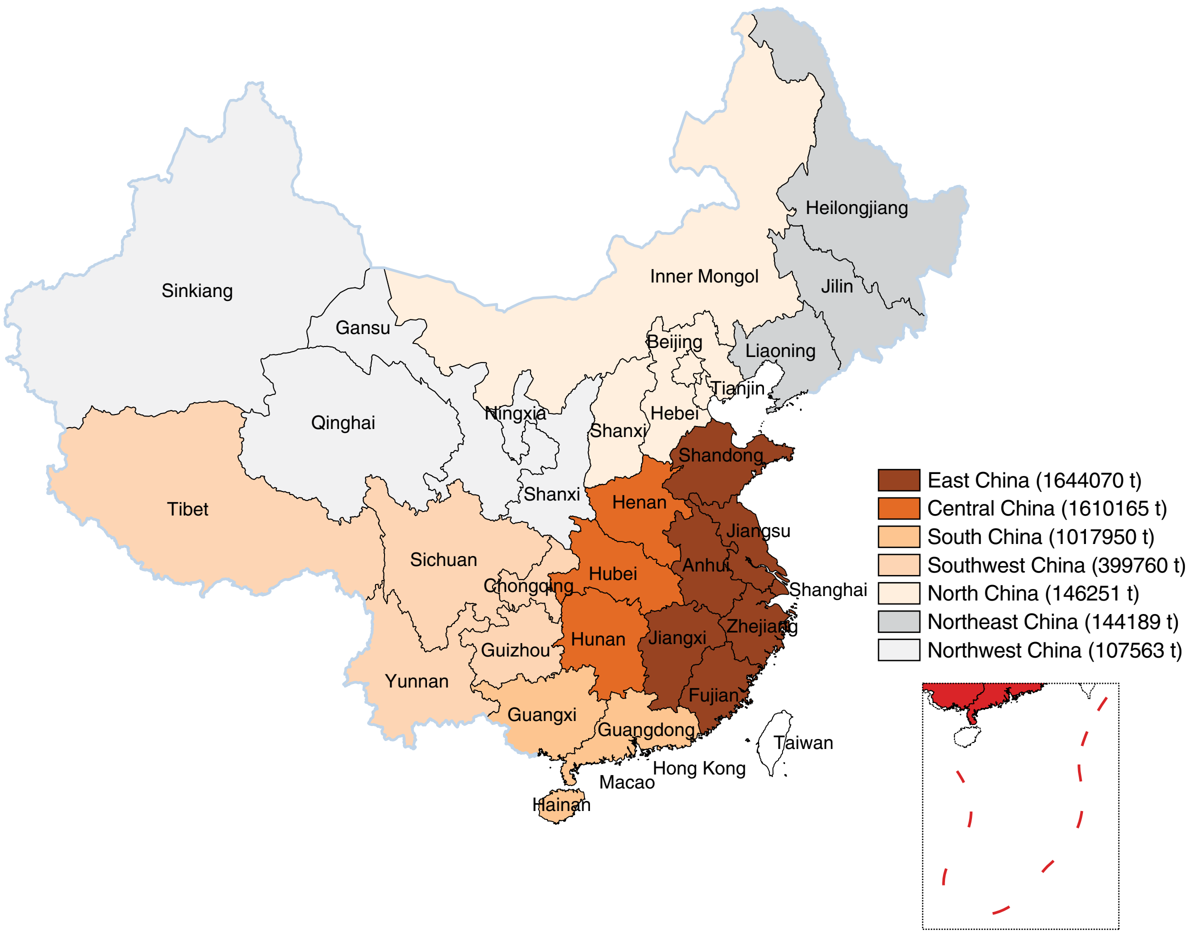

Figure 2.1.2 Yield of cultured grass carp in different regions of China. Data *source:* China Fisheries Yearbook (2014).

southern China, farmers have mastered the skills of carp culture, as well as various other aquaculture models. Annual grass carp yields in this region are about 1 017 950 tonnes. South-western China is characterized by mountains, with narrow and scattered areas of water, limiting water resources for carp culture. The yield of grass carp per year in south-western China is thus only about 399 760 tonnes. North-east China is characterized by high latitude, with long, cold winters and short, warm summers, leaving only a short period for fish culture, in addition to the disadvantage of limited water resources. The total grass carp yield in north-east China is thus only 146 251 tonnes a year. Year-round low water temperatures, and limited water resources mean that yields in south-west and north-east China are low. However, the scale of grass carp culture has gradually increased in these regions in recent years, accounting for 35–40 percent of local aquatic products, with total annual yields of 144 189 tonnes and 107 563 tonnes, respectively.

2.1.3 Culture Models

Several different grass carp culture models are practiced in China. They can be classified according to various characteristics: farm location (pond culture, river culture, lake culture, reservoir culture, cage culture, factory culture, paddy culture), water conditions (closed water culture, flowing water culture, circulating culture), grow-out species combination (monoculture, polyculture, mixed-culture), and culture intensity (intensive culture, semi-intensive culture, extensive culture). Pond culture is the main culture model for grass carp, accounting for 71 percent of all freshwater aquaculture production, followed by reservoirs culture (12.6 percent), lake culture (5.8 percent), culture in river channels and rivulets (3.1 percent), paddy culture (2.4 percent), and other models (5.1 percent).

2.1.3.1 Pond Culture of Grass Carp

China has a long history of grass carp culture and has thus developed sophisticated techniques over the years. However, pond cultures may be scattered over a wide geographical range. Most pond culture farms operate on a small scale with limited finances and anti-risk capacities. Professional aquaculture cooperatives have been established to help solve these problems and adapt to fast-changing market conditions. These cooperatives have several advantages, including centralized purchasing power which reduces production costs, negotiation initiatives in the target market, as well as the ability to improve individual farmers' anti-risk capacities through group development, improved product quality through standardization of operations, and mass production and focused productivity, making it possible to extend the industrial chain and establish aquatic product brands. Furthermore, aquaculture enterprises also play a decisive role in the sector.

2.1.3.1.1 Key Techniques of Pond Culture

There are four key factors of pond culture of grass carp.

- Selection of a suitable location: ponds must be located away from sources of chemical contamination or pollution, and the environment and water quality must be inspected regularly to ensure its suitability for growing grass carp/aquaculture.
- Water quality requirements include a water body that is easy to fill and drain using a system of water routes, instead of being cross-filled. The water must be kept clean and cool, with adequate nutrients, with an ideal transparency of 25–30 cm, and pH of 7–8.
- Robust seedstock should be selected, and released during cool weather, after disinfection. Grass carp is the main species, but are mixed with other omnivorous cyprinids and crucian carp, and filter-feeders such as silver carp and bighead carp. Grass carp grow fast with lower disease resistance, and are vulnerable to hemorrhages, gill rot disease, intestinal diseases, and red-skin disease. Fish should therefore be vaccinated by soaking, although vaccination by injection is preferable in fish older than two years.

- Compound feed used should meet the nutrient requirements of grass carp, without the need for additional ingredients. However, in addition to compound feeds, winter ryegrass (*Lolium perenne*), *Euphrasia americanum*, *Sorghum sudanense*, and hybrid pennisetum (*Pennisetum americanum* × *P. purpureum*) can also be grown to feed grass carp. The daily food consumption varies according to the weather and water conditions, with the fish usually being fed at 0800 hr or 0900 hr, with enough food to last them until 1600 hr or 1700 hr.
- It is necessary to prevent and treat fish diseases using preventive microbial preparations or low-toxicity drugs, with high efficiency and no residue.

2.1.3.1.2 Regional Characteristics of Pond Culture

China covers a huge geographical area, with abundant resources, complex landscapes, and multiple rivers. Aquaculture systems also differ among different regions. We now consider grass carp aquaculture features in seven areas, based on administrative divisions.

Common aquaculture models in eastern China include grass carp mixed culture with black carp, extensive grass carp culture with pearls, cage culture, crucian carp/grass carp polyculture, and culture with grass carp as the main species. In crucian carp/grass carp polycultures, 60–70 percent of the yield is accounted for by crucian carp. In culture practices with grass carp as the main species, 300–600 grass carp per mu (1 mu = 0.0667 ha) is stocked using two different strategies: first, carp of a size equivalent to 10 fish/kg are used, resulting in marketable fish weighing 1–2 kg at the end of the first year; second, carp weighing 0.25–0.75 kg are stocked at 100–150 fish/mu, producing fish of 1.5–2 kg by the middle of the year, marketable fish weighing 3–4 kg each by the end of the first year, and some fish may reach >8 kg.

Grass carp aquaculture in Central China is characterized by the green-grass aquaculture model – an ecologically efficient culture model – and intensive high-density culture model. In green-grass aquaculture, grass species edible to carp, such as *L. perenne*, *E. americanum*, and *S. sudanense*, are planted in the inner platform of the pond. Grass is used instead of artificial compound pellet feed, and compound feed used only as a supplement.

Intensive high-density culture is also promoted throughout the whole province. The species used in this system is grass carp in mixed culture with silver, spotted silver and crucian carp. This system mainly relies on the use of artificial compound pellet feed(s), and rarely uses green grass, although ecologically efficient cultures use *L. perenne* and *S. sudanense* together with commercial feed. The theory behind this is that the green grass improves digestion and immunity in grass carp, and also improves meat quality, while the fish feces facilitate the growth of photosynthetic bacteria, and increase the amount of dissolved oxygen in the water, thus also improving meat quality indirectly.

Grass carp farming in southern China is characterized by high-density intensive culture, resulting in high yields of about 2500 kg/mu (37 481 kg/ha) in the country. Carp here are harvested twice a year, involving grass carp and 'crisped grass carp' cultures (see section 2.1.8 below). In addition, the circulating-water pond-culture model, and 'slimming carp' culture model, in which less feed and more exercise are applied to carp culture so that carps become slim. Increasing scale of culturing, stable output, an integrated system, and advanced techniques mean that this twice-yearly harvesting system can generate good profits. The 'slimming carp' and spring culture systems remain small scale, because of their features and complex procedures, but they produce expensive fingerlings, with considerable economic value and huge market demand.

In south-west China, grass carp are mainly cultured based on the weight of fingerlings. Fingerlings can be further divided into three classes (50–150 g, 150–350 g, and 350–500 g), while adults are divided into two classes (1000–1500 g and 2000–2500 g), as well as a large size class for fish >2500 g. This system enables better utilization of the fodder by providing nutrition based on the size of fish. In addition, grass carp farmed in this way is considered delicious and has a high demand, generating good profits.

Pond culture is the main system in north-east China, in which spring fingerlings of grass carp and spotted silver carp are placed in ponds at a proportion of 4:1, and are fed pellet feed. This method reduces feed costs by about 19 percent through the use of a low-protein pellet feed.

In north and north-west China, intensive pond culture and large-water polyculture are the main systems, mainly farming grass carp or polyculturing silver and bighead carp. The whole culture process usually takes three years, during which time the carp are fed artificial feed. However, ecological breeding systems have recently emerged, in which the carp are fed artificial feed for the first two years and forage in the third year.

2.1.3.1.3 Typical Pond Culture Models

Typical grass carp pond farming systems in China include circulating-water culture model, high-density culture model, and green-grass culture model.

Circulating Water Culture Model: The circulating-water culture model, with circulating pond water, uses wetland ecosystems or ecological ditches to purify waste water from the ponds and refill, representing a "zero release" system (Figure 2.1.3). Circulating the pond water reduces occurrence of fish diseases by separating the inflow and drainage. The waste pond water is drained into an artificial wetland, and then purified to be reused for pond culture. Purification by circulating the pond water thus allows full control of the culture environment and conditions, while its energy efficiency and environmentally friendly features, together with the production of better quality products, makes it a desirable approach for an efficient ecological fishery, and a more suitable choice for protecting the environment. Purified cultures using circulating pond water thus reflect the trend towards the development of low-carbon fisheries.

A more advanced circulating purification system involves the use of standardized equipment and facilities to recycle tail water from the culture ponds through a constructed wetland, including a biological cleaning pool and water-treatment facilities. This system generally consists of ponds, channels, water-treatment facilities, and powered equipment (also see Chapter 7.2).

Figure 2.1.3 Exhibition board of recirculating pond aquaculture model for grass carp.

There are several inflow and drainage forms of this system, among which cascade connection is the most common, although some systems use a parallel connection. The cascade connection has the advantage of a larger water-carrying capacity, which promotes water-layer exchanges and provides the capacity for building terraced cultures. This system takes full advantage of food resources but creates greater discrepancy between ponds, which can lead to cross infection. The inflow and drainage channels in the cascade connection form a z-shape between the ponds, with the inflow located at the top of the water body and the drainage channel at the bottom, thus aiding exchange between the higher and lower water layers.

Effluent from the ponds first flows into ecological ditches for level-I purification, followed by level-II and level-III purification pools, after which the water is pumped back into the ponds to enter the next cycle, creating a complete recycling process. Level-I purification mostly occurs in ditches planted with water hyacinth and alligator weed, with frogs, silver carp, and bighead carp forming a natural purification system. Level-II purification pools are planted with water spinach in floating beds, together with other aquatic plants such as water lilies, water milfoil, and curled pondweed, and aquatic animals including clams, frogs, silver carp, and bighead carp. Level-II purification pools form the main part of the circulating water-purification system. Level-III pools are planted with emergent aquatic plants, as well as submerged and floating plants, such as lesser bulrush, triangular club-rush, reeds, dwarf bulrush, and sweet flag (*Acorus* spp.), together with aquatic animals such as clams, freshwater shrimp, silver carp, and bighead carp. Eutrophication in level-III pools is largely prevented by allelopathy, and the water is purified by the abundant plant growth.

High-Density Aquaculture Model: High-density grass carp aquaculture is used to farm grass carp and mixed cultures of grass, silver, bighead, and crucian carp. Precise management of feeding with compound feed helps to prevent diseases, and scientific control and real-time monitoring of water quality, and catching and stocking in rotation, support a high yield. Three main kinds of grass carp fingerling culture are currently used.

The first form of practice is small grass carp weighing 50–150 g stocked during the Spring Festival (from January to February), accounting for more than 80 percent of total pond stock. About 20 percent of pond stock consists of silver carp and crucian carp. The first sale of fish occurs in August when fish weight exceeds 1000 g. The smaller fish are still cultured until they reach a commercial size. At the end of the year, all fish in a pond are sold. The advantages of this model include lower upfront costs, a low feed coefficient, and high output, but the disadvantages include high disease incidence, and relatively low profit.

An alternative system involves mixed culture of large and small grass carp. Early in the year, grass carp weighing 50 g and 250–500 g, respectively, are stocked together with small numbers of silver, bighead, and crucian carp. From the beginning of May, large fish are sold, and fish weighing >1000 g are sold in August, with all fish being sold by the end of the year. This stocking method makes full use of the pond's capacity, generates good profit margins, and reduces disease incidence in small grass carp. However, frequent catching is associated with high costs and high operational requirements.

A third system is based on grazing large grass carp, sold at >4 kg. Stocking is mainly with grass carp of 750–1000 g, together with a few 50-g grass carp, and some silver, bighead, and crucian carp. This system is associated with ease of management and selling, and reduced incidence of disease, but the disadvantages include heavy investment, high risk, and low sale price and profitability.

Green-Grass Culture Model: The green-grass culture model is based on the natural habits of grass carp in the fish pond, and was established by Datonghu Farm in Honghu, under the leadership of Hongxianxi Aquaculture Special Cooperative (Figure 2.1.4). This model uses a "回" shaped pond, with an area of 40–60 mu, 15–20-m wide, a 3.5-m deep ditch, and a shallow central part which is 2 m deep, with 0.2–0.3 m of mud on the bottom. Each pond has at least two sets of aerating equipment (usually impeller-type or spraying-type aerators; Figure 2.1.4). This model operates as follows: the pond is drained and the fish caught at the end of October, and the pond is then disinfected during the Spring Festival. Fingerlings of grass carp, as well as spotted silver, bighead, black, and crucian carp, and yellow catfish are placed in the deep-water zone around the periphery of the pond, at a ratio of 65:12:13:3:5:2.

Figure 2.1.4 Green-grass aquaculture model of grass carp culture, in which the grass replaces the bulk need of compounded pellet feed. *Source:* Photo by Xiaodong Sun. (*See color plate section for the color representation of this figure.*)

In March, rye grass or millet grass is planted in the central pond and bank, and at the end of April or early May, water is injected into the pond to flood some of the grass, enabling the fish to eat the tender grass, and reducing mowing and feeding costs. In June, Sudan grass (*Sorghum sudanense*) is planted on the pond bank and fertilizer is applied to speed up growth. The Sudan grass is then mowed and fed to the fish. The rye grass and millet grass only need a small amount of organic phosphorus fertilizer and no pesticides, while the Sudan grass only requires some low-toxicity insecticides to control aphids. The minimal need for pesticides and chemical fertilizers during the growth of the rye grass and millet grass reduces both costs and pollution. Rye grass can usually be sown three times and millet grass twice a year, producing about 9000 kg of green feed per mu in each harvest, with an annual yield of 671 641 kg/ha (rye grass: 130 434 kg/ha × 3 = 391 304 kg/ha; millet grass: 130 434 kg/ha × 2 = 260 868 kg/ha). Sudan grass can usually be sown seven times in a year, yielding 63 000 kg of green feed (Sudan grass 130 434 kg/ha × 7 = 913 038 kg/ha). In the green-grass culture system, most farmers have >15 mu (~1 ha) of green grass, generating enough rye grass, millet grass, and Sudan grass to feed the grass carp between March and October. In the event of there being insufficient green feed, a small amount of pellet feed can be used (4–6 t/ha) to improve the output. Compared with intensive culture, green-grass culture replaces most pellet feed with green feed (Figure 2.1.5), thus significantly reducing feed costs, with little effect on yields. Regular management and pond inspections are carried out, and any fish diseases may be prevented and/or cured based on this regular monitoring.

In addition, the feed coefficient in high-density intensive culture is generally 1.8–2.3, compared with 25–60 in green-grass culture. Furthermore, much of the grass carp excrement in the green-feed system decomposes and is used as a natural feed for polycultures of spotted silver and bighead carp, thereby increasing yields.

2.1.3.1.4 Other Culture Modes

In addition to circulating-water, high-density intensive and grass-based cultures, other small-scale grass carp culture systems, such as stream and spring, and 'slimming fish' and 'crisped grass carp' culture systems are also practiced in China. Stream and spring culture use mountain streams to culture grass carp, with green

Figure 2.1.5 A pond for ecological grass-carp culture. Note: the central platform used for cultivation of different types of grasses that are used as food for the stock.

plants as the sole feed. This growth cycle may last up to three years, and produces brightly colored, fresh-tasting grass carp, with no "fishy" smell. These fish can sell for as much as 20 RMB/kg (6 RMB = 1 US$), compared with 7 RMB/kg for fish cultured using other methods. Hetian carp (a strain of grass carp) are the most famous stream- and spring-cultured grass carp. 'Diaoshuiyu' is a way of culturing grass carp in a freshwater system, with no additional pellet or green feed, such that the only food is plankton. The fish thus become thin and contain less fat, giving a good body shape and a fresh, tender taste. These fish may sell for up to 19.8 RMB/kg. 'Crisped grass carp' culture utilizes spring water from reservoirs to farm fish, and feeds them on water-immersed broad beans, producing grass carp with tender, crisp, and firm meat, able to be sold for about 13.5–14.0 RMB/kg.

2.1.3.2 Cage Culture

Cage culture involves the use of synthetic fiber or metal-mesh cages placed in large and middle-sized reservoirs, allowing water exchange through the mesh to create a flowing-water environment. This is practiced as a high-density intensive culture system, with high densities of fish, a high survival rate, and high yields. This method saves land use and provides many superior fingerlings for large-water-body culture, as well as restraining the excessive multiplication of other fish species (e.g. *Tilapia*). Cages are independent from each other for easy feed management and harvesting. This represents an effective and flexible way for China to exploit large- and middle-sized water bodies. China has about 5 000 000 ha of available water area, including 38 600 000 ha in large and middle-sized water bodies, of which only about 50 percent is currently exploited, indicating considerable potential for development.

Cage culture is currently practiced in Fujian and Guangxi. The key features of cage-culture techniques are as follows.

1) Location selection: Cages should be located in areas free from pollution, with a depth of >4 m, a large water surface, flat bottom, and smooth water flow, with little wind, some sun exposure, a stable water level, transparency 50 cm, pH 7.0–8.5, and >5 mg/L of dissolved oxygen. Flood drainage areas and areas with clumps of water grass should be avoided.
2) Cages and setting: Cages should be made of polyethylene mesh, and be double layered, measuring 3–5 m × 5 m × 2.5 m, with an internal mesh size of 3.5 cm and outer mesh size of 4 cm. The four sides

of the cage should be bound by large bamboo poles, with steel cable used to fix piles of flat racks. Foam plastic floats or old metal buckets can be used to provide buoyancy, and the frame anchored with sand bags and stone fixed to the bottom of the cage, and weighted to stretch the cage fully in different directions. Cages should be placed 2 m underwater and 0.5 m above the water surface, with a net cover to prevent grass carp jumping out of the cage. Cages should be established for a week before the fingerlings are introduced. Algal growth on the net minimize the risk of the fish getting injured as a result of friction with the netting. The cage should be placed perpendicular to the water flow, and care should be taken to prevent damage to the cages.

3) Stocking and feeding fingerlings: Fingerlings should be healthy and strong, have intact fins and scales, and be free from disease and damage. Fingerlings obtained from other places should be inspected, and are stocked at mean sizes of 300–500 g and 20–25 fish/m^2. The cages can also be used to culture some chub and bighead carp (200–300 g per fish) and gurnard (*Chelidonichthys cuculus*) (100 g per fish). Fingerlings should be immersed in a 3–4 percent salt solution or potassium permanganate solution (10 mg/l) for five to ten minutes before introducing them into the cages at the end of autumn or in early winter, and no later than the end of March, when the water temperature should be about 15°C. When grass carp are introduced into the cage, they are still able to eat, resulting in a recovery phase. Early feeding at the beginning of spring will extend their growth period.
4) Feed management: Caged fish should not be fed large amounts of grass. Extruded pellet feed should be used instead to improve feed ('bait') utilization ratio, and alleviate water pollution. After stocking, fingerlings will be trained to compete for feed. Feed is cast according to four key rules, i.e. fixed quality, fixed quantity, fixed time, and fixed location. The fish and water in each cage are inspected daily, and any damage to the cages noted, allowing any problems to be resolved. The cages are washed approximately every ten days, especially after floods, to ensure smooth water exchange is maintained.
5) Disease prevention and cure: The cages are sprayed with quick lime and bleaching powder every 15 days. 1-Bromo-3-chloro-5,5-dimethylhydantoin (BCDMH) bags and a mixture of copper sulfate and green vitriol (5:2) are attached to each side of the cage during the hot season.

2.1.4 Grass Carp Breeding

2.1.4.1 Artificial Propagation Technology

In 1958, Zhong Lin, a fish-breeding expert from China, developed a new method of artificial fish propagation called 'ecological and physiological oxytocin', which represented an end to the reliance on seed stock of freshwater fish from rivers and other natural habitats (Zhong 1965). The artificial propagation of fish also provides high-quality and cheap seed for reservoir and lake fish ponds in China (Sun and Ren 1992). Grass carp gonads reach maturity at different ages, depending on the climatic and nutritional status. Furthermore, the spawning season for grass carp varies according to the region: mid June in north-east China, mid May in the middle and lower reaches of the Yangtze River, and late April in the Chongqing area. However, artificial propagation is usually only carried out once a year (Zeng 1999), which limits the numbers of larvae available. The Shuang Zhu fishing ground at the Chongqing University of Arts and Science has explored ways to improve traditional breeding methods, and has succeeded in breeding grass carp three times a year, resulting in the production of large numbers of fry and leading to huge economic benefits (Sun 2008).

2.1.4.1.1 Parent Fish Selection and Cultivation

Mature grass carp used for artificial propagation should be sturdy, of normal color, and have no signs of injury or disease. The female to male ratio is 1:1 for natural spawning, and 2:1 or 3:2 for artificial insemination, with a stocking density of about 2250 kg/ha. To take full advantage of food and regulate the water quality, parent fish are usually polycultured with silver carp and bighead carp. The parent fish should be kept in ponds of good water quality and convenient for transportation. The water-circulation system should be easy to fill and drain. And the pond should have an area of 1334–2668 m^2, a depth of 1.5–2 m, should face east–west, and include a water-jet aerator to avoid eutrophication. The sediment should be < 20 cm.

Water is added to maintain water quality, while flushing simulates natural water flow to promote gonad development, especially during the prenatal period of intensive cultivation. Flushing needs to be performed in accordance with the water source and weather conditions, but prior to artificial spawning. Flushing usually takes place every two to three days, for 2 hr a time.

Additionally, parent fish are mainly fed cultivated grasses (rye grass, Sudan grass) mixed with various cereals and artificial feeds. The food intake of grass carp tends to decrease prior to spawning, and it is therefore necessary to adjust the amount of feed provided accordingly. Meanwhile, the ponds should be cleaned regularly with bleaching powder to prevent bacterial gill infections and gastroenteritis (Shan *et al.* 2015).

2.1.4.1.2 Artificial Spawning

Grass carp in the middle and lower reaches of the Yangtze River are generally inseminated in late May. When the water temperature reaches 20–30°C and it remains sunny, it is possible to stop feeding the fish for a day to carry out artificial insemination.

The common oxytocic hormones used for artificial propagation in the four major Chinese carp species include crucian carp pituitary gland (PG) hormone, human chorionic gonadotropin (hCG), luteinizing-hormone-releasing hormone and its analogues (LRH/LRH-A), domperidone (DOM), and reserpine (RES). The biological activity of LRH-A is considerably higher than that of LRH, although both affect the development and maturity of gonads. Because of the different pathways utilized by LRH-A, hCG, and PG, the oxytocin response time of LRH-A may be 3–4 hr longer than those for hCG and PG, or even longer.

Farmers have recently used new and more effective hormonal mixtures, including LRH-A plus DOM, and LRH-A plus RES. The doses for grass carp (females calculated according to weight, and half doses for males) are 3–5 mg/kg DOM plus 1.5–2 μg/kg LRH-A or 3–4 μg/kg S-GNRH-A (Du *et al.* 1994; Ku *et al.* 1995).

2.1.4.1.3 Fertilization and Hatching

The oxytocin response time of LRH-A plus DOM in grass carp is about 12 hr. The parental fish are captured at the appropriate time, wiped with a dry towel, and the eggs are squeezed into dry containers, followed by milt. After keeping the container stationary for a moment, the eggs and sperm are then stirred gently for one to two minutes using a feather, followed by three to four rinses with fresh water, and then moved to an incubator.

Typically, the conventional loop hatching method (Figure 2.1.6) is used for hatching, at a density of 900–1000 thousand eggs per m^3. Grass carp eggs are semi-floating, so the velocity and flow of water must be strictly controlled to ensure that the eggs float, and are uniformly distributed in the water column. During hatching, the water temperature is maintained at 22–25°C, pH 7.5–8.0, with 5 mg/L dissolved oxygen, and the water is kept fresh and filtered through mesh, respectively. The water flow is adjusted during hatching, according to changes in weather and temperature (Wang 1979; Xie 1980).

Fertilized eggs usually begin to hatch at 25 hr post-fertilization. The fry can be caught and cultured in ponds by seven days post-fertilization. The fry are fed on cooked egg yolks, which are parceled, kneaded, and washed with mesh screens and splashed around the incubator circuit, before transferring the fry to a pond 1 hr later.

2.1.4.2 Molecular Technology in Grass-Carp Breeding

Grass carp have 24 pairs of chromosomes. Traits of selective breeding interests of grass carp are for disease resistance and growth. The key to carrying out molecular breeding and marker-assisted selection is to obtain molecular markers that are closely linked to the target traits. Molecular markers were identified by quantitative trait loci (QTLs) mapping, and genome-wide and candidate-gene associated studies. The candidate gene association method is relatively cheap and easy to use, and has thus been widely applied for molecular marker identification in grass carp. Currently, parentage assignment using molecular markers is used to identify

Figure 2.1.6 A concrete hatching tank used for incubation of grass carp eggs, popularly referred to as "Chinese Design of Concrete Hatching Tanks", used for all major Chinese carp species. *Source:* Photo by Huihui Cheng.

parents of each individual in breeding schemes of grass carp (Fu *et al.* 2013). In addition, the first generation genetic linkage map of grass carp was constructed using microsatellite and single nucleotide polymorphism markers (Xia *et al.* 2010). The draft genome of the grass carp has also been developed (Wang Y. *et al.* 2015). Such work will help us to breed more improved varieties of grass carp, as well as provide a scientific basis for the application of modern biotechnology in aquaculture. Genetic breeding projects thus represent a promising way forward for grass carp aquaculture (Hu 2006).

2.1.4.3 Large-Scale Cultivation of Grass Carp Fry

Cultivation of grass carp fry and fingerlings refers to the culture of juvenile fish for 20–25 days to reach 3 cm, followed by feeding until they reach 3–15 cm. The success of rearing grass carp fry is directly related to the production output, size specifications, survival rate, and other features of the fingerlings. Selection of high-quality fingerlings thus provides the basis for cultivating excellent juvenile fish, which is a critical step in the grass carp breeding cycle (Yang *et al.* 2011).

2.1.4.3.1 Feeding

Larval fish undergo a transition from mixed nutrition to exogenous nutrition, when the yolk sac can no longer meet their metabolic needs. Under natural conditions, grass carp initially feed on zooplankton, including protozoans, rotifers, and other micro-zooplankton, followed by water fleas (Cladocerans), such as *Diaphanosoma*, *Cyclops*, and *Daphnia* as the grass carp grow.

Under artificial propagation conditions, grass carp fry are transferred to pools five–seven days after fertilization, when the numbers of rotifers and cladocerans reach a peak. The fry are fed one egg yolk per 100 000 fry, and then transferred to a pond 3–4 hr later. The fish are initially fed with soybean milk after transfer (14–16 kg/ha, 2–3 times a day, increased to 57–65 kg/ha), which acts as a fertilizer for the grass, as well as a food source for the fish.

After seven days, the fry can be fed on refined flour, rice bran, wheat bran, and other fine feeds, often mixed together. Fish also receive soybean-cake slurry daily at 8–10 percent of the fish weight, mixed with water at a ratio of 1:10. By 15–20 days incubation, the fish begin to eat Chironomid larvae, the roots of the duckweed species such as rootless duckweed (*Wolffia arrhiza*), lesser duckweed (*Lemna trisulca*), and greater duckweed *(Spirodela polyrhiza*), and other aquatic plants. When the fish reach 1.7–3.1 cm, the throat teeth have started to take shape, and the intestinal bend has formed. They continue to grow and develop into fingerlings. Once the grass carp have reached 5 cm, their staple diet consists of plants and invertebrates. In their natural habitat grass carp at this stage eat mostly submerged plants and gramineous plants in coastal shallow waters. When they are 8–12 cm long, they are fed on cobalt pigment, grain, and a compound feed at a daily feeding rate of seven to ten percent of fish weight, and once they reach 12–14 cm, their main fodder is 2.5-mm particle feed at a rate of 3–6 percent (Xiao 1975; Liao *et al.* 1979).

2.1.4.3.2 Stocking Density

For fry rearing, the pool area should be around 1–2 × 667 m^2, with a water depth of 1.0–1.5 m. Fry should be clean and healthy looking, with a bright body color, be plump, well-proportioned, swim actively, and with no signs of injury or disease. The stocking density used is around 10–15 million/mu. When fry reach 2.5–3 cm after 20–30 days' culture, they are removed at around 0800 hr or 0900 hr on a sunny day by trawling, when fry of the desired size are picked out and the rest returned to the original pond. This process is repeated daily to obtain fry of correct size for stocking in grow-out ponds.

For larval rearing, the larvae are transported in an oxygenated bag, which is then placed in the pool for 10 min (Li 1999). The larvae are then released uniformly along the border of the pool, once the temperature in the bag has equilibrated with that in the pool.

This breeding process can be divided into two stages (CCTV Agricultural Technology http://www.cctv-7.com.cn/). During the first stage, fry of 2.5–3.3 cm are grown to 7–9 cm in monocultures. Around 30 000–50 000 3-cm fry are stocked per 667 m^2. Water is added to increase the depth by 10–20 cm once a week, and the fry will grow to 7–9 cm in 10–15 days. The second stage involves culturing the fry from 7–9 cm up to 20–25 cm by the ecological polyculture method. About 4000–6000 individuals of 7–9-cm size are stocked per 667 m^2. In this polyculture system, grass carp is the primary fish species cultured in the pond which is generally 4002–6670 m^2 and the water depth is 1.8–2.5 m (Huang 2010), coupled with a smaller population of silver carp and bighead carp.

2.1.4.3.3 Temporary Holding and Transport

The demand for aquatic products is growing, along with developments in fishery production, while increased fish production and improved cultivation methods result in more frequent fish transportation. Dragnet fishing and temporary stocking of fry and fingerlings help to reduce mortality during transport. Strict management measures and production systems are needed to improve the quality of the aquatic products, and sampling for drugs should be carried out before the point of sale, to avoid the risk of drug residues in the final product (Guo 2009).

As indicated previously, grass carp fingerlings are hauled from fingerling rearing ponds using nylon nets, when undesirable animals in the hauls are removed. However, it is necessary to take care to avoid mechanical damage to the fingerlings during this process, which could result in infections, such as white mouth disease (Li 1999). The specification for grass carp fry for selling is 400–750 fish/kg, and >50 g/fish (Zeng 1999). Fry are filtered through bamboo screens and counted, and fry smaller than the specification are left to continue to grow in the original pond. Fry for sale may be kept in hanging culture for 2–3 hr before sale.

Grass carp fingerlings are usually transported in 70 × 40 cm plastic bags filled with oxygen, with a water temperature of 20–25°C. It is possible to ship 80 000–100 000 fry, 1200–1500 summerlings, 600–800 5–7 cm fingerlings, or 300–500 7–8 cm specification fingerlings in each bag, with a guaranteed survival rate >90 percent for 24 hr.

2.1.5 Water Quality Control

Using large amounts of feed and numerous chemicals, and changing large volumes of water are common procedures in high-density aquaculture. However, these processes increase water pollution, and may be a direct cause of fish diseases and reduced product quality. The above processes are also responsible for huge economic losses in the aquaculture industry. Compared with traditional physical and chemical remediation technologies, bioremediation is gaining popularity because of its low cost, low labor input, and its ability both to clean without producing secondary pollution, and to maintain an ecological balance (Meng *et al.* 2008).

2.1.5.1 Biological Floating-Bed Technology for Improving Water Quality

Floating beds (Figure 2.1.7) make full use of the microbes living on the surface of plant roots, which can decompose and utilize organic pollutants and excess nutrients in the water. The floating plants that absorb nitrogen, phosphate, and other nutrients be harvested by the end of October, to remove pollutants from the pond. This procedure can significantly reduce eutrophication, improve water quality, and repair the aquatic environment (Hu *et al.* 2010).

Water spinach (*Ipomoea aquatica*) has become the first choice of floating-bed plant in central China, because of its useful traits, including heat resistance, rapid growth, a well-developed root system, and strong ability to absorb minerals, as well as being economical and easily available (Figure 2.1.7). It is generally planted in late April, soil-cultured for 30–40 days, and then transplanted in sparse matrixes of floating beds 25 cm apart, when the stem length is >20 cm. The seedlings are used at about 0.2 kg/m^2. Biological floating beds occupy about 5 percent of the surface in fingerling-rearing ponds, and 7.5 percent in adult-cultivating ponds. They cannot be set up along the edge of the pond, and care must be taken to ensure that they do not interfere with the feeding and aeration equipment.

Floating beds can increase the overall production of cultured fish by 20 percent, enhance the survival rate of fry by >3 percent, and reduce the use of drugs by 40 percent compared to culture systems that do not use floating beds. However, floating beds also reduce the amounts of plankton and dissolved oxygen (1.76–6.82 mg/l) in the pond, and the optimal species ratio is thus 47 percent grass carp, 19 percent bream, 16 percent crucian carp, 8 percent carp, 8 percent silver carp, and 2 percent bighead carp.

2.1.5.2 Application of Probiotics in Water Quality Regulation

Micronutrients are low-cost, non-toxic, non-polluting additives made from beneficial bacteria, oligosaccharides, and other raw materials. These not only comply with the basic requirements for healthy farming of fish,

Figure 2.1.7 Biological floating-beds in grass-carp culture ponds that help in maintaining water quality. (*See color plate section for the color representation of this figure.*)

but also with the future prospects for aquaculture development. Common micronutrients used to improve water quality in grass-carp culture include photosynthetic bacteria, bacilli, nitrifying bacteria, as well as compound bacterial preparations (Gao and Xu 2012).

Compound micronutrients generally contain photosynthetic bacteria, lactic acid bacteria, actinomycetes, *Saccharomyces*, amino acids, vitamins, EM bacteria, bacilli, and nitrobacteria, diluted 100–200-fold with water and then sprinkled over the entire pool. One bottle of probiotics is sufficient to cover 0.13–0.2 ha when culturing fry, and 0.33 ha when culturing adult fish.

The biocompounds for bottom improvement are mixtures of *Thiobacillus*, nitrobacteria, denitrifying bacteria, bacilli, and *Rhodopseudomonas*. Micronutrients can significantly improve water quality, by maintaining ammonia levels at 0.45–0.5 mg/l, nitrite at 0.025–0.3 mg/l, and hydrogen sulfide at 0–0.025 mg/l, with degradation rates of ammonia, nitrite, and hydrogen sulfide of >40 percent, >99 percent, and >60 percent, respectively (Zhang *et al*. 2014).

Micronutrients should be used in the morning on sunny days to avoid anoxia as a result of oxygen consumption through cell activation and propagation. Furthermore, micronutrient preparations should not be used with bactericidal and antibacterial medications (Zhang *et al*. 2014).

2.1.6 Feeds

2.1.6.1 Nutritional Requirements of Grass Carp

Feed costs generally account for >50 percent of recurrent costs in most aquaculture practices, with protein costs accounting for about 25–30 percent. Protein is required to meet the demand for amino acids, especially essential amino acids (Liao 1996). In addition, dietary fat is a source of essential fatty acids, and acts as a carrier of fat-soluble vitamins, while carbohydrates are a major source of cheap energy. Vitamins are necessary for fish survival and play a key role in controlling nutrient metabolism, while minerals are important components of body tissues, and also maintain osmotic pressure and the acid–base balance. The calorie–protein ratio (total energy/crude protein (%) per unit weight of feed) is directly related to the utilization rates of protein and energy (Liu and Wang 2008; Yang *et al*. 2013). Compound feeds need to provide adequate and balanced nutrition to ensure maximum feed utilization, and meet the nutritional demands of rapid growth, whilst minimizing costs. Feed formulae and feed coefficients used in different growing environments are shown in 2.1.1.

2.1.6.2 Value and Application of Green Fodder

Soybean, rapeseed, and cottonseed meal are the main protein sources, but these contain anti-nutritional factors that decrease the feed-conversion rate and thus reduce fish growth and quality. Research aimed at improving grass carp feed formulations and clarifying the significance of green fodder has been ongoing in China for many years (Zeng 1987).

Compared with the history of freshwater aquaculture, the use of green fodder is relatively recent, but it is associated with certain advantages, including utilization of a variety of plants that are both nutritious and rich in essential vitamins and minerals for grass-carp growth. Importantly, green fodder results in high yields and cost less, which can effectively reduce the cost of grass-carp culture (Chen *et al.* 2013). Previous studies have demonstrated that green fodder affects the composition of amino acids in the muscle and improves the taste of grass carp (Bi *et al.* 2011). At present, planting fodder and cultivating fish has been used as an energy-conserving, safe, and healthy aquaculture system in the southern Yangtze River.

Feed prices have risen in line with increasing food safety measures, and the system of planting feed and cultivating fish has thus transformed the mode of fishery development, with both practical and strategic significance.

Table 2.1.1 Examples of typical grass carp feed formulations.

Formula provider and purpose	Ingredients (%)									
Shanghai Fisheries University	bean cake 30%	rapeseed cake 35%	fishmeal 2%	wheat bran 15%	mixed powder 14%	mineral substance 2%	salt 2%			
Hubei Fisheries Research Institute	bean cake 33%	fruits 1%	fishmeal 5%	wheat bran 26%	crude protein 25%	mineral substance 2%	fecula 12%	pine needle powder 7%		
Shunde Guangdong	silkworm chrysalis 6%	flour 15%	fishmea l2%	wheat bran 50%	crude protein 18.2%	corn meal 18%	salt 1%	groundnut cake 5%	auxin 0.5%	shell powder 1%
Pearl River Fisheries Research Institute	bean cake 10%	rice bran 40%	fishmeal 10%	wheat bran 38%	yeast powder 2%	greenfeed				
Shandong Fisheries School	bean cake 15%	sweet potato flour 12%	fishmeal 10%	wheat bran 5%	calcium hydrogen phosphate 2%	cornmeal 10%	salt 0.5%	auxin 2%		
Common feed	bean cake 15%	straw powder 70%	cornmeal 13.5%	bone meal 1%	salt 0.5%	Trace amount of vitamins				
Lake grass carp	bean cake 15%	rice bran 15%	fishmeal 3.5%	wheat bran 10%	Sweet potato vine powder 45%	cornmeal 10%	bone meal 1%	salt 0.5%		

2.1.6.3 Feed Additives

Feed additives refer to small amounts of substances used in feed processing and production, including nutritional and general feed additives. Additives comprise an important component of the feed. Aquaculture feed additives mainly include microbial or traditional Chinese medicine additives, Saccharicterpenin, oligosaccharides, enzyme preparations, and carnitine. These substances improve the basic nutritional value, and improve animal performance and health, reduce feed costs, and improve product quality. Some examples of microbial and plant feed additives are given below.

2.1.6.3.1 Microbial Feed Additives

People often refer to probiotics applied to animal cultures as microbial feed additives. Research on probiotics dates back to 1947, when it was reported that the addition of *Lactobacillus* to feed, effectively increased the weight of piglets and improved health (Hansen and Mollgaard 1947). The ideal probiotics should have no pathogenicity, be able to adapt and survive at low pH of the gastrointestinal tract, promote growth, and increase the resistance to diseases. The main probiotics on the market are photosynthetic bacteria, *Bacillus* spp., *Saccharomyces*, nitrobacteria, denitrifying bacteria, and EMs.

Photosynthetic bacteria are nutritious, including 65 percent crude protein and vitamin B, folic acid, and coenzyme Q. The use of 2 percent photosynthetic bacteria can improve the survival rates of grass carp, bighead, and silver carp summerlings by 5–28 percent, and the yield by 15–30 percent, while reducing the feed coefficient by 20–23 percent, with good economic benefit (Xu *et al*. 2012).

Yeast can be obtained from a variety of sources. It is relatively cheap, includes a largely complete range of amino acids, and can provide many vitamins and microelements suitable for aquatic animals (Xu *et al.* 2012). The addition of yeast reduces the feed coefficient by 10 percent, and increases amylase activity and fat deposition. Yeast spores in the intestine can produce protease, lipase, and other nutrient substances.

Bacillus subtilis can be added to feed at 1000–2000 mg/kg, and is associated with an increased growth rate of grass carp of 5 percent. *B. subtilis* can promote the activities of intestinal amylase and protease, and regulate lipid metabolism by improving intestinal mucosal morphology, thereby promoting the deposition of protein and fat, and accelerating growth (Xu *et al*. 2012).

2.1.6.3.2 Chinese Herbal Feed Additives

China have rich resources of Chinese herbal medicines derived from a huge number of species. The earliest record of Chinese herbal additives can be traced back to the Xi Han Dynasty (206 BCE–8 CE). In modern fisheries, Chinese herbal feed additives not only improve the production of aquatic animals and feed efficiency in aquaculture, but also ensure food safety for consumers, and result in fewer residues and less environmental pollution. The dual medicinal and nutritional roles are especially useful in current intensive and large-scale aquaculture production (Ge and Chen 2010).

Compounds that promote feeding can improve feed palatability, and efficiency of feed utilization, while growth-promoting additives can improve weight gain and feed utilization, and thus reduce farming costs. It is commonly believed that certain Chinese herbs facilitate detoxification of feed ingredients, when present, and also have an antibacterial effect, thus reducing the incidence of disease, increasing survival, and reducing costs. The quality of fish meat and skin were improved by adding a modifier to the feed, and the meat quality of fish fed with artificial feed differs from that of wild fish (see Chapter 5.1 for clarification).

2.1.7 Disease Prevention and Control in Grass Carp

With the development of grass carp culture in China, fish diseases have emerged as a bottleneck in the further development of the industry. New diseases, outbreaks, and difficult-to-treat diseases often occur, resulting in huge economic losses to the aquaculture industry. Aquatic disease control uses three main measures: ecological control, immune system control, and drug control.

Drug control is the most direct, effective, and economical method. It is difficult to administer drugs to fish in the water. The stability of drugs in water is relatively short, and drugs are impacted upon in the aquatic environment. All this results in higher drug requirements. Floating feeds can incorporate Chinese herbal medicines or drugs that can float on the water surface for prolonged periods. Floating microcapsules can float for even longer, because of swelling due to absorption of water. They can be adjusted in size to suit different fish, and can help to improve the recovery rate. A new type of fish medicine has been developed (see Chapter 7.3 for details) comprising a core of 10–80 percent infilling material, sprayed with 1–10 percent of specific binders, with 20–50 percent of Chinese herbal medicine and antibacterial drugs glued to the core, packaged within a coating layer.

The safety of aquatic products has been the focus of increasing attention, with limitations placed on the use of drugs to prevent and treat fish diseases. Vaccination has long been recognized as one of the best prevention and control measures for diseases of aquatic animals. Approved vaccines include methionine iodine for hemorrhage in grass carp, *Ctenopharyngodon idella* cell inactivated vaccine, fish *Aeromonas hydrophila* septicemia inactivated vaccine, and grass-carp hemorrhage attenuated live strain vaccine GCHV-892 (flounder soluble algae *Vibrio*, eel *Vibrio*, and *Edwardsiella tarda* disease) linked to anti-idiotypic antibodies.

Ecological control refers to the creation of a living environment suitable for healthy fish growth, with the need for minimal or no medication. Floating beds in grass-carp ponds can improve pond-water quality, especially by reducing the nitrite and ammonia contents. This practice also has a positive effect on reducing diurnal fluctuations in dissolved oxygen (DO) and pH. *Ipomoea* floating beds can significantly improve visibility within ponds, and reduce malondialdehyde (MDA) (an indicator of oxidative damage) and protein carbonyl levels in fish serum and liver homogenate. Floating beds improve the total antioxidant capacity and reduce disease in grass carp by improving pond-water quality (Wang *et al.* 2015).

2.1.8 Improved Muscle Quality in Cultured Grass Carp

2.1.8.1 Crisped Grass Carp Breeding Technology

An accidental discovery in 1973 revealed that feeding grass carp on broad/fave bean (*Vicia faba*) in the Yangtse reservoir (Zhongshan, Guangdong province) improved the flavor and cooking tolerance. Grass carp fed in this way are referred to as 'crisped grass carp'. They are characterized by thinning but dense muscle, thickened perimysium, and increase deposition of collagen in the diaphragm, making the fish flesh more brittle. The gap between the myofibrils, sarcomere length, and muscle fiber area are also increased. Crisped grass carp muscle has higher protein, fat, and ash contents than ordinary grass carp, and the firmness and chewiness of the muscles after cooking are significantly increased.

Cages for 'crisped' grass carp rearing should be cleaned and soaked for 30 minutes with five percent raw lime solution for disinfection, and then placed in the water prior to introducing the fish, to avoid scraping. Fish are then dosed with vaccine before releasing into the cages, and soaked for five to ten minutes with 20–30 g/m^3 of potassium permanganate. During rearing, close attention should be paid to water disinfection and water quality. The best stocking size of grass carp is about 1 kg, with a crisped grass carp specification of 2.5–3.5 kg after 105–120 days' culture (Xu *et al.* 2012). A higher proportion of broad beans in the feed will raise the feed coefficient and increase costs, but a lower proportion will prolong the culture time; the optimal formula is thus one containing 50 percent beans, together with fish meal, soybean meal, rapeseed meal, maize, rice bran, and trace elements. A crisped grass carp gourmet carnival in 2013 attracted over 40 million people from inside and outside Guangdong province, including tourists from Hong Kong, Macau, Europe, and the United States. In 2013, the sale of crisped grass carp reached almost 1 600 000 kg, worth around 70 million RMB per year. Crisped grass carp sell for about 44 RMB/kg, which is nearly two times higher than for ordinary grass carp.

2.1.8.2 Muscle Quality Related to Biological Floating-Bed Technology

Biological floating-bed technology purifies the water by adding aquatic water plants in an advanced state of growth to the eutrophic water surface to absorb and remove nitrogen, phosphorus, and organic matter (Xu *et al.* 2012). *Ipomoea* aquatic floating beds significantly improve muscle quality in grass carp, including muscle pH and water-holding capacity, and crude protein content, while reducing the crude fat content. Analysis of texture and sensory evaluation showed that biological floating beds improved muscle hardness, elasticity, and the overall acceptability of grass carp, suggesting that their use may increase the popularity of grass carp (Wang J. *et al*. 2015).

2.1.9 Culture Efficiency of Grass Carp

Grass carp is the most popular and the main aquacultured fish in China. However, over the last 10 years, the price of grass carp feed has increased, while the price of grass carp has remained relatively static (Figure 2.1.8). The costs of grass-carp culture have thus increased, and despite continuous improvements in culture technology leading to increased yields, the scale of the grass carp culture industry has declined as a result of static fish prices, and also increasing problems with disease. However, profits from grass-carp culture remain high as a result of market demand and the high yield. The incentive for culturing grass carp thus remains high, as long as the market price is good in that year.

Grass carp prices have fluctuated during 2012–2015, both among different regions and between years and months within the same area. The lowest price was around 7 RMB/kg, while the highest was approximately 14 RMB/kg. In addition, some ecologically or organically farmed grass carp can fetch 30–40 RMB/kg. In line with improved grass carp prices, stocking density and stocking area increased in early 2014, though prices fell again in early 2015, but recovered after April 2015. Factors affecting the farming efficiency of grass carp include feed costs, scale of farming, and short-term supply caused by market demands. However, the economic benefits of conventional grass-carp culture systems are relatively low, and farmers may increase efficiency through polyculture with other economic species in many areas.

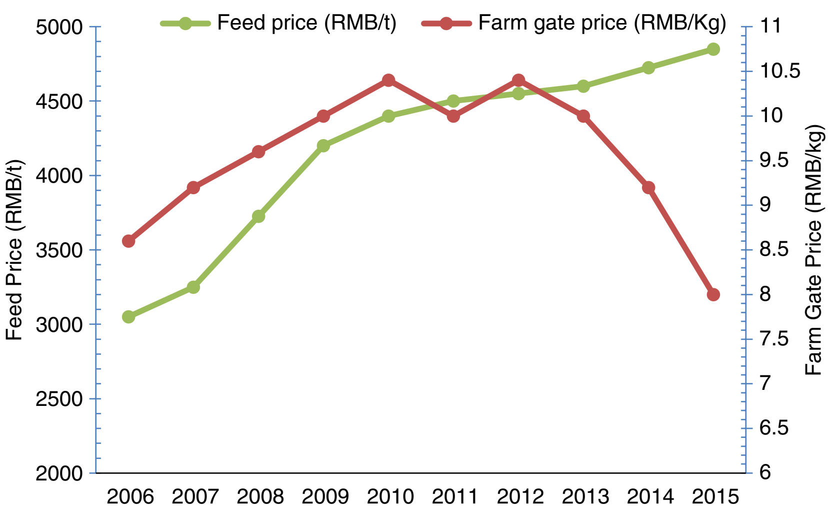

Figure 2.1.8 The chart of 2005–2015 annual price change trends in the farm gate price of grass carp, and the price of grass carp feed, in Honghu City. Data *source:* Honghu City, Hongxianxi aquaculture professional cooperatives.

Table 2.1.2 Costs of main items and associated profit comparison, based on annual averages, of different grass-carp culture models. Unit: RMB.

Culture model	Fry cost	Feed cost	Drug cost	Other costs (labor, energy, etc.)	Total sales	Feed coefficient	Profit/ha
High stocking density culture	6618	75650	5200	11400	115840	1.8–2.3	19,965
Culturing grass carp with grass	35000	82250	3000	30000	230000	25.3–60	23,925
Reservoir cage aquaculture	1767	4530	54	750	11134	1.93–2.18	60,485

The cultivation efficiency of grass carp using different systems vary. The pond recirculating aquaculture system has substantial economic and ecological benefits. This system reduces water consumption and thus saves on water costs, and also effectively reduces drug usage and costs. The circulated water and zero discharge of pollution can effectively help to combat eutrophication problems in lakes and rivers.

The grass system also has economic and ecological benefits, by reducing feed and labor costs, improving the nutritional quality of grass carp meat, reducing disease occurrence, and reducing the need for artificial feed, thereby also preventing the accumulation of excess nutrients, such as nitrogen and phosphorus, in the water and sediment.

The economic benefits of reservoir cage aquaculture are remarkable. In terms of ecological benefits, this system can increase the phytoplankton biomass in the water and improve fish food resources and water productivity. In addition, environmental resources such as temperature, light, and dissolved oxygen are fully utilized (Lu *et al.* 1995).

The different grass carp culture systems are compared in Table 2.1.2. Reservoir cage aquaculture results in the highest profits, followed by grass cultivation, while high-density precision feeding has the lowest profits (with Hubei Province as an example).

2.1.10 Prospects for Grass-Carp Culture in China

Grass carp is the most important freshwater aquaculture species in China, and pond culture of this carp is likely to be the country's main production system in the future. This will promote sustainable economic and environmental development, and benefit the grass-carp culture industry through the use of healthy ecological culture systems and modern biotechnology. Further development and promotion of the grass-carp culture industry relies on theoretical and practical understanding of ecological physiology, breeding techniques, and disease-causing agents/mechanisms, the interpretation and development of functional genomics, large-scale, high-efficiency raising of seed, ecological breeding technologies, and preservation of germplasm resources. A better understanding of the eco-physiological mechanisms responsible for grass carp meat quality will help to improve muscle quality through environmental and nutritional regulation.

Further scientific research into broodstock management is needed to improve production. Studies on environmentally friendly and efficient utilization of ecological feeding technologies, such as precision feeding, and researching individual commodity specifications, will also benefit grass carp culture. Consideration should be given to technologies related to the ecological management of multi-species polycultures, the application of data processing, enhancing and promoting efficient operating mechanisms, implementing and managing large-scale breeding and industrialization to incorporate developments in science and technology, and promoting market competitiveness in the grass carp industry.

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2.2

Typical Cases of Silver Carp Culture

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2.2.1 Introduction

Silver carp (*Hypophthalmichthys molitrix*) is known as the jumping carp. It is one of the most important commercially cultured fish that grow fast and can weigh up to 20 kg. Its natural distribution covers the rivers in the north-east, the central, the south-east and the south of China, except the area upstream of the Three Gorges of Yangtze River (Wang 1994). In 1958, China succeeded in the artificial propagation of "four major Chinese carps" (*Mylopharyngodon piceus*, *Ctenopharyngodon idella*, *H. molitrix* and *H. nobilis*), which completely changed the status of fishing and farming based on wild caught seed, and greatly accelerated silver carp cultivation. Moreover, cultivation of silver carp expanded from pond farming to culture and propagation in large water bodies (including lakes and reservoirs). Freshwater aquaculture production in China was spread over 6 080 390 ha in 2013, producing 24 817 300 tonnes of freshwater fish, among which were 3 850 900 tonnes of silver carp, accounting for 15.6 percent of the total production of cultured freshwater fish (China Fishery Statistical Yearbook 2014). Silver carp is nutritionally rich, readily available at an affordable price, either fresh, or as diversified products such as minced fillet, fish balls, and fish cakes, making it a favorite of the Chinese people. Accordingly, silver carp has become one of the important protein sources for a high proportion of the vast population, and is commonly known as the "grain of the poor". In addition, silver carp is a filter-feeding cyprinid fish. It has great values not only for food fish, but also for biological control of blooms of cyanobacteria in lakes, ponds and reservoirs, and in general to facilitate reduction of potential eutrophication (Ke *et al.* 2009). It feeds low in the food chain and plays an irreplaceable role in improving the aquatic environment. Culture and propagation of silver carp has become a key solution for developing an environmentally friendly aquaculture sector. An ecological model, in which other species are cultivated with silver carp, stabilizes the ecological community and balances the ecological fauna and flora, which generates aquatic animal protein with natural food organisms in the water body, without the need to provide external feed inputs (China Fishery Statistical Yearbook 2014). Due to fast growth rate, easy cultivation, high feed efficiency ratio and high nutritional value, commercial production of silver carp has steadily increased in China. This chapter presents descriptions of several typical cases of silver carp culture in China.

2.2.2 Pond Intercropping

The main production model of silver carp is intercropping of adult fish in ponds.

Aquaculture in China: Success Stories and Modern Trends, First Edition.
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2.2.2.1 Environmental Conditions of Aquaculture Ponds

2.2.2.1.1 Selection of Aquaculture Sites

It is required that the farming sites should be provided with sufficient water of good quality (see Section 2.1.2), in compliance with the national water quality standards for fishery, and be free from contaminants; in addition, the soil should be able to retain water, preferably neutral or weakly alkaline; irrigation or drainage should be fulfilled by gravity (or locally) by taking advantage of the terrain; the power supply should be guaranteed.

2.2.2.1.2 Water Source and Quality

Sufficient water of good quality is the most basic condition for fish farming. In a pond for intensive farming, the stocking rate is dense, and a lot of fish feed and fertilizers are applied resulting in reduced levels of dissolved oxygen (DO). Aerators might alleviate this situation, but do not provide a complete solution. It is preferable that the water source is pollutant free, and preferably from lakes or reservoirs. Well water can also be used, but should be warmed in a reservoir and aerated before transfer into ponds. The pH of the water used for aquaculture shall be kept at 6.5–8.5; dissolved oxygen should be higher than 5 mg/l for more than 16 hours and not less than 4.5mg/l in the remaining time; the total hardness should be 89.25–142.85 mg/l calcium carbonate. The COD should be below 305 mg/l, ammonia nitrogen content lower than 0.026mg/l, transparency higher than 30 cm.

The soil should be loamy, clay or sandy loamy, with good water-retaining properties. A grow-out pond is usually 0.3–0.7 ha, and 2.0–2.5 m deep. The slope should be provided around the pond bottom and the proper depth of silt layer should be kept at 10–15cm. Water quality and level should be flexibly adjusted according to the stage of growth of the silver carp. It is preferable that aerators are provided in the pond; usually two to three impeller-type aerators of 1.5 KW are provided per ha.

2.2.2.1.3 Pond Cleaning and Sterilization

Ponds should be dried and cleaned once a year. Excessive silt should be removed after drying, the pond bottom leveled, holes and cracks filled up, and the water inlet and outlet repaired. Quicklime or chlorinated powder should be applied to sterilize, and eliminate harmful organisms prior to stocking. There are two methods of cleaning ponds with quicklime: the dry method and the wet method. In the dry method, pond water is drained, lime slurry is made from chunks of quicklime (750–1125 kg/ha), mixed with water and sprayed over the entire pond; the lime slurry is stirred and mixed, and the pond sediment raked evenly the next day. The pond can be stocked with fish after seven to ten days. In the wet method, water is drained up to 6–10 cm, and quicklime applied (200–250 mm/l); or the water is not drained and 1500–2250 kg/ha of quicklime is applied. Ponds are cleaned with chlorinated powder (300–450 kg/ha for dry pond) or use 20 mg/L when the water is not drained. Mix the chlorinated powder that contains 30 percent of active chlorine content with water and evenly spray all over the pond. Stock fingerlings after four to five days when the toxic effect wears off. Check if the water body is toxic with a few fingerlings before stocking.

2.2.2.1.4 Water Injection and Fertilizing

After ponds are cleaned and sterilized, they should be exposed to the sun for two to three days before filling; when filled initially, the water depth should be a minimum of 1 m deep. Use 3000–6000 kg/ha fermented organic fertilizer or, if inorganic fertilizer is used, apply 75–150 kg ammonium hydroxide (or 30–75 kg carbamide) and 15–22.5 kg superphosphate (per ha). Spray the chemicals evenly on the water surface; make the pond water glossy dark green or dark brown, with a transparency between 25–30 cm. It is preferable that the total quantity of plankton in the pond is 60–100 mg/L.

2.2.2.2 Stocking

The quality of the silver carp seed should comply with stipulations of the national quality standard of silver carp fingerlings. The fingerlings should be stout, free from disease, not devoid of scales and fin rays; and the length should be 12–18 cm or above. In south and central China, stocking is conducted from December to the beginning of January in winter, and February to March in spring. In the north, stocking is mostly in the spring, between March and April. The stocking density is subjected to planned production, time of harvesting, farming pattern and regions. The pattern of stocking density and planned production are summarized in Table 2.2.1. Silver carp can be cultured as the primary species or secondary species. It is usually cultured as the secondary species, but in peri-urban areas with an abundance of domestic waste water, it is cultured as the primary species. The ratio of filter-feeding fish and other fish in intercropping should be controlled and adjusted based on factors such as pond conditions, local feed and fertilizer sources, fingerling source, and technical and management level.

(Note: From June to August, silver carp is harvested four to five times to meet market demands.)

In the intensive pond farming model, with grass carp or black carp as primary species, the quantity of the secondary species, silver carp, stocked and cultured accounts for 30–40 percent, and the net production is about 30 percent of the total. Silver carp are caught in rotation 4–6 times in a growth season; the net production of silver carp is 3000–3750 kg/ha, and the relevant details are given in Table 2.2.2 (Wang 1994).

The quantity stocked must be strictly controlled when silver carp and bighead carp are cultured together. The stocking ratio between silver carp and bighead carp is usually 3–5.1, because bighead carp is stronger than silver carp at snatching food.

Table 2.2.1 Fish stocking and harvesting pattern of farms with a net production above 10 500 kg/ha (in the middle and upper reaches of the Yangtze River).

Stocking				Harvesting			
					Production kg/hm		
Size (g)	Number/ha^2	Weight kg/ha^2	% in stocking weight,	Survival (%)	Gross	Net	% in total net production
Silver carp							
250 – 300	3000	900	26	95	1710	810	7
30 – 100	6750	465	14	90	3045	2610	24
10 – 20	4500			80	900	870	8
Total	14250	1365	40	88	5655	4290	39
Bighead carp							
300 – 400	300	105	3	95	225	120	1
30 – 100	450	30	1	90	240	210	2
Total	750	135	4	92	465	330	3
Grass carp							
250 – 750	2250	1125	33	80	4500	3375	30
50 – 100	3750	285	8	60	1695	1410	13
Total	6000	1400	41	68	6195	4785	43
Other fishes							
Total	13245	495	15	84	2145	1650	15
Grand total							
	34245	3405	100	83	14460	11055	100

Source: Adopted from Bai *et al.* (2008).

Table 2.2.2 Stocking and harvesting of silver carp as a secondary species (Wuxi, Jiangsu Province).

Stocking			Harvesting			Notes
			Size (kg)	Production (kg/hm²)		
Size (kg)	Number hm²	Weight (kg/hm²)		Gross	Net	
0.25–0.35	2250	667.5	Catching rotation	1500	3375	4–6 times from June to August
0.1	4500	450	0.6–0.75	2550		
(Xiahua) 3.3 cm	7500	7.5	0.1	450		
Total	14250	1125		4500	3375	

Data *source:* Wang (1994).

In the Pearl River Delta, bighead carp, grass carp and mud carp (*Cirrhinus molitorella*) are cultured as primary species, mostly with silver carp, common carp, crucian carp and Wuchang bream (*Megalobrama amblycephala*). Under such circumstances, the ratio between bighead carp and silver carp is 0.5–0.6:1; small silver carp (50–100 g) and large bighead carp (300–500 g); the density and size of silver carp should be controlled; the silver carp should be harvested when it weighs 0.5–0.75 kg, and replaced with an equivalent number of silver carp seed at each harvest (Wang 1994). In the north, the intensified pond production model is dominated by common carp mixed with silver carp. Usually 12 000–15 000 common carp, weighing 50–100 g, and 4500 silver carp, weighing 50–100 g, are stocked per ha, and the total production is expected to be 11 250–13 500 kg/ha.

In central and south China, intensive production models have been dominated by crucian carp. Usually, 22 500–30 000 crucian carp, and 45 000 silver carp, of mean weight of 50–100 g and 50–100 g, respectively are stocked per ha, and the total production is expected to be 7500–9000 kg/ha. For the model that utilizes five Chinese species, dominated by Wuchang bream, usually, 22 500 Wuchang bream, weighing 50–100 g, and 4500 silver carp, weighing 50–100 g, are stocked and the total production is expected to be 10 500–12 000 kg/ha (Bai *et al.* 2008).

2.2.2.3 Feed Management

Sufficient starter fertilizer, 3000–6000 kg/ha fermented organic fertilizers should be spread across ponds. Additional applications of 600–750 kg/ha in small quantities at a time should be sprayed all over the pond. The overall principle of fertilizer application should be flexible and controlled by watching the color of the water, activity, health and feeding of fish, weather changes, water fertility, water temperature, fertilizer source, and pond condition.

2.2.2.3.1 Feeding

When the water temperature is 20°C–30°C, the daily quantity of green feed accounts for 30–40 percent of the total weight of herbivorous fishes; and the daily feeding quantity of formulated feed accounts for 2–3 percent of the total weight of herbivorous and omnivorous fishes. The daily quantity of a formulated feed should be 4–8 percent of the total weight of the stocked fish. Stock should be fed two to three times per day. The specific times should be determined according to various conditions specific to the farm.

2.2.2.4 Regulation of Water Quality

Usually, water should be replenished two to three times per month in the production season. Add water 15–20 cm per time. Mechanical aerators should be provided between May and October, with aerators running for 1–2 hr in the afternoon on sunny days; if cloudy, run the aerators in the morning, and never run them in the evening.

2.2.2.5 Management

Patrol the pond once in the morning and once at night every day, to ascertain the weather, any water quality changes, fish activity and feeding. If fish are gasping for air start up the aerators or change the water. Keep ponds clean by clearing up feed residues, debris, and sick or dead fish in the pond.

2.2.2.6 Disease Prevention and Treatment

It is important to note that three sterilizations should be carried out for the prevention and treatment of disease, namely, sterilize the fingerlings before stocking; sterilize the pond before stocking, and sterilize the feeding frame on a regular basis.

2.2.3 Silver Carp Culture in Large Water Bodies

2.2.3.1 Farming in Lakes and Rivers

China is blessed with a large extent of inland waters covering more than 7 000 000 ha; and the lakes in the eastern plains were among the earliest utilized for fishery development (China Fishery Statistical Yearbook 2014). In 2014, the water area of lake culture in China was 1 015 300 ha (China Fishery Statistical Yearbook 2014). South China is endowed with abundant rainfall and dense river networks. The water level in most rivers is stable, especially in river network zones, such as the Yangtze River Delta, the Pearl River Delta and Jianghan Plain, the water is nutrient rich and abundant with natural food types.

2.2.3.1.1 Fish Farming Models

Lake and river fish farming modes can be extensive, intensive and/or comprehensive. In the extensive mode, artificially propagated fry and fingerlings are stocked into lakes. In some small lakes or rivers that are easily controlled, intensive or semi-intensive modes similar to pond farming can be implemented with increased stocking density and multiple species, and essentially managed as a large pond. The comprehensive mode features 3D utilization of the water body; for example, the greatest profit of water body is improved by raising fish in rivers and lakes, cage fish farming along the banks, raising poultry and livestock by the lake side, and planting lotus in shallow water, and more (Wang 1994).

Selection of Lakes and Rivers The water should be of good quality and fertile, with rich plankton, benthic animals, and aquatic plants.

- There shouldn't be too many tributaries; the water depth should be 1.5–5.0 m; the ridge around the water should be high, not prone to flooding or drying; the river or lake bottom should be flat, and suitable for erecting barricades and for catching.
- The maximum flow velocity should be less than 0.6m/s; the water level should be stable and the difference in perennial water level should be 2–3 m.

As a basic requirement, fish barricade facilities must be provided. It is required that the fish barricade facilities prevent the escape of fish below a certain size; barricades should have the mechanical strength to resist water flow, and wind gusts, and be able to withstand floods to some degree. Barricades should allow floating objects and boats to pass. Common fish barricade equipment includes bars (bamboo and or metal) mesh and electric fences. Bamboo poles are from *Phyllostachys* spp., have good barricading effects, are low cost with a have a life span of one to two years only. Mesh fences are usually made from polyethylene fiber or nylon, allowing a lot of water to pass. The fish barricade structures can be single or double layered. If they are double layered, the space between the two layers is 5–10 m; or one layer of net and one layer of bamboo can be used (Wang 1994).

After erecting barricades, carnivorous fish such as mandarin fish, snakehead and catfish should be removed.

Stocking The species and quantity of stocking should be determined according to the natural productivity of the water area. For lakes and rivers in the intensive mode, several fishes can be cultured together at a relatively high density of stocking, especially so when the practices are predominated by artificial feeding and fertilizer application. The lakes destined to be used for nurturing broodstock should be stocked with wild-caught fry and fingerlings from rivers, with a view to replenishing fishery resources. The stocked species include the four domestic fishes, common carp, crucian carp, Wuchang bream and *Xenocypris argentea*. In relatively fertile water bodies, silver carp and bighead carp are cultured as primary species, accounting for 60–80 percent of the total stocked, and the ratio between the silver carp and the bighead carp is 2:3. Size at stocking should exceed 13 cm. The total number of stocked fish for intensive culture is 4500–7500 /ha, and that of extensive culture is 1500–4500/ ha. If mainly two-year-old fingerlings are stocked, fingerlings of silver carp and bighead carp weighing 0.25–0.5 kg can be stocked, mixed together with one-year-old fingerlings. The ratio between silver carp and bighead carp is 3:7. It is preferable that two-year-old fingerlings are stocked in December, during the winter. Usually, the fish can be temporarily cultured in cages established in fertile lake branches and coves, and then released when the temperature reaches 10°C–18°C. Fingerlings above 13 cm can be directly stocked (Wang 1994).

Feeding and Fertilizing In lakes or rivers for semi-intensive or intensive culture, snails, food processing waste, water plants and terrestrial grass, and formulated feed can be directly used as feed. The fish are fed at a fixed time, at a fixed location, with fixed quantity and quality. A black light lamp can be used in the summer along the banks of the lake or river to attract worms for fish to feed on. All kinds of fermented organic fertilizers, green manure, or bio-bacterial fertilizer, can be added into the still water zones of bays and coves; or, domestic waste water from the city can be used as fertilizer to culture silver carp. In addition, fish farming can be combined with poultry and livestock; if pigs and chickens are cultured around the water body, and ducks are cultured in the water, their excrement fertilizes the water body.

Example I (In Net-Enclosed Lake Area)

A farming household in the lake area of Wujin District, Changzhou, Jiangsu Province encircled a 2-ha lake area with a net (mesh size of the outer layer was 3.5 cm, the inner layer was 3.0 cm) for fish culture; water depth 1.5 m, transparency 10 cm, with fertile water and abundant food organism; no fertilizer or chemicals were used. The lake bottom was flat.

The area demarcated was stocked with 9500 silver carp, 6200 bighead carp, and 1500 silver crucian carp of mean weight of 150 g, 450 g and 100 g, respectively in January 2012, and harvested in July. The harvest included 10 806 kg silver carp (survival rate 91 per cent), 9034 kg bighead carp (survival rate 96.5 percent) and 605 kg silver crucian carp (survival rate 95 percent) and of mean weight of 1250 g, 1510 g and 425 g, respectively. The total expenditure was 70 035 RMB (6 RMB = 1 US$), of which the cost of fingerlings was 34 035 RMB, the depreciation cost of net and boat was 7500 RMB, and labor cost was 28 500 RMB. The sales income was 169 240 RMB, and the net profit was 99 205 RMB. The profit per ha was 49 602 RMB; the input–output ratio was about 1:1.42 (Gu 2014); the harvest and profit would have been better if the fish had been kept until December or until the end of the year.

Example II (In Lake)

Dianshan Lake (31°04'–12'N, 120°53'–121°01'E), a part of the Taihu Lake system, covers 63.7 km^2 and is gourd shape, with a maximum water depth 4.36 m. The average depth is 2.5 m. As 47 km^2 of the lake is within the territory of Shanghai, the lake is also an important water source, and source of aquatic products for Shanghai. The lake's annual average fish catch is above 300 tonnes, and even reached 2000 tonnes at its peak. Since 2005, funds from both provincial governments and the private sector have been used for stocking; the

Figure 2.2.1 Harvesting of silver carp and bighead carp in Poyang Lake, Hubei Province. *Source:* Photos by Zhongjie Li.

Figure 2.2.2 Harvesting of silver carp and bighead carp in Poyang Lake, Hubei Province. *Source:* Photos by Zhongjie Li.

Figure 2.2.3 Harvesting of silver carp and bighead carp in Poyang Lake, Hubei Province. *Source:* Photos by Zhongjie Li.

main fingerlings released include silver carp and bighead carp; the main functions were oriented to improving fishery worker incomes and to ecological remediation. In 2005, the Dianshan Lake was stocked with 21 425 kg of silver carp and bighead carp, and the quantity was increased to 48 393 kg in 2007. Increased stocking of silver carp not only enabled full utilization of blue-green algae feed resources such as microcystis, but also played a role in inhibiting blooms of blue-green algae. From June to September, in its main growing period, silver carp feeds mainly on blue-green algae. The algal blooms were serious in 2007 and 2008. When sufficient fingerlings of silver carp were stocked in 2009, the algal blooms were controlled effectively (Ma *et al.* 2011).

Example III (In Reservoir)

Silver carp and bighead carp are cultured in Sanbanxi reservoir (26°33'–36'N, 108°52'–109°2'E) (4000 ha), Jinping County, Guizhou Province. The terrain there has a low hill ravine, a water table drop of 20 m, and the mesh-barricaded water area of the reservoir branch was 208 ha; dissolved oxygen (DO) was above 5mg/l, it had a pH of 7.1–8.0, and transparency of 50–75 cm. As the water level drops, a lot of tender grasses grow along the bank; on flooding the grasses rot and the water becomes fertile. In February/March 2009, 40 000 silver carp and bighead carp of average weight 300 g (weighing 12 000 kg in total) were stocked. The double-layered mesh barricade had a mesh size of 4 cm; the culture of fish within the barricaded area started in 2009; after three years, the harvest in 2011, and some of the other related details are given in Table 2.2.3.

Based on the information given in Table 2.2.3 and taking the cost of fingerlings (168 000 RMB), mesh fence (72 000 RMB), management costs (30 000 RMB), harvesting cost (50 000 RMB), and other miscellaneous costs

Table 2.2.3 Details on the stocking and harvesting in Sanbanxi reservoir (4000 ha) branch, Jinping County, Guizhou Province.

Stocking		Harvesting				
Species	**Weight (kg)**	**Survival (%)**	**Mean Weight (kg)**	**Total (kg)**	**Price/kg (RMB)**	**Total (RMB)**
Silver carp	4500	70%	2.2	23100	13	300300
Bighead carp	7500	58.4	2.6	38000	13	494000
Grass carp				1500	13	19500
Other fish				2400	18	38400
Total						852200

Source: original data from authors

(20 000 RMB), depreciation cost of fishing boat and mesh fence (10 000 RMB), the total expenditure was 350 000 RMB, and the total profit was 502 200 RMB (Zhou 2014).

2.2.4 Prospects

Silver carp feed mainly on phytoplankton. In the ecosystem of a water body, this carp has the shortest food chain and highest rate of food and energy efficiency conversion. Whether in the mode of pond intercropping, or of culture and propagation in large water bodies, good profits can be obtained; in addition, it plays a role in improving water quality and thus its ecological profit is also extremely significant. Silver carp is a favorite animal protein product for Chinese people; silver carp is affordable to most communities, and is often of good quality, and therefore enjoys a great market demand. The cost of culture and propagation of silver carp is low, and silver carp products are known to ordinary people as organic food fish that are environment friendly, healthy and free of contamination by toxic substances. Today, as mankind focuses more on sustainable development featuring resource conservation, environment friendliness and food security, the culture of silver carp has a promising prospect in China, and around the world.

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2.3

Developments in Common Carp Culture and Selective Breeding of New Varieties

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2.3.1 Introduction

Chinese aquaculture has made remarkable progress in the last three decades or more, due to the aquaculture-centered policy in fishery development proposed during the opening up of the economy during the 1980s (Mai 2012). Chinese aquaculture products account for about 73.5 percent of total global aquatic products, for 60 percent of global aquaculture production, and 50 percent of global aquaculture value in 2013 (FAO 2016; China Fishery Statistical Yearbook 2014). The area under freshwater aquaculture is 72 percent of the total area, and contributes 61.7 percent of all aquaculture output in China. At least 70 percent of freshwater aquaculture production is from conventional carp species, which include grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*), common carp (*Cyprinus carpio*), bighead carp (*Aristichthys nobilis*), crucian carp (*Carassius auratus*) and black carp (*Mylopharyngodon piceus*) (China Fishery Statistical Yearbook 2015).

China has a nearly 4000-year history of cultivation of the common carp, much earlier than in Europe (Wohlfarth 1984; Horváth 2002). In 475 BCE, Fan Li, a Chinese politician wrote *Yang Yu Ching*, or *A Treatise on Fish Culture*, which was the earliest known treatise on fish farming, in which was described the artificial pond culture of common carp (Wohlfarth 1995). In China, common carp has been regarded as an auspicious symbol of abundance, promotion, and prosperity. Nowadays, it has become the most typical representative of Chinese traditional fish culture.

By the middle of the nineteenth century, the common carp had spread all over the world (Welcomme 1988). However, it has only been in the last few decades, common carp culture grew into a global practice, resulting in significant worldwide production, especially concentrated in most of the countries in Asia and Eastern Europe. Asia accounted for ~93 percent of global common carp consumption in the last decade, and China accounted for more than four-fifths of the supply of common carp to Asia (FAO 2016; China Fishery Statistical Yearbook 2014). The proportional contribution to global common carp production in 2013 is shown in 2.3.1. (FAO 2016).

During the last three decades, common carp culture has changed considerably in China. From 1984 to 1993, the average annual production of common carp was less than 550 000 tonnes and only accounted for an average of 55 percent of global production. However, during the following two decades (1994–2013), the production grew rapidly at an annual rate of five to six percent. Production reached 2 000 000 tonnes in 2004, and 3 000 000 tonnes in 2013, which was 76 percent of the global output (FAO 2016; Figures 2.3.1 and 2.3.2).

Common carp is cultured in all 34 provinces and autonomous regions of China (China Fishery Statistical Yearbook 2014). The average annual production of six provinces reached 150 000 tonnes in the last five years each. Two provinces with the highest production are Shandong and Liaoning (Figure 2.3.3).

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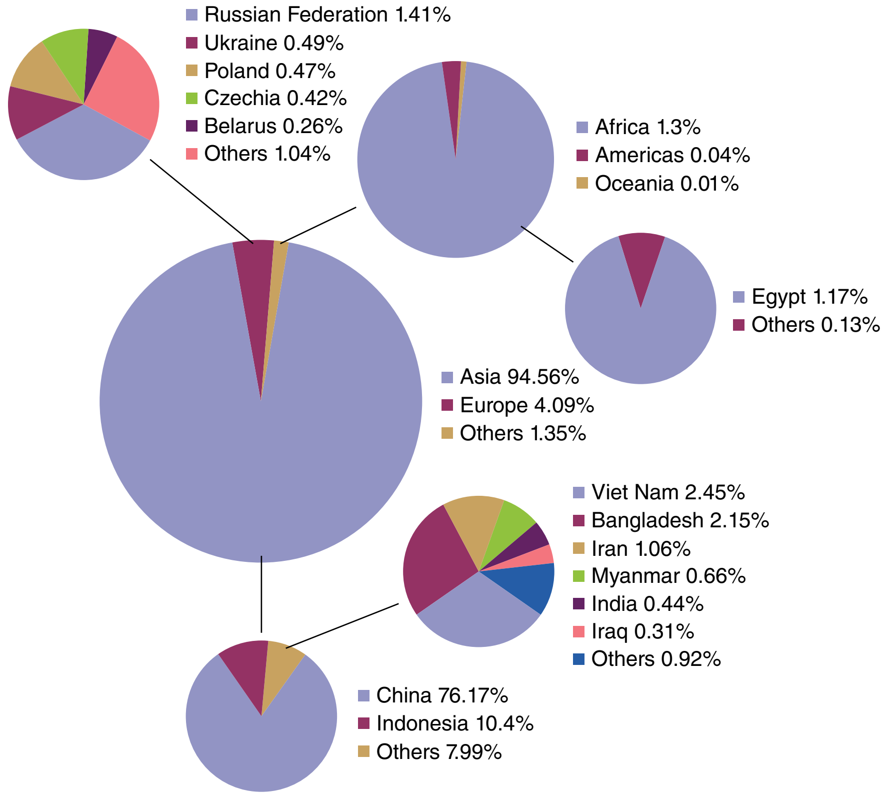

Figure 2.3.1 The proportionate production of cultured common carp in different countries in 2013.

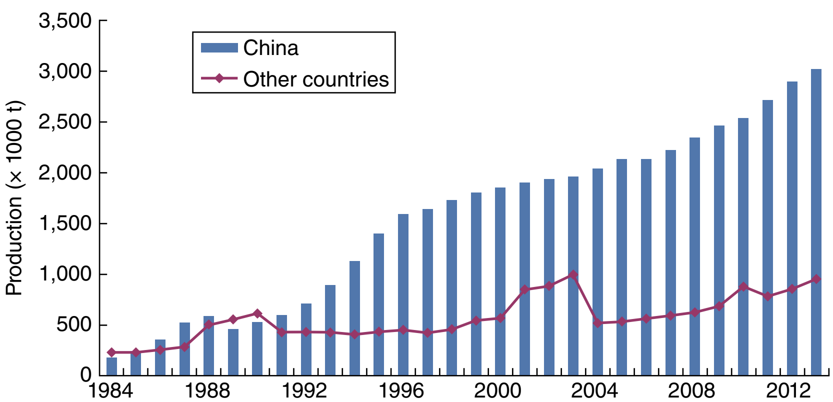

Figure 2.3.2 Trends in common carp production in China and other countries from 1984 to 2013.

Unlike filter-feeding carps, common carp aquaculture depends on formulated feeds. Therefore, the progress of the common carp culture industry depends on improvements and development of technical systems for freshwater fish farming in China. This includes accumulation of traditional experience, and regular innovation in culture practices, and related technologies, and also the selective breeding technologies of new varieties. However, few reports are currently available to summarize these experiences and key changes leading to higher productivity in common carp farming.

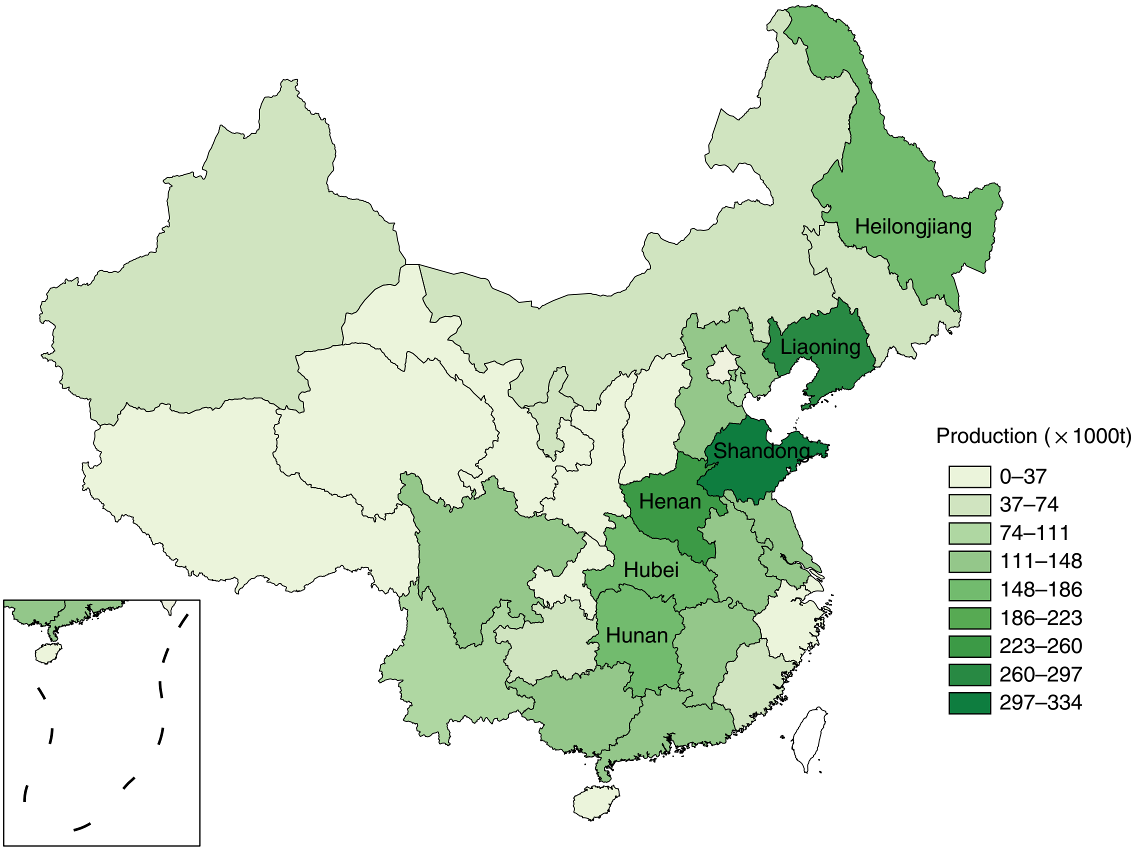

Figure 2.3.3 The mean production of cultured common carp in each province in China.

The boom in freshwater fish culture has made a great contribution to ensuring food security and accelerating strategic adjustment of fisheries. Meanwhile, it also facilitates domestic employment and income growth of related industries, and provides an affordable high-quality animal protein. The achievements of the common carp industry have made an important contribution to freshwater fishery development. A summary of the successful experiences of the development of common carp farming can be a guide for the future direction of aquaculture, and a reference for other areas in the world. In this Chapter, we focus on the progress in common carp culture and selective breeding of new varieties, especially the development and changes during last three decades, research progress, and future prospects.

2.3.2 Why Common Carp?

Common carp has many biological characteristics suitable for culture. Firstly, common carp is omnivorous. It prefers animal-based food, including zoobenthos, mollusks, worms, and aquatic insects. Meanwhile, common carp often consumes decayed plant debris. Common carp live in lower streams of rivers, lakes, reservoirs, and billabongs, but also feed on a few zooplankton species in the middle or upper layers of the water body (FAO 2004). Secondly, common carp has a strong stress resistance to changing environmental conditions. It can live in a broad temperature range between 3°C and 30°C. The species can endure water conditions with low oxygen concentration (0.3–0.5mg/l), and salinity up to 5 ‰ (FAO 2004). In addition, it has also a strong adaptation ability to capture and transportation. Thirdly, the fecundity of common carp is extremely high, and the quantity of eggs released reaches 100–230 g of eggs per kg body weight. A female can produce 0.3–0.8 million fry in one season (Bishai *et al.* 1974; FAO 2004). Last, the meat of the common carp is very tender and contains nutrient components, which are easily digested by humans. All advantages mentioned above have made common carp one of the most important aquaculture species in the world.

Common carp was the earliest cultured fish species in China, the culture activities could be found in oracle bone scripts of the Yin-Shang period dating to about 3500 years ago (Jiang *et al.* 2012). In the *Tang* period, common carp capture or culture was forbidden because the fish symbolized the royal family (Wohlfarth 1995). In *The Book of Songs, or Shijing*, China's earliest collection of poetry dating from the eleventh to seventh centuries BCE, it states that "if one eats fish, it must be Huanghe carp". At important festivals, many regions of China maintain the custom of eating common carp. In the Chinese New Year, people also like pasting paintings of common carp on to their windows to show happiness for the past successful year. All these suggest that common carp has a special status in Chinese history and culture.

2.3.3 Common Carp Farming

2.3.3.1 The Development of Seed Production Technologies

2.3.3.1.1 Natural to Artificial Propagation

In the 1960s–1980s, scarcity of seed hindered the development of freshwater finfish aquaculture. Although China has the longest culture and domestication history of finfish, the regulatory mechanisms of common carp reproduction were unknown. The spawning process could not be well controlled in culture conditions. The induction methods were mainly to provide necessary factors needed to simulate natural spawning conditions in a pond. At that time, the quality and quantity of fry were difficult to estimate, and it was difficult to synchronize ovulation and fertilization among broodfish. Gradually, pituitary extracts and hCG (human chorionic gonadotropin hormone) was used for artificial propagation (Jiang 2008), but because of high production costs, and unpredictable efficacy, this did not drive sustainable development of large-scale seed production (Lin 1991).

In the late 1980s, the dual regulation mechanism of hypothalamic neurons on GtH (gonadotropin hormone) secretion was clarified. Subsequently, Lin (1987, 1991) invented a new type of spawning agent (GnRH/dopamine antagonist) with high efficiency in stimulating spawning of most freshwater fish species (Lin 1987, 1988; Lin and Peter 1991). This novel spawning agent solved the key problem of synchronized ovulation among broodfish, and at a low cost. The injection time and dose of spawning agent could be arranged to suit the maturity stage of broodfish, water temperature, and hatching programs. Eggs, either naturally or artificially fertilized, were hatched in hatcheries. It became possible for breeding companies to provide a large amount of high-quality seed from different batches in the same season.

2.3.3.1.2 Development of Hatching Methods

Common carp eggs are demersal and sticky. Many hatching methods were developed based on special incubation conditions. The hatcheries may be in ponds, cement tanks, incubation jars, circular incubation pools, etc. (Figure 2.3.4).

Hatching in Ponds Based on Natural Spawning Before the 1970s, special hatching facilities were not available (Jiang 2008). Artificial spawning nests were usually made of palm leaves, and fibers of aquatic weeds or willow tree. Fertilized eggs attached to the nests were transferred into prepared incubation ponds with stagnant water for final hatching (Figure 2.3.4). Neither the amount of laid eggs nor the fertilization rates were not easy to monitor. The hatching rates and the seed output were also hard to estimate because of several factors, such as changes in water temperature, bacterial or fungal infection, and some unexpected losses. More importantly, hatched fry may vary in size due to the differences in hatching time, which affected the survival rate.

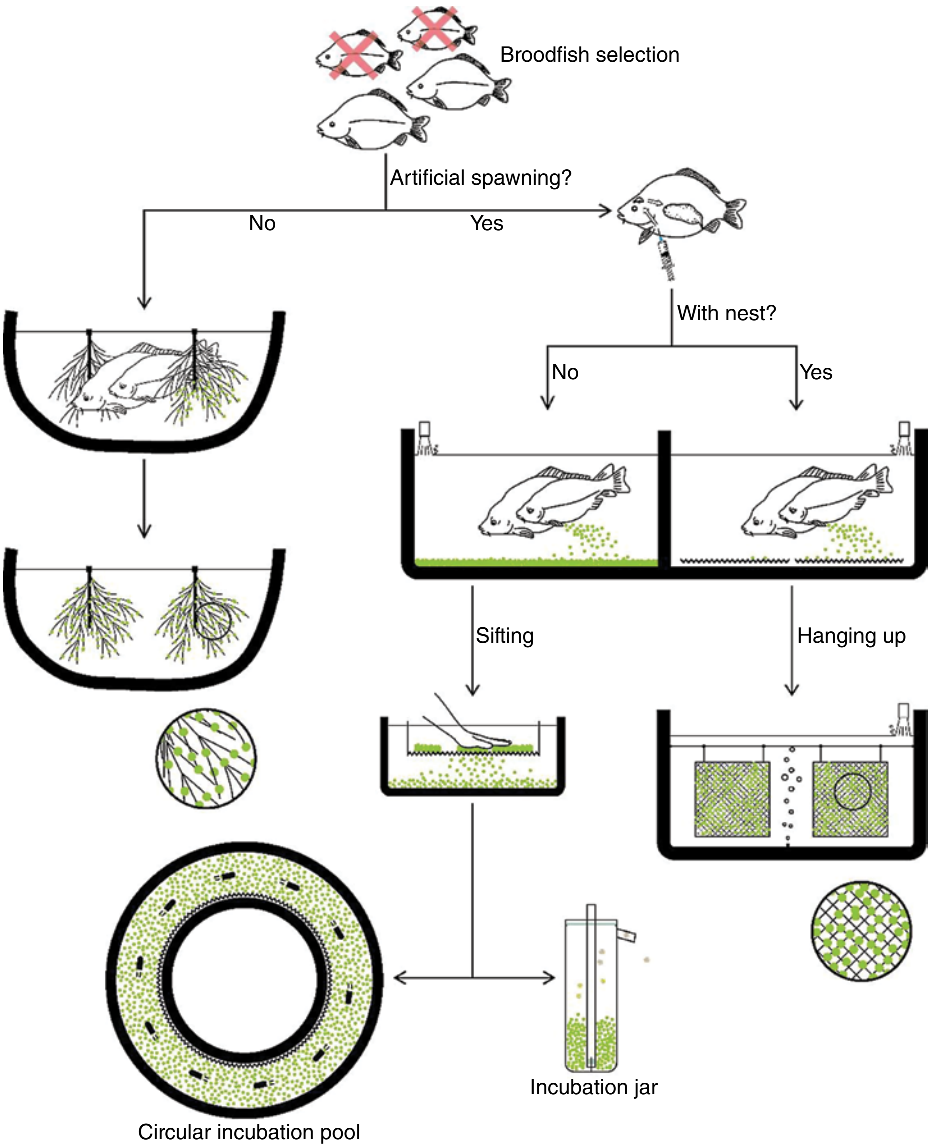

Figure 2.3.4 Commonly used spawning and hatching methods for common carp.

Hatching in Cement Tanks With the development of artificial propagation technology in the 1990s, a mass of eggs from the same spawn could be easily obtained. A variety of new hatching facilities and tools were developed based on the water resource and operating scale of the hatcheries. In one method, both spawning and hatching were conducted in indoor rectangular cement tanks (Figure 2.3.5a). Best results were obtained by using nylon bolting cloth as an artificial spawning nest. These nests were evenly spread over the bottom of cement tanks. Once a certain quantity of eggs have attached to the nests, new nests are provided for fresh batches of eggs. Then the nests with attached eggs were transferred to hatching tanks supplied with slow-flowing water, and were hung on the ropes until hatching (Figure 2.3.5a). This method required temperature control, good rate of water exchange and an oxygen supply. However, it was difficult to control the influences of anoxia caused by lumping or poor water flow. Such operations were popular before 2003, but currently only used in some small seed production farms.

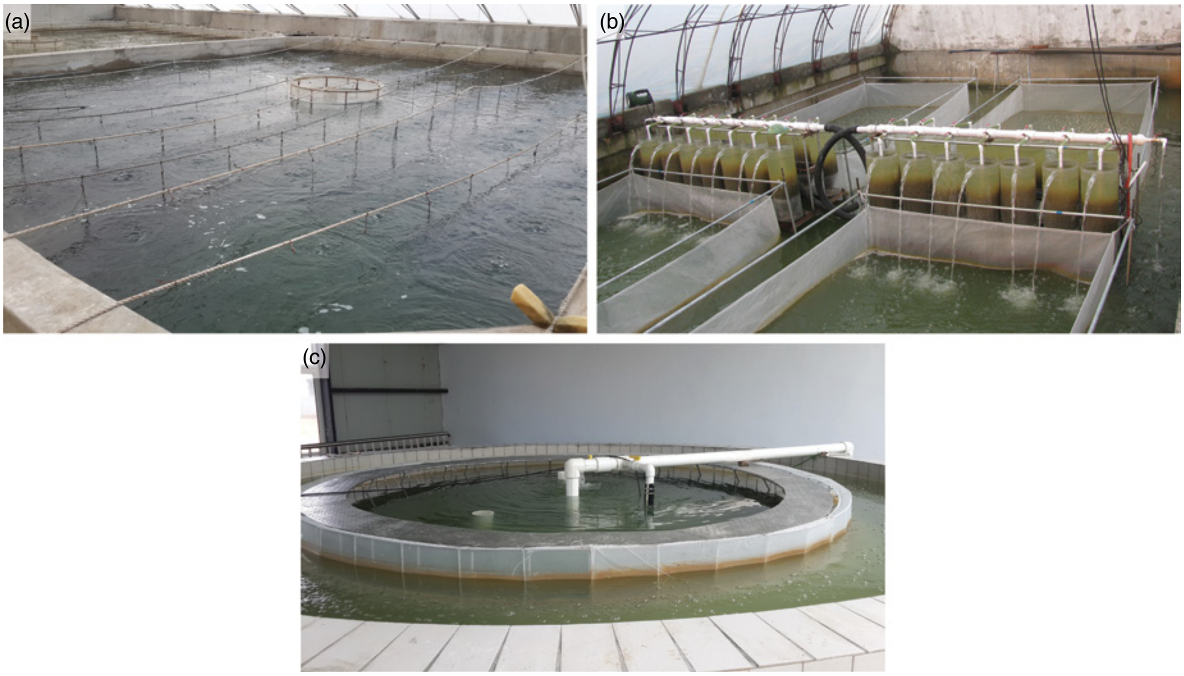

Figure 2.3.5 Hatching containers for common carp eggs. a. cement tanks; b. incubation jars; c. circular incubation pools. (*See color plate section for the color representation of this figure*.)

Hatching in Incubation Jars or Circular Incubation Pools Common carp eggs become sticky after coming in contact with water. To overcome the disadvantages of traditional hatching methods, finding effective ways to eliminate egg stickiness were essential. After 2003, one simple and effective method for eliminating stickiness was developed (Jin 2003). A cement tank with a smooth inner wall was used for spawning. Previously selected broodfish were put into the tank after hormonal treatment, maintaining a circular water flow until spawning and fertilization were complete. The constant circular water flow encouraged the spawned eggs to disperse, and they partly lost their stickiness. Then fertilized eggs were collected and isolated by hand sifting in a specially developed egg sieve. Moreover, individual eggs were immersed in Methylene blue solution for ten minutes (a practice discouraged at present) to prevent infection of *Saprolegniasis* (Li *et al*. 2011). Disinfected eggs were then placed in incubation jars (Figure 2.3.5b) or circular incubation pools (Figure 2.3.5c). Eggs are placed into an incubation jar of 15–30 l and the quantity is ~60 g per. The embryogenesis of common carp takes about three days at 20–23°C. Successful hatching depends on the environmental conditions, including sustainable water flow, good water quality and stable temperature. Fertilization status and the embryonic development process can be evaluated by observations of egg color. Normal eggs are greenish-yellow, then brown, and finally black. Unfertilized eggs will be milky white, and gradually congregated at the top of the egg mass due to the difference in gravity between dead eggs and normal eggs. Fungus infecting dead eggs could spread to living eggs, therefore they should be removed fast. The hatching larvae constantly enter into the net cages set up in tanks under the incubation jars (Figure 2.3.5b). At this time, a sufficient supply of oxygen, and continuous cleaning of the mesh of the collection net cages should be ensured.

If there are a large amount of eggs, the circular incubation pool is the first choice. This hatch facility contains two chambers, and the diameter of the outer chamber is about 6–10 m with a concrete wall (Figure 2.3.5c). The inner ring wall made partly of nylon sieve cloth, which prevents the eggs or hatched fry from being driven toward the outflow pipe. Duck beak-type water inlets are located at the bottom of the pool to provide the required velocity (0.2–0.3 m/sec) of water circulation. The rate of water exchange and the water temperature need to be monitored regularly throughout the whole hatching process. The circular

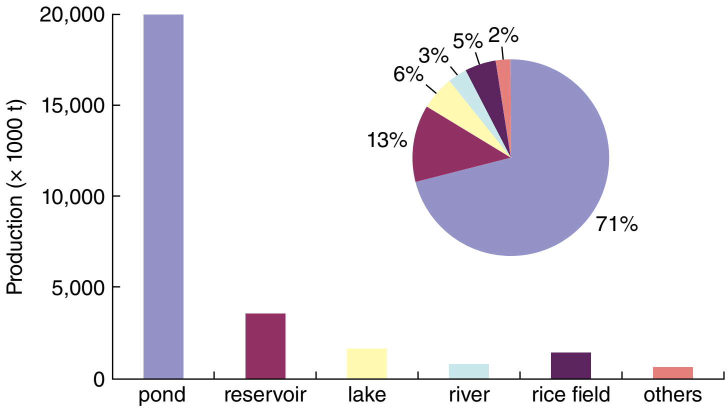

Figure 2.3.6 Production and percent contribution from different culture practices of freshwater fish in China in 2013.

incubation pool technology have been constantly improved and developed in last three decades. The combination of efficient spawning-induction agents, modified technology to eliminate stickiness, and circular hatching pools, enhanced the seed production efficiency, ensured large-scale seed supply, and further accelerated the development of the common carp culture industry.

2.3.3.2 Transition from Extensive to Intensive Pond Culture

2.3.3.2.1 Common Carp Culture Practices

Pond farming is a major type for freshwater fish culture in China. Pond aquaculture production was 19 80 000 tonnes, accounting for ~71 percent of total finfish production in 2013 (China Fishery Statistical Yearbook 2014; Figure 2.3.6). Common carp production was the third highest among all freshwater fish species from 2011 to 2016, and pond culture was the main farming practice. The transition from extensive to intensive pond culture was the most important driver for high yields. Several key factors led to changes in pond culture practices.

2.3.3.2.2 Feed Industry Development

Common carp culture depends on formulated feeds. Thus, the development of the aquatic feed industry promotes the transition from extensive to intensive pond culture of common carp. In the 1950s–1970s, the culture of common carp rested on the traditional extensive culture in ponds. Filter-feeding silver carp and bighead carp were the main culture species, and common carp was only a supplementary species accounting for 20 percent of the stock (Figure 2.3.7). Organic or inorganic manures were used to fertilize pond water, and the latter accelerated the proliferation of phytoplankton and zooplankton. Soybean meal, cereal meals, or simple mixtures of several raw materials were used as supplementary feeds. Extensive culture of common carp has very low efficiency and impacts on water quality. In the 1980s, intensive-culture practices were developed, together with the improvement of aquatic feeds. In this way, common carp became the main culture species in polyculture systems, with a smaller proportion of filter-feeding fish to maximize the growth potential of common carp, and productivity of the pond. In the three decades following the 1980s, the feed industry made great progress in processing and utilizing raw materials and additives, and developing nutritionally balanced feeds for cultured aquatic animals. In 1991, aquatic feed production was only 750 000 tonnes, but it reached 19 000 000 tonnes in 2013, surpassing the sum of aquatic feed outcome of other countries (CFIA 1992–2014; Figure 2.3.8). Han *et al.* (2016) described the development of the aquatic feed industry in China, and particularly pointed out the pros and cons of the use of fishmeal in the Chinese aquafeed industry, which has been a bone of contention in many critiques of Chinese aquaculture (see Chapter 5.1 for details).

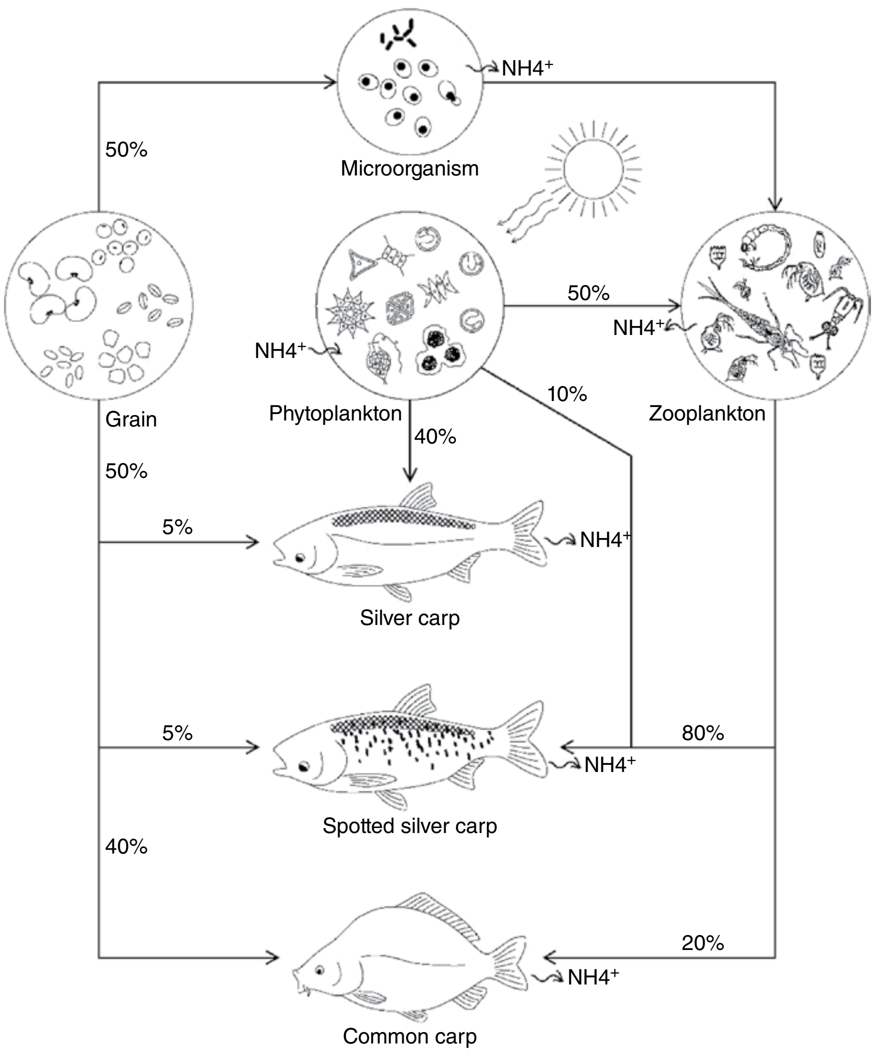

Figure 2.3.7 Schematic representation of the energy flow in traditional common carp culture.

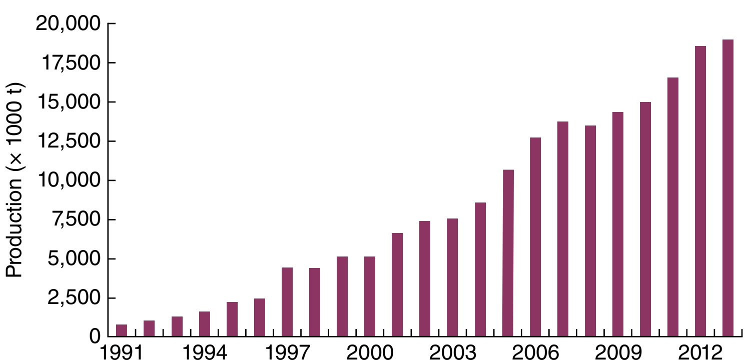

Figure 2.3.8 Trends in the production of aquatic feeds in China.

In China, common carp is ranked third in terms of aquaculture production volume, following grass carp, in first position, and silver carp. In the early stages of intensification, the average unit production of adult common carp was 4500–7500 kg/ha in three northern regions in China in 1985. Production increased by ~900 kg in 1990 (Tang 2000). Yet in recent years, the yield of common carp has reached 18 000–27 000 kg/ha in the north-east region (Zu *et al*. 2012; Wang *et al*. 2013; Zhang *et al.* 2014). The increase in common carp yield was associated with the use of new breeds, control of fingerling size and stocking density, nutrition, and management, culture conditions and technologies. However, continuous basic and applied research on nutritional balance in common carp feed formulae also played a key role in the rapid production increases (Zhou *et al.* 2002; Peng *et al*. 2009; Xia 2012).

2.3.3.2.3 Improvements of Culture Facilities

In traditional extensive-culture practices of common carp, the utilization efficiency of pond was very limited. The first indigenously designed Chinese oxygen-enriching machines were put into service in the mid 1970s. The yield per mu (0.06 ha) of common carp realized a historic breakthrough of 500 kg after aerators were utilized (Jiang 2008). With the use of pelleted feeds in fish culture, automatic feeders were successfully developed and used widely (Wu 1987), which saved labor costs and improved the feed conversion rates. Therefore, development of culture facilities played a significant role in the transition from extensive to intensive high-density culture of common carp, and increased the technological level in common carp culture.

2.3.3.2.4 Key Culture Technologies

Fish growth depends on the food source and maintaining a conducive temperature. In temperate regions, the culture process of common carp was generally divided into three phases; summerling, fingerling and adult stages (Figure 2.3.9).

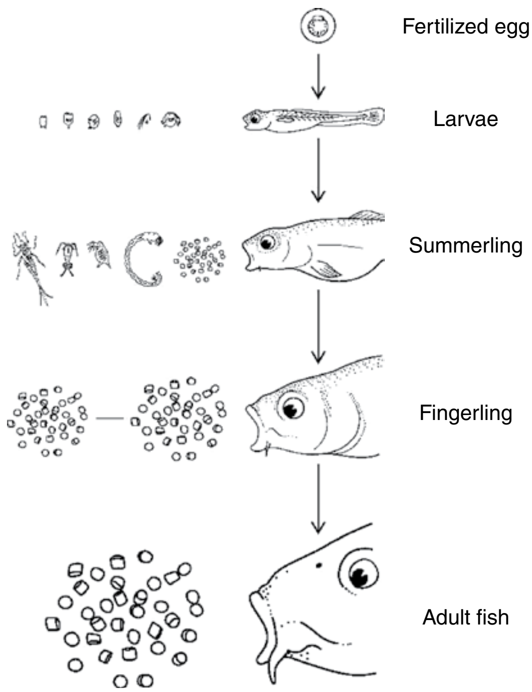

Figure 2.3.9 Schematic representation of the culture process of common carp through the life cycle.

Summerling Cultivation Hatched larvae begin to swim in three to four days. At this stage, the swim bladder is filled with air, and the digestive system is able to receive and digest external food. The next step is to transfer the fry into rearing ponds as soon as possible. To maintain available energy before being able to capture external food, it is necessary to feed fry with finely ground hard-boiled egg yolk for one to two days. Then larvae are stocked into nursery ponds for 20–25 days until they reach the summerling size of 3–5 cm. During this stage, larvae have to feed on large numbers of live organisms of appropriate size for early growth and development of ~10 d. The food types are successively rotifers, cladocerans, and copepods (Figure 2.3.9). Therefore, the most critical factor of summerling cultivation lies in ensuring that the rotifer population is at optimum density when the fry are ready to be stocked. In order to provide conducive pond conditions, organic fertilizer can be used to produce and control the plankton populations. Currently, many culture companies have replaced environmentally friendly microbial fertilizer with organic fertilizer.

Fingerling Cultivation When fry grow to summerling size of 3–5 cm, these will be harvested and restocked into fingerling ponds (Figure 2.3.10). The stocking density of summerlings can be adjusted according to the local climate, pond conditions, and expected size of fingerlings, prevailing culture practices and technologies. Pelleted feed will be the main nutritional source in current fingerling cultivation. It is much better to feed fish at fixed stations and regular times in the initial five to seven days. The daily feed ration and the diameter of pelleted feed gradually increased to keep pace with the growth (Figure 2.3.9). The estimation of feed consumption is very important for avoiding under- or over-feeding. In addition, disease control and water quality regulation are also key factors for fingerling cultivation. Common carp need to be cultured in ponds for two years until they reach a marketable size in most northern regions in China. Thus, fingerlings experience one overwintering period of four to five months below ice. In 1996, the overwintering survival rate of common carp fingerlings was only 53 percent in Jiamusi region of Heilongjiang Province (Liu 2001). Anoxia in overwintering ponds was a critical factor that resulted in low survival. The dissolved oxygen content of overwintering ponds should be maintained at 5 mg/ml, otherwise measures must be taken to increase circulation or provide micropore aeration. Additionally, to utilize the oxygen supply from photosynthesis beneath ice, 40 percent of the whole pond ice area should be clear, and less than 20 percent of the pond covered with snow (Figure 2.3.11). Another noticeable problem was weight loss during overwintering, which had significant influence on the growth in the following year (Hu *et al.* 2010). Recent studies have shown that overwintering weight loss of common carp occurred mainly at the stage before freezing (Yu *et al.* 2015). Therefore, monitoring water temperature and appropriate feeding strategies are necessary until the pond water began to freeze.

Figure 2.3.10 Summerling harvesting.

Figure 2.3.11 Removal of snow from overwintering ponds of common carp culture ponds in northern China. (*See color plate section for the color representation of this figure*.)

2.3.4 Selective Breeding for New Varieties

2.3.4.1 Abundant Germplasm Resources are the Basis of Selective Breeding

Common carp belongs to the genus *Cyprinus*, and it includes 16 species in China, 11 of them distributed in Yunnan Province (Table 2.3.1) (Yue 2000). Common carp have the most varieties and the most extensive distribution among *Cyprinus* species. A few common carp varieties inhabit different river systems and basins, such as Heilongjiang carp, Huanghe carp, Yangtze River carp and Oujiang color common carp. Some varieties of common carp are native to different regions, such as the "Three Kinds of Red Carp" in Jiangxi Province (Purse red carp, Xingguo red carp and Glass red carp), and Yuanjiang carp in Yunnan Province. There are three exotic varieties (Russian Scattered mirror carp, German mirror carp and Ukraine carp) with excellent stress-resistance and growth performance. The origin of common carp varieties is shown in Table 2.3.2. These local and exotic varieties evolved various genetic characteristics because of long-term geographic isolation, adaptation, natural and human selection pressures. They constitute the basis of selective breeding and improvement of new varieties. The following are several representative varieties.

2.3.4.1.1 Heilongjiang Carp

This variety has very high cold and disease resistance capabilities, as well as good fecundity, but has a slower growth rate than other cultured varieties (Figure 2.3.12a). The muscle of Heilongjiang carp has high protein and low fat content (Liu *et al*. 1993). In addition, this fish species has high combining ability with many varieties, such as the German mirror carp and the Purse red carp, and the hybrids showed significant growth advantage. The conformation factor (body length/body height, L/H) varies within 2.9–3.1 (Shen and Liu 1999). Both its genetic properties and body shape may be associated with its environment. As one of the hybridization parents, Heilongjiang carp is used in the breeding of cold-resistant strains of Purse red carp, Ropsha carp, Songpu carp and Songhe carp which are very well known in China (Shen and Liu 1999).

Table 2.3.1 Recorded *Cyprinus* species and their distribution in China.

Species	Distribution
Cyprinus carpio	Rivers, lakes and reservoirs in each province
Cyprinus multiltaeniata	Guangdong and Guangxi province; Xijiang river systems
Cyprinus longzhouensis	Longzhou county in Guangxi province, Xijiang river upper reaches
Cyprinus acutidorsalis	Qinjiang river system in Guangxi, Hainan
Cyprinus qionghaiensis	Qionghai in Sichuang province
Cyprinus micristius	Dianchi lake in Yunnan province
Cyprinus fuxianensis	Fuxian lake and Xingyun lake in Yunnan province
Cyprinus yilongensis	Yilong lake in Yunnan province
Cyprinus carpio chilia	Qilu lake and other all lakes in Yunnan province
Cyprinus megalophthalmus	Erhai lake in Yunnan province
Cyprinus longipectoralis	Erhai lake in Yunnan province
Cyprinus pellegrini	Qilu lake and Xingyun lake in Yunnan province
Cyprinus barbatus	Erhai lake in Yunnan province
Cyprinus daliensis	Erhai lake in Yunnan province
Cyprinus yunnanensis	Qilu lake in Yunnan province
Cyprinus ilishaestomus	Qilu lake in Yunnan province

Table 2.3.2 Current common carp varieties cultured in China and their places of origin.

Varieties	Original place
Heilongjiang wild carp	Heilongjiang river basin
Huanghe carp	Huanghe river basin
Yangtze wild carp	Yangtze river basin
Oujiang color carp	Oujiang river basin
Purse red carp	Wuyuan county in Jiangxi province
Xingguo red carp	Xingguo county in Jiangxi province
Glass red carp	Wanan county in Jiangxi province
Yuanjiang carp	Yuanjiang county in Yunnan province
Scattered mirror carp	Russia
German mirror carp	German
Ukraine carp	Ukraine

Heilongjiang carp provides important and unique gene resources, which have been preserved by the original seed farm.

2.3.4.1.2 Huanghe Carp

This variety has an elegant appearance with golden scales and red or orange tail fins (Figure 2.3.12b). This fish presents a long spindle-shaped body (L/H>3), and the length and height of caudal peduncle is almost equal (Feng *et al.* 1997). Huanghe carp is one of the best known freshwater fish species in China because of its body

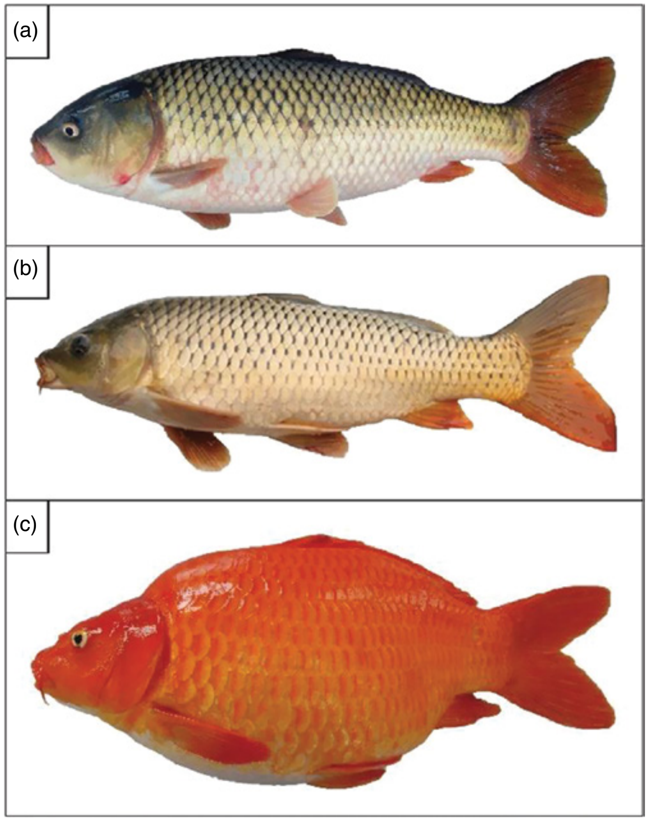

Figure 2.3.12 Representative common carp varieties. a. Heilongjiang wild carp; b. Huanghe carp; c. Purse red carp.

shape and palatability (Song and Li 2009). However, natural sources of Huanghe carp were under serious threat from environmental deterioration and overfishing in the 1950s–1980s.

2.3.4.1.3 Purse Red Carp

This variety is one of the Jiangxi "Three Kinds of Red". It has a long culture history of ~300 years (Figure 2.3.12c). The Purse red carp is so named because its short body is shaped like a purse (L/H = 2.0–2.3) (Lou 1998). The growth rate of this variety is in the medium range, but its adaptability and muscle quality is preferred by many farmers (Shen and Liu 1998). Its lipid content in muscle dry matter reaches 21.4 percent in an adult fish, significantly higher than that of wild carp (8.4 percent) (Lou 1998). Purse red carp has a high hybridizing ability similar to Heilongjiang carp, and has been widely used as parents to produce numerous hybrids with remarkable heterosis, or new varieties, such as the cold-resistant strain of Purse red carp, Heyuan carp, Yue carp, triple-hybrid carp, Jian carp and Songpu red mirror carp.

2.3.4.2 Improvement from F_1 Hybrids to New Varieties with High, Stable Production Performances

2.3.4.2.1 Hybridization

Since the 1970s, many countries have carried out successful crossbreeding studies among wild and domesticated carp varieties for heterosis for various production traits (Wohlfarth 1993; Hulata 1995). Chinese scientists also made a large number of attempts in cross-breeding experiments using different local and exotic common carp varieties. Several F_1 hybrid generations with significant heterosis in growth, reproduction, survival rate were selected and extended to farming practices. Representative hybrids were Feng carp (Xingguo red carp ♀ × Scattered mirror carp ♂) in 1972, Lotus carp (Scattered mirror carp ♀ × Xingguo red carp ♂)

in 1975, Yue carp (Purse red carp ♀ × Xiangjiang carp ♂) in 1975, Heyuan carp (Purse red carp ♀ × Yuanjiang carp ♂) in 1978, triple-hybrid carp (Heyuan carp ♀ × scattered mirror carp ♂) in 1985 (Lou 1989; Cheng *et al.* 2001). These hybrids were commercially cultured and played a key role in the development of the common carp industry at that time. However, there is a great limitation on the heterosis utilization of F_1 hybrid generation only. The performance of production traits may be unstable because it is difficult to maintain the high purity of at least two breeding stocks at a low cost.

2.3.4.2.2 Breeding Based on Traditional Mass Selection

In spite of the long history of culture and domestication of common carp in China, substantial selective breeding attempts started only in the late 1960s. All selected varieties experienced a period of at least ten years. On the one hand, selective breeding was carried out for purification and rejuvenation of germplasm (body color, body shape or growth) of local varieties. For example, the "Three Kinds of Red Carp" in Jiangxi Province experienced systematic selection. The selection time was in 1969–1979 (Purse red carp), 1972–1985 (Xingguo red carp) and 1973–1983 (Glass red carp), respectively (Li 2001). Another typical example was the Huanghe carp, which is well known in China. After 1985, it took breeding specialists over 20 years to restore its genetic properties (Song and Li 2009). This new variety is named Yuxuan Huanghe carp, and its growth rate increased by 12 percent and the feed efficiency improved by ten percent compared to the parental fish (Sun *et al.* 2013). On the other hand, a main selective breeding objective of German mirror carp is adaptability. This fish species did not adapt well to local pond culture conditions when it was first introduced into Heilongjiang Province. After selective breeding of four generations, the rearing and overwintering survival rate of selective strain (F_4) increased by 25 percent and 33 percent, respectively (Liu *et al.* 1995).

2.3.4.2.3 Breeding Based on Integrated Technologies of Selection and Genetic Manipulation

In the late 1980s, China bred the first new variety called Jian carp using family selection and gynogenesis methods. With the rapid development in selective breeding and genetic manipulation technologies, new varieties bred with stable genetic characteristics made prominent contributions to the common carp culture industry. The following are examples of several major new varieties, with a brief resume of the steps involved in their production.

- ***Jian carp*** is the first representative common carp variety bred by artificial breeding in the late 1980s. Jian carp has high stability of genetic characteristics in growth rate, disease resistance, muscle quality and adaptability (Sun 1988). It has now been widely cultured for more than two decades in China. Purse red carp and Yuanjiang carp were the original parents of Jian carp. These two varieties showed strong combining ability in previous breeding practices (Ma *et al.* 1981). The breeding process of Jian carp experienced intra-strain selection with high strength (F_1–F_3), inter-strain hybridization (F_4), and crossbreeding between F_4 and two gynogenesis strains (G_3 and G_4). Jian carp is the second generation (F_6) of the synthetic strain (Figure 2.3.13).
- ***Songpu carp** and **Songhe carp*** are two new varieties suitable for culture in the northern areas of relatively high latitude. It took researchers 15 years (1979–1995) to complete the selective breeding project (Shen *et al.* 1996; Liu *et al.* 1998). The shape of the Songpu carp is similar to the Purse red carp (L/H = 2.0–2.3), while the Songhe carp has an elongated shape (L/H = 2.4–2.6). Both new varieties have high cold resistance and growth rate. The overwintering survival rate exceeds 95 percent in north-eastern regions (Shen and Liu 1999). The growth rate of two-year-old Songhe carp and Songpu carp was respectively ~17 percent and ~20 percent higher than that of Heilongjiang carp (Liu *et al.* 1998; Shen and Liu 1999). The successful breeding of two new varieties solved the problem of low survival rate during overwintering in north-eastern areas. Their breeding uses systematic selection and gynogenesis technologies. Firstly, two trihybrids were obtained from crossbreeding and backcrossing Heilongjiang carp, Purse red carp, German mirror carp and Scattered mirror carp. Further, to stabilize heterosis, two synthetic strains of the above-mentioned hybrids and two artificial gynogenesis strains were set up. Songpu carp was bred based on synthetic strain one, and Songhe carp was bred based on synthetic strain two (Figure 2.3.14).

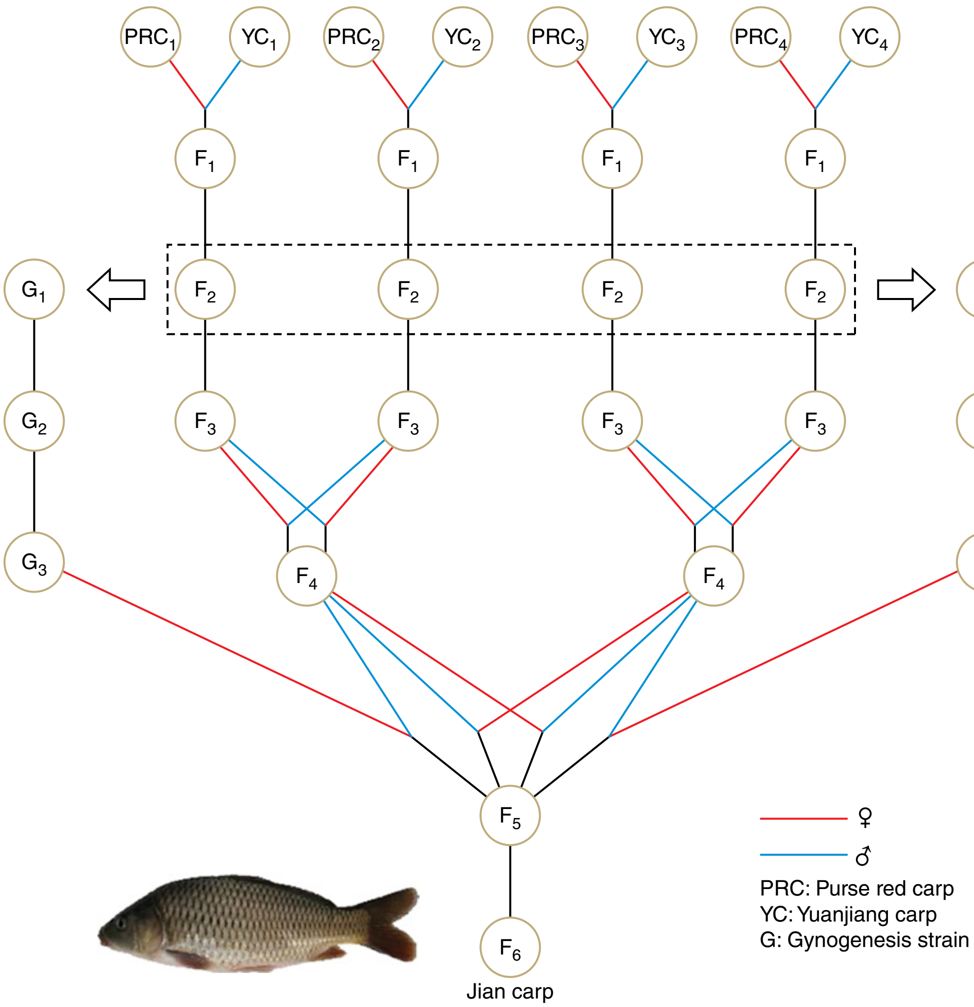

Figure 2.3.13 Schematic representation of selective breeding process of Jian carp.

- ***Cold-resistant strain of Purse red carp*** was the first cold-resistant variety bred by using the hybridization method. It had a similar body shape and body color to the Purse red carp, but the overwintering survival rate was more than 90 percent (Shen and Liu 1988). The cold-resistant strain was firstly from the hybridization between Heilongjiang carp (♂) and Purse red carp (♀). Then systematic selective breeding of four generations was conducted based on cold resistance, body shape and color (Figure 2.3.15). The new strain not only had high hypoxia resistance from Purse red carp but also inherited strong cold resistance capability from Heilongjiang carp (Liang and Sun 2003; Liang *et al.* 2006).
- ***Songpu mirror carp*** was the F_7 generation bred from the selective strain (F_4 generation) of German mirror carp, which was introduced into China in 1984 (Liu *et al.* 1995). The growth rate of two-year-old Songpu mirror carp increased by 45 percent compared to fish of F_4 generation. In addition, Songpu mirror carp showed fewer scales and high stress resistance in different culture environments (Li *et al.* 2008). Between 2010 and 2013, the Chinese Ministry of Agriculture recommended that farmers culture Songpu mirror carp. To date, this new variety has been extended to 20 provinces, and its culture area reached 65 000 ha. Songpu mirror carp has a higher market price per kilo of 2–3 RMB (6 RMB = 1 US$) than general common carp varieties. The systematic selective breeding of selective strain (F_4) cultured in four regions (Beilin,

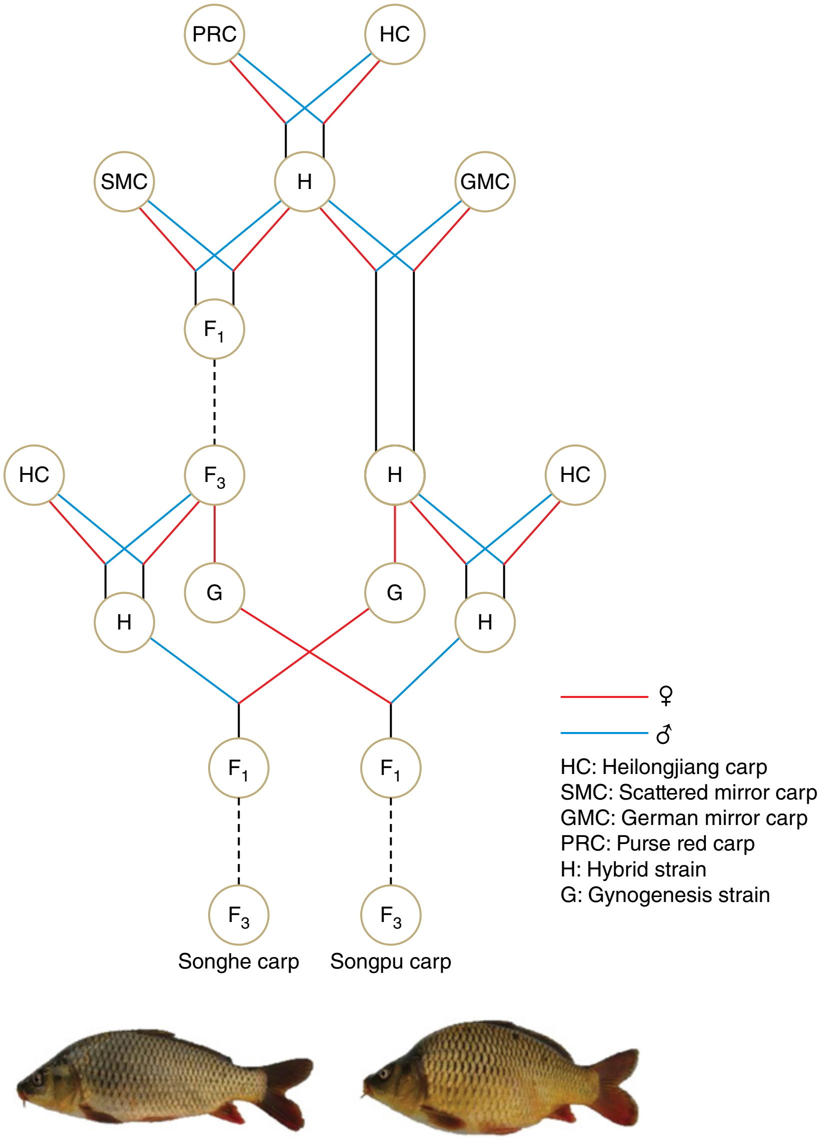

Figure 2.3.14 Schematic representation of the selective breeding process of Songpu carp and Songhe carp.

Tianjin, Songpu and Minfu) were performed. Inter-strain hybridization among Beilin F_6, Songpu F_6 and Minfu F_7 were completed to select the final F_7 generation (Figure 2.3.16). Passive integrated transponders (PIT) and molecular markers were used in the identification of the reproductive parents to control the inbreeding coefficient of each generation.

- ***Songpu red mirror carp*** has a fast growth rate and vivid body color, and is thus a new variety with edible and ornamental uses. Individual average weight gain and culture survival rate of two years old fish increased by 35 percent and 12 percent than that of the cold-resistant strain of Purse red carp. In numerous culture practices, this variety showed stable performances in scale form, body color and body shape. Fry production reached 73 000 000 in Heilongjiang, Jilin and Liaoning provinces during 2008–2012. The basic population of Songpu red mirror carp was from the hybrid between Russian scattered mirror carp (♂) and Purse red carp (♀). Moreover, the systematic selection of six generations was completed from 1990

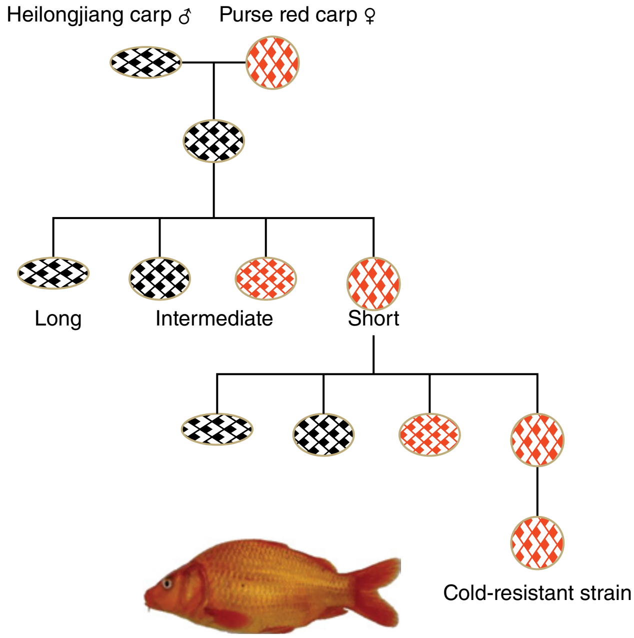

Figure 2.3.15 Schematic representation of the selective breeding process of the cold-resistant strain of Purse red carp.

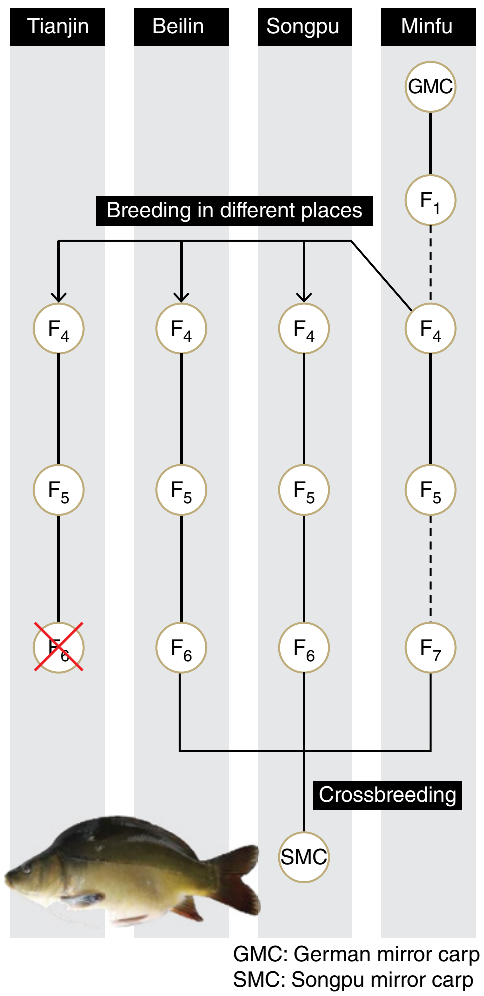

Figure 2.3.16 Schematic representation of the selective breeding process of Songpu mirror carp.

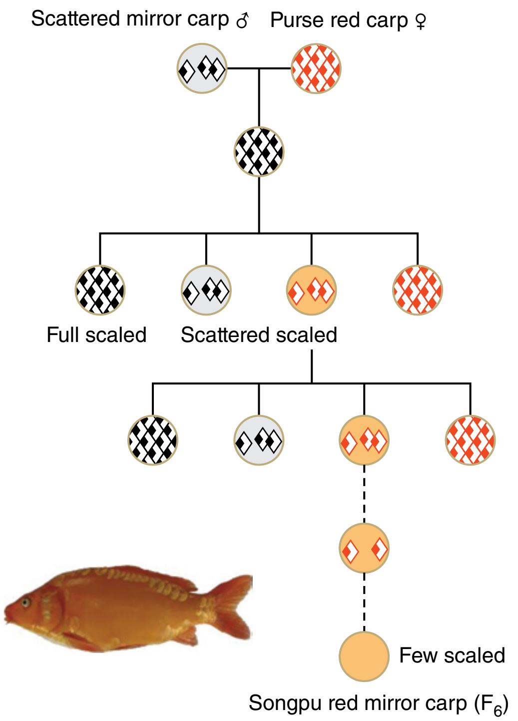

Figure 2.3.17 Schematic representation of the selective breeding process of Songpu red mirror carp.

to 2008 (Figure 2.3.17). Present fry production of this variety has also utilized the PIT and molecular markers to ensure fry quality.

- ***FFRC strain common carp*** (*Cyprinus carpio L.*) is the first common carp variety bred using best linear unbiased prediction (BLUP) technology. The growth rate of this variety enhanced by 20 percent over that of control fish (Dong 2011). Jian carp and wild Huanghe carp were the parent resource. The breeding process included mass selection of hybrid F_1 (Jian carp × Huanghe carp) and successive family selection of four generations (F_2–F_5). Parent fish were selected according to the breeding value estimated by BLUP method except for the first generation (Figure 2.3.18).
- ***Easy caught carp*** is a new variety bred in 2011 using the distant hybridization between common carp (*C. carpio*) × Barbless carp (*C. pellegrini*), backcrossing, and systematic selective breeding technologies (Figure 2.3.19). The parent varieties of common carp were Heilongjiang carp and Scattered mirror carp. Easy caught carp integrated the advantages of parents in the seinability and cold resistance. Easy caught carp live dominantly in the upper and middle layer of the water body and feed on plankton. Thus, it is suitable to be stocked in controlled large water bodies for natural propagation. For one-year-old fish, the seinability rate of twice seining was 93.4 percent, which increased by 113.4 percent and 38.7 percent than that of Heilongjiang carp and Songpu mirror carp, respectively. For two-year-old easy caught carp, seinability rate of twice seining could reach 96.5 percent, which elevated to 96.7 percent, 56.1 percent and 71.3 percent than that of Heilongjiang carp, Songpu mirror carp and Songhe carp, respectively. The growth rate of Easy caught carp is similar to Songhe carp (Li 2015).

2.3.5 Market Potential

Annual exported volume of common carp to Korea and Russian was only ~2100 tonnes, and valued at US$ 9 660 000 in 1997–2012. The population of China is predicted to reach 1.5 billion in 2030, and the supply/demand gap for aquatic products is likely to be around 20 000 000 tonnes (Tang 2012; see Chapters 1.4 and 8.1).

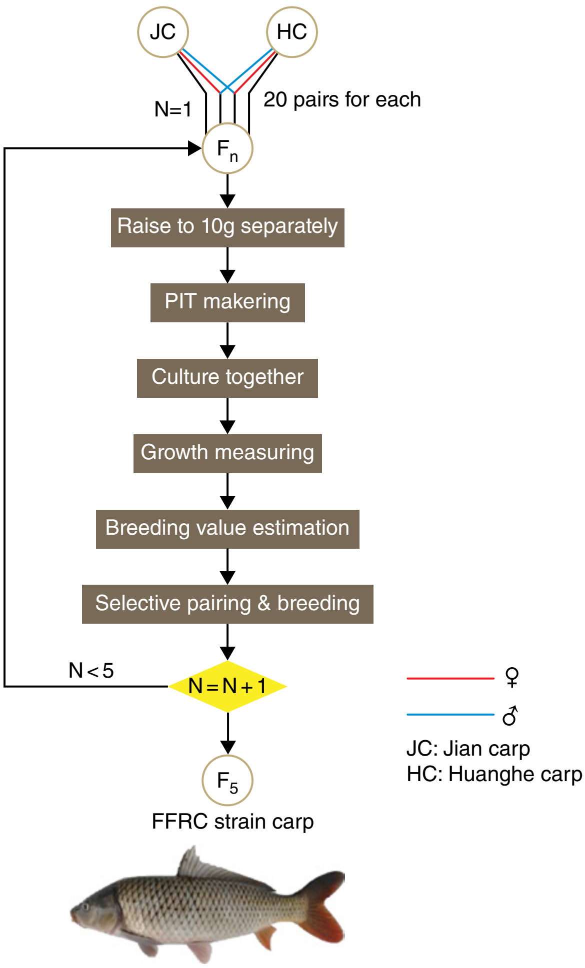

Figure 2.3.18 Schematic representation of the selective breeding process of FFRC strain carp.

The number of people living below the poverty line was ~70 000 000 in 2014 (https://www.odi.org/comment/9803-china-urban-poverty-reduction-sdgs-inequality). FAO has speculated that common carp production may come close to its limit in 2009. However, the output has been elevated from 2009 to 2013 in China. The domestic consumption demand for this affordable freshwater cultured product is difficult to estimate, but domestic consumption will continue to predominate. The production of common carp may still continue to show an elevated trend over the next decade.

2.3.6 Current Problems and Future Prospects

Common carp is the most representative freshwater species cultured all over the world. Its history and culture, and domestication in China determined its important and long-lived status. However, with the increasing intensification of culture practices, problems with disease occurrence, quality, safety, and environmental pollution are attracting more attention (Cao *et al.* 2007; Tang *et al.* 2014). It has become urgent to set up environmentally friendly integrated systems to realize sustainable development of common carp culture in different regions. In the past ten years, increasing numbers of investigations were carried out on

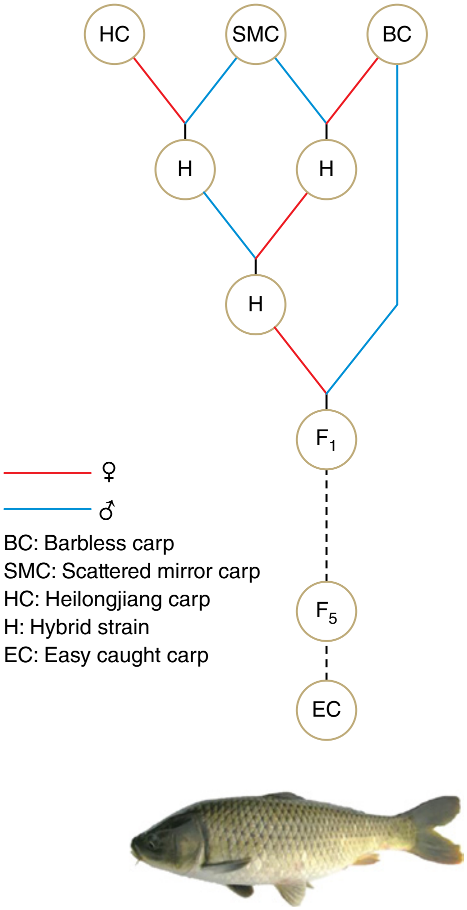

Figure 2.3.19 Schematic representation of the selective breeding process of Easy caught carp.

pond ecological culture technologies represented by the Fish-Vegetable integrated mode (Bing and Chen 2001; Miao *et al.*, 2007; Chen *et al.* 2010) and the Recirulating Aquaculture System mode (Wu *et al.* 2006; Sheng 2013). A combination of these two modes might be the best pattern for the sustainable development of pond culture of common carp.

China has considerable genetic resources of common carp. These wild or artificially improved varieties constitute the basis for selective breeding of new varieties. However, wild populations of common carp usually do not have direct commercial value due to their relatively low growth performance. Therefore, the protection of wild resources was associated with the extent of utilization in producing commercial varieties. Unfortunately, in the past few decades some of the undeveloped pure wild varieties have become endangered due to habitat degradation, overfishing and gene pollution. Particular habitats and reproductive patterns of fish species easily result in inbreeding depression and genetic drift, especially when the broodstock populations are too small, and pedigrees are unclear. Therefore, scientific management is necessary for maintaining excellent performance of desirable varieties in conservation farms. Recently, molecular breeding technology based on the analysis of genetic backgrounding of broodstock have been established and applied in practice (Sun 2010). This has been very effective in maintaining population diversity and preventing inbreeding, and should be popularized in conservation farms, and seed production enterprises.

To date, the total coverage rate of desirable breeds for aquaculture was only ~16.4 percent in China (Mai 2012). However, statistics from National Fisheries Technology Extension Center (NFTEC) indicate that the coverage rate of six varieties – Songpu mirror carp, FFRC strain carp, Yuxuan Huanghe carp, Songhe carp, Selective strain of German mirror carp (F_4), and the cold-resistant strain of Purse red carp – are more than

80 percent in main rearing areas of common carp during 1996–2010. About 20 reproduction bases and 106 demonstration sites were set up in 25 provinces, such as Henan, Hebei, Liaoning and Helongjiang. During 2011 to 2013, the above six varieties contributed to sales of RMB 20 billion and profits of RMB 1.4 billion. These data indicate that breeding achievements of common carp have played a significant role in promoting the development of industrial culture of this species. However, some potential problems in future development need to be addressed.

Present selective breeding was generally focused on only one trait in common carp. However, the potential antagonistic relationship might be present between the objective trait and another economic trait. So the genetic and phenotypic associations among different traits, and compound breeding technologies based on BLUP should be paid adequate attention. Secondly, research on genetic basis and biological mechanisms corresponding to some major economic traits have been limited in common carp. The accuracy of traditional selection was poor because of the relatively long generation interval, and complex environmental conditions. Molecular breeding technologies provide the possibility of identifying determinants of desired traits, and scan broodfish with desirable genetic properties in early stages of life. Third generation high-density linkage maps with ~5000 markers have been constructed for common carp. Markers associated with quantitative trait loci (QTLs) have been successively isolated for some valuable traits such as cold tolerance (Sun and Liang 2004), body size (Zhang *et al.* 2007; Wang *et al.* 2012), feed conversion (Li *et al.* 2009) and body shape (Zhang *et al.* 2013). Recently, Chinese scientists have completed the draft of the common carp genome, and predicted more than 50 000 protein-coding genes (Xu *et al.* 2014). These findings will contribute to further develop QTLs mapping and genetic mechanism dissection of complex traits, and facilitate new selection programs based on genomic level. Achieving practical progress in selection accuracy of objective traits may be still one of the most important issues in future breeding domains. This will facilitate sustainable development of common carp aquaculture.

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2.4

Crucian Carp and Gibel Carp Culture

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2.4.1 Introduction

2.4.1.1 *Carassius auratus* complex and Genetic Discrimination

Carassius auratus complex is composed of ornamental varieties of goldfish (*C. auratus*), wild crucian carp (*C. auratus*), and the polyploid form of gibel carp (*C. auratus gibelio*). This fish originates from East Asia and is widely distributed in the Eurasian continent. Chromosome and karyotype analyses indicate that the natural complex consists of both diploid form with 100 chromosomes and polyploid form with more than 150 chromosomes, even though the individuals cannot be differentiated morphologically from each other (Zhou and Gui 2002; Zhu *et al.* 2006; Gui and Zhou 2010; Jakovlic and Gui 2011; Jiang *et al.* 2013; Li *et al.* 2014 a,b). Tetraploidization has been revealed to occur in the diploid form with 100 chromosomes (Ohno *et al.* 1967), and evolutionary hexaploid has been also suggested for the polyploid form with more than 150 chromosomes (Zhou and Gui 2002; Yang and Gui 2004; Zhu *et al.* 2006; Li *et al.* 2014b).

The goldfish is the domesticated variety of wild crucian carp. Both of these possess 100 chromosomes and reproduce sexually. Gibel carp, also commonly known as silver crucian carp or Prussian carp, has been recognized as a subspecies *C. auratus gibelio* (Cherfas 1981; Jiang *et al.* 1983), or currently even as a separate species *C. gibelio* (Rylkova *et al.* 2010; Zhang *et al.* 2015). Because of the controversial taxonomic status and contentious morphological classification of the genus Carassius, it is hard to discriminate gibel carp from the *C. auratus* complex. In the last century, polyploid gibel carp was recorded only in China (Zan 1981; Zhou and Gui 2002) and in Russia (Cherfas 1981). Along with the application of cytogenetic and molecular biotechniques, polyploid gibel carp has since been extensively identified in many countries on the Eurasian continent (Gui and Zhou 2010), such as in Britain (Hanfling *et al.* 2005), Italy (Hanfling *et al.* 2005), Germany (Hanfling *et al.* 2005), Hungary (Toth *et al.* 2005), Greece (Liousia *et al.* 2008), Czech Republic (Vetesnik *et al.* 2007), Kazakhstan (Sakai *et al.* 2009), and Croatia (Jakovlic and Gui 2011). Preliminarily, gibel carp was found to be able to reproduce gynogenetically (Jiang *et al.* 1983). Along with the identification of a minor but significant portion of males in the natural population, multiple reproduction modes, including sexual reproduction, unisexual gynogenesis, or even androgenesis, have been demonstrated to coexist in the polyploid gibel carp (Zhou *et al.* 2000; Gui and Zhou 2010; Wang *et al.* 2011). Moreover, a recent study has revealed the developmental mechanism why unisexual and sexual reproductions are able to coexist in clone D of polyploid *C. gibelio*, because its mature eggs have completed normal meiosis, and have three various development modes, such as sexual reproduction, in response to the same

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clone sperm, unisexual gynogenesis to another species sperm, and hybrid-similar development mode to another different clone sperm (Zhang *et al.* 2015).

2.4.1.2 Culture History and Development Status

Based on archeological records, the culture history of *C. auratus* can be traced back about 2000 years ago, to the Eastern Han Dynasty (25–189 CE). As the most popular ornamental fish in aquariums and water gardens, the goldfish was first recorded as golden or red mutants in the Jin Dynasty (265–420 CE), and successfully domesticated more than 1000 years ago, during the Song Dynasty (960–1279 CE). After that, the fish was bred commercially as an ornamental fish. It was introduced to Japan in 1603, Europe in 1611 and North America in 1850, and quickly became popular across the world. Previous experiments have demonstrated that the goldfish originated from wild *C. auratus* (Chen 1928). To date, more than 300 varieties have been recognized based on color variations, body shape changes, fin alterations, and eye configurations. The main varieties that are currently cultured include common goldfish, with various colors including red, gold, white, black, yellow, or lemon, comet-tailed goldfish, the bubble eye goldfish, celestial eye goldfish, fantail goldfish, lionhead goldfish, pearlscale goldfish, butterfly tail goldfish, and so on.

In fact, wild resources of *C. auratus* are abundant in lakes, rivers and reservoirs. It has a good flavor and is a popular with Chinese fish farmers. However, before 1980, it was not considered an important aquaculture target because of its low yields produced by common diploid *C. auratus*. Polyploid gibel carp with more than 150 chromosomes were identified from cytogenetic analyses of several wild populations including Fangzheng in Helongjiang Province (Shen *et al.* 1983), Dianchi in Yunnan province (Zan 1981), Qihe in Henan province, and Pengze in Jiangxi province, and the reproduction mode of unisexual gynogenesis was reported in the early 1980s (Cui and Zan 1982; Jiang *et al.* 1983; Zhou *et al.* 1983; Fan and Shen 1990). Aquaculture application of polyploid all-female gibel carp produced by heterologous sperm gynogenesis (termed allogynogenesis) to activate embryo development (Jiang *et al.* 1983) revolutionized its culture status. The resulting allogynogenetic gibel carp was introduced into almost all areas in China, which led to a period of rapid development (Wu and Gui 1999). Along with wide application of diverse local gibel carp stocks, and several improved varieties over the whole country, production increased from 48 000 tonnes in 1983 to 2 912 258 tonnes in 2015 (Figure 2.4.1), and almost 99.6 percent of global *C. auratus* productions occur in China (FAO 2016).

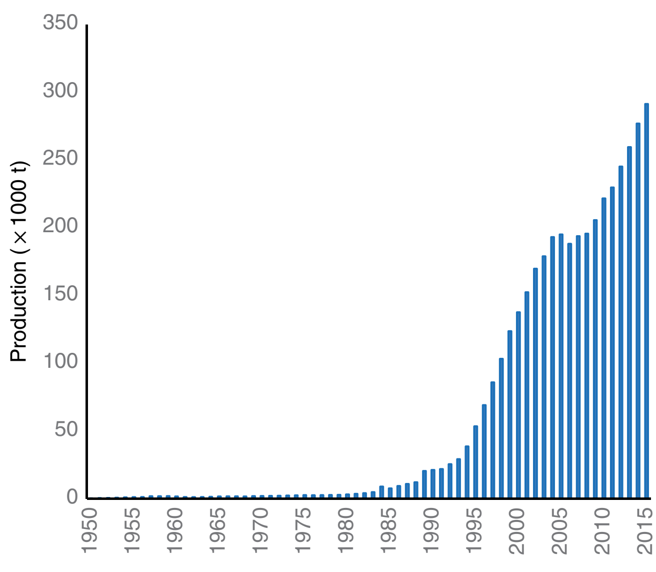

Figure 2.4.1 The annual production of crucian carp in China (China Fishery Statistical Yearbook 2016).

2.4.2 Main Varieties and Centers of Culture

Besides allogynogenetic gibel carp, two other improved varieties, high dorsal allogynogenetic gibel carp (Zhu and Jiang 1993), and allogynogenetic gibel carp "CAS III" (Gui and Zhou 2010; Wang *et al*. 2011), have been successively bred and cultured since 1990 and 2008, respectively (Figure 2.4.2). Owing to the excellent growth performance of these improved varieties, these have become one of the most popular cultured fish in China (Gui and Zhou 2010; Wang *et al*. 2011; Gui and Zhu 2012), and contributed significantly to the overall production capacity (Figure 2.4.1). The allogynogenetic gibel carp "CAS III", in particular, grows faster than the parent fish by more than 20 percent and this enables yield gains of two to three times more than other varieties of *C. auratus* (Gui 2009). Since 2009, more than 30 billion fry of the new variety have been produced, and the culture scale has accounted for about 70 percent of *C. auratus* culture in China. Currently, the production capacity of *C. auratus* ranks fifth among all cultured freshwater fishes, and contributes approximately 10 percent to Chinese freshwater aquaculture production. Owing to its excellent growth performance, the large-sized individuals that are marketed significantly alleviate the problem resulting from fine inter-muscular bones.

At the same time, diverse local populations, or various gynogenetic clones, were found in different regions of China, and their culture performances were also evaluated from a genetic background to culture practice (Gui and Zhu 2012). Several local clones, such as "Fangzheng" gibel carp (Shen *et al*. 1983), "Dianchi high-backed" gibel carp (Zan 1981), "Pu'an" gibel carp (Yu *et al*. 1992), "Songpu" gibel carp (Liu *et al*. 1994), "Pengze" gibel carp (Shu *et al*. 2000), "Qihe" gibel carp (Li *et al*. 2010), "Pingxiang" red transparent gibel carp (Hong *et al*. 2005), and "Chuzhou" gibel carp (Ling *et al*. 2009), were used as culture stocks, which accelerated development of gibel carp culture.

In addition, two sterile triploid hybrids with better growth performance, named "XiangYun" crucian carp and "XiangYun No. 2" crucian carp, have also been bred and cultured by mating artificial allotetraploid hybrids with diploid crucian carp (Liu 2010; Xu *et al*. 2015).

Most of the *C. auratus* currently cultured in ponds and controllable water bodies are the improved allogynogenetic gibel carp varieties, and most of them are of the variety "CAS III". The main culture centers are in Jiangsu and Hubei provinces, with productions of 630 935 tonnes and 478 682 tonnes in 2015, respectively. Other provinces with an annual production capacity of more than 100 000 tonnes include Jiangxi, Anhui, Shandong, Sichuan, Guangdong, Chongqing and Hunan provinces (Figure 2.4.3).

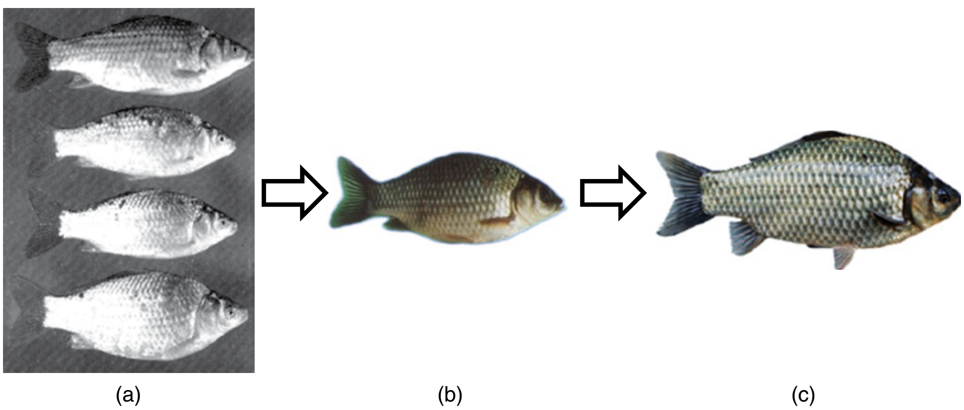

Figure 2.4.2 Phenotypes of the most popularly improved varieties of gibel carp in China. a. allogynogenetic gibel carp; b. high dorsal allogynogenetic gibel carp; c. allogynogenetic gibel carp "CAS III".

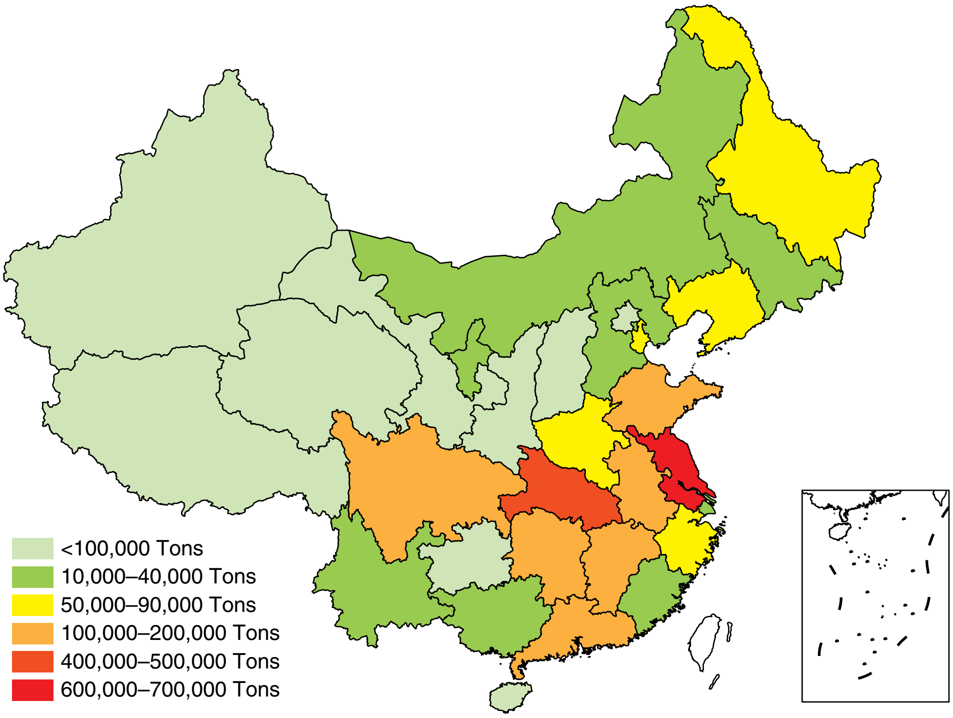

Figure 2.4.3 The main regions of *Carassius auratus* culture activities in China (*China Fishery Statistical Yearbook* 2016).

2.4.3 Habitats and Nutritional Requirements

Gibel carp is benthic. It exhibits remarkable physiological adaptations to various environments, and can tolerate a very wide range of temperatures and amount of dissolved oxygen (DO). Therefore, they have a wide geographical distribution from eastern Asia (high up to 42°C) to northern Europe (low to −40°C). Even under anoxic conditions, they can survive for days in summer and months in winter by anaerobic respiration, depending on the temperature (Shoubridge and Hochachka 1980). Gibel carp also can tolerate high salinity and alkalinity. The salinity tolerance and or carbonate alkalinity of allogynogenetic gibel carp "CAS III" is 4.63 and 20.33 mmol·L^{-1} (Shen *et al.* 2014). In saline-alkaline areas of Jiangsu province near the coast, large numbers of ponds (6.67–33.3 ha) have been excavated for gibel carp culture.

Gibel carp is an omnivore, and its natural diet is extremely diverse including organic detritus, filamentous algae, aquatic weeds, and small benthic animals. The hatched larvae and fry feed on zooplankton, such as water fleas and rotifers. In aquaculture, various commercial feeds have been developed for the different growth stages of gibel carp. Fry, summer fingerlings, and juveniles require higher protein levels to satisfy nutritional requirements, and to maintain fast growth, and lower protein levels during grow-out. For example, Ye *et al.* (2015) have evaluated the dietary protein requirements of allogynogenetic gibel carp "CAS III", and recommended that the dietary protein levels for maximum growth of fingerlings (~3g) and juveniles (~80g) are 402–427 g kg^{-1} and 337–423 g kg^{-1}, respectively. The dietary lipid requirement for optimal growth of gibel carp juveniles is reported to be 140.5 g kg^{-1} (Pei *et al.* 2004). In current commercial feeds for gibel carp, the gross protein levels are usually about 30–32 percent for fingerlings and 28–30 percent for juveniles.

2.4.4 Hatching, Fry Rearing and Seed Supply

Gibel carp have been found to be able to reproduce by unisexual gynogenesis or sexual reproduction dependent on the responding sperms (Zhou *et al*. 2000; Yang and Gui 2004). A large number of propagation experiments show that the survival rates of embryos and larvae of the unisexual gynogenesis groups stimulated by heterologous sperm are higher than that in the groups that have been reproduced sexually via insemination with homologous sperm (Zhou *et al*. 2000). In aquaculture practices, therefore, gibel carp seed should be produced strictly by unisexual allogynogenesis to maintain variety purity and high survival rates of seed. In general, fully-grown two-year-old fish in good condition are selected as broodstock in winter and the intensified rearing is performed for one to two months before the breeding season. Spawning is artificially induced by intraperitoneal injections with a mixture of acetone-dried carp pituitary, HCG and LRH-A (Wu and Gui 1999; Gui *et al*. 2003; Gui 2011) or with other commercial hormones. The ovulated eggs are inseminated with sperm from "Xingguo" red common carp to activate gynogenesis. Prior to hatching, egg adhesiveness is generally removed by mixing the fertilized eggs with a yellow clay solution. After incubating for three to four days in running water in hatching jars/tanks/raceways at 20–24°C, the larvae are hatched (Figure 2.4.4). After depletion of endogenous nutrition of the yolk sac, the three-to-four-day-old larvae can swim, and may be fed with water fleas and rotifers, or with chicken-egg yolk solution. This fry stage can be supplied to farmers as seed for further nursery culture, or directly transferred to nursery ponds for summer fingerling culture.

Nursery ponds are usually 0.067–0.2 ha in size, and 1.5 m in depth. Five to seven days prior to nursery culture, the ponds should be chemically treated to eliminate harmful organisms, and then prepared to stimulate the growth of natural food organisms, zooplankton and phytoplankton, by fertilizing with animal manure,

Figure 2.4.4 The allogynogenesis, seed production, and commercial fish culture of allogynogenetic gibel carp "CAS III". (*See color plate section for the color representation of this figure*.)

green manure or soybean milk. Monoculture is one popular method of fry nursing. Depending on the length of the rearing period and the size required, stocking density is usually 1.5–4.5 million/ha. Soybean milk is usually used as a direct feed at 30–45 Kg/ha daily. After two to three weeks, the fry usually grow into fingerlings of 20–30 mm. At this time, they are called summer fingerlings, and can be supplied to farmers as seed for juvenile culture or commercial production (Figure 2.4.4). The stocking density of juvenile culture is usually 150 000–300 000/ha. The ponds for juveniles are usually 0.2–0.4 ha and 2.0–2.5 m in depth. The stocked fingerlings initially feed on mash commercial feeds for two weeks or more. After 15 days, commercial pellet feeds with 28–30 percent gross protein are fed twice daily. In Hubei and southern areas, the juveniles are usually reared until November. They are able to grow up to about 50 g or larger, and are optimally sized seed for commercial fish production in the following year (Figure 2.4.4).

Gibel carp seed is supplied at three different stages; three-to-five-day-old fry, summer fingerlings of 20–30 mm length, and 25–50 g juveniles (Figure 2.4.4). They are usually transported in polyethylene nylon bags (70 cm length and 30 cm width) filled with oxygen. Firstly, a small amount of water is filled into bags. Then, 100 000 fry, 5 000–10 000 fingerlings, or 300–500 juveniles with water are poured into bags, respectively. After air exclusion, the nylon bags are filled with oxygen. The transported seed can tolerate high-density stress for 20–30 h. Before the transported seed are released into culture ponds, the bags are firstly placed in the ponds, and kept for about 10 min to balance the internal and external water temperatures (Gui *et al.* 2003; Gui 2011).

Generally, the commercial fish size of gibel carp depends on the seed size and culture density. If about 50 g or larger juveniles are used for commercial fish culture, the individuals can grow up to 500–1000 g at the end of one year and are marketed (Figure 2.4.4).

2.4.5 Mono- and Polyculture of Gibel Carp

In the past, gibel carp was generally used as a secondary species in pond polyculture. Along with the application of modern culture technology, a greater variety of farmed species can be used for monoculture or polyculture. Since early in the last century, gibel carp has been widely used for monoculture or polyculture as the major species.

Gibel carp monoculture is commonly practiced in Jiangsu Province, because a large number of ponds of 10–40 ha were constructed in the 1980s in coastal saline-alkaline areas. In these ponds, the stocking density of 50 g or larger gibel carp juveniles is about 30 000/ha. To inhibit algal over-proliferation, about 600 bighead carp juveniles (about 20 g in size)/ha, and 600 silver carp juveniles (about 20 g in size)/ha are stocked simultaneously. Average production using this system can reach about 15 000 kg/ha and the net profit can exceed 24 000 RMB/ha (6 RMB = 1 US$) (Li *et al.* 2012).

Two polyculture modes are practiced with gibel carp. In the first mode, gibel carp is used as the major species. The stocking density is usually about 20 000 gibel carp, 500 grass carp, 500 bighead carp, and 1000 silver carp/ha. In the second mode, gibel carp is usually used as a secondary species, and grass carp as the major culture target. Usually, stocking density of fish is about 10 000 gibel carp, 4000 grass carp, 4000 blunt-head bream, 750 bighead carp, and 2000 silver carp/ha. Especially in northern coastal areas of Jiangsu Province, the two polyculture modes have been widely applied in ponds of 10–40 ha and water depth of about 2.5 m. Grass is planted in early spring, and grass carp density is dependent on grass abundance. In order to promote better grass growth, a 3-m wide and 1-m deep channel is constructed around the ponds. In addition, automatic feeders and aerators (gear impeller aerators or pipe aerators) are installed, two each per ha, respectively. The commercial feeds generally contain 28–30 percent gross protein. Harvesting is done in one of three ways. The highest profit will be obtained by partial harvesting through netting once or twice in summer, and total harvesting after drainage in winter. This method can decrease mortality from high temperature and stress. In addition, the price of grass carp is higher in summer. In order to be able to harvest grass carp over 2 kg in July or August, about 0.5–1 kg juvenile grass carp should be stocked at a density of 1500–3000/ha. In this case, total profit might reach about 30 000–45 000 RMB/ha, and the highest profit is about 110 000 RMB/ha. The second way of harvesting is to stock at the beginning of the year and to harvest at the year end. The third is to stock in May and to harvest the following May.

Along with the rapid increase in production and highly intensive cultivation in the past 30 years, however, some aquaculture varieties of gibel carp had been threatened by certain serious diseases caused by a number of different pathogens, such as parasitic myxosporeans, bacterial septicemia, scale erecting disease, stigmatosis, saprolegniasis, and Cyprinid herpesvirus II (Gui *et al.* 2003; Zhai *et al.* 2012; Zhai *et al.* 2014; Zhang and Gui 2015; Zeng *et al.* 2016). The genetic breeding program for increasing disease resistance in gibel carp has been supported by national and local governments, and performed in our laboratory at the Institute of Hydrobiology in Hubei Province (Zhang and Gui 2015).

2.4.6 Conclusions and Possible Future

Gibel carp is a favorite fish in most areas of China owing to its delicious taste and good meat quality. The fish are sold live or fresh. The price is moderate (about 20 RMB/kg) and is affordable for middle- and low-income people. With the prominent advances in genetic improvement and culture technology of gibel carp, this fish has acquired a more important position in Chinese aquaculture. Gibel carp contains a large number of fine inter-muscular bones which make it not so easy to eat. However, genetically improved varieties and modern culture technologies have significantly enhanced the marketable size from about 100 g to 500 g, or even more than 1000 g, and thereby reducing the impacts of intermuscular bones when eating. Improving growth performance and increasing disease resistance are still priorities for the genetic breeding program (Gui 2015). Disease prevention and control are also research priorities (Zhang and Gui 2012; Zhang and Gui 2015). Other research work has also focused on nutritional studies, including developing more suitable commercial feeds, and better improved managed feeding technology.

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2.5

Recent Developments in Bream Culture: Culture Systems and Genetic Improvement

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2.5.1 Introduction

There are five bream species, belonging to two genera *Megalobrama* and *Parabramis* indigenous to China, and include *Megalobrama amblycephala*, *M.skolkovii*, *M. hoffmanni* and *M. pellegrini* and *Parabramis pekinensis*. These bream species have been cultured in certain areas of China; however, blunt snout bream (*M. amblycephala*), also known as Wuchang fish, is the most important aquaculture species. In 1956, the founder of the People's Republic of China, Chairman Mao Zedong wrote a poem, "Swimming" including two sentences "I have just drunk the waters of Changsha, and come to eat the fish of Wuchang". Since then, blunt snout bream has become famous in China. This species was the first freshwater fish domesticated by Chinese researchers. Because of its desirable qualities for aquaculture, such as herbivorous feeding habit, general hardiness, resistance to diseases and reproductive performance, this species has become a major species for freshwater aquaculture in China since the 1960s, and has greatly developed over recent decades, with a total output of 705 821 tonnes in 2014.

2.5.2 The Main Regions of Bream Culture Activities in China

Blunt snout bream (*M. amblycephala*) or Wuchang fish (Figure 2.5.1), is endemic to China. It is a Cypriniformes, Cyprinidae, belonging to the subfamily Culter. Its natural distribution is restricted to the middle and lower reaches of the Yangtze River, such as Liangzi, Poyang and Yuni lakes. Blunt snout bream is a species of ray-finned fish of the genus *Megalobrama*, which includes three other species *M. skolkovii*, *M. hoffmanni* and *M. pellegrini* (Chen *et al.* 1998; Xu and Xiong 2008) (Figure 2.5.2). *M. skolkovii* is widespread across China and the Russian Far East, from the north Heilongjiang river system to the south extension of the Minjiang river system, including the Yellow River, Yangtze River and the south-east coast. *M. hoffmanni* is mainly distributed in the Pearl River and Hainan Island water systems in South China, as well as in the north of Vietnam. *M. pellegrini* is restricted to the upper reaches of the Yangtze River (Chen *et al.* 1998). The white Amur bream (*Parabramis pekinensis*) (Figure 2.5.2) is the only species with high economic value of the genus *Parabramis*. It is native to eastern Asia, and occurs in the Amur River basin in southern Russia, as well as in many rivers in China (Froese *et al.* 2014). The natural distribution of these five species of bream in China is shown in Figure 2.5.3. These bream species are all food fish and have been translocated beyond their native ranges except *M. elongate*.

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Figure 2.5.1 Blunt snout bream (*Megalobrama amblycephala*).

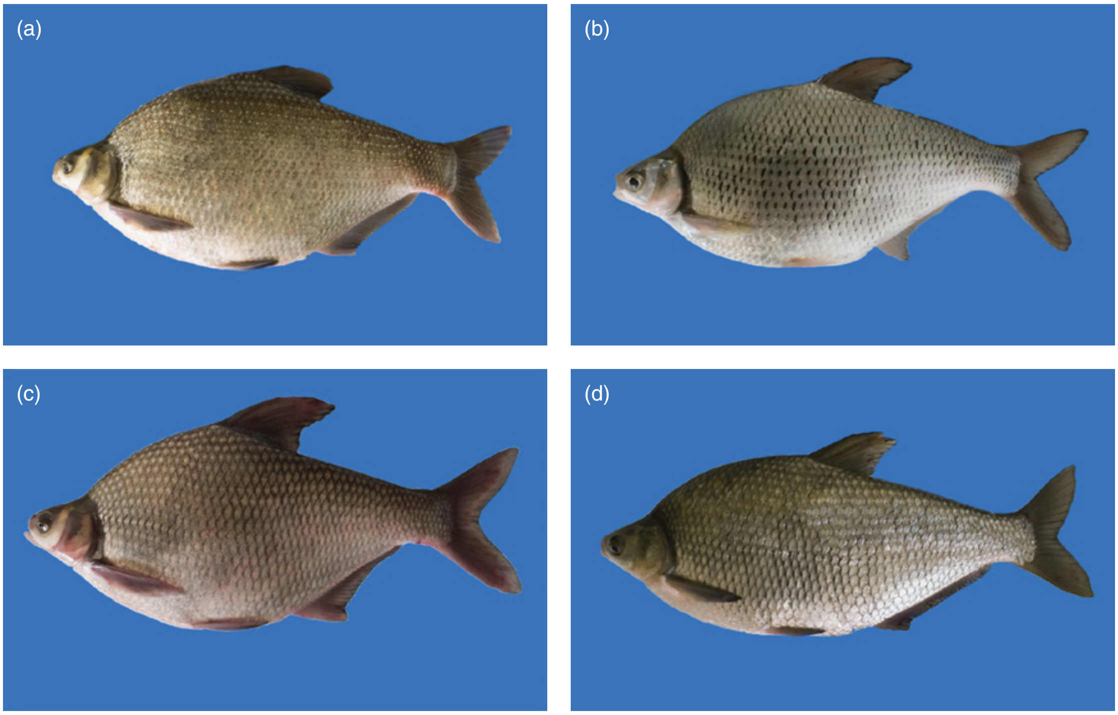

Figure 2.5.2 Other breams of the genera *Megalobrama* and *Parabramis*. a. *M. skolkovii*; b. *M. hoffmanni*; c. *M. pellegrini*; d. *P. pekinensis*.

These species have very similar morphological characteristics. Species taxonomy within the genus *Megalobrama* is traditionally based on morphological and anatomical traits, such as the thickness of the jaw, the ratio of the last unbranched dorsal fin ray length to head length, the ratio of peduncle length to peduncle depth, and various relative measurements of body parts (Li *et al.* 1993). However, in some cases, morphological features are of limited value for identification and differentiation purposes, even with whole specimens, because they can show either considerable intraspecific variations or small differences between species (Teletchea 2009). Song *et al.* (2013) studied the morphological variations among the genus *Megalobrama*, and found significant differences in the number of caudal vertebrae. As to the genera *Megalobrama* and *Parabramis*, *P. pekinensis* has a full ventral edge, which exists from the basal part of the pectoral fin to the anus, while *Megalobrama* species have a half ventral edge, which begins from the basal part of ventral fin.

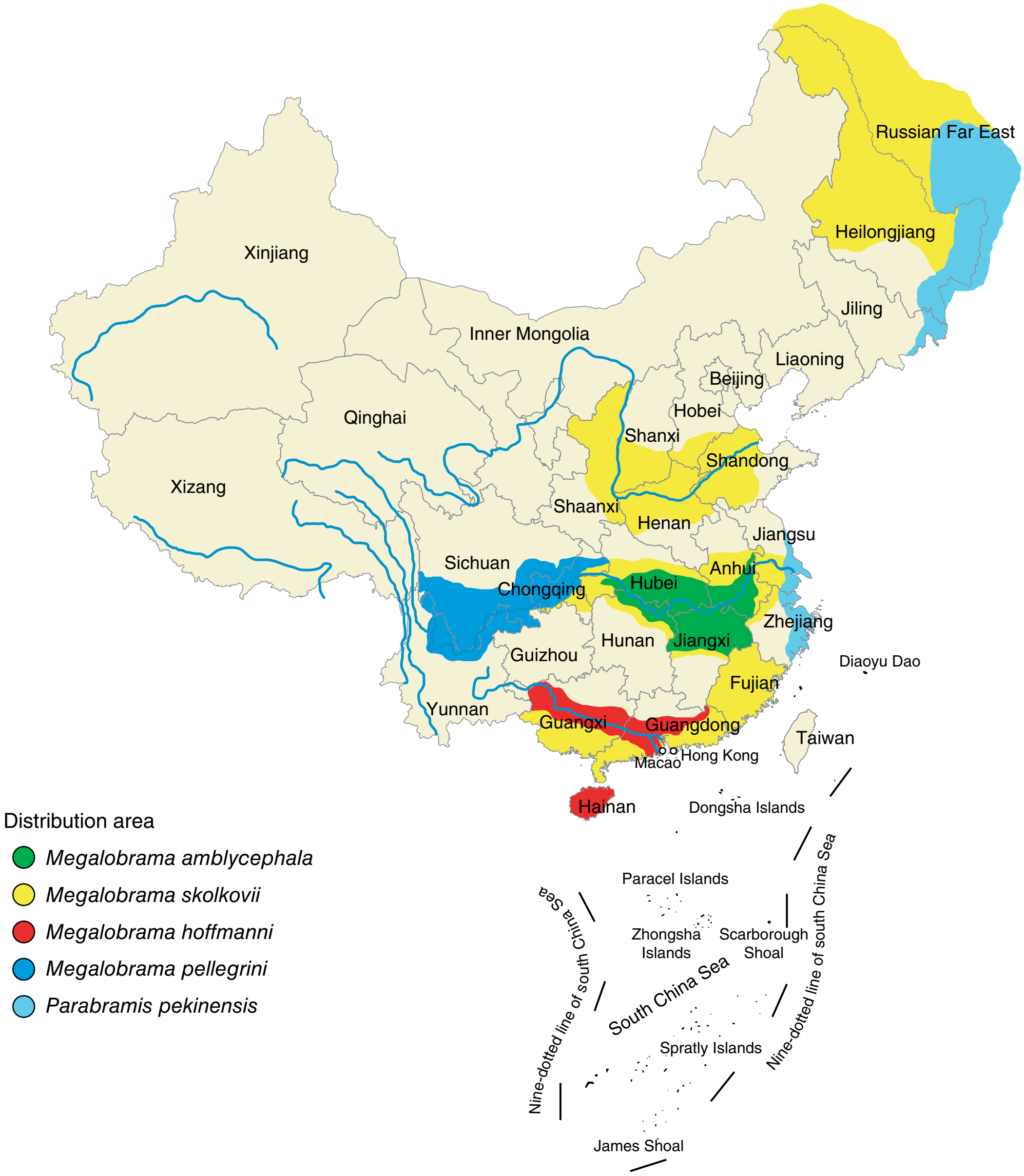

Figure 2.5.3 The natural distribution of five bream species in China. *Source:* Data from *China Fishery Statistical Yearbook* (2004–2016).

Among these bream species, *M. amblycephala* has been widely favored for its flavor, and recognized as a main aquaculture species in freshwater polyculture systems since the 1960s in China (Ke 1965). Due to its desirable qualities for aquaculture, such as herbivorous feeding habit, general hardiness, resistance to disease, good catchability and reproductive performance, aquaculture of *M. amblycephala* has developed in the past decades (Figure 2.5.4). Its total output reached 705 821 tonnes in 2014 (CAFS 2014). The main culture of the bream aquaculture industry include Jiangsu, Hubei and Anhui provinces (Table 2.5.1), of which Jiangsu has been dominant. The species *M. skolkovii* is mainly cultured in Zhejiang province, while *M. pellegrini* is mainly cultured in Sichuan province, and *M. hoffmanni* and *P. pekinensis* mainly in Guangdong province. The production of these four species accounts for just ten percent of the total bream output.

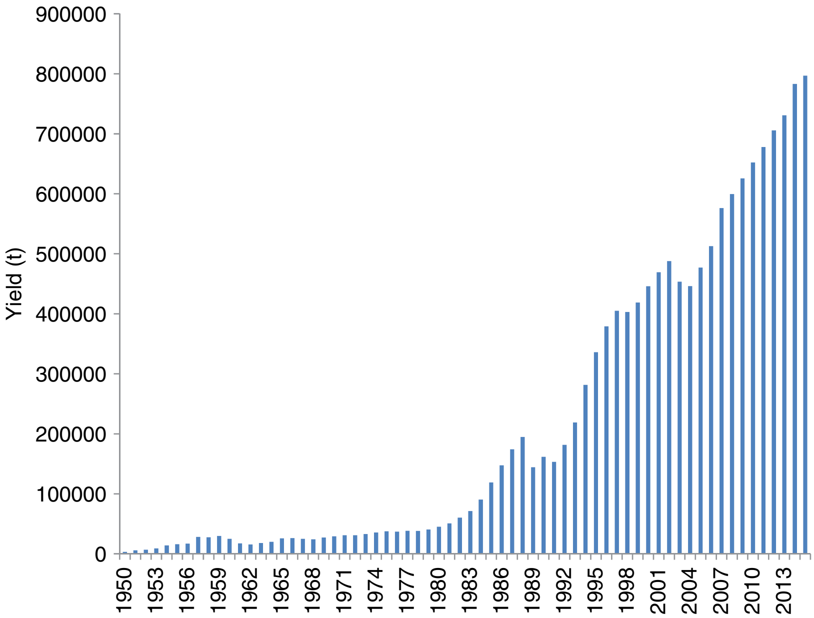

Figure 2.5.4 Trends in aquaculture production of all bream species since 1950. *Source:* data from FAO and CAFS.

Table 2.5.1 Aquaculture production of blunt snout bream (in t) in different regions of China.

Years / Provinces	2005	2006	2007	2008	2009	2010	2011	2012	2013
Jiangsu	148101	154198	148872	150030	168443	162558	171769	179952	187969
Hubei	109302	131877	125300	121951	121767	135283	145256	157406	170669
Zhejiang	28745	28489	23325	23797	24207	26210	27241	27476	28167
Anhui	68022	75351	65619	70703	74620	83654	86740	88389	93707
Fujian	3150	3945	3594	2693	3267	3568	3941	4606	4328
Jiangxi	45668	47900	48255	51547	55033	54077	55654	59810	59172
Shandong	13811	12410	11581	11031	7920	14100	14681	14468	14988
Henan	11227	12220	9312	10437	11442	11652	13205	11531	13170
Hunan	51769	51816	51518	56115	50920	61135	66268	67749	71424
Guangdong	15663	12709	31597	38291	38757	36364	14681	36632	20979
Chongqing	2579	2897	2014	2029	2258	2341	3738	3240	4932
Sichuan	18847	26839	26401	27409	27575	27021	29118	30749	32946
Total	516884	560651	547388	566033	586209	617963	632292	682008	702451

Source: Based on data from the Chinese Academy of Fishery Sciences (2014), *Fishery Statistics.*

2.5.3 Biological Characteristics Related to Aquaculture

Bream are warm-water species, and can survive in a wide range of temperatures, with the optimum growth temperature being 20–30°C. They have a high requirement for dissolved oxygen (DO) of above 5 mg/l. *M. amblycephala* prefers to live in still water, and inhabits the middle and lower layers of a water body with a sludge substrate and submerged plants. In nature, *M. amblycephala* and *P. pekinensis* are typically herbivorous, while the other three are omnivorous. Special commercial feeds for bream have been developed for aquaculture. These five bream species all have a fast growth rate, and can reach a marketable size at the second year of culture. *M. amblycephala* has a relatively fast growth rate, and can reach 12–23 cm in the first year, reaching a marketable size at the second year, with a body length of about 30 cm and weight of about 500 g. The largest individuals can exceed 3 kg. All five bream species reach maturation at two to three years of age. As to the characteristics of eggs, there is a big difference between the two genera. *Megalobrama* species produce adhesive mature eggs, while eggs of *Parabramis* are pelagic. In nature, *M. amblycephala* always spawn in shallow water with aquatic plants and in the night at a temperature of about 22–26°C.

2.5.4 Culture / Farming Systems

Generally, fingerlings of 30–80 g are cultured in ponds and reach a marketable size at about 500 g. The culture systems are different in different regions, primarily using a pond structure, with species combinations and feeds used. Existing systems can be summarized into four types: (a) blunt snout bream and grass carp as the major culture species, (b) blunt snout bream and black carp as the major culture species, (c) blunt snout bream and crucian carp as the major culture species, and (d) mono culture of blunt snout bream. Among these systems, (c) and (d) are used in most regions (Table 2.5.2).

As to the benefits of different culture systems, Xu (2013) concluded that the system in which the blunt snout bream is the main cultured species, with subsidiary species such as crucian, bighead, and/or silver carp as the filter-feeding fish, result in significant added value and benefits. The study also showed that better growth was achieved when the density of blunt snout bream (40–50 g mean wt.), crucian carp (about 50 g mean wt.), silver carp (about 125 g mean wt.) and bighead carp (about 125 g mean wt.) were 1700 to 1800, 160 to 200, 130 to 150 and 60 to 80 per 666.7 m^2, respectively. Cage culture has also been used for blunt snout bream since the 1980s, in conjunction with the development of commercial feeds. The cages are always set up in reservoirs/lakes of more than 2-m water depth. Rectangular cages are preferred, and commonly consist of small (4–2 m^2), medium size (21–32 m^2), and large (60-100 m^2). The depth of the cage is about 2.5 m for all different sizes of cages. The medium size cage is the commonest. The average stocking density of blunt snout bream is 2000–2500 individuals (mean weight of 0.10–015 kg), while crucian carp, silver carp and bighead carp are stocked at a ratio of 4:2:1 with a total of 50 individuals (5.0–10.0 g/ individual). After about one year culture, the bream can reach a mean weight of 0.7–0.8 kg.

2.5.4.1 Advances in Culture Technology Over the Last Decade or More

In recent years, with rapid urbanization and industrial development, areas available for aquaculture are gradually declining, and high density aquaculture is being encouraged. In these circumstances, efficient ecological culture models were developed for blunt snout bream, and schematically depicted in Figure 2.5.5. It consists of a batch of purification tanks, with biofilters, in addition to culture ponds. A submerged pump in the pond is connected with the purification tanks through parallel pipelines. An osculum is set up at the bottom of each purification tank to let the water flow into the ridges of the pond, then into the ecological slope. The ecological slope is covered by a three-dimensional vegetation net or hollow green bricks, with aquatic plants growing on the covers. After biological purification, the clean water can flow into the pond. This is equivalent to a flow-through pond culture system. This culture system has been developed for blunt snout bream in Jiangsu Province. Using this culture system, water quality can be improved greatly, the survival rate of fish increased

Table 2.5.2 The two main culture systems for blunt snout bream.

Items		Blunt snout bream		Crucian carp		Bighead carp		Silver carp	
		Size (No. of individuals/kg)	Density (No. of individuals/kg/ 666.7 m^2)	Size (No. of individuals/kg)	Density (No. of individuals/kg/ 666.7 m^2)	Size (No. of individuals/ kg)	Density (No. of individuals/ kg/666.7 m^2)	Size (No. of individuals/kg)	Density (No. of individuals/kg/ 666.7 m^2)
Refined model	Input	20–30	1800–2200	—	—	0.15–0.25	50–60	0.15–0.25	50–100
	Output	Above 0.6 kg		—		1.5–2.5 kg		1.5–2.5 kg	
Polyculture model	Input	20–30	1200–150	20–30	600–800	0.15–0.25	50–60	0.15–0.25	50–100
	Output	Above 0.6 kg		0.4 kg		1.5–2.5 kg		1.5–2.5 kg	

Source: modified after Gu *et al.* (2014).

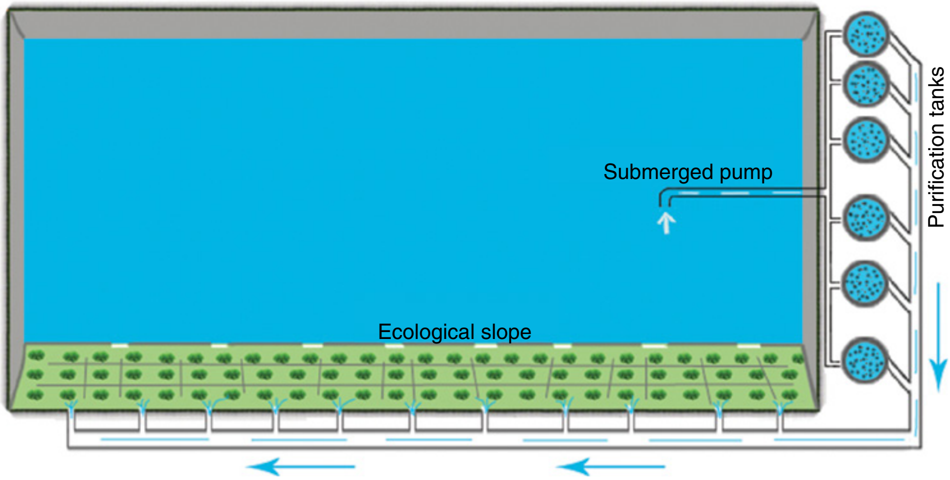

Figure 2.5.5 Schematic representation of the layout of the ecosystem for aquaculture of blunt snout bream in Jiangsu Province (after Gu *et al.* 2013).

by 2 percent, and the average rate of body weight gain improved by 111 percent. Taking into consideration the increase in production costs, as well as the construction fee and running costs, the economic benefits can be improved by about 700 RMB/667 m^2 (6 RMB = 1 US$).

2.5.5 Germplasm Resources

2.5.5.1 Cytogenetics

Cytogenetical studies of blunt snout bream have focused mainly on karyotype and nuclear DNA. There have been some reports on karyotype and nuclear DNA content of *M. amblycephala*. As far as the karyotype is concerned, the karyotype formulae of *M. amblycephala*, reported by Zan and Song (1979) and Li *et al.* (1993), were expressed as 2n = 48 = 20m + 24sm + 4st; while it was expressed as 2n = 48 = 26m + 18sm + 4st in reports by Yin *et al.* (1995). After cell culture, Zhu *et al.* (2013) identified the karyotype of *M. amblycephala* as 2n = 48 = 26m + 18sm + 4st. However, it still remains to be verified whether the aforesaid deviations were caused by manual operation, or the difference in collection site, or population differences. Currently, the universally accepted karyotype is 2n = 48 = 26m + 18sm + 4st. The DNA content of *M. amblycephala* has been reported successively by Li *et al.* (1993) and Yin *et al.* (1995) with the genome size of about 2.6 pg. The results showed that *M. amblycephala* was significantly higher in diploid cell DNA content than other known (2n = 48) cyprinidae fishes.

2.5.5.2 Population Genetics

Since the 1980s, there has been a boom in various molecular marker methods intended for studies on population genetic diversity, the studies of the genetic relationship and phyletic evolution of species, the establishment of molecular genetic linkage maps, germplasm identification and other related aspects. Major methods included RFLP, microsatellites, mtDNA, RAPD, AFLP and so on. Since the start of the twenty-first century, natural germplasm resources of *M. amblycephala* have been endangered, primarily due to human domestication of *M. amblycephala* which has resulted in widespread and increasingly serious degradation, overfishing, and worsening environmental degradation. Considering this, many researchers began to turn to RAPD, mtDNA, microsatellite and other molecular marker methods to investigate and evaluate the genetic diversity status of wild and cultured *M. amblycephala* populations (Bian *et al.* 2007).

With the application of RAPD technologies, Zhang (2001) analyzed the genetic structure of wild *M. amblycephala* populations inhabiting Lake Yuni and Lake Liangzi. It was found that the individual genetic similarity of the *M. amblycephala* from the two lakes remained between 0.9395 and 0.9614, and averaged 0.9541. The wild populations in Lake Yuni and Lake Liangzi showed a relatively poor genetic diversity. Tang *et al.* (2008) measured the mitochondrial DNA control region sequence of a total of 53 samples of *M. amblycephala* from lakes Yuni, Liangzi and Poyang. However, only three mutation sites and five haplotypes were detected in the 411-bp control regional sequence available. This indicated that the genetic diversity of the three populations was relatively poor, and that of Lake Yuni was the poorest. Li (2010) analyzed the genetic diversity of the three wild populations (lakes Liangzi, Poyang and Yuni) using microsatellite methods. It was observed that there was little genetic differentiation between *M. amblycephala* populations inhabiting the three geographically divergent colonies. This indicated that the intraspecific differentiation of *M. amblycephala* caused by geographic isolation was not significant. There was insignificant genetic differentiation (Fst = 0.0376) between Lake Liangzi and Lake Poyang populations, while the genetic differentiation (Fst = 0.0733) between Lake Liangzi and Lake Poyang was relatively significant. With the combined application of the mitochondrial DNA control region and Cytochrome Oxidase I (COI) gene sequence, Zhao *et al.* (2009) studied the genetic diversity and differentiation of three *M. amblycephala* genetic populations (including four wild populations, two domesticated populations and one improved selective variety – No.1 Pujiang population). The relatively poor genetic diversity of the selectively bred populations showed artificial selection has had a great impact on genetic structure of populations.

2.5.5.3 Genomics

The development of second generation high-throughput sequencing technology in the twenty-first century, mainly in the exploration of functional gene resources, comes as a revolution in the studies of genomics. Using the new high-throughput sequencing technology 454 GS FLX Titanium, Gao *et al.* (2012) sequenced the mixed-tissue-sample transcriptome of individuals with divergent growth traits from different *M. amblycephala* populations. A total of 100 477 unigenes of *M. amblycephala* were obtained, including 26 802 pieces of contigs and 73 675 pieces of singletons. The unigene GO classification information of *M. amblycephala* was obtained through comparison with the proteome sequence of zebrafish. A total of 266 486 pieces were classified into molecular function, 140 785 pieces into biological process and 130,135 pieces into intracellular localization. Based on the Kyoto Encyclopedia of Genes and Genomes (KEGG) note, these unigenes can be classified into 150 kinds of signal path. These transcriptome resources laid a solid foundation for the functional gene studies of *M. amblycephala*. Based on the genetic resources available, the full-length cDNA sequence of a series of functional genes of *M. amblycephala* was cloned (Gao *et al.* 2014), including genes related to growth traits, growth hormone receptor *(GHR1 and GHR2)*, insulin-like growth factor (*IGF-I* and *IGF-II*), myostatin (*MSTN a* and *MSTN b*), and so on. Immune-related genes were cloned, including heat shock protein 90 (Hsp90α and *Hsp90β*), major histocompatibility complex (*MHC IIA* and *MHC IIB*), liver-expressed antimicrobial peptide (*LEAP-1* and *LEAP-2*), chemokine receptor (*CXCR4b*), and β-defensin. Ingestion-related genes were cloned, including ghrelin, cholecystokinin (*CCK*), and neuropeptide Y (*NPY*). Reproduction-related genes were cloned, including kisspeptin and kiss receptor. Also spermatogenesis associated 4 (*SPATA4*), cardiac troponin T and peroxisome proliferator-activated receptor r (*PPARr*) were cloned. Researchers have made a further analysis of the regulating effect of the aforesaid genes on the growth, reproduction and disease resistance of *M. amblycephala* through quantitative gene expression.

With the development of molecular biological technologies, molecular markers such as AFLP, SSR and SNP are currently commonly being used. In the field of molecular markers, researches on *M. amblycephala*, Rao *et al.* (2012) scanned the male and female gene pool of *M. amblycephala* from lakes Liangzi, Poyang and Yuni by using 64 pairs of AFLP primer combinations, and collected 4789 pieces of amplified fragments in all.

However, the specific markers of the male and female were not collected. By building an enriched microsatellite library and adopting PCR scanning respectively, Li *et al.* (2007) and Tang *et al.* (2009) screened out nine and ten polymorphic SSR markers. Using 454 high-throughput sequencing methods, Gao *et al.* (2012) obtained 4952 pieces of microsatellite sequence, developed 116 polymorphic SSR markers, and got 25 697 high-quality cSNP loci and 23 287 indels loci. These markers laid a solid foundation for molecular breeding of *M. amblycephala*.

Recently, Dr. Weimin Wang's team has finished the whole genome sequence of *M. amblycephala*, which provides a valuable resource for the genomic study on this species. A 1.116-Gb reference genome sequence was assembled for *M. amblycephala* genome using genomic DNA from a double-haploid line by a whole-genome shotgun strategy. The contig and scaffold N50 lengths reached 49 Kb and 839 Kb, respectively, with the largest scaffold being 8951 Kb and the 4034 largest scaffolds constituting 90 percent of the assembly. A total of 23 696 protein-coding genes were annotated for *M. amblycephala*.

2.5.6 Improvements in Artificial Propagation

After domestication of blunt snout bream since the 1960s, germplasm resources of this species are under threat of losing diversity and of mixing due to its artificial breeding. The aquaculture performance of many hatchery populations of bream deteriorated, as indicated by slower growth rate, early maturity, increased susceptibility to disease, as well as thin and longer body. Poor management of broodstocks and inbreeding depression were thought to be the major causes for this deterioration. In view of this, some breeding technologies were used to address these problems, including hybridization, selective breeding, gynogenesis and polyploidy.

2.5.6.1 Hybridization

As a commonly-used breeding technique, hybridization mainly aims to benefit from heterosis, and develop new varieties or strains through hybridization. Current reports on hybridization of bream covered interspecific hybridization, intergeneric hybridization and inter-subfamily hybridization.

Existing research on interspecific hybridization focused mainly on hybridization among *M. amblycephala*, *M. terminalis* and *M. hoffmanni*; however, filial generations with obvious advantages are yet to be developed. Xie *et al.* (2002) compared the major morphological traits of the hybrid *M. hoffmanni* (♀) × *M. amblycephala* (♂) and its parents, and discovered that the morphological traits of the first generation of the hybrid mainly shared the morphological traits of the parents. Further practices discovered that the first generation of hybrids featured a high survival rate and fertility. In addition, it resembled *M. hoffmanni* in flesh quality, and had advantages over *M. hoffmanni* in resistance to hypoxia and transport. However, first hybrid generation grew slower than *M. amblycephala*, so the expected growth advantages were not so obvious. By using cluster analysis, principal component analysis, and discriminant analysis, Yang *et al.* (2002) studied the morphometric traits and framework parameters of *M. amblycephala*, *M. skolkovii* and their reciprocal hybrids. It was found that the reciprocal hybrid F_1 shared more genetic characters of the female parent, and the *M. skolkovii* female parent had a greater effect on the genetic characteristics of hybrid than the *M. amblycephala* female parent.

In the field of intergeneric hybridization, Gu *et al.* (2008) analyzed the morphological and genetic characteristics of the hybrid F_1 of *Erythroculte rilishaeformis* (♀) × *M. amblycephala* (♂). It was found that most of the countable and measurable traits of the F_1 hybrid remained at an intermediate level. The cluster and discriminant analysis of framework parameters discovered the chromosome number (2n) of F_1 hybrid was 48 and the karyotype formula was expressed as 18m + 26sm + 4st (NF = 92). The genetic analysis indicated that their hybrid was much closer to that of the male parent. Jin *et al.* (2006) analyzed the flesh content and nutrient content in muscles of the F_1 hybrid of *E. ilishaeformis* (♀) × *M. amblycephala* (♂). The results showed that this hybrid featured significantly higher flesh, protein, fat and amino acid contents than other commercial freshwater fishes, which suggested that this F_1 hybrid can be developed as a new variety for aquaculture.

So far hybrids based on inter-subfamily hybridization has been developed from the three hybridized combinations of *Cyprinus carpio* var. specularis and (♀) and *M. amblycephala* (♂), *C. carpio* L. mirror (♀) and *M. amblycephala* (♂), and *Tincatinca* (♀) and *M. amblycephala* (♂) (Gao *et al.* 2014). However, the aquaculture potential of these hybrids still remains to be verified.

2.5.6.2 Selective Breeding

A systematic selection program for blunt snout bream was started in 1986 for faster growth rate, and deeper body shape (measured as the ratio of body length to body depth), and was one of the first attempts to selectively breed a species of aquaculture importance in the Asian region (Li 2008). In this endeavor the founder population was established mainly on the wild populations inhabiting Lake Yuni of Gongan County, Hubei Province. With the combined application of selective mass breeding and biotechnology, the world's first herbivorous fish, No.1 Pujiang blunt snout bream, was successfully bred after 16 years (six generations) of intensive selective breeding. This improved variety was characterized by 30 percent faster growth rate than the stock, a graceful shape and fairly stable genetic characteristics (Li and Cai 2003). In 2000, it was announced to be an excellent variety suitable for extension to farmers after being examined by the China Stock and Improved Fisheries Variety Examination Committee, and approved by the Ministry of Agriculture.

However, the No.1 Pujiang blunt snout bream strains only focused on growth rate during the selection procedure and the strains were obtained through traditional technology. Currently, these varieties tend to have increased susceptibility to disease. Consequently, the Chinese Ministry of Agriculture initiated the Modern Agriculture Industry Technology System for preserving blunt snout bream germplasm resources, and a breeding technological system since 2007. A team of researchers from Huazhong Agricultural University, began to use modern molecular technology, based on molecular markers, to improve breeding efficiency and accuracy, as well as to improve growth rate and strengthen stress resistance. Since then, the team has been devoted to its molecular breeding technology approach, and the cultivation and popularization of high-yielding and stress-resistant superior varieties, based on wild stocks of bream from lakes Liangzi, Yuni and Poyang. The heritability of body weight, body length, overall length and height of 20-month-old bream were assessed as 0.65, 0.53, 0.53 and 0.50, respectively. It showed there was relatively high genetic correlation among various growth traits (Luo *et al.* 2014a).

The advantageous growth traits of crossbred wild bream populations were assessed by means of self-cross and hybridization of the three populations. It was found that the hybrid of Lake Yuni ♀ × Lake Poyang ♂ showed significant growth advantages. Besides, microsatellite markers were used to evaluate the correlation between the parental population genetic diversity and first generation growth traits. It showed that there was significant positive correlation ($p<0.05$) (Luo *et al.* 2014b). Bream from the three populations were used as parents, and complete diallel cross was adopted to establish the full-sib family. By analysing combining ability and microsatellite molecular markers, it was preliminarily predicated that the combination, in which Lake Liangzi served as male parent and Lake Yuni counterpart served as female parent (Zeng *et al.* 2012), featured the best growth traits. In addition, methods of mixed-family genetic parameter estimations were adopted to evaluate the length and weight parameters of six-month-old bream, and their breeding value (Zeng *et al.* 2014). To date, superior families with good growth traits and stress-disease resistance have been developed by the research team. Liu (2012) have screened out four microsatellite markers relevant to growth traits of bream, and have obtained the superior and inferior genotypes related to growth traits.

This research team has produced a good variety of *M. amblycephala* with a fast growth rate and good survival rate. Figures 2.5.6 and 2.5.7 show the characteristics of this improved strain, which indicated that the mean body weight and survival rate of selected line (F5) were both significantly higher than that of control group ($P<0.05$). This improved variety was characterized by 26.6 percent faster growth rate and 27.0 percent higher survival rate. Through working with Animal Husbandry and Fisheries Research Center of Haid Group

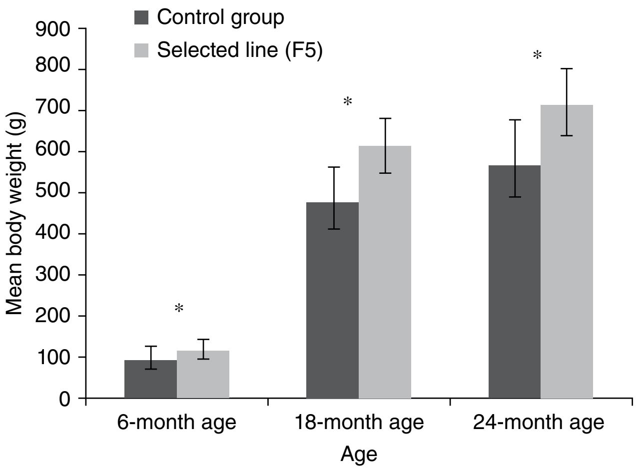

Figure 2.5.6 Comparison of mean body weight between the selected line (F_5) and control group. The fish from these two groups were reproduced artificially on the same day.

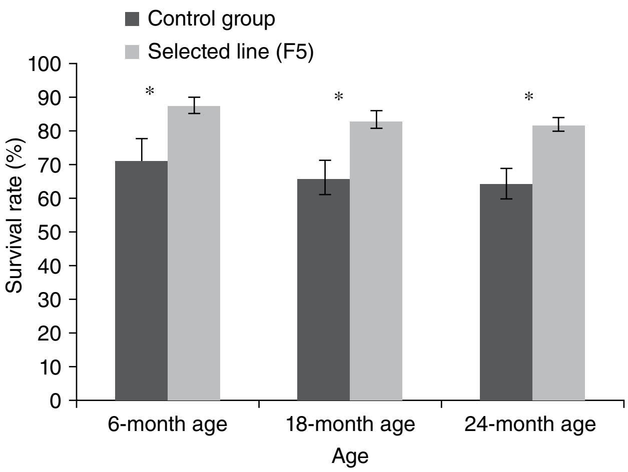

Figure 2.5.7 Comparison of survival rate between the selected line (F_5) and control group. The fish from these two groups were reproduced artificially on the same day.

Co., Ltd, these varieties have been distributed to farmers. However, none of related selective program has been conducted in other bream species.

2.5.6.3 Gynogenesis Breeding

Being one of the major approaches to haploid breeding, gynogenesis can be defined as a chromosome set engineering. Gynogenesis of fish is of vital application value in aquaculture. Induction of gynogenesis is able to accelerate the formation of varieties and populations, analyze quantitative character heredity, and locate genes (Gui and Zhu 2012).

Zou *et al*. (2001) studied the artificial gynogenesis (inhibit the second maturation division) of two- and three-year-old selectively-bred blunt snout bream. UV radiation was used to induce the genetically inactive sperm from common carp (*Cyprinus carpio*), and cold shock was used to inhibit the secondary polar body release of bream. Shock temperature, starting time and duration suitable to two- and three-year-old bream were studied. The results showed that for two- and three-year-old bream, the optimal induction starting time was three minutes after fertilization, while there was a slight difference in shock temperature and duration between the two groups. For three-year-old bream, 30-minute cold shock treatment at 0–2°C achieved a better effect. For two-year-olds, 20-minute cold shock treatment at 4–6°C achieved a better effect. By using microsatellite markers, Zhang *et al.* (2012) evaluated the genetic diversity of individuals whose secondary polar body gynogenesis was inhibited. It was found that all the genetic materials of gynogenetic individuals sourced from the female parent, without genetic materials from the male parent. Secondary polar body inhibition failed to produce the individuals with high purity. However, due to relatively high genetic homogeneity of the female parent, these gynogenetic individuals can serve as desirable breeding material.

2.5.6.4 Others

Also researchers have carried out experimental studies on polyploid breeding, nuclear transplantation breeding, and transgenic breeding of bream. Taking polyploid breeding as an example, Zou *et al.* (2004) obtained an artificial autotetraploid foundation group of blunt snout bream by inhibiting the first cleavage of eggs through heat shock. Some female parents of the artificial autotetraploid foundation group were sexually mature, while all the male parents were sexually mature. After self-reproduction, the tetraploid was used to hybridize with the diploid and large quantities of autotetraploid F_1 and reciprocal crossbred triploid (Li *et al.* 2006) were obtained. Meanwhile, by combining interspecific cross and physical induction (heat shock), it was established that the allotetraploid foundation group (Zou *et al.* 2008) for *M. amblycephala* (♀) × *M. skolkovii* (♂). Also normal hybridized heterologous "interploid" triploid was obtained by hybridizing allotetraploid female fish with male diploid *M. amblycephala*. In the field of nuclear transplantation breeding, Yan *et al.* (1985) developed a crossbred fish by bonding grass carp (*Ctenopharyngodon idella*) blastomere with denucleated spawn of *M. amblycephala*. By bonding bighead carp, *Hypophthalmichthys nobilis* cell nucleus with *M. amblycephala* cytoplasm, Qi and Xu (1994) developed the nucleo cytoplasmic hybrid trans-nucleus fish of the bighead carp and of the *M.amblycephala*. In the transgenic breeding field, there were reports, both at home and abroad, on the integration and expression of human growth hormone gene in *M. amblycephala* (Wu *et al.* 1994). By means of microinjection, the linear DNA fragments, in which mouse MT-1 gene starting sequence and human growth hormone hGH gene sequence were recombined, and were injected into fertilized eggs of *M. amblycephala*. According to the testing results of marking, Southern hybridization, Northern hybridization, radio-immunity, ELISA, and other methods, exogenous genes were integrated, transcribed, translated and expressed in receptors, and exerted a growth acceleration effect. Exogenous genes could be found in young fish from sexual reproduction between transgenic female and male fish. This shows that exogenous genes can be passed down to later generations through sexual cells and still work effectively in growth acceleration.

2.5.7 Constraints

2.5.7.1 Impacts on Benefits by Poor Culture Facilities and High Pond Rentals

As in the case of most aquaculture facilities in China, the lack of safe facilities, serious degradation of facilities and unreasonable drainage also confront bream culture. Although some modern equipment has been used, such as automatic feeding machines, automatic dissolved oxygen (DO) detectors, electric wind-feeding system, the culture systems for bream are still relatively underdeveloped aquaculture systems in China. Moreover, along with the increase of pond rental fees in the recent years, the profit for bream culture is greatly affected.

2.5.7.2 Feed Waste and Lack of Technology for Meat Quality Improvement and Processing

In recent years, the prices of raw ingredients for feeds, such as fish meal, soybean meal, rapeseed meal, cottonseed meal and corn, have gradually increased, resulting in increased commercial feed prices. However, because of fierce competition, the price of fish products has not kept pace. Feed costs account for above

70 percent of aquaculture inputs. The feed coefficient for bream culture is 1.8–2.0 for pellet feed and 1.3–1.6 for extruded feed. The high feed coefficient not only increases inputs, but also leads to feed wastage and pollution of the environment. Moreover, in recent years, it has been observed that bream fed an extruded feed during the whole culture period have a reduction of body surface mucus, loss of scales, a body color becoming red, and are more susceptible to disease, etc. So, the recipe for extruded feed needs to be improved, as do feeding techniques.

In current culture systems, there is still a lack of techniques for improving fillet quality and nutrition. Processing technology for bream is still in its infancy, with most bream being pickled, and other value added products are not that well developed. Chinese people prefer to eat braised bream in brown sauce, or steamed bream. So, its added value needs to be improved.

2.5.7.3 Shortage of Labor

With rural labor migrations to the city, fish farmers tend to be relatively old. Bream culture is facing a labor shortage. At the same time, along with improvement in the economy and better living standards of Chinese people, labor costs are gradually increasing, which of course affect the profitability of bream culture.

Although several culture models have been established for bream, most of these models still belong to open and extensive culture methods. Some integrated techniques have also been developed, such as using recirculating water, and ecosystem culture. However, the uptake of these improvements by farmers needs to be increased.

2.5.7.4 Lack of Improved Strains for Bream Aquaculture

The bream aquaculture sector made notable improvements following the development of the fast growth strain of blunt snout bream in 2000. However, over the last 15 years, it has been seen that this strain cannot satisfy the needs of farmers. Along with worsening culture environments and inbreeding depression, culture populations of bream have become more susceptible to disease. New aquaculture strains with improved traits need to be developed. In addition to blunt snout bream, good aquaculture varieties of other bream species also need to be selected.

2.5.8 Markets and Marketing

Bream commands a relatively higher price than other carps in Chinese domestic markets, but prices may differ between the five species of breams. Normally, for blunt snout bream, the price is about 9.0–10.0 RMB per kg in Hubei and Jiangsu provinces, while it increases to 18.0–20.0 RMB per kg in Beijing, Inner Mongolia, and other Northern regions. For the processing industry of bream, there are about 200 factories in China, mostly located in Ezhou City in Hubei Province. About 200 000 tonnes was processed in 2014 valued at 50 million RMB. Generally, the price of other bream species is a little higher than blunt snout bream; however, their markets are restricted to some provinces, and not nationally widespread like blunt snout bream.

2.5.9 Conclusions

2.5.9.1 Protection and Rational Utilization of Germplasm Resources

As blunt snout bream is distributed in only a few regions in China, it is necessary to comprehensively investigate and monitor its germplasm resources. Efforts should be made to protect original habitats where the blunt snout bream reproduces, grows and evolves. Active and effective measures should be taken to restore those damaged environments, and gradually regain the natural ecosystem of such areas. Meanwhile, economical utilization of wild resources should be reduced so as to regain the natural characters of germplasm resources. In addition, an artificial germplasm resource library or stock conservation base of blunt snout bream should be established, which should include allopatric wild genetic resources, and protection of living biological body and germplasm cryopreservation, for example gene and gamete preservation. Moreover, a series of standardized, large-scale, intensive and modernized superior variety breeding bases should be established, to supply superior young fish to bream farmers nationwide, and avoid blind reproduction by these farmers.

2.5.9.2 Further Genetic Improvement in Varieties

Although the current No.1 Pujiang blunt snout bream features a desirable growth rate, there is still a need to develop new high yielding varieties with good flesh quality and strong resistance to disease. On the one hand, the worsening aquaculture environment, and the increased frequency of occurrence of diseases trigger demands for developing new disease-resistant varieties. Concurrently, in genome, SCNT and stem cell technologies are constantly being improved, and important genes related to fertility, gender, growth, disease resistance, cold resistance and hypoxia resistance are being identified, and functionality analyzed. A new era in which breeding by molecular design typical of genetic improvement in cultured fish has only recently begun for bream. So it is hopeful that, in an effort to fuel sustainable development of blunt snout bream aquaculture, new high-yielding varieties will be developed using advanced breeding technologies, with good flesh quality and strong resistance to disease. Moreover, along with the development of aquaculture industry of other bream species, their selective breeding program could also be considered in the future.

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2.6

Integrated Rice-Field Aquaculture in China, A Long-Standing Practice, with Recent Leapfrog Developments

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2.6.1 Introduction

Fish culture practice in rice fields has a history of more than 2000 years in China (Huang and Zong 2007), and archeological and written records trace rice-fish culture to over 1700 years (Li 1992; Xiang 1995; Halwart and Gupta 2004). In June 2005, the Qingtian Rice-Fish Culture System in Zhejiang Province, China, was designated by the FAO-GEF (Global Environment Facility) as one of the first five ***Globally Important Agricultural Heritage Systems*** (**GIAHS**) pilot sites in the world. However, this traditional farming sector has witnessed leapfrog developments during the past three decades only. As one of the main contributors to freshwater aquaculture, production from paddy fields amounted to 5.4 percent (1 560 000 tonnes) of the total freshwater aquaculture production, and the farming area of paddy fields amounted to 21.6 percent (1 500 000 ha) of the total freshwater aquaculture area in China in 2015 (Figure 2.6.1). It is worthy to describe the transformation of the ancient fish farming experience in rice fields to the modern rice-field aquaculture practices in China.

2.6.2 Evolutionary Developments of Integrated Rice-Field Aquaculture

Evolutionary development of integrated rice-field aquaculture in China can be divided into three phases: the slow maintenance phase, the rapid development phase, and the leapfrog development phase.

2.6.2.1 Slow maintenance phase

This phase of rice-fish culture development lasted from 2000 years ago to the start of the 1980s. Ancient Chinese people realized the socio-economic importance of fish culture in rice fields. There may have been two main drivers for this culture experience. One driver was the limited availability of animal protein in densely populated rice-planting areas, where usually all the available field space was used for rice, leaving little space for husbandry and poultry production, as was the case in most Asian countries (Coche 1967). In China, 2000 years ago, fish culture was very popular in the Yangtze basin, and fish seed was abundant and exceeded the needs for that of pond culture (Ni and Wang 1988). The availability of excess seed may have been an additional driver for rice-fish culture. This practice was used by individual small-scale farmers. It was an ideal use of land and an easy source of cheap, fresh fish that gave convenient access to sources of animal

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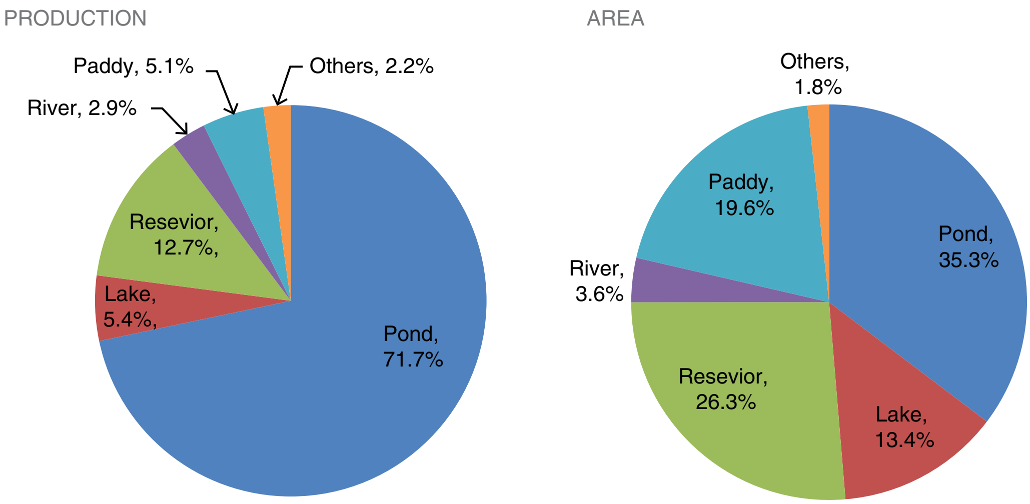

Figure 2.6.1 Percent contribution of production (left) and farming area for each of the freshwater environment types in China. Data *source:* China Fishery Statistical Yearbook (1984–2016).

protein, maintaining farms and ensuring livelihoods. However, it remained at a low level of operation for more than 2000 years.

After the founding of the People's Republic of China, the central government encouraged further development of this traditional practice. Two nationwide fisheries conferences were held in 1954 and 1958, respectively, to extend rice-fish culture techniques. At the same time, Dashu Ni, a famous aquaculture scientist from the Institute of Hydrobiology, Chinese Academy of Sciences, summarized fish culture techniques in rice fields and started systematic theoretical studies (Ni and Wang 1988). All of these policies and technical endeavors promoted temporary development of fish culture in rice fields in China, when the total area for fish culture in rice fields reached 590 000 ha by about 2000 (Huang and Zong 2007). However, wide use of pesticides for rice growing prohibited the development of fish culture in rice fields, and resulted in a trough of this practice in the 1960s and 1970s (Huang and Zong 2007).

2.6.2.2 Rapid Development Phase

From the beginning of the 1980s to 1994, fish culture in rice fields entered a rapid development phase. Area used for aquaculture in rice fields increased from 441 027 ha to 853,150 from 1983 to 1994, whilst production increased from 36 330 tonnes to 206 915 tonnes (Figure 2.6.2). In the meantime, fish culture in rice fields with only a few carp species such as common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idellus*) and crussian carp (*Carassius auratus*) evolved into integrated rice-field aquaculture that incorporated more species and included Chinese mitten crab (*Eriocheir sinensis*), crayfish (*Procambarus clarkii*), turtles, soft-shelled turtles and other high-valued fish species. Rapid development of this industry at this stage was due to innovation of theories and technology, policy support, and the introduction of new species suitable for culture in rice fields, and the use of supplemental feeds.

2.6.2.2.1 Innovation Technologies

In 1981, following many years' of study, the Theory of Rice-Fish Symbiosis was put forward (Ni and Wang 1988). The main crux of this theory was to place rice and fish into the same ecosystem, and bring into full play the contribution of fish in removing weeds, decreasing plant diseases and insect pests, maintaining fertility of the land, promoting multiple-level cyclic utilization of nutrients, and channeling more energy flow into rice and fish. The introduction of fish causes major changes of population and community structure, and their

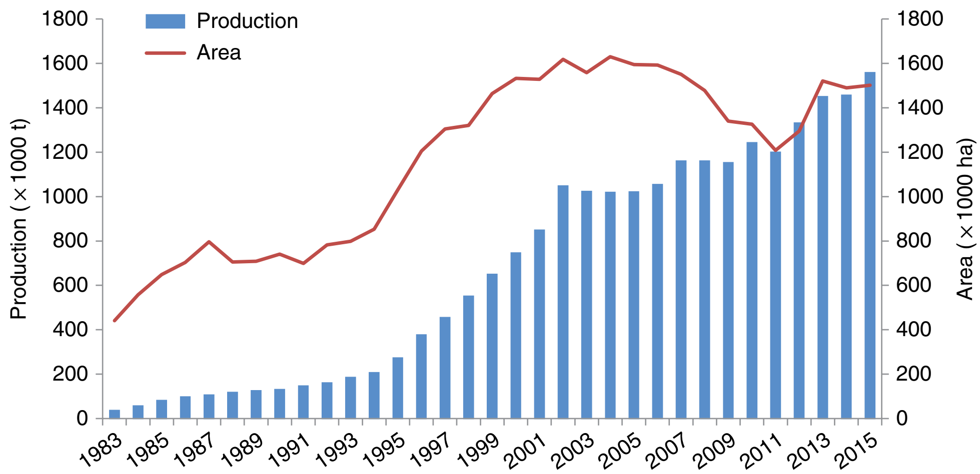

Figure 2.6.2 Production and farming area for integrated rice-field aquaculture from 1983–2015 in China. Data *source:* China Fishery Statistical Yearbook (1984–2016).

relationships in the rice-field ecosystem. Fish can directly or indirectly utilize weeds, zoobenthos, plankton and detritus, decrease competition of weeds for fertilizer, and utilize the food types and energy that cannot be utilized by rice. On the other hand, loadings from fish can also provide nutrients for rice and plankton, and CO_2 released by fish can also be utilized by rice, weeds and algae. Besides, fish may loosen the surface soil and improve oxygen level of the soil to promote mineralization of organic matter and release of nutrients (Ni and Wang 1988).

A series of technical innovations for fish culture in rice fields were also achieved during this phase. The most important innovation was to dig channels in the flat rice fields, which allow fish or other aquaculture species to grow even during rice harvest time or the dry season. There are several different patterns of channels for integrated rice-field aquaculture, but the four main patterns are shown in Figure 2.6.3. The widths and depths of channels are 1.5–4.0 m and 1.0–1.5 m, respectively, and the area of channels normally amounts to eight to ten percent of the rice field area (Zhang *et al*. 2017). The mud from channels is used to build dykes. Normally the dyke is 0.5–1.0 m higher than the rice-field surface.

Some other infrastructure is also important for the success of integrated rice field aquaculture, such as fence building to prevent the escape of crayfish, Chinese mitten crab and soft-shelled turtles from rice fields (Figure 2.6.4). Plastic fencing is more popular than ceramic tile fencing because of its low cost, but has a shorter lifespan.

2.6.2.2.2 Policy Support

In 1981, a suggestion by Ni received an active response from the Health Commission of China (the former Ministry of Health) of the central government, culminating in the listing of fish culture in rice fields as an important measure for killing mosquitos in 1983. In August of the same year, the Ministry of Agriculture, Husbandry and Fisheries held the First Nationwide "On-Site Experience Exchange Conference on Fish Culture in Rice Fields" in Wenjiang County, Sichuan Province. One year later, the National Economic Commission (former National Development and Reform Commission) listed fish culture in rice fields as a national technical development project and extended this technique to 18 provinces. In 1987, technical extension of fish culture in rice fields was accepted into the National Harvest Project and the State Key Agricultural Extension Project. In 1990, the Ministry of Agriculture held the Second Nationwide "On-Site Experience Exchange Conference on Fish Culture in Rice Fields" in Chongqing. Policy support accelerated the development of fish culture in rice fields in the 1980s.

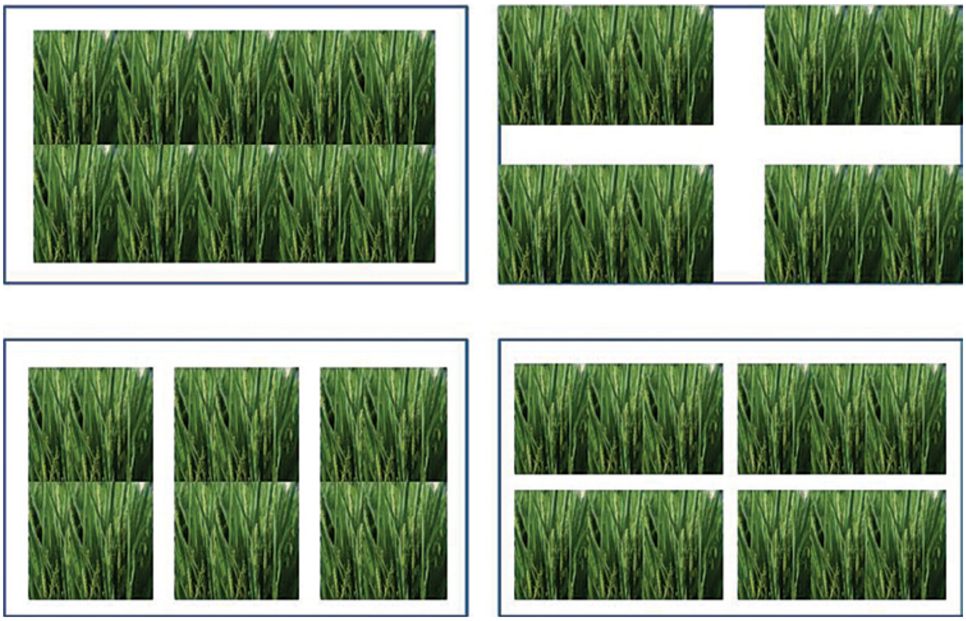

Figure 2.6.3 Four basic patterns of channels dug in rice fields to facilitate integrated rice-animal culture. *Source:* modified from Zhang *et al*. (2017).

2.6.2.2.3 Introduction of New Species and Use of Supplemental Feeds

At this stage, new species such as silver carp (*Hypophthalmichthys molitrix*), bream (*Megalobrama amblycephala*), tilapia, catfish, shrimp, snails, swamp loach (*Misgurnus anguillicaudatus*) were introduced into rice fields for culture in addition to the species originally used, e.g. common carp, grass carp and crucian carp. What is more important, supplementary feeds were used in rice fields, which increased fish production to a new level (Huang and Zong 2007). Fish culture in rice fields evolved into integrated rice-field aquaculture.

2.6.2.3 Leapfrog Development Phase

From 1995 to date, integrated rice-field aquaculture has entered a leapfrog development phase. The area used for integrated aquaculture in rice fields increased from 1 029 300 ha to 1 501 629 ha, an increase of 45.9 percent between 1995 and 2015, whilst production increased from 272 942 tonnes to 1 558 187 tonnes, an increase of 470.9 percent over the same time period (see Figure 2.6.2 above). High-valued species such as crayfish, Chinese mitten crab, turtle (*Chincmys reevesii*) and soft-shelled turtle (*Trionyx sinensis*) have become the main species cultured in rice fields. In this phase, the central government strengthened the policy support for the sector. In September 1994, the Ministry of Agriculture held the Third Nationwide, "On Site Experience Exchange Conference on Fish (Mitten Crab) Culture in Rice Fields" in Panjin, Niaoning Province. In December 1994, the Ministry of Agriculture, authorized by the State Council, promulgated the announcement on Accelerating Fish Culture in Rice Fields to Promote Sustainable Food Increase and Income Increase at all level agencies of agriculture, fisheries and water resources in China. Later in 1996, and in 2000, there were nationwide conferences on, "On Site Experience Exchange Conferences on Fish Culture in Rice Fields" conducted by the Ministry of Agriculture. With the co-endeavor of agencies of fisheries administration and fisheries extension at all levels, new technologies and new species for integrated rice-field aquaculture were rapidly and widely extended to most provinces, which increased the food production, aquaculture production, income and efficiency (Huang and Zong 2007). Zhejiang, Sichuan, Hubei, Jiangsu and Anhui were the top five provinces for integrated rice-field aquaculture with production of 339 186, 330 956, 256 611, 197 876

Figure 2.6.4 Examples of fence types (top – plastic fence; bottom – ceramic fence) installed to prevent escape of cultured animals in rice fields. *Source:* Photo by Jiashou Liu and Tanglin Zhang.

and 83 069 tonnes, respectively and the corresponding areas utilized were 83 060, 308 938, 200 863, 109 758 and 54 882 ha (Figure 2.6.5). Zhejiang has the highest production at 4083 kg/ha.

Besides policy support, there were other important contributing factors for this leapfrog development. One was the drive on marketing. During the past two decades, transportation infrastructure has improved at a rapid speed and a large number of express delivery companies have emerged. This has resulted in

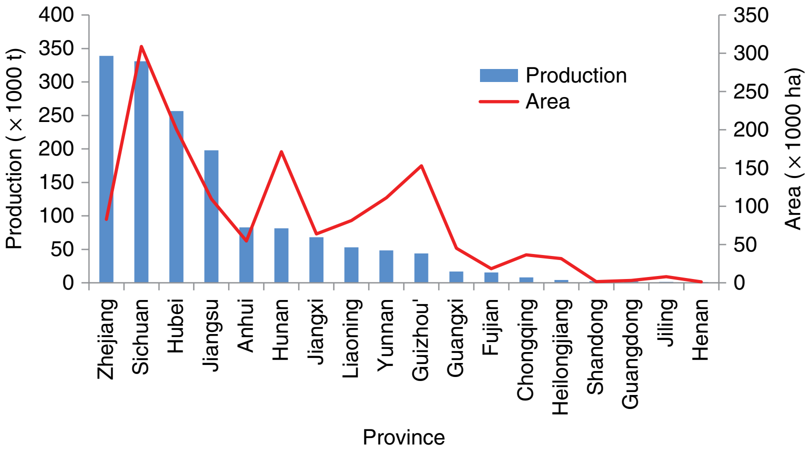

Figure 2.6.5 Main provincial production and area for integrated rice-field aquaculture in 2015 in China. Data *source:* China Fishery Statistical Yearbook (1984–2016).

improved delivery of aquaculture products, which can now be transferred from farm gates to consumers in a few hours. This is particularly important for Chinese consumers, who prefer live aquatic products. In addition, the price of live products is normally one or two times higher than when sold fresh. Convenient transportation and express delivery for easily caught rice-field aquaculture products enable consumers to get what they want at any time and at a reasonable price. Another contributing factor for this leapfrog development is consumer acceptance of crayfish. Crayfish were introduced into China in 1929, and were considered an invasive species (Cai *et al.* 2010). Crayfish had strong tolerance to low oxygen, polluted waters and pesticides that enabled it to spread quickly. In view of the above features, in the early years after its introduction, it was suggested that its spread be strictly controlled (Xu *et al.* 2010). With the development of integrated rice-field aquaculture, almost all crayfish are from rice fields or from other aquaculture sources, not from polluted water bodies any more. This changed the consumers' traditional point of view on crayfish.

Dozens of cooking methods for crayfish have been innovated (Shen 2010; Hu 2011). In Hubei Province, Qianjiang City, also called Crayfish City, is famous not only for crayfish production in rice-field aquaculture systems, but also for its crayfish cuisine. Every year, a crayfish festival is held in the city. More than ten streets are full of restaurants serving crayfish all of which are well patronized in May–June, the main harvesting period. Another important city for crayfish is Nanjing, the capital of Jiangsu Province. Yangsi Crayfish and Redleaf Crayfish are the two most famous crayfish "brands" there (Hu 2011). It is estimated that the income from the crayfish restaurants is more than 20 billion RMB (6.0 RMB = I US$) per year in this city.

Another reason for the leapfrog development of integrated rice-field aquaculture is increasing concerns about food safety. In the integrated rice-field aquaculture system, no pesticides and much less chemical fertilizers are used (Ma *et al.* 2016). Both aquatic products and rice from such systems are believed to be organically produced and command a better price (Ma *et* al. 2016). For example, the price of normal rice is about 5 RMB/kg, but rice from the integrated rice-field aquaculture is more than 10 RMB/kg in Qianjiang City.

2.6.3 Main Models for Integrated Rice Field Aquaculture

There are 19 different models of integrated rice-field aquaculture in different regions of China which can be divided into four groups, i.e. rice-fish aquaculture, rice-crayfish aquaculture, rice-crab aquaculture, and rice-turtle aquaculture (Ma *et al.* 2016). In the following sections we introduce four of the most successful integrated rice-field aquaculture models.

2.6.3.1 Integrated Rice-Swamp Loach Aquaculture Model

The integrated rice-swamp loach aquaculture model is one of the most poular rice-fish aquaculture models in operation in recent years. Increasing demand for the swamp loach in China, Japan and Korea, a small-sized but high-priced fish (also known colloquially as “ginseng in the water”) with a total length of about 15 cm at first maturation, has driven this development.

Before rice planting at the end of April, 300–350 kg of organic manure per 667 m^2 is applied to rice fields. In addition, in the main growing season, fermented organic manure is also applied at a rate of 100 kg/ 667m^2 every 15 days to provide nutrients for rice, and also culture plankton and benthos for the swamp loach (Tang and Ma 2013).

Fingerlings of swamp loach (5–8 cm in length) are stocked (75 kg/667m^2) into rice field channels eight days after rice planting in early May (Tang and Ma 2013). Supplementary feeds need to be given once or twice a day in the main growing season, including combined ingredients of fish meal, soybean cake, rice bran and wheat bran, or special commercial swamp loach feeds. The feeding rate is 4–5 percent of the swamp loach weight (Zhang *et al*. 2013). Since the size of the swamp loach is very small, special attention should be paid to prevent the accidental introduction of piscivorous fish like paddy eel (*Monopterus albus*), snakehead (*Channa argus*) and catfish, when water is added to the field. Some nets to prevent predatory birds should also be installed. Swamp loach are harvested in November with fyke nets.

In the Chenghu Fish Farm (150 mu; 1 mu = 667m^2) in Tianmen City, Hubei Province, the yearly production of swamp loach is 24 300 kg and the income generated is 874 800 RMB with an average production of 162 kg and the income of 5832 RMB per 667 m^2. Besides fish, rice production is 650 kg per 667m^2 and the income is 800 RMB per 667m^2. Totally, the net income from this model is 3207 RMB per 667m^2 (Tang and Ma 2013).

2.6.3.2 Integrated Rice-Crayfish Aquaculture Model

Integrated rice-crayfish aquaculture is the most popular model for shellfish culture in rice fields in China, although some other species such as Japanese freshwater prawn (*Macrobrachium nipponense*) or Asian giant freshwater prawn (*M. rosenbergii*) are also cultured in rice fields. Broodstock crayfish are stocked into rice fields (Figure 2.6.6) in August or September at a stocking density of 20–30 kg per 667m^2 for the first year

Figure 2.6.6 Large-scale rice crayfish aquaculture in Qianjiang, Hubei Province. *Source:* Photo by Zhonghu Tao. (*See color plate section for the color representation of this figure*.)

(Zhang *et al.* 2017), and from the second year onwards at a stocking rate of 10–15 kg per 667m^2 (Li *et al.* 2016). Fertilizers and supplementary feeds are used during the production period. In November, fermented pig manure (100–300 kg/667m^2) or rapeseed cake (50 kg/667m^2) or a combination of fertilizers (50 kg/667m^2) can be used in November the time when crayfish larvae hatch. In the following March or April, fermented pig manure (100–200 kg/667m^2) or rapeseed cake (50 kg/667m^2) or combination of fertilizers (50 kg/667m^2) are applied to the rice fields (Li *et al.* 2016).

When the water temperature exceeds 15°C in March, supplementary feeds are used in rice fields, including rapeseed cake, soybean and pelleted feeds. Feeding is conducted twice a day at a minimum area of 30 percent of the channel area, and feeding rates are determined by the standard that the crayfish can consume all the feed within two hours (Li *et al.* 2016). Macrophytes are planted in channels to adjust water quality, and also to provide shelter for molting crayfish. The crayfish are normally harvested two times a year with fyke nets (Figure 2.6.7), in late April to late May, and the in August–September. Broodstock crayfish should be kept in rice fields for the following year's production at a density of about 10–15 kg/667m^2.

The average production from this model is about 100–150 kg/667m^2 of crayfish and 450–500 kg/667m^2 of rice. An average income from crayfish and rice in Kuanglao Village Aquaculture Association in Jianli County, Hubei Province, in an area of 11 000 mu (1 mu = 667m^2) was 5159 RMB/667m^2 and the net income was 2810 RMB/667m^2 (Li *et al.* 2016).

2.6.3.3 Integrated Rice Crab Aquaculture Model

Integrated aquaculture of rice and the Chinese mitten crab is popular in North-eastern China. Coin-sized crabs (100–200 ind./kg) are stocked into rice fields at a density of 400–600 ind./667m^2 from late May to early

Figure 2.6.7 Integrated rice field aquaculture with crayfish (right) and the fyke net (left) for harvest in Jianli County, Hubei Province. *Source:* Photo by Qidong Wang. (*See color plate section for the color representation of this figure.*)

Table 2.6.1 Feeding rates (% of body weight) of supplementary feeds for the soft-shelled turtle in rice fields (Jiang *et al.* 2015).

Month	May	Jun.	Jul.	Aug.	Sept.	Oct.
Feeding rate	0.3–0.8	0.8–1.5	1.5–2.0	1.5-2.0	2.0–1.0	0.5–0.1

June (Zhang *et al.* 2017). In some other cases, soybeans are planted on rice-field dykes to utilize all the land area (Wang 2011).

In a village of Panshan County, Liaoning Province, an average rice production of 699 kg/667m^2 from this model is obtained, 8.5 percent higher than from rice farming alone, and the increased profit is 484 RMB/667m^2. The production of crabs is about 30 kg/ 667m^2 of average size of 106 g, the average selling price of 60 RMB/kg and bring about a profit of 1134 RMB/ 667m^2 (Wang 2011). The total profit from rice fields is 2232 RMB/667m^2, 2.64 times higher than pure rice culture (613 yuan/667m^2) (Zhang *et al.* 2017). Crab production is very low in this model because no supplementary feeds are used. In recent years, there is a trend to use low-valued supplementary feeds such as rice bran and iced fish when crab production can exceed 50 kg/667m^2 (Tang 2008).

2.6.3.4 Integrated Rice Turtle Aquaculture Model

Soft-shelled turtle is a traditional high-valued species for pond aquaculture (Wang *et al.* 2015). Two-year-old soft-shelled turtles are normally stocked in rice fields seven to ten days after the planting of rice. The size of stocked soft-shelled turtles are 300–500 g and are stocked at a density of 200–300 ind./667m^2 (Hu and Wang 2013; Jiang *et al.* 2015). The male-to-female ratio ranges from 1:2–1:3 (Jiang *et al.* 2015). Some fingerlings such as of crucian carp, silver carp, bighead carp and/or snails, can be stocked into the rice fields as feed for soft-shelled turtle. When the water temperature is below 25°C, the turtles are fed once a day, while more than 25°C, the turtles are fed twice a day at different feeding rates (Table 2.6.1).

Soft-shelled turtles are harvested in October or November, and production is about 75–100 kg/667m^2, together with a rice production of 400–500 kg/667m^2. The net income is normally over 10 000 RMB/667m^2 (Jiang *et al.* 2015; Zhang *et al.* 2017). This model is widely practiced in Zhejiang, Hubei, Jiangsu, Anhui and Fujian provinces. A similar model to this is the integrated aquaculture of rice and turtle (Shi and Yu 2002).

The shortcoming of this model is the high cost. The investment for this model is more than 5000 RMB/667m^2, which cannot be afforded by many small scale farmers.

2.6.4 Take Home Message and Conclusions

Integrated rice-field aquaculture is a sector with a long history, but which has undergone fast development only during the last three decades. This development has been due to continued innovation of theories and technologies, the introduction of new and high-valued species, enabling government policies, marketing drives, improvement in cooking methods, and increasing concerns on food safety. There are 19 different integrated rice-field aquaculture systems in China, but rice-swamp loach, rice-crayfish, rice-crab and rice-turtle are the most popular models currently in operation. In general, integrated rice-field aquaculture is a low-cost, high-benefit industry suitable especially for small-scale farmers, and its popularization reflects one of the many paradigm changes in modern inland aquaculture in China (see Wang *et al.* 2017). Techniques of this industry are simple for farmers to master. It can make better use of space of rice fields to produce safer aquatic and rice products at less cost. The Chinese government has prioritized this industry as one of the most important aquaculture sectors for the future.

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Section 3

Emerging Cultured Species/Species Groups

3.1

Freshwater Pearl Culture

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3.1.1 Introduction

Pearls are not only important for ornaments and handicrafts, but also have nutritive and medicinal functions. Pearls have long been used in Chinese medicines. Freshwater pearl culture technology was developed in China some 2000 years ago. However, modern commercial freshwater pearl culture dates back only to the late 1950s. Since this time, the technologies used for pearl culture have been continuously reformed. Pearl culture has become the largest freshwater mussel farming industry in China, with an annual yield of around 2000 tonnes, and China is the largest pearl producer in the world, accounting for over 80 percent of global production (Li and Li 2009). In recent years, there have been technical advances in terms of the artificial propagation of freshwater pearl mussels, screening of germplasm, the breeding of new varieties and further development of freshwater nucleated pearl culture. These developments have not only stabilized the yield of freshwater pearls, but also have greatly enhanced the quality of pearls; in fact recently, the industry in China has transformed from a focus on quantity to one on quality. In China, freshwater pearl culture is concentrated in the middle and downstream regions of the Yangtze River. The main bivalve species used for freshwater pearl culture include *Hyriopsis cumingii*, *H. schlegelii* and their hybrid "Kangle Mussel" (*H. schlegelii* (♀) × *H. cumingii* (♂)). Environmentally friendly polycultures have been adopted largely by culturing pearl mussels in hanging-cage systems together with fishes in ponds. The pearl mussel has been one of the most important species in freshwater multitrophic level cultivation systems and have been widely applied in restoring degraded waters (Fang *et al.* 2011; Tang *et al.* 2014).

3.1.2 Major Culture Areas

China's freshwater pearl culture industry was initiated in Jiangsu and Zhejiang provinces, and then gradually expanded to other areas (Li and Li 2009). Currently, the industry is largely distributed across Jiangxi, Anhui, Jiangsu, Hunan, Hubei, Fujian and Zhejiang. Among them, Jiangxi boasts the highest yields of freshwater pearls; its annual output is nearly 1000 tonnes (Figure 3.1.1) (Fisheries Administration, Ministry of Agriculture, the People's Republic of China 2015).

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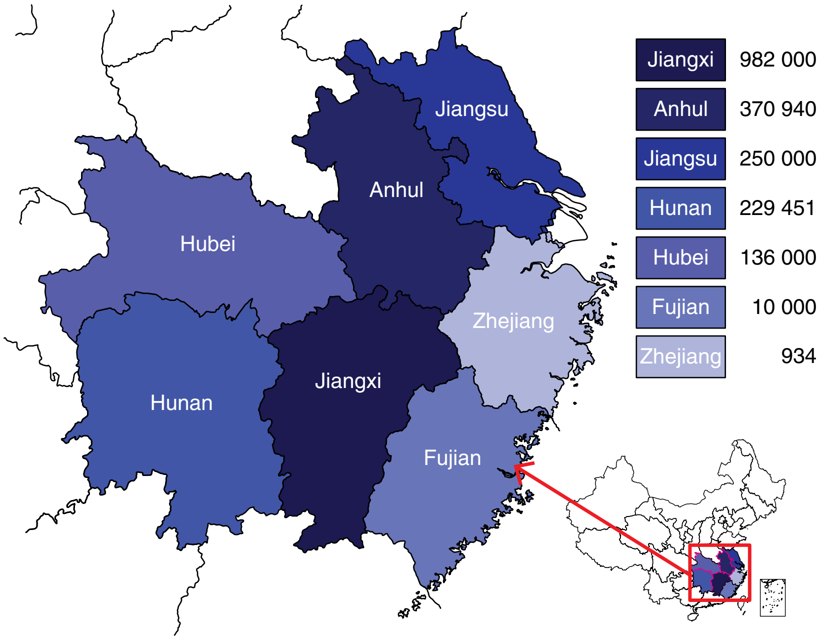


Figure 3.1.1 The major provinces that produce freshwater pearls and their yields (in kg) in China during 2014 (Ministry of Agriculture, Fisheries Administration 2015).

3.1.3 Development History of the Industry

The former Zhanjiang Fisheries College and Shanghai Fisheries College started to trial freshwater pearl culture in 1958; after this point, China's freshwater pearl culture industry developed, first gradually, and then rapidly. The first batches of freshwater pearls in China were harvested in Jiangsu and Zhejiang in 1967 and 1968, respectively. These provinces then gradually developed into the two pearl culture centers of China. China's pearl industry has undergone one trial period, and four development stages since 1958 (Table 3.1.1) (Bai *et al.* 2014). The fourth development stage, since 2008, has seen vast improvements in the quality of production (Figure 3.1.2). These stages are described below.

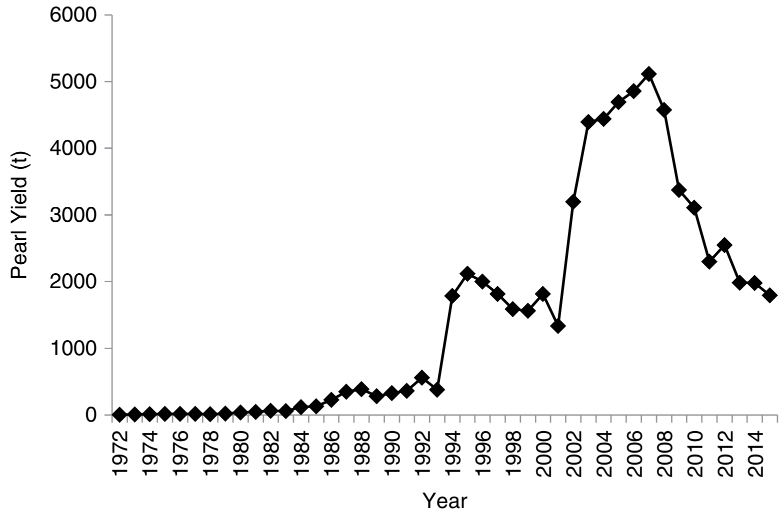
- **Trial stage (1958–1971):** This was the stage where trial cultures were carried out. During this stage, all pearl mussels were obtained from natural resources.

Table 3.1.1 A summary of the development stages of the freshwater pearl industry in China.

Development stages	Annual average yield/t	Annual average growth	Length	Development characteristics
Trial stage: 1958–1971	3.5	—	14 years	Poor yield
Stage 1: 1972–1983	27.5	22.4%	12 years	Rapid Development
Stage 2: 1984–1993	313.1	13.9%	10 years	Moderate development
Stage 3: 1994–2001	1753.7	—	8 years	Steady development
Stage 3 extension: 2002–2007	4448.3	—	6 years	Repeated statistics
Stage 4*: 2008–2014	2981.4	−12.6%	7 years	Industrial transformation

* After Bai *et al.* (2014), production data are sourced from China Fisheries Yearbook (2013–2015).

Figure 3.1.2 Freshwater pearl yields from 1972 to 2014.



- **Development stage 1 (1972–1983):** In the late 1970s, changes in the economic system and needs of international pearl markets boosted the development of China's freshwater pearl culture industry. During this stage, the technology used for freshwater pearl culture matured, but the decline in natural resources of pearl mussels became a bottleneck for further development of the industry.
- **Development stage 2 (1984–1993):** In 1978, artificial propagation of freshwater mussels was achieved and this promoted China's freshwater pearl industry into the second development stage. During this stage, the technological advances mainly comprised two aspects:
  - artificial propagation technologies for freshwater mussels were promoted vigorously, supplying sufficient seed for culturing and protecting natural resources;
  - a dozen varieties of mussel were used for freshwater pearl production in China. Repeated trials of freshwater pearl culture revealed that *H. cumingii* and Cockscomb pearl mussel (*Cristaria plicata*) were the best mussels to be used; the trials considered many factors, such as luster, color, fineness, shape, size and yield of the pearls, as well as the efficacy of surgical procedures. In 1984, China yielded over 100 tonnes of freshwater pearls, and became the leader in the world's pearl market.
- **Development stage 3 (1994–2001):** During this stage, the general public became more conscious of freshwater pearls, as the market was reformed and opened. A number of pearl trading markets and pearl merchants emerged, and private pearl enterprises developed rapidly. Two particular markets were promoted; one was Weitang Pearl City, China, which had an annual turnover of one billion RMB (6 RMB = 1 US$), and the other was Shanxiahu Pearl Market, Zhuji, which had an annual turnover of two billion RMB.
- **Development stage 3 extension (2002–2007):** The cross-province contracting of aquaculture waters commenced, in the context of large-scale enterprise operations. There was also further progress in production technologies, mainly characterized by three factors:
  - early propagation of mussel seed accelerated cultivation development, shortening the pearl production cycle;
  - the techniques and procedures of graft operation became regulated;
  - further improvements in farming methods were made; first, string-hanging culture was changed to cage-hanging culture; second, small pond culture was changed to large ponds, rivers, lakes and reservoir culture, allowing large-scale farming; third, extensive breeding methods were changed to intensive methods; and fourth, the hanging depth of mussels moved from deep to surface waters.
- **Development stage 4 (2008–2014):** The demand for pearls declined during this stage, influenced by the global financial crisis. However, pearl jewelry is still in short supply. China's freshwater pearl industry has

followed the industry trend of transforming from high-yield practices to the production of high-quality pearls. The successful transformation of these industrial practices will promote China's freshwater pearl industry through the fourth development stage.

3.1.4 Farm Environment

The freshwater environment in which the mussels are grown not only determines the survival and growth of the pearl mussel, but also influences the yield and quality of the cultured pearls. Hence, selection of the appropriate water environment is of great importance (Li and Li 2014).

3.1.4.1 Physical and Chemical Indices of the Culture Environment

In general, for pearl mussel culture, pollutant-free water sources, a convenient water supply and discharge facilities (micro-flow quality preferred), more eutrophic waters, and conditions that promote rapid growth are required. The water body should be free of aquatic plants; there should be little bottom sludge and there should be a water depth of 1.5–4 m (optimum 2 m). A pH 6.5–8.5 is suitable for pearl cultivation, but neutral and somewhat alkaline waters (pH 7–8) are more favorable for mussel growth and nacre secretion. Pearl mussels require high concentrations of calcium, generally over 15 mg/l.

Water temperature also affects growth, development, reproduction and distribution of the mussels, as well as the formation and growth of the pearls. The appropriate temperatures for pearl mussels range from 20°C to 30°C. When the water temperature is 8°C or lower, the metabolism of mussels becomes weak and the nacre secretion stops. When the water temperature is 35°C or higher, the growth of the mussels is also repressed; dissimilation becomes greater than assimilation, leading to the decline and death of the mussels.

3.1.4.2 Food

Plankton contributes as the food source that enable mussels to live and grow. Pearl mussels are almost unable to ingest plankton actively. They produce a water current by swinging the cilia on their gills and flaps; this moves water through the water inlet, and animals trap the plankton by filtration. This is a very passive way of feeding. The components of the plankton in the water inevitably vary and the growth of the mussels is directly tied to its richness and species composition. Plankton comprises phytoplankton, zooplankton and protozoans; phytoplankton includes cryptophyta, diatoms, chrysophyceae, and chlorophyta, while zooplanktons include rotifers, copepoda, and cladocerans. Phytoplankton is the major food source for pearl mussels; *H. cumingii* mainly live on diatoms and other algae, supplemented by protozoans and organic detritus (Yang *et al.* 2005).

3.1.4.3 Disease Prevention

Culture environments need to be free of disease-causing organisms. Aquaculture waters need to be free of blue-green algae and euglenophyta blooms, to prevent poisoning of the mussels. For freshwater pearl mussels, bacterial diseases are the most hazardous; there are many varieties of bacterial diseases (Zhang *et al.* 2005). Moreover, bacterial diseases will induce secondary diseases. *Aeromonas hydrophila* is one of the most common pathogenic bacteria. If mussels are affected by *A. hydrophila*, at the early stage of the disease there is much mucilage in the body of infected animals, and the two shells open slightly. As the disease progresses, the adductor muscle becomes non-functional, and the shells open wide. Sick mussels have intestinal edema and ascites, with no food in their intestines, eroded-like liver, a pale leg and darkened yellow gills (Wen *et al.* 2001). Higher temperatures and excessively eutrophic waters tend to induce such diseases. The pathogen inducing the red foot disease is a variant of *Vibrio fluvialis*. It is also a gram-negative bacterium, shaped like a bent pipe. This pathogen also occasionally infects the mantle or adductor (Xu and Yin 1993).

There are often multiple parasitic diseases in freshwater pearl mussels, and complications are very common (Zhang *et al.* 2003). In particular, nematodes and rotifers are more common than in other cultured aquatic animals. Currently, widespread parasites include *Trichodina spp.*, *Colpoda spp.*, nematodes, and rotifers, among others. In addition, the roe of *Rhodeus sinensis* are often found in the gills, and excessive amounts can cause difficulties in breathing, affecting the normal growth of the mussels, and promoting infections with other diseases.

3.1.5 Culture Methods

The majority of freshwater pearl mussels are cultivated in ponds. Culture methods include rope and cage that are hung in the water column, and bottom-culture methods (Figure 3.1.3). Production practices have proved that the pearl yields from cage-hanging cultures are 38 percent higher than those from bottom-cultures, while, in turn, the yields from rope-hanging cultures are 27.4 percent higher than those of cage-hanging cultures (Li and Li 2014). However, the aliform parts of pearl mussels are relatively weak, and the drill holes needed for rope-hanging cultures easily break, making them sink. In addition, drilling tends to wound the body, causing death as a result of inflammation. Therefore, the cage-hanging culture method is the most prevalent at present. The cage, usually 40×25 cm, is made of bamboo cane struts, and polyethylene net (Figure 3.1.3). Three mussels are placed into each cage, and the cages tied on to a rope at 50 cm intervals, and hung at 40 cm depth from the water surface.

Currently, polycultures containing fish and mussels are widely applied; these comprise multi-trophic level culture systems in which the varieties of fish used are compatible with the feeding habits of the mussels. This culture method makes most use of the resources in the water body and enhances economic output. There are two main stocking patterns of polycultures containing fish and mussels: (1) mussel cultures supplemented by fish; and (2) fish farming supplemented by mussel cultures.

Figure 3.1.3 Cage-hanging cultivation of freshwater pearl mussels. (*See color plate section for the color representation of this figure*.)

3.1.5.1 Mussel Cultures Supplemented with Fish

In the culture ponds of freshwater pearl mussels, fish, including grass carp (*Ctenopharyngodon idella*), crucian carp (*Carassius auratus*), bighead carp (*Hypophthalmichthys molitrix*) and silver carp (*Aristichthys nobilis*), are often cultivated together. The ratios of fish to mussels generally range from 1:7 to 1:10 with mussel density at 0.75 ind./m^3 (Yan *et al.* 2009). The supplemented fish are favorable for the growth of *H. cumingii*. In polycultures, optimization of the types of fish, and the ratio of fish to mussels can help enhance both pearl and fish yields. It can also increase the utilization efficiency of nitrogen and phosphorous inputs, reducing the outputs of nitrogen and phosphorous during the culture.

Case 1 A culture pond for *H cumingii* was suitable for supplementing some silver carp and bighead carp The ratio of mussels to fish was kept at 10:1, and the culture ratio of silver carp and bighead carp was kept at 3:7 (Yan *et al.* 2009).

3.1.5.2 Fish Farming Supplemented with Mussels

In ponds mainly farming fish, polycultures with *H. cumingii* can improve the water quality of the ponds and the community structure of the phytoplankton; this helps to reduce nitrogen, phosphorous and organic wastes from the culture system. Thus, the polyculture promotes ecological and economic benefits.

In a pond of 6667 m^2 and an average depth of 1.63 m, the density of four fish species was 1.5 m^{-3}. For the polycultures with *H. cumingii*, the density was maintained at 0.8 m^{-3}, 1.0 m^{-3} and 1.2 m^{-3}. The fish yields demonstrated that the polycultures were superior to monoculture, in terms of survival rates and average growth rates in wet weight. The pond with a culture density of 0.8 m^{-3} achieved the highest fish survival rates and average growth rates in wet weight, creating optimal fish farming output (Hu *et al.* 2014).

In a traditional polyculture system containing *C. idella*, *C. auratus*, *H. molitrix* and *A. nobilis*, when supplemented with a culture of *H. cumingii* at a ratio of 1:1, the yields of *C. idella* and *C. auratus* remained the same, but lower yields of *A. nobilis* occurred. Polyculture with *H.cumingii* enhanced phytoplankton diversity. In addition, it reduced the concentrations of total nitrogen, total phosphorus, and total organic carbon, as well as the chemical oxygen and biological oxygen demands (Tang *et al.* 2014).

3.1.6 Recent Technological Progress

3.1.6.1 Seed Rearing Technology

From the 1960s to 1970s, freshwater mussels were collected from the wild and grafted for pearl production. Due to limited resources, the yield of freshwater pearls was very low. In 1978, there was a breakthrough in China, in terms of the artificial propagation of freshwater mussels, which terminated the need to collect natural seed. In 1984, the freshwater pearl yield of China became the highest in the world. In recent years, in order to optimize seed-rearing technology and the processes of growing freshwater pearl mussels, such as *H. cumingii*, China has:

- conducted research into the changes of the outer gill of *H. cumingii*, as a nurturing pouch, during the egg-bearing period; the embryonic development of *H. cumingii* within the nurturing pouch of the outer gill; the selectivity of glochidia on host fish; and morphological changes of glochidia during the parasitic life stage;
- explored the zero and accumulated temperatures for glochidia development, as well as the effects of environmental conditions, like pH and salinity, for the development of juvenile mussels (Bai *et al.* 2014);
- invented a method of "early breeding of *H. cumingii* seeds", in which parent mussels and seed are reared in greenhouses. Water temperature adjustments and designated culture technologies of live food (phytoplankton) are adopted, to promote the gonads to ripen early, and encourage rapid growth of seed in early

spring. This means that *H. cumingii* bred in the current year can be big enough for graft operations by late November, effectively shortening the pearl production cycle by half a year;

- invented a specialized pond for collecting juvenile mussels taken off host fish firstly and rearing juvenile mussels. The pond provides a temporary area for separating host fish from juvenile mussels until fish are free of glochidia and as a consequence, the rate of seeding emergence is enhanced by 20 percent;
- Chinese research has also led to a "duplex culture apparatus for juvenile mussel of *H. cumingii*"; this apparatus has reduced the floor area required by 50 percent, which has greatly lowered seed production costs.

The above technological innovations have continuously promoted improvement in the industrialization of seeding propagation for freshwater pearl mussels.

3.1.6.2 Screening of Germplasm and Breeding of New Varieties

There is an abundance of freshwater pearl mussel germplasm resources in China. The growth performance, pearl culture performance, and genetic diversity of *H. cumingii* from five freshwater lakes (Poyang Lake, Dongting Lake, Tai Lake, Chao Lake and Hongze Lake) and from the Zhuji cultured population have been investigated (Wang *et al.* 2014). These analyses revealed that *H. cumingii* in Poyang, Dongting and Tai lakes had outstanding germplasm, and these have gradually been used by farmers as parent mussel for seed production. The scientific research institutes have adopted and identified *H. cumingii* as the basic group for selective breeding, or as lines in crossbreeding systems (Wang *et al.* 2014).

H. schlegelii, which produces high-quality freshwater pearls, were introduced from Japan. Shanghai Ocean University managed to achieve distant hybridization between *H.cumingii* and *H. schlegelii*; the evaluation of hybrids revealed that of *Hyriopsis schlegelii* (♀) × *Hyriopsis cumingii* (♂) had remarkable advantages. Hybrids had more stable heterosis in the crossbreeding system with female *H. schlegelii* and male *H. cumingii* from Poyang Lake have undergone mass selective breeding. In 2006, the Kangle mussel, the first new variety of pearl mussel, was certified by the National Appraisal Committee of Aquatic Proto Species and Improved Varieties. Kangle mussel had significant heterosis, as well as strong resistance to disease. Compared with *H.cumingii*, Kangle mussels have 25.66 percent and 46.98 percent larger shell width and weight, respectively. The pearl yield increased by 31.96 percent, the size of pearls increased by 23.32 percent, and the ratio of pearl with eight mm or higher diameter increased by 3.72 times (Li and Bai 2007).

In 2014, Shanghai Ocean University developed a new variety, "Shenzi No. 1" *Hyriopsis cumingii*, after five generations of successive selective breeding (Figure 3.1.4). The shell nacre is deep purple, and the percentage of purple pearls produced by "Shenzi No. 1" was 97.2 percent. However, in the eighteenth month after

Figure 3.1.4 "Shenzi No. 1" *Hyriopsis cumingii*.

grafting, the percentage of purple pearls was 50.1 percent, on average. Nevertheless, the large-scale production of rare purple pearls has been realized (Wang *et al.* 2014).

3.1.6.3 Polycultures of Mussels with Other Aquatic Species

Traditional pearl culture needs frequent fertilization (organic) to facilitate phytoplankton growth. This results in high loads of nutrients, and frequent outbreaks of harmful algal blooms (especially cyanobacterial blooms) in mussel ponds, increasing the risk of pollution of the surrounding environment, and becoming an obstacle to the sustainable development of this industry. In order to solve the problem, many environmentally-friendly polycultures have been developed (Wang *et al.* 2014). Apart from the optimization of polycultures of fish and mussel (see Section 4: Culture methods), other advances have included: polyculture of crab and mussel, polyculture of shrimp and mussel and polyculture of giant freshwater prawn with *H. cumingii,* silver carp and bighead carp (Liu *et al.* 2014).

3.1.6.4 Process of Development of Nucleated Pearls

During the culture of freshwater non-nucleated pearls, only mantle saibo made by donor mussels are implanted in the mantle of host mussels. The pearl-culturing cycle is five years, but the cultivated pearls are smaller with low rates of round pearls. Hence, there is a need to cultivate nucleated pearls with a short cycle, large size, round shape and good luster (Xie 2010). However, the mantle of freshwater mussels is very thin; the full-membrane is only 1–1.5 mm thick. In addition, the texture of the membrane is so tender that it struggles to hold the round pearl nuclei when the diameter exceeds 6 mm. The mantle saibo is so thin and tender that it cannot closely adhere to the pearl nucleus. In relation to these difficulties, anatomical analyses, and pearl-nucleus-inserting experiments are used to determine the timing and optimal positioning for pearl-nucleus-insertion. To overcome these issues, the pearl-nucleus-inserting method, "simultaneous delivery of nucleus and saibo", has been invented; this has resulted in an increase in the survival rate of host mussels to over 95 percent, the rate of nucleus maintenance to over 80 percent, and the rate of pearl formation to over 90 percent.

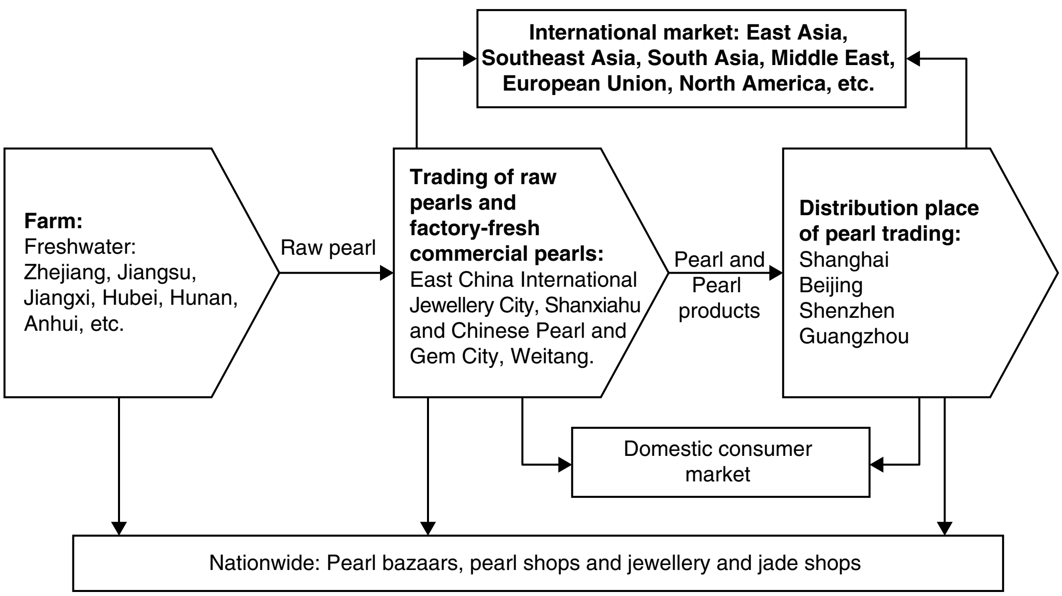


Figure 3.1.5 Schematic representation of the layout and features of the Chinese freshwater pearl trading markets.

3.1.7 Marketing

Currently, China has two major freshwater pearl markets for trading raw pearls and factory-fresh commercial pearls: East China International Jewelry City, at Shanxiahu Town, Zhuji City, Zhejiang Province, and Chinese Pearl and Gem City, at Weitang Town, Suzhou City, Jiangsu Province (Figure 3.1.5). There are four pearl distribution centers for trading commercial pearls and pearl products: Shanghai Hongqiao Pearl City, Beijing Hongqiao Pearl Trading Center, Shenzhen International Jewelry Trading Center, and Guangzhou Pearl Wholesales Market. These markets have gradually promoted the movement of freshwater pearls from farms to domestic, and then to foreign markets (Chen and Li 2007).

3.1.8 Development Prospects

Over the past decades, there have been significant breakthroughs in Chinese freshwater pearl culture technologies, in terms of artificial propagation of pearl mussels, seed rearing, grafting operations and pearl mussel-farming technologies, among others. A set of mature systems for freshwater pearl culture technologies has been established. This has not only promoted the development of the pearl industry of China, but has also continuously consolidated China's status as the country that produces the highest yields of freshwater pearls. However, the imbalance between pearl production and quality enhancement, and large yields of low-grade pearls, means that there has been an increasing problem of high production rates, but of low-grade freshwater pearls. High-grade freshwater pearls are rare. For example, in the Zhejiang Province market, about 80 percent of the pearls are medium- and low-grade pearls; this has greatly impacted on market price. A reduced yield of medium- and low-grade pearls will not substantially impact the output value of the freshwater pearl industry, but would be of great significance in protecting resources. Hence, since 2008, a new tendency in the freshwater pearl industry has been to enhance the quality of pearls. In the future, efforts should be made to develop new varieties of mussels which may produce high-quality pearls, to invent new grafting techniques, and to research and develop intelligent and factory-based pearl mussel culture technologies. This will lead to important technological breakthroughs that will improve the quality of the pearls. In addition, in order to enhance the value of low-grade pearls, we should formulate corresponding specification of the culture technologies for the development of low-grade pearls, for use in pharmaceuticals, healthcare products, nutritional foods and beauty products.

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3.2

Chinese mitten Crab Culture: Current Status and Recent Progress Towards Sustainable Development

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3.2.1 Introduction

The Chinese mitten crab (*Eriocheir sinensis*) is a native freshwater crab that is widely distributed throughout the eastern region of China (Sui *et al*. 2009c). Although the species is considered to be invasive in Europe and northern America (Ruiz *et al*. 2006), it has traditionally been regarded as a culinary delicacy and high-valued aquatic product in China (Wu *et al*. 2007c). A famous quote from Zhuo Bi dated to about 1700 years ago, "Wine on the right hand, mitten crab claw on the left hand, relaxing in a drifting boat, what more can I ask for?" illustrates the love Chinese people have for this crab. Since the 1960s, the wild stock of *E. sinensis* and its fisheries production have declined sharply due to overfishing, and obstructions to its migration paths by the construction of dams and flood gates between rivers and lakes (Zhao 1980). This decline in the wild resources stimulated the development of hatchery techniques to produce artificial seed for stock enhancement and aquaculture in China (Sui *et al.* 2011a). The breakthrough in hatchery techniques of *E. sinensis* was achieved at the beginning of the 1980s (Zhao 1980), and the techniques were gradually developed and improved for practical, large-scale production by the late 1990s (Cheng *et al*. 2008). As a result, the commercial farming industry of *E. sinensis* was established and has developed since 1980s (Wang *et al*. 2016). In general, the history of the development of *E. sinensis* culture can be divided into four phases based on changes in aquaculture production, and expansion of the culture area: (1) infancy stage from the end of 1970s to 1992. Before the 1980s: aquaculture production of mitten crab relied on the provision of wild megalopae and stocking in lakes, when the adult crabs were harvested every year; (2) popularization stage from 1993 to 2003: hatchery techniques were gradually developed to practical, steady and large-scale production of crab seed megalopae, which provided artificial seed for the expansion of pond culture area of *E. sinensis*; (3) steady development from 2004 to 2010: the total aquaculture production increased steadily, with a large improvement on the size of adult crabs harvested; (4) quality improvement stage from 2011 to present: annual aquaculture production ranged from 700 000 to 800 000 tonnes, but quality was improved to meet market demands for taste, smell and nutritional values (Cheng e*t al*. 2008; Gu *et al.* 2013; Wang *et al*. 2014; Wang *et al.* 2016). Annual farmed mitten crab production has reportedly increased from 17 500 tonnes in 1993 to 796 535 tonnes in 2014 (China Fishery Yearbook 2015; Figure 3.2.1).

Chinese mitten crab farming now occurs in all provinces and regions of mainland China, but the Yangtze river basin (middle and eastern China, near the Yangtze river) contribute more than 80 percent to the total culture production (Wang *et al*. 2014). The most important provinces for the production of farmed mitten crab are Jiangsu, Anhui, Hubei provinces (China Fishery Yearbook 2015; Figure 3.2.2). Based on the statistics of China Fisheries Bureau, hatchery-produced crab seed, in the form of postlarval megalopae, has exceeded 200 000 kg (approximately 140 000 megalopae per kg) per year since 2001, and the figure increased

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to 346 000 kg in 2002, and further to 942 388 kg in 2014. Despite the fact that grow-out of Chinese mitten crab is practiced all over the country, the hatcheries are mainly located in the Yangtze River Delta in eastern China, producing more than 90 percent of the megalopae. For example, of 942 388 kg megalopae produced in 2014, 858 658 kg was produced in Jiangsu province (China Fishery Yearbook 2015). Overall, Chinese mitten crab

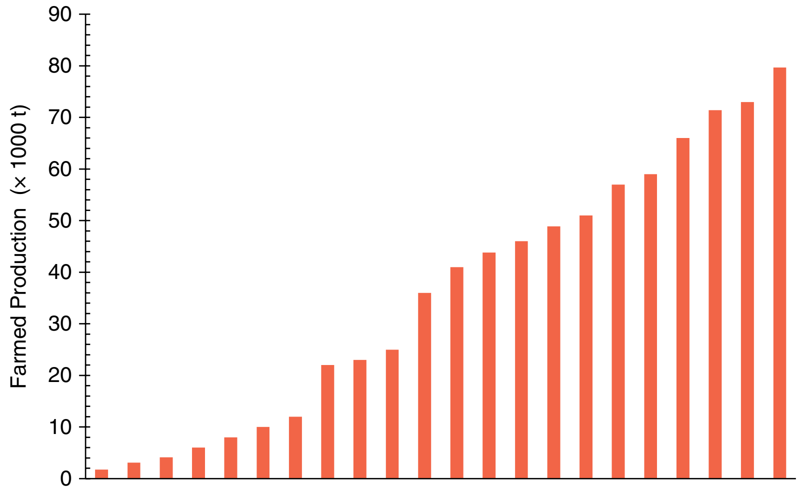

Figure 3.2.1 Trends in the annual farmed production of adult *E. sinensis* from 1993 to 2015.

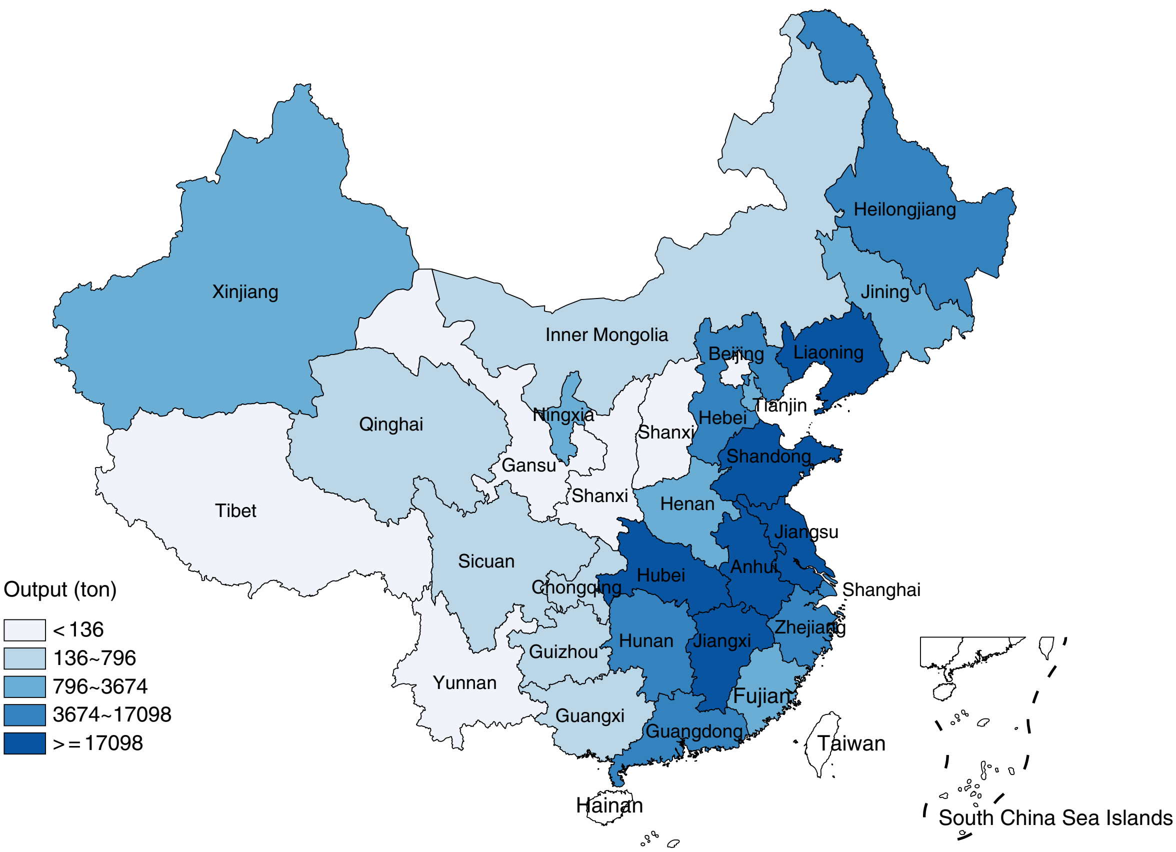

Figure 3.2.2 The distribution of annual farmed production of adult *E. sinensis* in China in 2015.

farming is a good success story of Chinese aquaculture development, which provide a reliable source of income for many rural people.

3.2.2 Lifecycle and Biology

The post-larval stages of Chinese mitten crab inhabit fresh water streams and lakes, particularly those with lush growth of aquatic plants. They are omnivorous and forage mainly during night time; their diets include mollusks, organic debris, earth worms, aquatic insects and various plants (Jin *et al.* 2003). Aquatic plants often make up the bulk of their gut contents. Mitten crab has broad tolerance to temperature, and can survive at a wide range of 1–35°C although in winter when temperature drops below 5°C, they often stop feeding and hide in burrows or mud. The Chinese mitten crab has a strong resistance to starvation, and can survive without feeding for more than one month (Wen *et al*. 2006).

Chinese mitten crab are catadromous, which means that they spend most of their life in freshwater, but must return to the estuaries or coastal waters to breed (Zhang *et al.* 1973). In the wild, the crabs attain puberty molting (morphologically mature) and start migrating downstream in later fall. Females attain ovarian maturity when they reach tidal estuaries, where male and female crabs mate and spawn. Extruded eggs are attached to the pleopods of the female (Lai 1994). After spawning, the females generally overwinter in estuarine waters until the spring, when the eggs hatch (Zhang and Li 2002).

Larval development of *E. sinensis* occurs in brackish water. The newly hatched larvae are planktonic, and the tiny, first stage zoea larvae (Zoea I) goes through five zoeal stages (Zoea I to Zoea V), before metamorphosis into megalopal stage (Figure 3.2.3). Megalopae then migrate with tides upstream, and metamorphose to become first-stage crabs, which are benthic (Montú *et al*. 1996). The juvenile crabs continue to migrate further inland into freshwater systems, where they will grow until their terminal molts (Lai 1994). From the first-stage crab, it takes 13-16 molts over a period of about two years to reach the terminal molt, which indicates reaching sexual maturity, and attaining a maximum size (Figure 3.2.3).

Based on the lifecycle of *E. sinensis*, the production cycle normally involves three distinct culture phases: larval or hatchery stage (2–4 months, to produce megalopae), coin-sized juvenile culture or nursery stage (eight to ten months, to produce coin-sized crablets for grow-out), and market-sized or adult grow-out culture (seven to ten months, to produce market-sized adult crabs) (Cheng *et al*. 2008). The following sections review the current status, and recent progress for each culture stage.

3.2.3 Seed Production

3.2.3.1 Broodstock Selection

Obtaining high-quality broodstock is the first step to ensuring successful hatchery operations. Ideally, female broodstock crabs should be 125–150 g, and males more than 175 g. Only healthy, active crabs with all appendages intact should be selected as broodstock. Although crabs collected from lakes and streams are believed to have better reproductive performance than those from ponds (Wu *et al.* 2007c), pond-reared broodstocks are the major source for commercial hatcheries (Sui *et al.* 2011b). Broodstock nutrition is also crucial during the gonadal maturation period, from middle-to-late September to middle November (Wu *et al.* 2007a). The traditional diets commonly used for broodstock are fresh natural food, such as low-valued fish, e.g. *Chaeturichthys stigmatia*, the Chinese razor clam (*Sinonovacula constricta*) and sandworm (*Nereis japonicus*) (Wu *et al.* 2010). Since mid 2000, optimized formulated diets have been developed to replace natural food for *E. sinensis* broodstock. In general, broodstock-formulated diets are supplemented with balanced HUFA (highly unsaturated fatty acids), phospholipids, cholesterol, vitamin C and vitamin E (Wu *et al.* 2007a; Sui *et al.* 2011b). Broodstock dietary enrichment is currently emphasized as a necessity for maternal conditioning prior to mating and spawning in hatcheries (Sui *et al.* 2011b). Although in hatcheries, broodstock are generally cultured

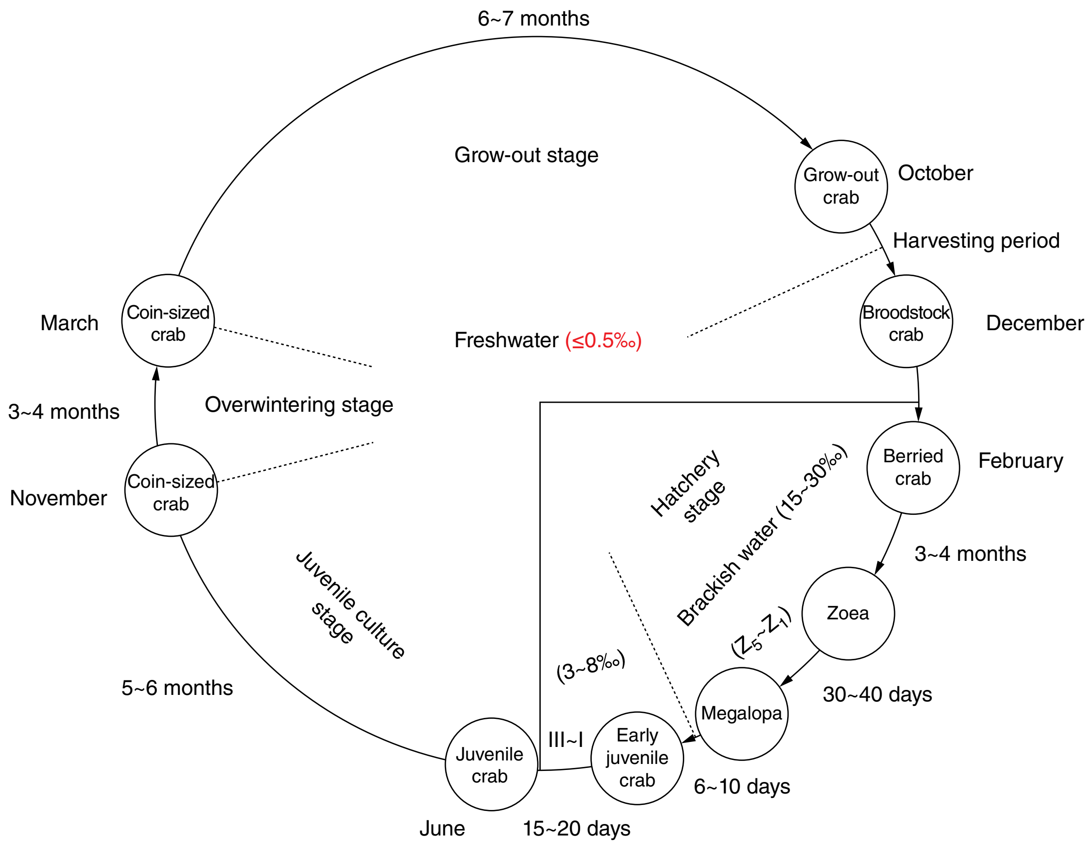

Figure 3.2.3 The lifecycle and relevant culture stages of *E. sinensis*. Source: Modified after Wang *et al.* (2013).

in freshwater and without temperature control, appropriate water salinity can accelerate the gonadal development of broodstock (Wu *et al.* 2013).

The native range of *E. sinensis* includes three main drainage basins: the Liaohe, Yangtze, and Oujiang rivers (Sui *et al.* 2009c), the Yangtze population of *E. sinensis* has the largest adult body size, as well as the best growth performance and taste (Li *et al.* 2000; Zhang *et al.* 2000; Li *et al.* 2002). Therefore, most pond-reared populations of *E. sinensis* in middle and eastern China originate from the wild Yangtze populations (Wang *et al.* 2014). Between 1990 and 1995, pond-reared broodstock were successfully used for seed production in commercial hatcheries, thereby closing the lifecycle of this species in captivity (Wang *et al.* 2014). However, in order to reduce broodstock costs, most commercial hatcheries in China at this time tended to select small, pond-reared adult *E. sinensis* (females: 60–100 g/ind; males: 80–150 g/ind) – broodstock which had not undergone genetic improvement through selective breeding programs before 2008 (Zhang and Li 2002; Sui *et al.* 2011a; 2011b). This resulted in selection for small-sized crabs, and often led to inbreeding and the degradation of genetic diversity of pond-reared *E. sinensis* stocks which originated from the Yangtze basin (Wang *et al.* 2014). In addition, during the 1990s and early 2000s, megalopae and juveniles from the Yangtze population of *E. sinensis* were more expensive than those from elsewhere (Zhang and Li 2002), and this stimulated significant demand for megalopae and juvenile *E sinensis* from this region. Wild or artificial seedstocks from other *E. sinensis* populations were subsequently introduced to the Yangtze basin for aquaculture purposes (Wang *et al.* 2014). Such introductions, and the subsequent culture of different *E. sinensis* populations within the Yangtze basin undoubtedly lead to germplasm hybrids among pond-reared Yangtze populations (He *et al.* 2014). As a result, there was a consistent decline in performance in culture, characterized by slow growth rates, and a high percentage of small-sized adult crabs (Wang *et al.* 2014).

Since 2000, in order to improve the culture performance of *E. sinensis*, several selective breeding programs on Yangtze and Liaohe populations were initiated. As a result, three genetically improved strains/breeds with better growth performance, and larger adult size have been obtained, and certified by the Chinese Appraisal Committee of Aquatic Protospecies and Improved Varieties in 2011 and 2013, respectively (National Fisheries Technology Extension Station 2011). Currently, the Key Laboratory of Freshwater Aquatic Genetic Resources, Ministry of Agriculture, Shanghai Ocean University, is conducting a selective breeding program for the extension of the period of marketing (controlling the time of gonadal development), as well as the improvement of nutritional quality (He *et al.* 2015), and these improved breeds have reached the third generation.

3.2.3.2 Spawning and Berried Crab Culture

After maturation, through nutritional enrichment of the broodstock, male and female crabs are put together at a sex ratio of female:male = 2–3:1, and brackish water is introduced to initiate mating (Sui *et al.* 2011a). The optimal salinity and temperature range for inducing copulation is 14–20 ppt and 8–12 °C, respectively, and a firm sand or mud substrate should be provided to facilitate the attachment of newly extruded eggs to the abdomen of the female (Zhang and Li 2002). Soon after the brackish water has been introduced, the crabs will pair, mate and spawn. Berried crabs can be found on the next day, and in one week, 70–80 percent females will carry eggs. After about two weeks, nearly all females will spawn. This spawning induction process helps generate synchronized spawning, and enables hatcheries to select the most suitable time for larval culture. Fecundity of Chinese mitten crab is relatively high, with a range of 3500–5000 eggs per g, and females weighing between 100 g and 200 g can produce between 400 000 to 900 000 eggs (Wu *et al.* 2006). After spawning, the female crabs carry their eggs on the abdomen for incubation; the incubation duration lasts two to four months depending on the water temperature, and during this period the water temperature can be manipulated to either speed up or slow down embryonic development (Sui *et al.* 2011a). When the water temperature exceeds 12°C, the berried female would feed every two to three days (Wang *et al.* 2014). The common diets for berried females are similar to those for broodstock.

Female *E. sinensis* are capable of spawning up to three times from a single mating. Second maturation of the ovary in captive crabs occurs about a month after the first spawn, depending on water temperature and feeds, and is much shorter than for the first maturation, which lasts three to four months (Yu *et al.* 2007; Liu *et al.* 2011). However, a substantial reduction of broodstock survival, egg production and larval quality is generally observed with subsequent spawns (Ji *et al.* 2006; Nan *et al.* 2006). Few hatcheries make use of re-matured broodstock due to the fact that egg supply is not a limiting factor in mitten crab larviculture.

3.2.3.3 Larval Rearing Techniques

During the past four decades intensive research on larval culture of *E. sinensis* has been conducted (Cheng *et al.* 2008; Sui *et al.* 2011a). As a result, two commercial-scale larval culture models have been developed. General information and recent progress on these hatchery techniques are described in the following sections.

3.2.3.3.1 Intensive Indoor Larval Rearing

In indoor intensive larval-rearing systems (Table 3.2.1), the fertilized eggs can develop into zoeal larvae within 20 days at temperatures of 15–21 °C and salinity of 18–23‰ (Zhang and Li 2002). A higher incubation temperature leads to a shorter incubation period, but resultant larvae are smaller (Zhao *et al.* 1993). Time of hatching can be predicted by monitoring development of the embryo under a dissecting microscope. The grey color and transparency of the eggs, as well as a heart beat of more than 150 min^{-1}, are all indicators of imminent hatching (Zhao *et al.* 1993). Before being transferred into a hatching tank, the berried crabs are usually disinfected in a 100–200 g l^{-1} formalin bath for 1–2 h, in order to remove attached parasites and fungi. The berried crabs are normally placed in cages suspended inside the hatching tank, to which the initial diet for the larvae (usually microalgae and rotifers) has been added or bloomed in advance (Zhang and Li 2002).

Table 3.2.1 General protocol for indoor intensive larval rearing of *E. sinensis* in commercial hatcheries.

Larval stage	Zoea I	Zoea II	Zoea III	Zoea IV	Zoea V	Megalopa
Water temp. (°C)	20–21	21–22	22–23	22-23	23–24	23–room temperature
Larval duration (days)	3–4	2–3	2–3	3	4	5–7
Water exchange	No water exchange	10–20%	20–30%	30–40%	4–50%	100–200%
Aeration	small	small	small	middle	high	very high
Salinity (‰)	18–22	18–22	18–22	18–22	18–22	22 decreased to 4
Feeding regime	Rotifers 20–40 mL^{-1}	Rotifers 20–40 mL^{-1} *Artemia* nauplii 0.5–1 ind. mL^{-1}	*Artemia* 2 –3 ind. mL^{-1}	*Artemia*, frozen *Artemia or* copepods	*Artemia*, frozen *Artemia or* copepods	Frozen *Artemia*, copepods and minced fish
Microalgae 10^{4} mL^{-1}	30–40	20–30	10–20	5–10	5–10	5–8

In order to maintain a better water quality, berried crabs are not fed in the hatching tanks. When larval density in the tank reaches a preset level (0.2–0.4 million larvae per m^3), the cages are removed from the hatching tank and transferred to another hatching tank, where the females will continue to release larvae (Sui *et al.* 2011a).

The eggs hatch as zoeal larvae at an optimal temperature of 18–21°C. Larval development includes five zoeal stages, and one megalopa stage. In order to shorten the production cycle, and consequently reduce production costs, in practice the temperature is gradually increased from 20°C at zoea 1 (Z1) to 24–25°C at Z5, and then decreased gently to the natural temperature range at megalopa stage (Zhang and Li 2002). In commercial hatcheries, larval development takes two to four days for each of the zoeal stages, and five to eight days for the megalopa stage, depending on the rearing temperature, food conditions and water salinity.

Although the initial breakthrough in the mitten crab larviculture was achieved in artificial seawater (Zhao 1980), intensive larval rearing is currently mostly performed using natural seawater, or ground-sourced brackish water (Zhu *et al.* 1997; Liu and Gao 2004). The optimal water salinity for larval rearing is 20–25‰ (Anger 1991). Several water-exchange regimes are employed in intensive larval-rearing systems. Water is not exchanged in the first three to four days of culture (Z1), thereafter, daily water renewal is slowly increased from 10–20 per cent (Z2–Z3) to 40–50 percent (Z4–Z5), and 100–200 percent at megalopal stage, as biomass and feeding levels are increased. In order to reduce the requirement of rotifers and algae, and to improve water quality in larval rearing tanks, green water with a certain density of macro-algae (such as *Chlorella* spp. and diatoms) is generally used in the larval rearing (Table 3.2.1) tanks during the early larval culture period (Z1–Z3) (Zhang and Li 2002). Recently, probiotics have been used in larval rearing, coupled with other water treatments, and zero water exchange can be achieved during the whole larval-rearing process (Wang *et al.* 2014).

Temperature and aeration are closely controlled in the rearing tanks. Live rotifers, brine shrimp (*Artemia* nauplii), and egg yolk are the major food for early stage larvae (Z1–Z3), while frozen *Artemia*, cladocera and copepods are the main food for later stage larvae (Z4–megalopae). In order to maintain food density and reduce cannibalism after Z5 stage, larvae should be fed four to six times per day, if frozen food and egg yolk are used as the major food (Wang *et al.* 2014). In practice, Z1 and Z2 are usually fed rotifers, while *Artemia* nauplii are usually introduced from Z3 onwards. On-grown and adult *Artemia* provide a large-sized prey item, and are fed to Z5 and megalopa (Sui *et al.* 2008; 2009a). Yields up to 0.15-0.5 kg megalopa m^{-3} at stocking densities of 0.2–0.5 million Z1 m^{-3} can be obtained with a survival rate of about 10–15 percent from Z1 to megalopa. In nature, megalopa would move further upstream to rivers and lakes, where they grow into adults

(Lai 1994). Therefore, water salinity is thus commonly diluted ("desalting") at the end of the Z5 stage, or at the beginning of the megalopa stage in the hatchery, and daily salinity reduction normally should be controlled to less than 5 ppt. For six- to-seven-day old megalopae, the water salinity should be reduced to less than 5 ppt in larval tanks (Zhang and Li 2002).

After desalination, megalopae are usually sold as coin-sized crab to grow-out farms, or are reared on in the hatchery until the juvenile stage. Megalopa can tolerate long distance transportation when placed on a surface of moist water grass or wet towels in air (survival up to 90 percent during 24 hr transportation). The optimum transportation temperature is 14–18°C (Cheng *et al.* 2008). The process of indoor larviculture can be completed two to three times in a year (Table 3.2.1), starting from January. However, the cost for indoor intensive larval rearing is high, and megalopal quality is generally not very good compared to wild or outdoor larviculture (Wu *et al.* 2006).

3.2.3.3.2 Outdoor Extensive Larval Rearing

Outdoor extensive larval rearing systems are usually managed at low stocking densities in outdoor earthen ponds where fluctuations of water temperature and salinity are similar to those occurring in the wild. The quality of the larvae in these conditions is considered to be similar to wild larvae, with better resistance to disease and extreme culture conditions, and they command a higher market price. Consequently, this approach emerged as a new trend since 2000, and became the major larval rearing method for the provision of megalopal seed since 2006 in China (Xu and He 2006). Currently, more than 90 percent of megalopae is produced in outdoor earthen ponds, which are mainly located in the coastal area of Jiangsu Province and Liaoning Provinces, particularly in Rudong, Sheyang and Panjian counties (Chinese Fisheries Yearbook 2015). There are a couple of reasons for the rapid spreading of this larval rearing model. First, the technique is simple, and easily accepted by farmers; outdoor extensive rearing models require fewer facilities than intensive hatchery models, which often require heating and aeration systems, larval rearing tanks, and a building; second, antibiotics typically are not used in this model, and the quality of the megalopae is better, and is more favored by farmers who use these for the culture of "coin-sized seed crab" (described as follows) (Wu *et al.* 2006; Cheng *et al.* 2008).

The outdoor larviculture technique generally uses ponds of 0.5–1.5 ha, and with aeration. The water depth ranges from 1 to 2 m depending on the larval stage. Larval ponds should be near estuarine areas and must be capable of taking in both seawater (20–25 ppt) and freshwater. A 1.5-m-deep channel is dug around the perimeter of each pond to minimize water temperature fluctuations during the rearing season – from April to late May in the Yangtze River area. The hatching and rearing of outdoor larviculture occur during late March to mid May in the Yangtze delta, when ambient water temperature ranges from 14–25°C (Wu *et al.* 2006). To prepare larval rearing, ponds are typically disinfected by using 750–1000 kg bleaching powder (Cl >30 percent)/ha, 15–20 days before the start of larvae hatching. About seven days before releasing the larvae, the ponds are supplied with 40–50-cm-deep filtrated sea water, and may be fertilized in order to stimulate algal growth to provide live food for the larvae (Wang *et al.* 2014).

The stocking density of Z1 is typically 20 000–40 000 larvae per m^{-2} (10–20 million larvae per 667 m^2 pond), but the megalopa yield is not stable and varies from 20–100 g m^{-2} (Wang *et al.* 2014). The larvae in all stages are mainly fed with live rotifers – *Brachionus plicatilis,* while Z5 and megalopal stages may be supplemented with frozen copepod or adult *Artemia.* Z1–Z3 stages are fed 35–40 kg wet weight rotifers per ha per day to maintain a density of 2000–3000 ind. l^{-1} in the earthen rearing ponds; Z4 stage larvae are fed 70–80 kg wet weight rotifers per ha per day; Z5 and megalopal stage larvae are fed 120–130 kg wet weight rotifers per ha per day, as well as some frozen copepod or adult *Artemia*, depending on the larval density and food availability in ponds. The rotifers fed to larvae are also reared in earth ponds located near the larviculture earthen ponds, with a 1:1–3 ratio of pond areas for rotifer culture to crab larval rearing (Wu *et al.* 2007b). In addition, there are some farmers who specialize in rearing rotifers in earthen ponds to supply the needs of mitten crab larviculture. Rotifers are reared largely on fermented organic fertilizer. The nutritional value of rotifers fed with organic fertilizer is almost identical to those fed with algae, based on HUFA composition and levels (Wu *et al.* 2007b). Rotifer culture needs inoculate a certain density of seed rotifer, and organic fertilizers are used for algae and microorganism blooms, or as food for rotifer. Rotifers are harvested seven to ten days after inoculation, and can continue up to a period of 20–25 days. Average production is 1000–3000 kg of rotifers per ha per crop. The price of live rotifers is about 05–15 US$ per kg wet weight (Wu *et al*. 2015; unpublished data).

To acclimate megalopae for transition to freshwater salinity reduction ("desalting") is typically begun after three days post-molting to megalopa, and water salinity is reduced to less than 5 ppt in larval ponds for six-to-seven-day old megalopae. Pond-reared megalopae are harvested using drag nets (Figure 3.2.4).

3.2.4 Juvenile Culture (The First Year Culture of Crablets)

After desalination at the end of the zoeal stage, or the beginning of the megalopa stage in the hatchery, the megalopae are usually sold to a "coin-sized crab culture farm", or are further reared in the hatchery until juveniles (Sui *et al*. 2011a).

3.2.4.1 Pond Design and Facilities

In the Yangtze River basin area, ponds are commonly used for the breeding of juvenile crabs. These ponds consist of a primary pool (also known as seed crab breeding pool) and secondary pools (also called coin-sized crab pool). The primary pool area occupies one-tenth to one-eighth of the whole pool, is 1m–1.5 m deep, with a water depth of 0.4m–0.8 m and a slope of 2:1. Secondary pools are built around a circular groove of 3 m width, 1.5 m depth, 0.8 m–1.2 m water depth; there is generally a field in the middle of the pond occupying one-fifth to a quarter of the pool, and often rice is grown in this central platform (Figure 3.2.5). Walls 0.5 m to 0.6 m high, made of aluminum and or plastic, are set around the pools to prevent escape.

Figure 3.2.4 The harvesting of pond-reared megalopae of *E. sinensis* using a drag net.

Figure 3.2.5 Typical juvenile crab pond in China (Jintan crab farm, Jiangsu Province, China, 2015). Note the macrophyte beds in the ponds. (*See color plate section for the color representation of this figure*.)

3.2.4.2 Rearing Environment of Juvenile Crabs

3.2.4.2.1 Problems in the Early Years

Overuse of fertilizer and drugs during pond preparation, the use of traditional feed (raw feed ingredients like low-valued fish, rice bran, maize etc.) in the early years of crab farming contributed to a deterioration of water quality, which restricted further development of juvenile crab production. For example, in the past, copper sulfate was often used to clear pond algae, mercurous nitrate was used to deal with parasitic diseases; all practices that were detrimental to aquaculture in the long term and impeded mitten crab culture development.

So far, the cultivation of juvenile crab is still mainly based on earthen pond culture. Because of the low water level the dissolved oxygen (DO) in ponds vary markedly diurnally, and therefore aeration has to be provided to prevent hypoxia (Dai *et al.* 2013). The uneven distribution of aquatic plants in ponds sometimes caused regional hypoxia conditions. Studies show that the oxygen-carrying capacity of juvenile crab can be affected by ambient nitrite through oxyhemocyanin reduction, and an increase of energy catabolism in crabs (Hong *et al.* 2008). Nitrite can be detoxified through the pathway of nitrate, urea and glutamine formation in crabs. Under hypoxic conditions, crabs increase metabolic energy demand as indicated by elevated levels of glucose and lactate in hemolymph (Hong *et al.* 2008). Further research indicates that parameters such as the total hemocyte counts (THC), superoxide dismutase (SOD) activity, concentrations of lactic acid and hemocyanin (Hc) in hemolymph were significantly affected under hypoxic conditions (Qiu *et al.* 2011).

3.2.4.2.2 Technologies for Improving Pond Environment

Before introducing megalopae, several steps are needed to prepare ponds to ensure a conducive culture environment.

a) Pond cleaning

After years of practice, a protocol for the clean-up process for rearing ponds has been developed which includes draining the pond water, digging up silt, and flattening the bottom of the pond, fixing the bank, inlet and drainage systems, cleaning the pond with bleaching powder or quick lime. All of these steps are to ensure a suitable growth environment for juveniles—better water quality, fewer pathogenic bacteria and fewer harmful organisms are provided.

b) Planting aquatic plants

Aquatic plants are an important food source and habitat, providing shelter for crabs, and have a positive effect on water purification, stabilizing water quality and improving substrate. For juvenile crab rearing, Alligator weed (*Alternanthera philoxeroides*) is easy to cultivate and widely used. It provides food and shelter, it also has its regulating effect on removing nitrogen, phosphorus and reducing COD (Huang *et al*. 2007).

In the 1990s, in the early years of commercial mitten crab farming, *A. philoxeroides* was the only species planted in juvenile crab ponds. Currently, the number of species used has increased, and the management of aquatic plants has also improved. The coverage of aquatic plants is increased with the growth of crabs. Before the juvenile crabs go through the fifth molting, *A. philoxeroides* should be distributed along the pool as well, with a preferred coverage of a fifth to a third (Figure 3.2.6). For deep ponds, except *A. philoxeroides*, waterweed and *Hydrilla verticillata* should be cultivated before the harvest.

Compared to past patterns, the most important change in planting aquatic plants in juvenile crab ponds is the management of the distribution of aquatic plants —from a partial distribution pattern to even distribution across the pond. Experimental results indicate that regardless of stocking densities, early juvenile crabs with a mean carapace width (CW) of 70 mm had little effect on plant biomass. However, significant influence on plant biomass began to emerge along with the growth of the crabs (Jin *et al.* 2001). A well-managed pond provides more stable water temperature, dissolved oxygen (DO), pH leading to yields (Dai *et al*. 2013; Meng *et al*. 2013; Ren *et al*. 2014).

c) Green water techniques

Before introducing megalopae, green water techniques are usually used to provide a culture medium, which employ fertilization and a supplementary feeding strategy. Mitten crab larvae feed primarily on phytoplankton, rotifers, copepods and *Artemia*. Rotifers and *Artemia* are still the most widely used live foods in *E. sinensis* larviculture, while adult *Artemia* provide a large-sized prey item, and are fed to Z5 and megalopae (Sui *et al.* 2008; 2009a). In pond-culture practice of juvenile *E. sinensis*, green water could provide partial zooplankton for megalopae and early juveniles (the first–third crab stages).

d) Application of micropore button aeration systems

In order to solve hypoxic problems, the micropore button aeration system was developed and used from 2007 (Figure 3.2.7). Years of production practice has showed that the application of this new technology provide clear improvement to production (Lin *et al*. 2010; Dai *et al*. 2012; 2013). Related studies have indicated that this new technology can increase the average size, yield, gross profit margin by 11.37–36.26 percent, 7.07–36.26 percent, and 50.29–71.67 percent, respectively compared to the conventional technology. The DO, NH_3-N, NO_2-N, TN, TP, COD index of water in crab ponds (with micropore button aeration systems) were also superior than those of pond without micropore button aeration systems (Liu *et al.* 2009; Lv 2011; Qiu *et al.* 2011; Xu *et al.* 2012).

Figure 3.2.6 The aquatic plant *Alternanthera philoxeroides* in a typical juvenile crab pond of *E. sinensis* (Jintan crab farm, Jiangsu Province, China, 2015).

Figure 3.2.7 The bottom aeration system using micropore used in juvenile rearing ponds of *E. sinensis* (Jintan crab farm, Jiangsu Province, China, 2015). (*See color plate section for the color representation of this figure*.)

e) Salinity

The ability of *E. sinensis* to adapt to salinity variations occurring during its lifecycle is strong. In the wild, larval development takes place in estuarine and marine coastal waters, and, after metamorphosis, juveniles have to acclimate to decreasing salinity in the migration to inland waters. Though it is a strongly euryhaline brachyuran, changes of environmental salinity conditions can lead to changes of many aspects of its physiology: (1) energy metabolism, such as rate of oxygen consumption, CO_2 production rate, ammoniacal nitrogen excretion rate, O/N ratio, respiratory quotient and C/N ratio etc; (2) Ion transport and regulation, including ion transport enzymes such as Na^+-K^+-ATPase, V-type H^+-ATPase, carbonic anhydrase and HCO_3-ATPase; (3) hemolymph composition etc. (Weng 1996; Wang *et al.* 2011c; Zhao *et al.* 2016). Previous studies have shown salinity of juvenile ponds should be less than 2 ppt (Gu and Jiang 2002).

3.2.4.2.3 Nutrition and Feeds for Rearing of Juvenile *E. sinensis*

a) Traditional feeds for juvenile crab

In addition to live feeds, conventional feed for the crab breeding stage includes egg yolk, soybean milk, fish paste, etc. The variety of these diets generally results in an uneven food intake, and nutritional imbalances, which do not favor the synchronous metamorphosis and development of megalopae to juvenile crabs. In addition, these kinds of feed tend to deteriorate water quality, and are not conducive to disease prevention. Therefore, during juvenile breeding, feeding pellet feeds is good for the maintenance of a better culture environment. As the density of crabs is relatively high, it is necessary and important to feed pellet diets for juvenile *E. sinensis* (He *et al.* 2016).

***b)* Nutritional requirements of juvenile crab and improvement of artificial feeds**

Since Chinese mitten crab became a species of economic importance in the 1990s, lack of knowledge on its nutrient requirements hindered the development of its culture (Mu *et al.* 1998). Follow-up studies focused on the effect of protein and lipid levels on growth performance of juvenile Chinese mitten crab (Chen *et al.* 1994; Mu *et al.* 1998; Zhu *et al.* 2000; Chen *et al.* 2008 ; Lin *et al.* 2010; Chang *et al.* 2011; Deng *et al.* 2011). The results of the above studies confirmed that the requirements of lipid, phospholipids and highly unsaturated fatty acids are relatively higher for seed crab (stage 1 to stage 5). It is suggested that for juvenile diets, crude protein content and total lipids should be more than 35 percent and 8 percent, respectively; while fish meal and fish oil content should exceed 8 percent and 2 percent, respectively (He *et al.* 2016).

Beside the crabs' main nutritional requirements of protein, lipid and carbohydrate, the requirement for amino acids, vitamins, fatty acids and other micro / trace nutrients has attracted more attention in recent years. Experiments have been conducted to determine the threonine (Wang *et al.* 2015), lysine, methionine and arginine (Ye *et al.* 2011) requirements of juvenile Chinese mitten crab, which were proved to play important roles in protein metabolism and synthesis. Selenium, copper and zinc are important trace elements for a number of biochemical functions, and deficiencies may result in growth impairment, anorexia and depression of immune responses (Sun *et al.* 2011; Tian *et al.* 2014). The optimal requirements of mineral mix (Zhang and Wang 1998), Vitamins A (Sun *et al.* 2009), B6 (Wang *et al.* 2009), C (Chen *et al.* 2005) and E (Ai *et al.* 2002) are now known, and have provided the theoretical basis for further improvement of artificial feeds for mitten crab culture.

3.2.4.3 Integrated Rice-crab Farming of Juvenile Crab

The strategy of ecosystem-based integrated management of land, water and living resources is considered to be a sustainable approach to balance the social, economic and environmental benefits in aquaculture practices (Ahmed *et al.* 2013). In China, following the success of rice-fish integrated culture in rice fields (Lu and Li 2006), the rice-crab (crab seed) co-culture system has been promoted by government and non-government agencies, and has achieved remarkable success (Li *et al.* 2007). This culture model has been largely extended into the north of China, particularly in Liaoning Province and Jilin Province (also see Chapter 2.6).

3.2.4.3.1 Soil Humus, Pysical and Chemical Properties

Results have shown that the rice-crab production mode can be improved in output and quality by increasing the soil extractable humus carbon (HEC), humic acid carbon (HAC), and the ratio of HAC/HEC, whereas it decreased with increase in folic acid carbon (FAC), and ratio of FAC/HEC. Compared with conventional rice monoculture (Wang *et al.* 2013) co-culture of rice with mitten crab is shown to improve soil fertility and texture, and provides many other benefits. The integrated rice-crab mode can improve the content of total nitrogen, total phosphorus, NH_4+-N, available P, and easily oxidized organic carbon of paddy soil, increasing the content of larger aggregates (0.2 mm), and reducing smaller aggregates (0.002 mm), helping to improve the soil texture (Wang *et al.* 2011a; 2011b; 2013).

3.2.4.3.2 Zoobenthos Diversity in Paddy Fields

It has been demonstrated that the impact of crabs on zoobenthos in paddy fields becomes increasingly significant with the growth of the crabs. The species number, average density, diversity index and Pielou's evenness index of zoobenthos in paddy fields showed a significant difference between rice-crab system and rice monoculture systems. The species number and average density were inversely related to crab density. To maintain the zoobenthos diversity in rice-crab culture systems, the crab density of 10 ind./m^{-2} is recommended (Li *et al.* 2013).

3.2.4.3.3 Weed Control

A reduction in weeds can help reduce competition for nutrients and light, reduce the reliance on herbicides, and thereby increase the rice yield (Xu *et al.* 2014). The effect of weed control was studied by assessing the dynamics of weed growth in rice-crab systems: in rice-crab fields, the weed cover decreased by 2643–4433 percent in quantity, and 1772–4284 percent in wet weight; while in paddy fields where mitten crab was not provided with supplementary feed weed cover in quantity and weight, decreased by over 50 percent (Lv *et al.* 2011).

3.2.4.3.4 Water Parameters in Rice Field

During hot summer months, temperatures could be higher in the absence of rice plants, which can cause stress to crabs, and increase the ratio of precocity. Therefore, a trench/canal around the paddy field was suggested which could protect crabs from being subjected to high temperatures (Wang *et al.* 2011b). Rice plants provide shelter for crabs, and keep the water temperature close to optimum levels. The changes in water-quality parameters in rice-crab culture systems indicated that environment was suitable for the growth of *E. sinensis* (Wang *et al.* 2011a; 2011b).

3.2.4.3.5 Cost-benefit of Rice-crab Production Systems

Since the rice-crab culture system is an efficient and environmentally friendly practice, the Chinese government has been encouraging the development of this form of culture system. In 2013, an investigation was conducted to analyze and compare the current status of this system, including production inputs, economic benefits, and fertilizer and pesticide utilization in different rice-based culture systems in China. The results indicated that rice-crab systems had better economic and ecological benefits compared to rice monoculture systems. The study suggested that further development of key technologies, increasing governmental support, and improvement of production scales will be important factors in overcoming future problems, and improving cost-benefits (Li *et al.* 2014).

3.2.5 Grow-out Culture (The Second Year Culture of Market-sized Adults)

The grow-out of adult Chinese mitten crab (second-year culture) occurs in three major forms, i.e. pond culture, lake stocking or net enclosures, and rice field co-culture, with pond culture being the major form, contributing more than 80 percent to total production (Wang *et al.* 2014). The detailed practices of these three culture forms have changed with time and location, depending on economic efficiency, technological advances, culture habits and prevailing environmental protection policies (e.g. restriction of lake aquaculture in China). From the early 1970s to the middle 1990s, wild-caught or hatchery-produced megalopae were stocked into open lakes or net enclosures (Zhang and Li 2002). Because of the low recapture rate, an unstable supply of wild-megalopae, as well as the unreliable supply of pond-reared coin-sized crab seed, farmers changed from releasing megalopae into open waters to releasing coin-sized crab seed into net enclosures in lakes (Li *et al.* 2000). However, for several reasons, lake stocking or net enclosure culture have a high risk. First, the production per hectare and recapture rate of adult crabs are not stable; second, the water depth of lakes is generally not stable over the year, and stocked crabs can escape into rivers during floods, leading to lower recapture rates (Cheng *et al.* 2008); third, inappropriate culture practice in lakes can result in deterioration of water quality and a decline in biodiversity. Consequently, a series of policies and measures have been formulated and executed to restrict lake aquaculture since 2000 (Xu *et al.* 2003; Wang *et al.* 2014). Since the beginning of the 1990s, pond-culture technology of Chinese mitten crab has gradually been developed and improved to commercial scales in many regions of China, and the sector includes many pond-culture modes (Zhang and Li 2002; Wang *et al.* 2014).

3.2.5.1 Earthen Pond culture

Earthen ponds are used for grow-out, the size of the ponds being generally between 0.6 ha and 2 ha, with a water depth of 1.0–1.8 m. Fences similar to those of nursery ponds are erected to prevent escape and predator access. Sometimes prior to stocking, the ponds are disinfected with lime (2000–3000 kg/ha) and 10–20 days after disinfection, aquatic plants, such as *Vallisneria spiralis*, *Hydrilla verticillata*, *Ceratophyllum demersum*, *Potamogeton maackianus* and *Myriophyllum spicatum*, may be introduced. Aquatic plants are very important for the growth and molting of *E. sinensis.* In addition, live freshwater snails, *Bellamya purificata*, a favorite food for mitten crabs, may be stocked one to three times in the ponds at a rate of 1000–7000 kg/ha during the culture process. Finally, fertilization using fermented organic fertilizers is often applied 10–20 days prior to stocking, to increase the natural biomass in ponds. The stocking density of coin-sized crabs is normally around 7500– 8000 crabs/ha depending on pond condition and culture management, while stocking time is often in the period of late winter to early spring, depending on the farm and location. In grow-out culture of *E. sinensis*, the crabs are often polycultured with various freshwater fish and shrimp, which may be stocked at different times of the year. An important consideration for the selection of fish species is that their feeding habits should complement rather than compete with that of the Chinese mitten crab (Luo *et al.* 2012). Over the culture period, water quality needs to be closely monitored; pH 7.0–9.0, DO >3 mg/l, ammonia <04 mg/l, and nitrite <015 mg/l, are within suitable ranges for *E. sinensis* (Wang *et al.* 2014). The major diets for grow-out are formulated feeds, low-valued fish, maize and soybean seeds and there are increasing trends for the application of formulated feeds in pond culture of *E. sinensis* (Pan *et al.* 2016). The nutrient composition and general parameter of different formulated diets are shown in Table 3.2.2. If only formulated diets are fed during the grow-out, the feed conversion rate generally range from two to three, depending on the diet formulation, stocking density and time of harvest (Pan *et al.* 2016). Feed costs normally account for 30–60 percent of total pond-culture costs during the grow-out stages (He *et al.* 2014). It has been pointed out by Wang *et al.* (2016) that there is a lot of scope for improving feeding practices in mitten crab pond grow-out farming that could potentially lead to significant improvements in net profits, and improved water quality.

During the grow-out phase *E. sinensis* molts three to four times, and undergoes one puberty molting. Males have a significantly higher mean body weight after the third molting, normally during the period of June to July (He *et al.* 2016; Figure 3.2.8). Table 3.2.3 shows the timing and weight growth rate (WGR) of each

Table 3.2.2 Proximate composition of formulated diets used in grow-out culture stages for *E. sinensis* (crude protein, total lipid and ash are expressed as percent dry weight).

Adult crab culture stage	Diameter/mm	Crude protein	Total lipids	Ash	Feeding time	Feeding frequency/time·d $^{-1}$
Adult 1#	2.0	41.3	10.4	9.3	Apr–mid Jun	1
Adult 2#	2.5	38.8	9.5	10.5	Mid Jun–mid Aug	1
Adult 3#	3.5	37.3	12.5	10.3	Late Aug–ate Nov	0.3–1

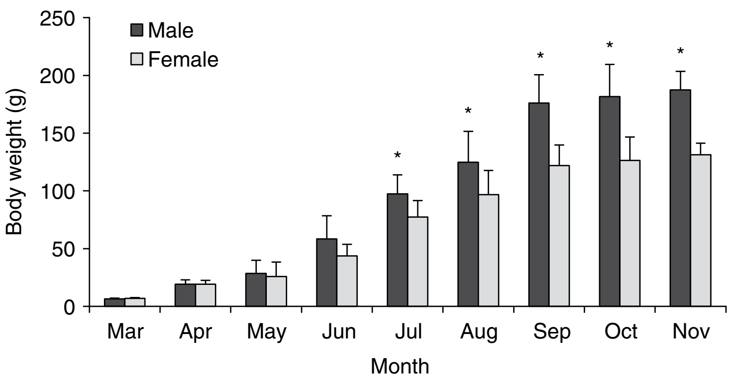

Figure 3.2.8 The changes of monthly body weight (WG) of *E.sinensis* during the adult culture stage. "*" indicates a significant difference between males and females in a particular month ($P < 0.05$).

Table 3.2.3 The molting time and growth in weight (% WGR) at each molting for both males and females during adult culture of *Eriocheir sinensis*.

	Female		Male	
No. of molting	Time	Weight growth rate	Time	Weight growth rate
First	Apr.	60–150%	Apr.	60–120%
Second	May	70–120%	May	70–120%
Third	June	50–100%	June-July	60–120%
Fourth	July	50–80%	July-Aug	70–100%
Fifth (puberty)	Aug.	40–70%	Aug.-Early Sep.	50–80%

molting for males and females. During grow-out, the body weight increases significantly, while the WGR decreases significantly (He *et al.* 2014). After the puberty molting, both male and female gonads develop quickly; males and females reach maturity during the period of the end of October to November in Yangtze populations, but female gonads mature 15–30 days earlier (He *et al.* 2014). Because the gonads are one of major edible parts of adult *E. sinensis*, adult crabs with fully developed gonads (mature or nearly mature) are generally sold at a substantially higher price (Wu *et al.* 2007c). Therefore, fattening immature crabs has become a very important measure to improve the market value of adult crabs (Wu *et al.* 2004). Lipid nutrition during gonadal development has been studied, and several fattening diets have been developed and applied during the past ten years (Wu *et al.* 2007a; Sui *et al.* 2009b; Zhao *et al.* 2016). After the puberty molting, both males and females should be fattened with formulated feeds or low-valued fish for a period of 30–60 days (Shao *et al.* 2013; 2014). Moreover, during the summer season, the density of different aquatic plants (including *E. Canadensis*, *V. spiralis* and *H. verticillata*) should be well distributed to cover 30–50 percent of the pond bottom. If this distribution is not achieved it can lead to low survival, slow growth and deterioration of water quality (Wang *et al.* 2014). In addition, bottom aeration in summer is an important measure to improving the production and survival of pond-culture of *E. sinensis* (Wang 2015).

In general, the survival of pond-reared *E. sinensis* during grow-out ranges from 50–80 percent depending on density and management (He *et al.* 2014). The final body weight of adult males and females are 120–200 g and 90–140 g, respectively, and the normal size distribution of adult crabs at harvesting is shown in Figure 3.2.9. (He *et al.* 2016). The yields per hectare per year are variable, depending on intensity of the polyculture, but they are normally close to 750–1500 kg of market-sized crabs, plus twice that weight of various freshwater fish and shrimp (He *et al.* 2014).

3.2.5.2 Other Culture Practices

Net enclosure grow-out has been practiced in most of Chinese inland lakes in the Yangtze basin, but the total area has declined because of environmental issues (Meng *et al.* 2013). Polythene nets of 1–2 cm mesh size is a common material used. The nets are fixed in place with bamboo stakes. The net walls are folded inwards and held on the bottom with rocks, causing them to sink into the mud. The upper edge of the net is typically 50–60 cm above the water level. Suitable sites should have good water quality and slow water flow, a stable water level, and suitable depth (1–2 m); and, most importantly, abundant submerged aquatic plants and high benthic biomass (Xu *et al.* 2003). Stocking density used in net enclosures range from 1500 to 9000 crabs/ ha. For some enclosures, crabs can rely totally on natural food. For others with lower natural biomass,

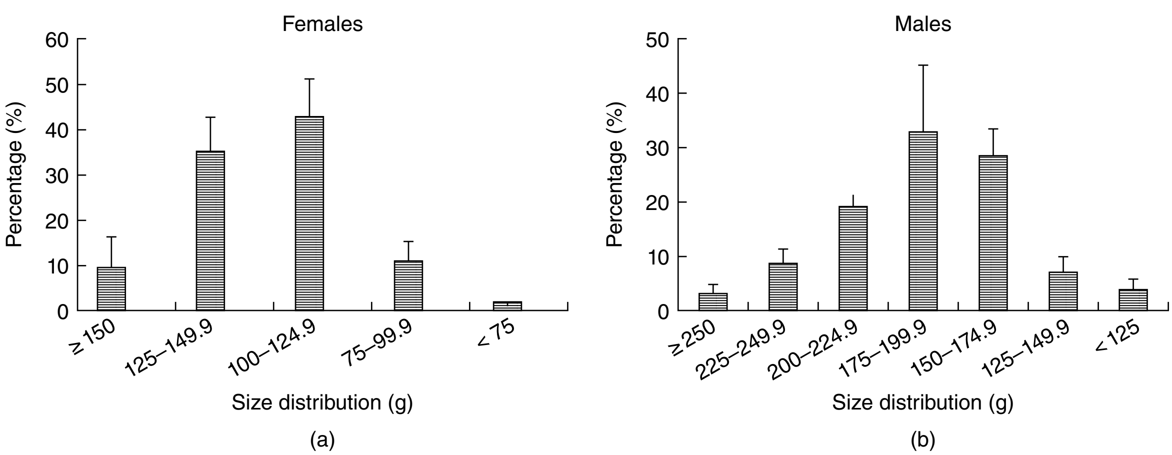

Figure 3.2.9 Size distribution frequency of adult *E. sinensis* at harvest (%). A: Females, B: Males.

freshwater snail *B. purificata* may be stocked at 1000–7500 kg/ha prior to stocking and sometimes again after stocking. Other supplementary feeds include chopped low-valued fish, and cooked corn and soybean (Meng *et al.* 2013). Survival is normally around 40–50 percent. Generally, the yield from net enclosure culture is about 150–450 kg/ha of market-sized crabs although higher yields of close to 1000 kg/ ha are possible.

The rice-crab co-culture system is also popular in northern China for grow-out of adult *E. sinensis* (Figure 3.2.10). The general methodology and field preparation are similar to those for nursery culture described previously. One of the main differences is that the channel needs to be deeper at 1.5 m for grow-out. In addition, a small pond (100–200 m^2 with 15 m depth) needs to be dug for acclimatization, temporary culture of coin-sized crabs and for temporary storage of market-sized crabs during harvesting. Stocking density ranges from one to five coin-sized crabs/m^2. As the natural benthic biomass in the rice fields is relatively low, the crabs need regular feeding with supplemental feeds, such as corn, wheat, low-valued fish, shrimp or mud snails, once or twice daily. These feeds are normally cooked to avoid water quality problems. With proper management, rice field culture can achieve yields of 300–450 kg/ha, and occasionally 750 kg/ha. The integrated culture system produces good-quality rice and crabs, which generally command a higher market price than normal from monoculture (pond-reared crabs or rice field). Therefore, the paddy-field co-culture system has high economic profits. and ecological benefits (Wang *et al.* 2014).

3.2.6 Markets and Marketing

Because the hepatopancreas, gonads and meat are the three major edible parts of adult *E. sinensis*, the adult crabs with fully developed gonads (mature or nearly mature) are generally sold at a substantially higher price (Wu *et al.* 2007c). In the Yangtze river basin the gonads of female and male *E. sinensis* become mature or nearly mature around the end of October and middle–late November, and the marketing time of adult *E. sinensis* peaks during the period of late October to November (Wang *et al.* 2014). The Chinese mitten crab is largely consumed domestically, and recently significant volumes have also been exported to Singapore, Japan, South Korea and Hong Kong (Wang *et al.* 2014). In 2005, the total value of exported

Figure 3.2.10 The paddy-field culture system, integrating rice production and Chinese mitten crab grow-out in northern China.

E. sinensis exceeded US$ 100 million. The Hong Kong market prefers large-sized males because the female gonad contains a relatively high level of cholesterol, while the Japanese and South Korean markets prefer middle- and small-sized crabs, because they are consumed in hot pots, giving the soup an intense flavor. Moreover, a number of different crab products have been developed, including crab meat powder, crab oil from the hepatopancreas, crab paste from the ovaries, etc. These products extend the market time and storage time, which promote the development of this industry.

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3.3

Culture of the Oriental River Prawn *(Macrobrachium nipponense)*

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3.3.1 Introduction

The indigenous oriental river prawn (*Macrobrachium nipponense*) (Figure 3.3.1) is distributed throughout China and is farmed on a large scale. Its natural habitats include rivers, lakes, reservoirs and ditches from the south to the north of the country. Some market supplies of *M. nipponense* come from wild stocks, but it is also a commercially important farmed species in China, with a culture area of about 400 000 ha, an annual farmed production of 265 000 tonnes, and an annual output value of RMB 20 billion (China Fishery Statistical Yearbook 2016; 6 RMB = I US$). *M. nipponense* has a high consumer demand because of its tender meat and delicious taste, and is favored among farmers because it provides high economic gains.

3.3.2 Main Cultivation Regions and Past Trends

Farming of *M. nipponense* began in the mid 1960s in Jiangsu Province. A slow start in the 1970s and 1980s was followed by rapid expansion in the 1990s, to a farming peak in 1999 or 2000. However, adverse selection and inbreeding (Hongtuo *et al*. 2012) are common problems in *M. nipponense* farming; large-sized prawns were sold to the market for high prices, leaving the remaining small prawns for breeding. This process was repeated for multiple generations, resulting in genetic retrogression in China in the late 1990s, including low growth rates, smaller body size, low resistance to diseases, and early maturation (neoteny). Germplasm degradation thus led to reduced or loss of incomes, which dramatically restricted the development of *M. nipponense* farming.

Some research institutes, including the Freshwater Fisheries Research Center (FFRC) of the Chinese Academy of Fishery Sciences, started to conduct genetic improvements of *M. nipponense* populations from 2001, including screening wild populations for better commercial traits for breeding, in order to renew the germplasm for production. Subsequent hybridization and multiple-generation selection led to the development of an improved variety of *M. nipponense* referred to as Taihu Lake No. 1 (Hongtuo *et al*. 2012). This new variety was certificated by the National Certification Committee for Aquatic Varieties of China, and identified as the first new variety of freshwater prawn and crab in China (Ministry of Agriculture 2009). The Taihu Lake No. 1 variety shows good production performance, including a high growth rate, large body size and strong disease resistance.

M. nipponense farming recovered gradually from 2003 through the use of wild *M. nipponense* populations with better commercial traits as broodstock, in place of multi-generation farmed populations. As a result, farmed production increased and stabilized after 2003. The application of Taihu Lake No. 1 from 2009, along

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Figure 3.3.1 *Macrobrachium nipponense* (left: male; right: female).

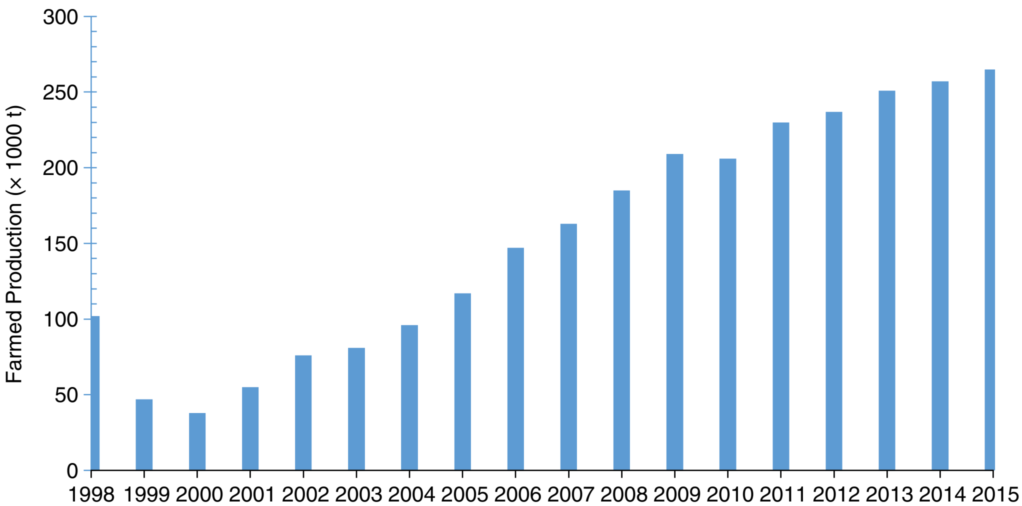

Figure 3.3.2 Trends in annual farmed production of *M. nipponense* in China.

with improved farming techniques, promoted further developments. *M. nipponense* farming lead to a second production peak with an annual farmed production of >200 000 tonnes (Figure 3.3.2) covering a farming area of about 400 000 ha, with monoculture and polyculture practices. According to the China Fishery Statistical Yearbook 2016, aquaculture production of *M. nipponense* reached 265 000 tonnes in China in 2015, with farming being carried out in 18 provinces. East China, including Jiangsu, Zhejiang, Anhui, and Shanghai, are the main farming areas for *M. nipponense*, with Jiangsu Province ranking top in terms of both production and farming area, accounting for almost 50 percent of the total production of this species. The annual farming production in some provinces reached or exceeded 20 000 tonnes (Jiangsu, 120 734 t; Anhui, 50 805 t;

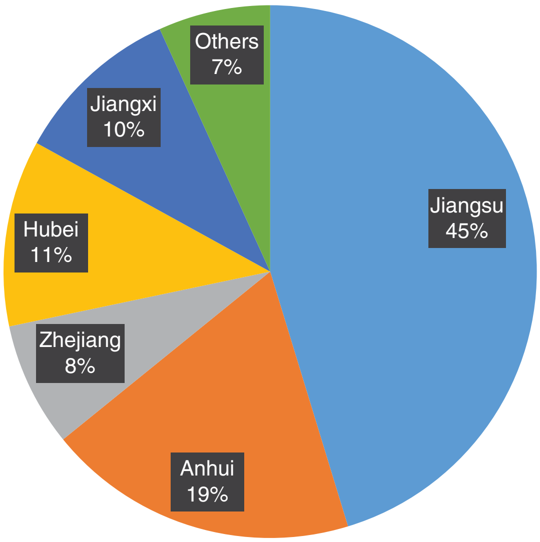

Figure 3.3.3 Annual farmed production of *M. nipponense* in different provinces of China for 2015.

Zhejiang, 20 805 t; Hubei, 30 846 t; Jiangxi, 27 906 t) (Figure 3.3.3). The total annual production value of the *M. nipponense* industry in China in 2013 was near to RMB 20 billion (China Fishery Statistical Yearbook 2016; 6 RMB = 1 US$).

3.3.3 Culture/farming Systems

3.3.3.1 Breeding and Larval Rearing

Breeding and larval rearing of *M. nipponense* have been established for large-scale commercial production (Fu and Gong 2006). The annual production of post-larvae (PL) was approximately 30 billion. The following data relating to breeding and larval technology are based on the Yangtze River basin, which is the largest producer of *M. nipponense* in China.

M. nipponense is able to overwinter successfully, without the need for greenhouses or heating. As a freshwater species, unlike related species such as *M. rosenbergii* (the giant freshwater prawn), it completes its lifecycle in freshwater, and the entire process of breeding and larval rearing is therefore conducted in outdoor freshwater ponds. The capacity of seedling production is around 7.5–18 million/ha, with an average of 12 000 000 million/ha.

Broodstock is obtained from farmed ponds and/or wild populations in lakes and/or rivers. The chosen breeders are cultured in earthen ponds. Their body size doubles, and gonads mature within about one month of culture, from late March to late April.

Mating and spawning occur when the water temperature exceeds 18 °C in late April or early May, with the peak spawning season occurring from mid May to early June. Berried prawns are transferred to incubation ponds during in this period, with a density of around 75–150 kg berried females/ha. The rate of embryonic development depends on the water temperature. Zoea hatch out within 15–25 days of embryonic development, from mid June to early July. The breeders are harvested for marketing after hatching, and the zoea reared in incubation ponds.

Within 15–20 days of rearing and 9–11 molts, the zoea metamorphoses into PL in early to late July. After a further 15–20 days (26 °C–32 °C), the PL grow into juveniles about 1.5–2.5 cm long and weighing about 0.1 g. The juveniles are then trawled and stocked into grow-out ponds.

3.3.3.2 Grow-Out Technology

The technology of *M. nipponense* farming in China has made much progress over the past 20 years, and some feasible models of commercial farming have been established. The following accounts are based on farming in the Yangtze River basin. *M. nipponense* can be farmed successfully in ponds in either monoculture or polycultures, with the latter being more prevalent.

3.3.3.2.1 Monoculture

M. nipponense monoculture in China is generally conducted over two cycles each year, spring–summer and summer–autumn, with total annual yield from both cycles reaching 1500–2250 kg/ha (average 1725 kg/ha).

Spring–summer Cycle This first cycle of farming begins in March and ends in June. The body size of individuals in the summer–autumn cycle is not uniform; larger prawns are therefore caught for marketing and the remaining undersized prawns are collected in March, and stocked into ponds for the spring–summer cycle at a density of 300–450 kg/ha. Marketing begins in early May and ends in mid June. Most of the stocked prawns grow to marketable size, resulting in a yield of 600–900 kg/ha, subject to stocking density.

Summer–autumn Cycle The second cycle begins in July and ends in February of the following year. PL weighing 0.05–0.15 g are stocked at a density of 750 000–1 500 000/ ha from early July to early August. However, before stocking, ponds are disinfected using calcium oxide or bleaching powder in mid June to early July. The best method of pond disinfection involves exposing the pond bottom to sunlight for 15–30 days until it becomes crusty. This is an essential process and is effective in helping to prevent diseases, decompose toxicants, and increase production.

The presence of aquatic grass is vital for high yields during the summer–autumn cycle. Aquatic grass serves many important functions, including providing refuge for molting prawns to reduce cannibalism, improving water quality, decreasing water temperature in summer, and allowing full utilization of all water layers, from shallow to deep, as habitats. Submerged plants are most suitable, and the most extensively used in China include *Hydrilla verticillata*, *Potamogeton crispus* (curled pond weed) and *Elodea nuttallii* (Nuttall's waterweed). The optimal grass-planted area comprises 30–50 percent of the total pond water area.

Autumn reproduction is a phenomenon whereby some juveniles mature within 45 days of rearing ,and produce large numbers of offspring during late August to early October. This represents a serious problem for the summer–autumn cycle. Large numbers of newly-hatched small prawns use up space, oxygen and food, thus increasing the risk of low dissolved-oxygen (DO) levels, greater variation in body size, and low market value. Techniques to restrain autumn reproduction include stocking some silver and bighead carp fingerlings (density 1000–1500/ha; body weight 30–50 g) 10–15 days after stocking with *M. nipponense* PL, and maintaining the clarity (transparency) of the water >30 cm to decrease planktonic biomass.

M. nipponense are marketed at 2.5–7 g. Harvest begins in late October and ends in late February of the following year. The prawns are caught using trapping cages or dragnets. However, most prawns are sold during the Chinese Spring Festival, when the price is at a maximum.

3.3.3.2.2 Polyculture

M. nipponense polycultures include combinations with various other species, such as mitten crabs (*Eriocheir sinensis*), giant river prawn (*M. rosenbergii*), marine penaeid shrimp (*L. vannamei*), or fish (adults or fingerlings).

The most popular polyculture combination involves mixed crab and prawn farming of *E. sinensis* and *M. nipponense*, as practiced in over 300 000 ha in China, accounting for >90 percent of the total polycultured area of *M. nipponense.* Typical stocking densities of this polyculture are 6000–15 000/ha of crab and 300 000–600 000/ha of prawn, with variations in terms of seedling size, pond facilities, water quality and the technical capabilities of individual farms. The annual outputs per unit area are 600–1125 kg/ha of crab and about 750 kg/ha of prawn.

E. sinensis and *M. nipponense* have similar habits, pond requirements, grow-out technologies, and temperature tolerances. *M. nipponense* can eat the food left over by *E. sinensis*, thus improving the overall feed conversion ratio. Profits are greatly increased compared with monocultures of *E. sinensis* without *M. nipponense*.

3.3.4 Advances in Genetics and Culture Technology

The main setbacks in *M. nipponense* farming have included genetic retrogression of breeding stocks, and poor farming techniques. However, under the support of national and provincial research programs, the FFRC and other research institutes have worked together to improve both genetic traits and farming technologies since 2001, and have made a series of advances over the last decade

3.3.4.1 Genetic Improvement

Broodstocks are the basis of aquaculture. Developing high-quality broodstocks help to increase yield, reduce disease, and improve tolerance to unfavorable conditions. Renewal of breeders, and the application of genetically improved varieties are expected to play major roles in resolving the issue of genetic retrogression. The main advances aimed at improving the genetics of farmed *M. nipponense* are noted below.

1) In order to select high-quality wild populations, the FFRC and other research institutes have systematically analyzed the genetic diversity and structures of wild *M nipponense* populations from different origins using Random Amplified Polymorphic DNA (RAPD), Inter-simple sequence repeat (ISSR), microsatellite, COI and 16S rRNA markers. Wild populations were collected from lakes (Taihu, Hongze, Weishan, Poyang, Dongting, Chaohu, Hong and Bosten), rivers (Yangtze, Yellow, Pearl, Huai, Lancang, Qiantang), and other water bodies from different provinces (Jiangsu, Zhejiang, Shanghai, Anhui, Jiangxi, Hubei, Chongqing, Guangxi and Yunnan). Systematic analyses provided basic data on genetic backgrounds for assessing the germplasm in different populations.
   Based on the genetic analyses, some wild populations with high genetic diversity were chosen for pond-farming experiments, after which populations from Taihu Lake and Yangtze River were selected for use as breeders At the same time as these genetic improvements, related techniques including wild-breeder collection, live-prawn transportation, and pond domestication were improved. Patterns of decline in commercial traits in serial multi-generation pond farming were also monitored and assessed. A 'wild breeder utilization technique' was established, which resolved three main problems, including which wild populations to use, how to use them, and how many generations can be farmed before degradation occurs This technique provided a quick and effective way of renewing *M. nipponense* germplasm, and its application played an important role in the recovery of *M. nipponense* farming from 2003 to 2009.
2) *M nipponense* has some special features, including berried eggs, molting and multi-generation breeding in ponds, which have negative effects on hybridization, *in vivo* markers and farming experiments. These mean that breeding techniques established in fish, and other aquaculture species cannot be applied to *M nipponense* However, the FFRC achieved artificial interspecific hybridization and selection among *Macrobrachium* species to create a new variety, Taihu Lake No. 1, by hybridization between *M. nipponense* and *M. hainanense*, followed by hybrid selection This new variety inherited desirable commercial traits of both species.
   To produce hybrids, males and females must be collected separately from the maternal and paternal populations, respectively, before hybridization. However, problems associated with large-scale parental sorting include small body size, lower fecundity, poor resistance to low oxygen, and difficulty distinguishing sexes. These problems were overcome by the application of two new techniques established by FFRC: the differential harvesting technique allows effective selective capture of female prawns, while a second technique allows embryo removal from berried females with high efficiency and low damage. Use of these methods improved efficiency more than ten-fold, and reduced the wrong-picking rate to <1 percent.

3.3.4.2 Innovative Breeding and Farming Techniques

M. nipponense breeding and farming techniques prior to 2009 were relatively primitive and underdeveloped, and were unable to meet the requirements of large-scale extension of new varieties. However, these techniques have now been improved and extended.

3.3.4.2.1 Large-Scale Post-Larval Breeding

The long duration of the larval phase, cannibalism, and high mortality associated with harvesting during post-larval rearing meant that the output of *M. nipponense* juveniles remained at around 7 500 000 individuals/ha for a long time. Many factors were investigated, including breeding abilities and habits, control of parental quality and numbers, optimal sex ratio, removal of harmful organisms, plankton culturing, feeding patterns, water quality, and catch and transport of juveniles. The introduction of a range of techniques resulted in an increase in the output of *M. nipponense* juveniles to 11 250 000 individuals/ha in large-scale production, and an increase in the output of PL prawns from 40 000 to 100 000 individuals per kilogram of parents.

3.3.4.2.2 Farming Techniques

Characteristics of *M. nipponense*, including asphyxiation point, and pH, temperature and salinity tolerances were analyzed, and key techniques were improved and optimized, including juvenile stocking, feeding, disease prevention and harvesting. Some new techniques were also applied to *M. nipponense* farming, including macrophyte planting in ponds, probiotic application, and underwater microporous aeration. Aquatic-grass planting provided necessary hiding spaces for *M. nipponense*, increased the utilization efficiency of vertical pond space and improved water quality, resulting in dramatically reduced cannibalism, and improved survival rates. The use of probiotics, including photosynthetic bacteria, bacilli and other beneficial microorganisms, was shown to improve water quality. Microporous aeration using underwater pipelines greatly increase dissolved oxygen levels, especially in deep water, allowing ponds to accept a higher stocking density and achieve a higher adult yield, whilst reducing the risk of anoxia.

The optimization and innovation of breeding and farming techniques produced good results in terms of increasing the yield per unit, decreasing disease outbreaks and improving product quality. On the basis of this progress, many integrated farming models were established, of which the most successful have been two-batch per year farming, and mixed prawn and crab farming. These new techniques and models are now widely used in the production *of M. nipponense* in China.

3.3.5 Constraints

Although the technology and production of *M. nipponense* farming in China has progressed well, some problems still hinder its further progress.

1) Undersupply of good-quality seed: most *M. nipponense* seed are produced separately by farmers. The quality of PL was previously irregular and unstable because of chaotic parental origins, adverse selection and inbreeding. The new hybrid Taihu Lake No. 1 has been farmed across 60 000 ha since 2009, and has demonstrated better production and disease resistance, with positive economic and social benefits, compared with selected wild *M. nipponense* populations. However, the production capacity of PL of Taihu Lake No. 1 hybrids is unable to meet the market demand, and is therefore restricting further expansion. The demand for more and better varieties continues with advances in aquaculture, but Taihu Lake No. 1 remains the only available hybrid to date.
2) Restrictions on farming techniques and models: breeding and farming techniques have made considerable progress over the past two decades. However, large-scale production remains unstable, and subject to weather conditions, daily management and other factors. Further optimization is therefore needed to allow its sustainable development.

M nipponense is a popular aquaculture species with high market demand in China. Farmed production thus needs to increase rapidly to satisfy increasing consumer demand. However, the average annual growth rate of *M. nipponense* farming is low, with bottlenecks restricting further expansion of production. These bottlenecks include multiple-generation rearing in ponds, and cannibalism, which restrict the increase per unit yield. Precocious sexual development is also a problem in *M. nipponense* whereby PL mature within 45 days after stocking and begin to reproduce, referred to as autumn reproduction, resulting in multiple generations of prawns coexisting in a pond, thus increasing the overall density and the variability in body size. Cannibalism is another major problem; molting prawns are eaten, resulting in a survival rate of only 20 percent during farming. Another bottleneck involves poor tolerance to hypoxia. Prawns die rapidly out of water or in hypoxic water, leading to high environmental demands and management requirements, thus restricting the expansion rate of *M. nipponense* farming.

3) Irregular feedstuff quality, and need for specific feeds: feed quality plays an essential role in farming. Insufficient basic research on the nutritional requirements of *M. nipponense* mean that no specific feeds are available, and commercially available feeds are based on formulae for other species, such as *M. rosenbergii* or *Litopenaeus vannamei*. Some farmers still feed *M. nipponense* raw food, including wheat, corn and frozen fish. Low food palatability and a poor conversion rate may lead to wasted feed, and poor growth performance.
4) Diseases: *M. nipponense* is an indigenous species and the frequency of disease outbreaks before 2009 was low. However, disease incidences have since increased, primarily as a result of genetic retrogression. This remains a problem in *M. nipponense* farming, despite some alleviation in recent years through the application of new varieties and new farming techniques. However, studies on disease control in *M. nipponense* have been poor, and there is a lack of systematic research into disease prevention, diagnosis and treatment.
5) Poor processing techniques: *M. nipponense* sold in the domestic market is mainly consumed fresh, while exported prawns are usually frozen. Although some simply processed products exist, including "snap frozen prawns", chitin and astaxanthin, only a low percentage of prawns is processed, and processing technologies for *M. nipponense* are seriously lagging behind.

Chitin is the second largest renewable resource after cellulose, and the only natural alkaline polysaccharide identified to date. Astaxanthin has dramatic effects as an antioxidant, and consequently is of high economic value. Although the carapace of *M. nipponense* consists mainly of chitin and is rich in astaxanthin, the carapace-utilization rate in *M. nipponense* is almost zero, resulting in a waste of resources and increased pressure on the environment.

3.3.6 Markets and Marketing

M. nipponense is popular in China, especially in the Yangtze delta. The price of *M. nipponense* has continued to increase over the past decade, despite increased farmed production, and relatively large catches of wild prawns. The current market price of commercial *M. nipponense* is 35 US$/kg. As a delicious food with high nutritional value, the market demand for *M. nipponense* is likely to continue to increase in line with increasing economic development.

3.3.7 Future Prospects and Conclusions

M. nipponense farming has made great progress in recent decades and is expected to have a great future because of the enormous market demand for, and high economic value of the product. However, certain strategies are needed to maintain the healthy and sustainable development of *M. nipponense* farming.

1) Establish a system of genetic improvement and high-quality-seed production. Search for and collect *M. nipponense* germplasm based on technological innovations in wild-resource assessments; optimize genetic breeding techniques suitable for *M. nipponense*; conduct continuous genetic selection of multiple traits in order to obtain better varieties. To resolve the problem of a shortage of high-quality seed, techniques need to be established for the efficient and large-scale breeding of good varieties, while the use of high-quality seed must be promoted to increase farming profits.
2) Establish techniques to increase yield and promote environmentally friendly farming. Optimize farming parameters and pond facilities; equip with intelligent monitoring and control systems; improve farming models, including monoculture and polycultures; update farming techniques and systems.
3) Develop high-quality feeds specific for *M. nipponense*. Evaluate the nutritional requirements of different developmental stages of *M. nipponense*; evaluate the effects of ecotype additives and probiotics; develop a series of high-quality feeds suitable for the different developmental stages; establish technology for large-scale feed production. Such newly developed feeds would reduce farming costs, increase profits, and decrease environmental pollution.
4) Establish early warning systems for the prevention and control of the main diseases affecting *M. nipponense*. Investigate the pathogens, pathology and epidemiology of the main diseases; develop techniques for early detection, rapid diagnosis, as well as prevention and control of such diseases; establish a monitoring system throughout the whole farming process, and provide these services to farmers in a timely manner.
5) Develop new products and processing technologies. Study processing technologies for the edible parts of *M. nipponense*, and develop new products for consumption; study processing technologies for the carapace, and develop new products for industrial production, including chitosan and astaxanthin; promote full utilization of prawns to maximize economic benefits.
6) Establish a public service system to share technologies and information. Establish a public platform to collect and analyze data or information relating to technologies, techniques, production and markets; this open platform will further new technological applications, disease prevention and farm-management plans.
7) Establish multi-level demonstration bases to promote the large-scale application of new technologies and new varieties. Establish multi-level bases, supported by the government, including breeders, seed production, farming and processing, to demonstrate and extend new technologies and supplies of seed; multi-level governmental service stations for fisheries technology could provide technical training and services, and promote the large-scale application of new achievements.

In conclusion, we foresee that a larger scale of commercially successful, environmentally friendly and socio-economically sustainable production of *M. nipponense* farming can be achieved in China in the future (Hongtuo *et al*. 2012).

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3.4

Mud Crab, *Scylla paramamosain* China's Leading Maricultured Crab

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3.4.1 Introduction

3.4.1.1 Taxonomic Status

The mud crab, *Scylla paramamosain* belongs to Portuninae, Portunidae, Reptantia, Decapoda, Malacostraca, Crustacea and Arthropoda. Traditionally, Giant mud crab (*S. serrata*) had been considered to be the dominant species of mud crab cultured in China, but recent taxonomic revisions have suggested that *S. paramamosain* is the dominant (Lin *et al*. 2007, 2008; Ma *et al*. 2012). Most of the past research data on *S. serrata* in fact are for *S. paramamosain*. Both species belong to the genus *Scylla* (Figure 3.4.1), and are commonly referred to as mud crab.

3.4.1.2 Distribution

Mud crabs are euryhaline and distributed worldwide, and are found in tropical, subtropical and temperate waters. They are widely distributed in the border of islands with high organic content and low tidal fluctuations, fissures of harbors, shallow sea inner bays, estuarine and mangrove systems, reclamation areas and mud flats of estuaries (Huang and Zhang 2009). Mud crab occur in most south-eastern coastal provinces of China (Hainan, Guangdong, Fujian, Guangxi, Zhejiang, Jiangsu and Taiwan), and are commonest in Hainan, Guangdong, Fujian and Zhejiang.

3.4.1.3 Lifecycle

Mud crab growth can be roughly divided into five stages (Figure 3.4.2): embryonic stage, zoea, megalopa, juvenile crab and adult crab. On completion of embryonic development, zoea larvae pierce the egg membrane, and start their planktonic life. Zoea feed on zooplankton chiefly, and go through five molts, and transform into megalopa. After a single molt the megalopae transform into juvenile crabs, and assume a completely benthic habitat with adult crab external morphology. After six molts, they finally develop into adults.

3.4.1.4 Habits

Mud crabs are euryhaline and eurythermic, living in estuarine, intertidal zones in inner bays, mud flats and beaches with a high tidal range. *S. paramamosain* also inhabit mangrove swamps and shallow estuarine areas.

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They live in burrows or in seclusion and are territorial. Mud crabs prefer to move at night and have sensitive eyes and tentacles; in the daytime they hide in burrows and fissures. Mud crab burrows are deep in summer and shallow in winter, in accordance with their higher level of activity in summer and less in winter. During low tides in midsummer, groups of mud crab usually straighten their ambulatory legs to leave head and chest off the beach, but they hide in the mud with only their eyes protruding when it is cold. When swimming, only swimming legs are used, and they have three pairs of ambulatory legs for walking. Nevertheless they use both swimming and ambulatory legs when escaping from predators.

Figure 3.4.1 *Scylla paramamosain* (top) and *S. serrata* (bottom).

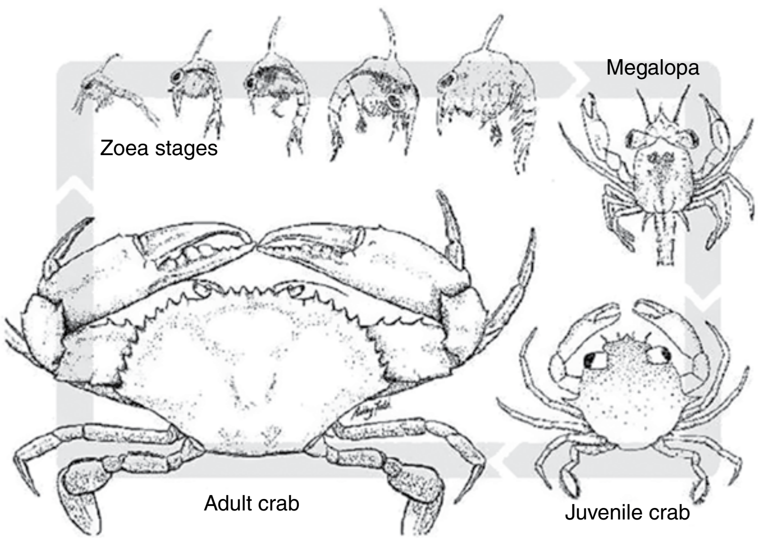

Figure 3.4.2 Lifecycle of *Scylla paramamosain*. *Source:* After Holme *et al*. (2009).

The suitable salinity and temperature for mud crabs are 5–33 ‰ and 14–32 °C, and the optimum values are 12.5–27.0‰ and 18–25 °C, respectively. The lowest limiting temperature is 7 °C. When the water temperature drops to 7 °C, crabs will stop feeding and exercising, hide themselves in silt or sludge, and be dormant. During summer, they will feel discomfort when the water temperature rises to 35 °C and feeding will cease above 37 °C. When water DO content is over 2mg/l, food intake increases, activity levels and growth become normal. When DO content is below 1mg/l, they stop feeding, move slowly, appear hypoxic, and may even die. More oxygen is needed during the period of molting. Mud crabs have a high drought-resistant ability, and can survive out of water for a few days as long as some water is saved in gill cavities and gill filaments are moist.

3.4.1.5 Feeding Habits

Mud crabs are carnivorous crustaceans, and in nature usually feed on small-sized fish, shrimp, crabs, and some shellfish, such as oysters, clams, razor clam, and blood clam. Crabs also eat carcasses and occasionally some types of algae. Mud crabs have different feeding habits during the various development stages. Zoea are omnivorous, megalopa are omnivorous and also feed on dead animal matter where as adult crab tend to feed on dead carcasses. Mud crabs exhibit cannibalism. Crabs have acute sense organs they prefer to hide by day and come out at night, usually foraging in the dark. Once prey is caught, mud crabs use their chelipeds to direct the food, and pass it to the third ambulatory legs, then to the mandibles, mandibles chew, and the food is ingested.

3.4.2 Economic Value and Aquaculture Yield of Mud Crabs

3.4.2.1 Economic Value

Mud crabs are popular with consumers all over the world. Crabs possess many desirable features including large individual size, tender meat with desirable flavor, and are of high nutritional value, because of their high content of protein, unsaturated fatty acids, trace elements such as selenium, organic calcium, as well as vitamins. Crabs have and always been looked on in China as a desired food item for nourishment with purportedly anti-aging functions (Su 2013). During the maturation period, the ovary or called crab cream will be orange-yellow after cooking, and has an intense flavor. Many active materials, such as chitin and chitosan can be extracted from crab shell, which are important raw materials for textile dyeing, food manufacture, and other industries. For instance, calcium oxide from crab shell can be used as a catalyst in industrial production, and can even be reused 11 times (Boey *et al.* 2009).

3.4.2.2 Mud Crab Farming in China and the World

The culture of mud crabs in China began 125 years ago, when it was begun in 1890 at Humen, Guangdong Province. At present, mud crab farming has spread throughout the south-eastern coastal provinces of China, such as Guangdong, Fujian, Zhejiang, Hainan, Guangxi, Jiangsu, Shandong and Chinese Province of Taiwan (Figure 3.4.3). Other countries have also started mud crabs farming since the last decade, and the major countries are Australia, Vietnam, the Philippines and Indonesia (Broadhurst *et al.* 2014). It is reported that in 2005, world mud crab production reached 123 100 tonnes, 21.38 times higher than in 1996 (5500 tonnes). Mud crab production in China reached 108 500 tonnes in 2005, and accounted for 88.14 percent of world production (Pan 2008). According to the *China Fishery Statistical Yearbook,* from 2007 to 2014 the culture production output of mud crab in China increased year by year in the last decade (Figure 3.4.4). Regardless of Taiwan province, in the year of 2013, the mud crab production was 138 000 tonnes, valued at 14 billion RMB (6 RMB = 1 US$). Guangdong was the main centre of mud crab production (44 700 tonnes) accounting for 32 percent of the total, followed by Fujian and Zhejiang with productions of 29 700 and 27 300 tonnes, accounting for 22 percent and 20 percent of the total, respectively.

Figure 3.4.3 Main mud crab farming provinces (highlighted in purple) in China.

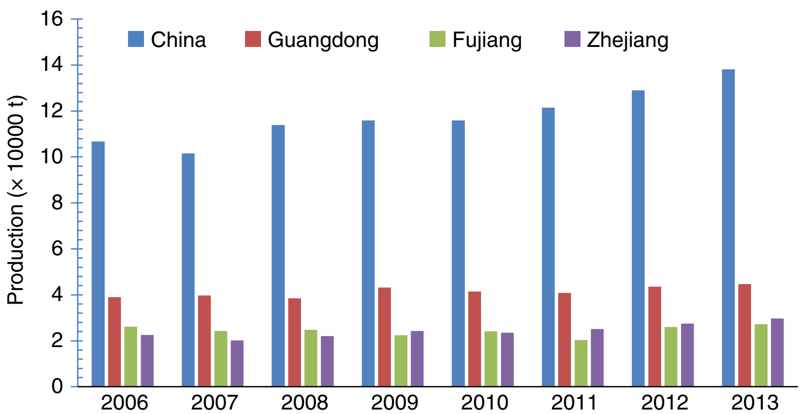

Figure 3.4.4 Mud crab production in the three major provinces of China, from 2006 to 2013. Source: China Fishery Statistical Yearbook (2007–2014).

3.4.3 Culture Practices

Pond culture is the main culture mode for mud crab in China. Other modes include enclosure (pen) culture in mud flats, cage culture, ceramic altar culture and industrial aquaculture. There are two primary sources of mud crab seed, wild caught and hatchery produced seed. Robust body, uniform size, intact appendages, responsiveness to external stimuli, and disease free are the selection criteria of healthy mud crab seed.

3.4.3.1 Pond Culture

There are two main kinds of pond culture modes for mud crab, i.e. monoculture and ecological polyculture, and the latter is dominant. In recent years, the total culture area for mud crab has reached nearly 66 000 ha in China, most in brackish water ponds. For monoculture, 0.2–0.35 ha pond size produces the best results, while 0.67–1.35 ha ponds are preferred for polyculture. When the pond is too large, it can be fenced into several small compartments so as to meet the requirements of separate culture for crabs of different body sizes. Ponds are usually rectangular (the aspect ratio is 5:3–3:2), water depth is 1–1.5 m. Through years of practice it is known that the preferred orientation of ponds is east and west lengthwise and north–south width wise. To prevent mud crabs from escaping, a fence should be built around and inside the pond dam. In the case of monoculture, mud crabs are usually fed with low-valued shellfish, small fish and other fresh bait, and partly with compound feed. Monoculture has the advantages of high stocking density and high survival rate (Xiao 2012). However, monoculture may easily lead to the occurrence of disease and low economic benefits, and has gradually been replaced by polyculture.

Currently, the preferred culture mode is polyculture, when mud crab culture is combined with one or several other species including fish, shrimp, shellfish and algae. Polyculture has the advantages of less disease occurrence.

Species cultured together with mud crabs are usually tiger prawn (*Penaeus monodon*), white shrimp (*Litopenaeus vannamei*), *Palaemon carinicauda* and kuruma prawn *(Marsupenaeus japonicas)*; mullet, milkfish and tilapia; oyster, razor clam and carididae for shellfish; and *Gracilaria tenuistipitata* for algae (Wang *et al.* 2012; You *et al.* 2012; Qi 2015). Algae can increase dissolved oxygen (DO) in water, improve water quality, and offer shelter for crabs, and reduce cannibalism. For example, in two semi-closed culture ponds of 0.067 ha, the same density of *S. paramamosain* crab (67 500/hm^2), shrimp *P. monodon* (82500/hm^2) and fish *Mugil cephalus* (7500/hm^2) were cultured in each pond. In the late cultivation period, 21 kg of fresh seaweed *G. tenuistipitata* was introduced into one of the ponds (Table 3.4.1). Some parameters, including environmental factors, crab yields and survival rate were determined, so as to evaluate the effects of seaweed culture on water quality in the following 40 days. The results showed that, compared with the pond without seaweed, the levels of DO and pH in the pond with seaweed were significantly higher *(P <0.05)*, DO was 9.32mg/l vs 6.96mg/l and pH was 9.24 vs 8.83, respectively. On the fortieth day of the cultivation period, salinity was significantly lower than it had been on the twentieth day (P <0.05), while the level of ammoniacal nitrogen and nitrite-N became lower from the tenth day. These results indicate that the culture of seaweed has an obvious positive effect on pond water quality. In addition, crab yields and survival rate in ponds with seaweed were respectively 14.30 kg and 2.23 percent higher than those in the ponds without seaweed. A similar trend was observed for other cultured animals (Table 3.4.1). The yield of seaweed *G. tenuistipitata* increased from 21 kg to 262 kg after 75 days of culture (Wang *et al.* 2012; You *et al.* 2012).

The stocking density (seed density) of mud crab can be flexible according to local conditions, such as pond depth and water temperature, conditions of water exchange, seedling sources, prey resources, feed resources,

Table 3.4.1 Effects of seaweed on yields and survival rate of cultured animals.

Pond no.	Cultured species	Yield (kg)	Survival rate (%)
1	*S. paramamosain*	78.15	12.17
	P. monodon	52.70	34.49
	M. cephalus	36.25	65.25
2	*S. paramamosain*	63.85	9.94
	P. monodon	45.05	29.48
	M. cephalus	29.30	52.74

Notes: seaweed *G. tenuistipitata* was added into pond 1 but not in pond 2.
Source: Modified from You *et al.* (2012).

Figure 3.4.5 Factory culture system for mud crab; each container (30 x 200 x 180 cm) accommodates 100 crabs on average.

feed types, management level, and so on. In monoculture crabs pond of 0.2–0.35 ha, the seedling density is 1.5–3 individuals per m^2 or 15 000–22 500 individuals per ha if they grow from juveniles (summer seedlings) to adult in the same year; if autumn seedlings are used, the seedling density should be 22 500–30 000 per ha. When the pond area is over 0.7 ha, stocking density should be reduced (12 000–15 000 per ha for summer seedlings). As for crab-shrimp polyculture (mud crab is the main species, shrimps and fishes are the secondary), if pond size is 1.35 ha, crab seedling density usually should be controlled under 9000 per ha. Crabs can reach marketable size with a weight of 200–250 g after for three to five months.

3.4.3.2 Other Culture Modes

With the increasing demand for mud crab, its culture systems and patterns have been continuously improved. Other crab culture systems are enclosure culture, cage culture (basket culture), ceramic altar culture, and industrialized culture systems (Figure 3.4.5), and so on.

Enclosure culture uses a net to demarcate the culture area in intertidal zones or harbors which have large water area. This kind of culture mode, which takes advantage of natural water resources to conduct mud crab cultivation, can maintain good water quality with the help of tidal exchange, and has the merit of being low cost, with a short farming cycle and high survival rate.

Cage culture, ceramic altar culture, and industrialized culture can effectively avoid cannibalism, and result in high survival rates, farming operation is easy, and the cost of production is low (Zhou *et al.* 2005). Mangrove beach ecological culture, for instance, arranges mud crab cultivation jars on a mangrove beach, utilizes natural ecosystem itself to control water quality. Fresh shellfish attached to the trees provide food for the mud crabs, thereby reducing feed quantity, avoiding environmental pollution, and supplying nutrition to the mangrove, and is ecologically favorable (Zeng *et al.* 2011; Wei *et al.* 2012).

3.4.4 Major Challenges and Solutions in Mud Crab Farming

Seedling, feed, and disease are the major factors impeding the development of mud crab culture. Although artificial propagation of mud crab has been successful (Li and Wang 2001, 2007), large-scale seed production has not yet been fully commercialized and disseminated across the country. Sourcing seed from the wild is susceptible to many environmental influences, and the quantity and quality of supplies are not always reliable. Many achievements have been made in the field of mud crab nutrition and feed development, but this sector still lacks feeds that meet the basic nutrient requirements of mud crab. Low-valued fish are the main feed of mud crab, partly supplemented by formulated feed (Ai 2002; Ai *et al.* 2005, 2007, 2010). The utilization of low-valued fish may cause environmental pollution, and transmit diseases and parasites, leading to a decrease of economic benefits. Thus formulated feeds to meet the nutritional requirement of mud crab during different growth and development stages are an urgent need for healthy and sustainable development of the mud crab culture industry (Li *et al.* 2008; Xia *et al.* 2010). Meanwhile, generalizing and applying healthy mud crab culture, namely ecological polyculture of mud crab with seaweed, fish, shrimp and shellfish, combined with measures for prevention and control of diseases contribute to sustainable development of the mud crab industry.

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3.5

Sturgeon Culture: Status and Practices

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3.5.1 Introduction

Commercial sturgeon farming in China is less than 30 years old, with the earliest farming attempts occurring during the early 1990s (Sun *et al.* 2011). After the initial attempts in the 1990s, many developments were made in the following decade, and sturgeon farming yields started to be included in the national statistics around 2000.

After 2000, sturgeon gradually began to be accepted by consumers, and demand increased year on year, which further promoted development. Sturgeon farming in China in 2003 yielded 9400 tonnes, accounting for approximately 70 percent of global production (FAO 2015). Since then, the development of sturgeon farming in China has proceeded rapidly. In the following decade, accompanied by developments in farming technology and larval production, annual yields increased to 55 200 tonnes in 2012, 4.8 times that in 2003, and accounted for 85.2 perecent of global production (Figure 3.5.1).

The fast development of sturgeon farming in China is closely associated with progress in technology in resource conservation, acclimatization, artificial propagation, and culture practices and management. The development of sturgeon aquaculture in China can be roughly divided into five phases (Table 3.5.1).

- surveys of wild resources, and control reproduction research (1950–1972);
- breakthrough phase, including artificial propagation and stock enhancement (1972–1991);
- intensive culture and natural resource enhancement (1991–2001),
- controlled reproduction and large-scale production of cultured sturgeon (2001–2006); and
- caviar production and export from cultured sturgeon (2006 and later) (Sun *et al.* 2011).

3.5.2 Sturgeon Resources and the Main Farmed Species

Globally, the living Acipenseriformes occur only in the northern hemisphere, and are concentrated in three main areas; in the ranges from Eastern Europe to the Caspian Sea, the Black Sea, Aral Sea, and the rivers flowing into them; in the north circum-Pacific, including the east of the Asian mainland and the west of North America; and on the east coast of North America. In all, 13 sturgeon species have been recorded from the former Soviet Union, and 10 species each in Asia and North America.

There are eight sturgeon species indigenous to China. These belong to Acipenseridae and Polyodontidae. Among them, seven species belong to two genera, *Acipenser* and *Huso*, of Acipenseridae, and one species

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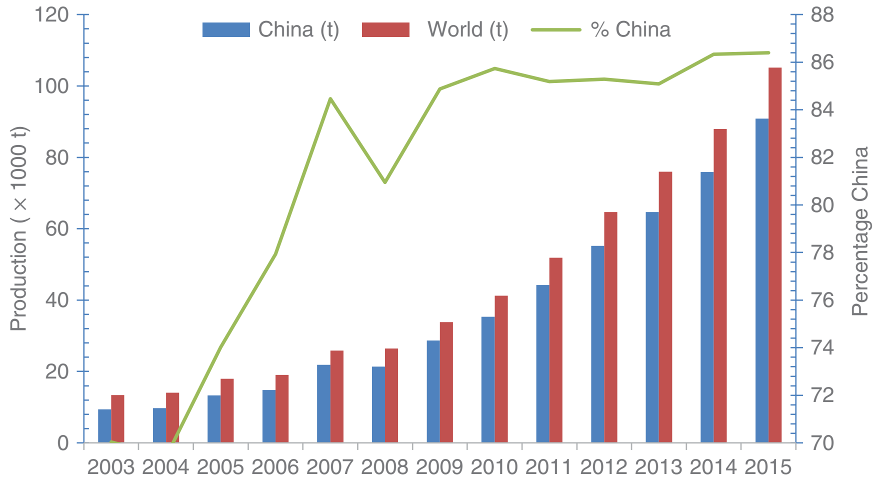

Figure 3.5.1 Trends in sturgeon aquaculture production in China and in the world, and the percentage contribution of the former to world production (FAO 2015).

Table 3.5.1 The developmental phases of sturgeon aquaculture in China.

1950–1972	**Wild resources survey and control reproduction research**
	• 1950s – sturgeon resources survey in Amur River basin completed.
	• In 1957, success of control reproduction using wild mature broodstock in China for Amur sturgeon (*Acipenser schrenckii*)
	• In 1970s, wide survey of Chinese sturgeon (*Acipenser sinensis*) carried out downstream of Jinsha River, and the Chinese sturgeon, Yangtze sturgeon (*Acipenser dabryanus*), Chinese paddlefish (*Psephurus gladius*) in the Yangtze River basin.
1972–1991	**Breakthrough in artificial propagation and stock enhancement**
	• 1973 and 1976, breakthroughs made in control reproduction of Chinese sturgeon and Yangtze sturgeon, respectively.
	• 1982, research commenced on stock enhancement of Chinese sturgeon enhancement and farming technology.
	• 1983, Chinese sturgeon larvae and juveniles released for the first time.
	• 1989, success in Amur sturgeon stock enhancement
1991–2001	**Intensive culture and resource enhancement**
	• 1991, Russian hybrid, Sterlet sturgeon (*Acipenser ruthenus*) and Russia sturgeon (*Acipenser gueldenstaedtii*) introduced for industrial aquaculture.
	• 1992–1998, success in Amur sturgeon artificial propagation in north-eastern China, and then successfully introduced into southern China.
	• 1997, breakthroughs achieved in juvenile culture of Chinese sturgeon, and stock enhancement; released numbers of Chinese sturgeon reached 100 000 per year from 1999 to 2001.
	• 2000, sturgeon farming production reached 3000 t, and production of larvae reached 20 million.
2001–2006	**Control reproduction and large scale culture of sturgeon**
	• 2002, cultured mature Amur sturgeon utilized for the first time as broodstock.
	• Cultured sturgeon control reproduction extended to Siberian sturgeon (*Acipenser baerii*), starlet sturgeon, Russian sturgeon, hybrid sturgeon and paddlefish, and juvenile production reach requirements of aquaculture
2006 onwards	**Caviar production and export from cultured sturgeon**
	• 2006, caviar export amounted to 0.5 t, the emphasis of sturgeon aquaculture began to transfer to caviar production and export.
	• Currently, caviar export from cultured sturgeon is 30 t per year.

belongs to *Psephurus* of the Polyodontidae. In China, sturgeon are mainly distributed in the basins of the Amur River in north-east China, the Yangtze River in the center of the country, and the Pearl River in the south, as well as along the eastern coastal shelf, ranging from the Yellow Sea to the East China Sea. Sturgeon also occur in the Ili River, and Irtysh River basin in Xinjiang in north-west China.

Of the three sturgeon species of the Yangtze River, Yangtze sturgeon (*Acipenser dabryanus*), and Chinese paddlefish (*Psephurus gladius*) are endemic to the Yangtze River, while Chinese sturgeon (*A. sinensis*) is a typical anadromous fish, distributed along the eastern coastal shelf of the Yellow Sea and the East China Sea to the Yangtze River basin. With the pattern of geographical distribution and their endangered status, these three sturgeon were all categorized as Class I in China's Catalogue of Aquatic Wildlife under Key State Protection in 1988 (Wang 1994). Since then, wild resources of sturgeon have been conserved, and sturgeon fishing has been banned. In addition to the three species above, other sturgeon include the Amur sturgeon and the Kaluga in the Amur River, the Fringebarbel sturgeon in the Irtysh River, and the Siberian and Sterlet sturgeons in the Ili River. These five species are all in international rivers shared by China with Russia or Kazakhstan (Table 3.5.2).

With the rapid development in sturgeon aquaculture over the past two decades, many sturgeon species have been screened for suitability for farming. So far, over ten species in three groups are farmed on a large-scale (Table 3.5.3). The first group is the native species which includes Amur sturgeon and Kaluga which are farmed on a large scale, and Fringebarbel sturgeon farmed on a small scale. Although artificial propagation of Chinese and Yangtze sturgeons has been developed, commercial farming of these is forbidden as these are Class I in the Catalogue of Aquatic Wildlife under Key State Protection.

The second group of farmed sturgeons are introduced species. These include paddlefish, Siberian sturgeon, Beluga, Sterlet sturgeon, Starry sturgeon, and Russian sturgeon. Among these, paddlefish, Siberian sturgeon and Beluga are farmed on a large scale. The third group is hybrid sturgeons. The hybrids between Russian

Table 3.5.2 Native sturgeon species and their main distribution areas in China.

Family/ Genus/ Species	Common Name	Distribution	Status
Acipenseridae			
Acipenser			
A. sinensis	Chinese sturgeon	Yangtze River, Yellow sea, East China Sea, Pearl River	Class I state protected species. Annual stock enhancement using cultured sturgeon
A. dabryanus	Yangtze sturgeon	Yangtze River	
A. baeri	Siberian sturgeon	Irtysh River	Few wild resources; Introduced for farming
A. ruthenus	Sterlet sturgeon	Irtysh River	Few wild resources; Introduced for farming
A. nudiventris	Fringebarbel sturgeon	Ili River	
A. schrenckii	Amur sturgeon	Amur River	Farming; Enhancement release
Huso			
H. dauricus	Kaluga	Amur River	Farming; Enhancement release
Polyodontidae			
Psephurus			
P. gladius	Chinese paddlefish	Yangtze River	Class I state protection animals; Endangered

sturgeon (♂) and Siberian sturgeon (♀), Beluga (♂) and Siberian sturgeon (♀) in China, as well as the cross and back-crosses between Amur sturgeon and Kaluga and Amur sturgeon and Siberian sturgeon are farmed. Among the farmed hybrid sturgeons, the major Amur sturgeon (♀) and Kaluga (♂) hybrid, is suitable for caviar production, due to its fast growth, easy domestication, high-quality caviar, and shortened maturation time compared with the female parent. While the performance of the crosses and back-crosses of Amur and Siberian sturgeons are indistinctive and both exhibit better growth rates, adaptability and survival in transportation than the parents. The hybrid cross from Amur sturgeon and Siberian sturgeon, named West hybrid, are the major sturgeon species in fresh fish markets in China presently.

3.5.3 Sturgeon Farming Areas and Practices

Sturgeon farming now has expanded to most provinces in China. Since environmental conditions are very diverse over the vast territory of China, the scale of culture, species and practices differ between sturgeon-farming provinces.

In China, sturgeon farming provinces (Table 3.5.4) can be divided into two categories based on yield. The first category includes Inner Mongolia, Ningxia, Tibet, Tianjin, Shanghai, Qinghai and Jilin, where annual yields are less than 30 tonnes. In the other category, covering 23 provinces, sturgeon farming yields are high, such as, for example, in Hubei, Shandong, Hebei and Zhejiang where production exceeded 2000 tonnes, and

Table 3.5.3 Main sturgeon species groups commercially farmed in China.

Species	Farming mode
Native species	
Amur sturgeon Kaluga	Major farming; Running water concrete ponds; Cages
Fringebarbel sturgeon	Small scale
Introduced species	
Paddlefish	Major farming; Extensive culture; Ponds; Cages
Siberian sturgeon Beluga	Major farming; Running water concrete ponds; Cages
Sterlet sturgeon Russian sturgeon	Minor farming; Running water concrete ponds; Cages
Starry sturgeon	Small scale
Hybrids	
Major hybrid (Amur sturgeon ♀ × Kaluga ♂)	Major farming; Running water concrete ponds; Cages
Minor hybrid (Amur sturgeon ♂ × Kaluga ♀)	Minor farming; Running water concrete ponds; Cages
West hybrid (Amur sturgeon ♀ × Siberian sturgeon ♂ Amur sturgeon ♂ × Siberian sturgeon ♀)	Major farming; Running water concrete ponds; Cages

Table 3.5.4 Sturgeon farming scale, based on average annual production in 2011 in different provinces in China.

Annual yield in t	Province
more than 2000	Hubei, Shandong, Hebei, Zhejiang
1000 to 2000	Jiangxi, Shanxi, Henan, Liaoning, Yunnan
50 to 1000	Guizhou, Sichuan, Jiangsu, Shannxi, Guangdong, Beijing, Hunan, Chongqing, Fujian, Gansu, Heilongjiang, Anhui, Guangxi, Xinjiang
less than 30	Inner Mongolia, Ningxia, Tibet, Tianjin, Shanghai, Qinhai, Jilin

Source: After Sun (2015).

accounted for 65.1 percent of the domestic production. Provinces with annual yields ranging from 1000 to 2000 tonnes include Jiangxi, Shanxi, Henan, Liaoning and Yunnan.

The sturgeon species farmed also vary in the different regions. In the high latitude areas such as north-east China, the major farmed sturgeon species are Amur sturgeon, Kaluga, Siberian sturgeon, and other introduced frigostable species. While, in north China, which has the proper climate for sturgeon farming, small sturgeon species like the West Hybrid (Amur sturgeon ♀ × Siberian sturgeon ♂; Amur sturgeon ♂ × Siberian sturgeon ♀) and the Siberian sturgeon are much popular. Sturgeon farming in East and Central China is also well developed with various farmed species. The sturgeons in these two areas are mainly supplied for the fresh market, and also for caviar production. The sturgeons for the fresh markets include Kaluga, the Major hybrid (Amur sturgeon ♀ × Kaluga ♂), the West hybrid [male and female symbols here x 6 total] (Amur sturgeon ♀ × Siberian sturgeon ♂; Amur sturgeon ♂ × Siberian sturgeon ♀), Siberian sturgeon and paddlefish. The farmed sturgeons mainly for caviar contain Kaluga, Amur sturgeon, the Major hybrid (Amur sturgeon ♀ × Kaluga ♂) and Beluga. In Southwest China, favorable climate and abundant water resources are suitable for sturgeon farming, and the consumption patterns are also similar to East and Central China, where the major farmed species include the major hybrid (Amur sturgeon ♀ × Kaluga ♂), and Beluga. In south-west China, a favorable climate and abundant water resources make the area suitable for sturgeon farming, and the consumption patterns are also similar to East and Central China, where the major farmed species include the major hybrid (Amur sturgeon ♀ × Kaluga ♂), Russian sturgeon, paddlefish, Kaluga, Amur sturgeon, Siberian sturgeon and the West hybrid.

3.5.4 The Major Farming Practices

In China, sturgeon farming typically means feeding larval sturgeons of 10 to 20 cm to adult or sub-adult fish, when, depending on local consumption patterns fish will be sold fresh, while a proportion will be retained for caviar production. The most popular marketable size is around 0.75 kg, but in some places, especially in north-east China, frozen sturgeon of over 10 kg is much more popular. For caviar production, sturgeons are reared up to seven to ten years.

With its vast territory, huge temperature differences between the north and south, and the variety of water resource characteristics, farming patterns in China are highly diverse. Major patterns of sturgeon farming include running water farming, cage farming, pond farming, recirculating water farming, and extensive farming (Sun 2015). Among these, running water farming and cage farming are the most popular. Recirculating water farming and extensive farming are emerging patterns. Recirculating water permits better adaptability, but the capital and recurrent costs associated with maintaining recirculating systems are too high to gain wide popularity/adoption by farmers. Extensive farming is more suitable for those producing large or caviar-producing sturgeons. Pond farming is much more common in Guangdong and Hubei for paddlefish.

3.5.4.1 Running Water Farming

In running water farming, water run continuously through the culture ponds for the whole farming period, and is discharged. In some mountain or hilly areas, farms are built at different altitudes, the water in higher place can be reused for agriculture at the lower heights, often untreated.

Running water farming is one of the major patterns for adult sturgeon farming, and accounts for around 40 percent of sturgeon production in China. Running water farming is commonly utilized for all species except Amur sturgeon (Yang 2012).

The water in running water farming is seldom pretreated. As a result, abundant water resources at the correct temperature and of the right quality are a necessity. Therefore, running water farming often occurs around pollution-free rivers, lakes, reservoirs, or in some areas with abundant underground water (include artesian springs and wells). The net benefit of running water farming is closely related to the water-supply methods. Because of the characteristics of running water farming, it is more common in those areas with numerous streams, springs and reservoirs, such as in south-east, central and east China. Energy-saving patterns are incorporated into running water sturgeon farming. For example, farms operate downstream of a reservoir dam enabling the utilization of bottom layers of low temperature water that is discharged. The other ones directly use the natural streams, springs and rivers along the platform of hills, which is more popular in south-west China (Figures 3.5.2 and 3.5.3).

Normally, the ponds in running water farming are made of brick or reinforced concrete, and are circular, oval, rectangular, or octangular. The pond area and depth range from 100–200 m^2 and 1.5–1.8 m, respectively. In hilly areas like Sichuan, Yunnan and Guizhou provinces, ponds are constructed of stone or are excavated, and the shape often depends on the local landscape (Yang 2012).

Running water farming occupies less space, and makes better faming conditions, and results in a high-quality product which is popular in the markets. This form of farming allows high-density stocking and results in higher yields. Depending on differences in the water resources, facilities, management and water exchange ratio, yields can range from 25–30 kg/m^3 (Xiang 2014; Pang and Cui 2015).

3.5.4.2 Cage Farming

Cage farming of sturgeon is a characteristic Chinese farming pattern, which began around 2000 (Huang *et al.* 2000). Now in China, it has become a major farming practice accounting for nearly 50 percent of domestic production. Cage farming is common, except in north-east and north-west China. It is widely adopted in large-sized reservoirs, rivers and deep lakes in south-west, central and in east China (Sun 2015).

Cages are often made of polyethylene or metal netting, assembled into rectangular or circular cages with support frame, fixed blocks and floats. In some provinces such as Hubei, the surface water temperature in summer often exceeds 28°C, which is beyond the tolerance range for certain sturgeon species, and could result in high mortality. To compensate for high summer temperature cages are modified to enable moving down the water column to depths of lower temperature (Figures 3.5.4 and 3.5.5).

As cages permit effective water exchange higher stocking densities can be maintained, with resulting high yields. Yields in sturgeon cage farming can range from 35–40 kg/m^3 (Ji *et al.* 2011; Zhu *et al.* 2011; Jiang 2014; Chen 2015).

The main advantages of cage farming include low capital costs and easy harvesting. However, the open farming environment leads to a relatively low feeding rate, and higher food coefficient (about 1.8–2.0). This not only increases the farming costs, but also increases levels of N, P in the effluent. In some reservoirs with large-scale cage farming, degradation of water quality and resulting eutrophication problems impact on the morbidity of farmed sturgeon. These issues in cage farming have drawn the attention of the national government which has introduced strict management measures and improved cage technology. In Qingjiang River in Hubei, a novel two-layer cage has been developed for sturgeon farming (Zhu *et al.* 2011). In these systems the space between the two cages is utilized to raise bighead carp or black carp, so the feed wastes of sturgeon

Figure 3.5.2 A sturgeon farm in Dujiangyan, Sichuan, located below a reservoir dam, utilizing the water discharged.

Figure 3.5.3 Amur sturgeon farm in Yunnan province, using water from a stream.

Figure 3.5.4 Sturgeon farm base of Hangzhou Qiandaohu Xunlong Sci-tech Co. Ltd.

Figure 3.5.5 Liujiaxia reservoir sturgeon base of Haidong Sturgeon Exploitation Co. Ltd., Ningxia Province.

in the inner cage can be used by the latter (Chen 2015). These systems result in increased yields around 7.1 kg/m^2, enabling profit increases of about 15 percent (Yang and Zhu 2011; Zhu *et al*. 2011).

3.5.4.3 Pond Farming

Pond farming is a historical fish farming pattern in China. Water could be still, exchanged regularly or running slowly. The major farmed species are carps including grass carp (*Ctenopharyngodon idellus*), black carp (*Mylopharyngodon piceus*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), common carp (*Cyprinus carpio*), and crucian carp (*Carassius auratus*). Pond farming of sturgeon started recently, and occurs on a small scale (Figure 3.5.6). The main reasons are that ponds cannot meet the sturgeon's needs for higher dissolved oxygen (DO) concentration, and water temperature often exceeds 30°C in the major sturgeon farming areas in east and central China. These conditions make it hard for sturgeon to survive in ponds, and lead to low farming profit.

However, paddlefish can tolerate a wider temperature range, and can feed on zooplankton. As such, paddlefish are widely raised in Hubei and Guangdong provinces in ponds (Luo *et al*. 2011). In addition, pond farming of sturgeon is practiced on a small scale in other areas such as Hebei, Beijing and Heilongjiang, primarily for broodstock.

Sturgeon pond farming can either be monoculture, the farmed species being only paddlefish, and or polyculture of paddlefish with a few other fish to regulate water quality and to utilize the pond space more

Figure 3.5.6 Ponds farming of sturgeon of Hubei Yangtze River Aquatic strains testing station. (*See color plate section for the color representation of this figure*.)

effectively. In Guangdong, the major species is paddlefish, cultured with channel catfish (*Ictalurus punctatus*), or grass carp. In other areas where the major fish is Sterlet sturgeon, silver carp and bighead carp are more commonly used as subsidiary species.

The other mode of pond farming sturgeon is polyculture, where the major species are traditional farmed fish such as silver carp, bighead carp, grass carp, black carp, channel catfish and mandarin fish (*Siniperca chuatsi*), and the minor species is sturgeon. The mass of the major species is dependent on the water quality, and on the feeding habits of the minor sturgeon. In ponds where the major species is grass carp, profit can increase significantly when culturing with 300–450 ind./ha paddlefish of average weight of 250 g (Chen *et al*. 2011, 2012; Luo *et al*. 2011; Li *et al*. 2013).

Guangdong and Hubei are the main provinces of sturgeon pond farming, and both provinces have developed special farming methods. In Hubei, ponds are used mainly to raise broodstock and for seed production instead of table-size fish for the market. In recent years, 15–20 million fertilized eggs, and over 15 million fry of paddlefish were produced from pond farming operations in Hubei. In contrast, pond farming in Guangdong is often for the production of table-size fish. In Foshan in Guangdong, paddlefish can grow to an average weight of 2.3–3.0 kg in just one year, with yields up to 37.5–45.0 t/ha. Overall, pond farming of sturgeon in Guangdong produces 2500–3000 t/year.

3.5.4.4 Farming in Recirculating Systems

Sturgeon farming in recirculating systems in China is still in early stages of development. The main aim of this type of system is to create suitable ecological conditions for the last stage of gonad development using the advantage of controllable water quality. This can promote egg maturation, and produce large quantities of fry, as well as caviar. Some hatcheries also use recirculating systems to produce fry, as the controlled environment can improve the survival rate of fry. However, use of recirculating systems for farming table-size sturgeon is rare. The main limiting factors in this regard are the large investment needed, high operating costs, and that

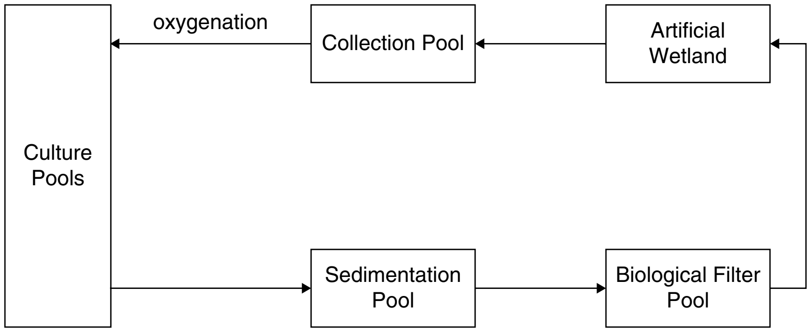

Figure 3.5.7 Schematic representation of the basic process of ecologically integrated recirculating sturgeon farming systems. *Source:* After Sun (2015).

overall returns are low. Therefore, a new ecologically integrated recirculating farming system, outlined below, has been developed, and is used for production.

The theory of ecologically integrated recirculating farming system is the incorporation of a biological filter to purify water which makes use of the absorption ability of hydrophytes and the decomposition ability of microbes. Recirculating farming is composed of a culture pool, a physical filter pool, a biological filter pool and a hydrophyte culture shelf, and associated facilities includes water and gas pumps (Figure 3.5.7). The effluent from culture pools flow through successive sedimentation pools, biological filter pools, artificial wetland planted with hydrophytes, and a collection pool. The purified water is pumped back into the culture pools after oxygenation. In sedimentation pools, solid wastes can be filtered and removed. In the biological filter pool, ammonia and nitrite in the water is transformed to nitrates by microbes. Ornamental water grass, hydroponic vegetables, and flowers planted in the artificial wetland can absorb nitrogen and phosphorus in the water. After the treatment through the wetland, water runs into the collection pool where it is oxygenated, and pumped back to the culture pools. Harvesting of the hydrophytes in the artificial wetland can remove excess nutrients from the water (Lin *et al.* 2011).

High farming density makes sturgeon prone to injury through contact, and as such lower densities are preferred in recirculating water farming systems compared to others. Nowadays, the most common density used is 50 kg/m^3. When it comes to ecological farming, the density needs to be continually lowered to 20–30 kg/m^3 (He *et al.* 2006; Ren *et al.* 2013).

In recent years, a new farming pattern has appeared especially used for the production of large-sized sturgeons. In this practice, sturgeon fry are released into large reservoirs, deep lakes and or old river ways. Animals grow on the natural feed resources as well as on supplemental feeds. This form of extensive farming is practiced mainly for Amur sturgeon, Sterlet sturgeon and paddlefish in Qionghai Lake in Sichuan, Yangtze old river ways in Hubei, and Shengli reservoir in the north east. Amur sturgeon and Sterlet sturgeon extensive farming experiments are still in progress in reservoirs and lakes in Sichuan and Xinjiang provinces (Sun 2015).

3.5.5 Problems and Challenges

It took only 20 years for sturgeon farming for China to become the largest sturgeon nation producer accounting for over 80 percent of world production. This development is a consequence of the large market demand, and also of the breakthroughs in technology on sturgeon biology, controlled reproduction, and culture. The artificial propagation of Amur and Chinese sturgeons, and fry-to-fingerling rearing (Sun *et al.* 2003; Yang *et al.* 2008), regulation of gonadal development by controlling water temperature in the case of Amur and Russian sturgeons and paddlefish (Hu *et al.* 2007; Zhang *et al.* 2012b), and sturgeon sex identification technology in the early stages (Chen *et al.* 2004; Zhang *et al.* 2012a) are significant developments that have impacted on sturgeon farming. These advances guaranteed the supply of fingerlings, and permitted sturgeon farming though the year. Hatcheries in Hubei and Beijing are capable of producing paddlefish, Siberian sturgeon, and hybrid sturgeon seedlings for six months of the year. Sturgeon egg production has reached 150 000 000 per year, and can fully meet the needs of the sturgeon farming sector in China (Sun 2015).

As sturgeon farming has intensified, as expected, many new problems have emerged that require attention. The first is sturgeon germplasm conservation, and maintaining pure breeding lines. In the wake of meeting the seed requirements for sturgeon farming, there has been unplanned broodstock management, as well as hybridization between many species. All this has led to a degeneration of germplasm, and a decrease in fry quality and productivity in certain instances. The second is the lack of comprehensive utilization, and appropriate development of processing of farmed sturgeon. The third is the lack of attention on the relevant environmental problems in sturgeon farming.

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3.6

Snakehead Culture

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3.6.1 Introduction

Snakeheads (Perciformes, Channoidei, Channidae) are a group of freshwater fish that are able to breathe air directly through their gill apparatus. The placoid scales of snakeheads are covered with a protective layer of slime. The shape and stripes of the head resemble a snake, hence the name "snake head". These are highly aggressive predators, and even become cannibalistic when food is in short supply. Snakeheads show an amazing tolerance of harsh conditions. Parents construct nests and take care of the young, and prefer to live in swamps, streams and lakes with aquatic vegetation.

Snakeheads are a freshwater fish species of high economic value in China, since they are considered to be of high nutritional value, with tender flesh as well as an intense flavor, and are thought to have medicinal properties, such as promoting muscle growth and hematopoiesis. The northern snakehead (*Channa argus*) and blotched snakehead (*C. maculata*) are two of the most important cultured snakeheads and are native to China. The snakehead *C. argus* is widely distributed, except in the Tibetan plateau area. *C. maculata* is mainly spread in the Pearl and Hainan river basins. Snakeheads have always been highly prized in Hong Kong, Macao and Asian countries, and consequently has been one of the primary aquatic products of the Chinese export trade. In 1994, researchers from Shunde Guangdong successfully bred hybrids using female *C. maculata* (♀) and male *C. argus* (♂) (Yang 2004). After nearly 20 years of promotion and improvement of farming technology, the hybrid snakehead fish has become more popular in China (Figure 3.6.1).

3.6.2 The Main Region of Culture Activities in China

Over the past 30 years, overfishing of wild snakehead resources has led to a sharp reduction in the domestic supply, as well as a rise in price, which have significantly stimulated intensive snakehead farming. Data from 2003–2014 (China Fishery Statistical Yearbook 2014) show that, the aquaculture production of snakehead ranked ninth in national freshwater fish production for eight years. In 2014, the snakehead farming yield (including hybrid snakehead) reached 510 340 tonnes (Figure 3.6.2), of which the snakehead yield in Shandong Province was 113 278 tonnes, and the hybrid snakehead in Guangdong Province was 114 981 tonnes, accounting for almost half the national farmed snakehead output.

In the last decade, eight main farming regions of snakeheads have emerged in China; include Shandong, Guangdong, Jiangxi, Zhejiang, Jiangsu, Hubei, Anhui and Hunan provinces (Figure 3.6.3). In 2003 and 2013, the annual production of the smallest main farming region reached 10 000 tonnes and 30 000 tonnes,

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Channa argus

Channa maculata

C.argus ♀ × *C. maculata* ♂
(from Kunci Chen)

C.maculata ♀ × *C. argus* ♂

Figure 3.6.1 Snakeheads cultured in China.

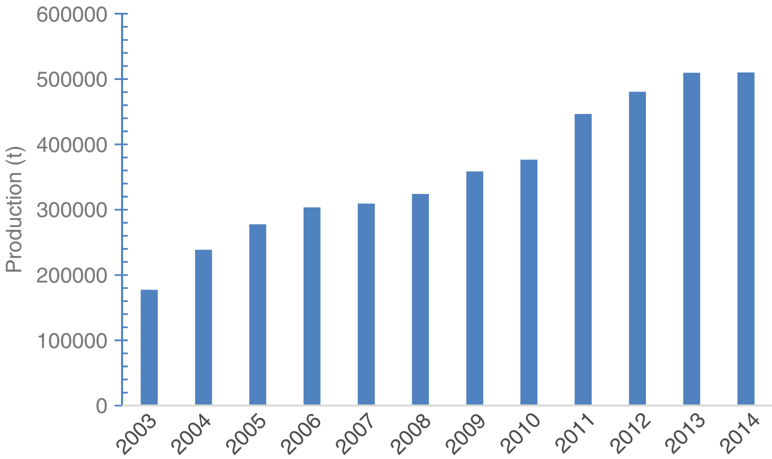

Figure 3.6.2 Trends in the aquaculture production of snakehead in China.

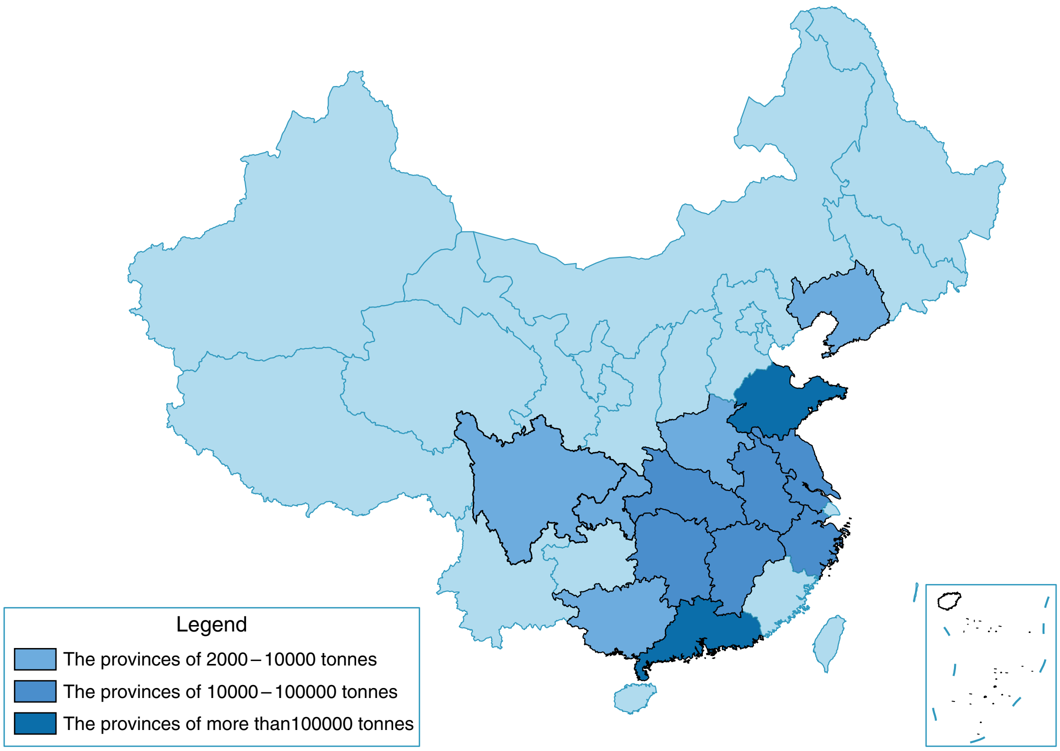

Figure 3.6.3 The distribution map of main farming regions of snakehead.

respectively. In the past, *C. argus* and *C. maculata* were cultivated in northern and southern China, respectively. Due to favorable and desired characteristics of hybrids, hybrid snakehead has become the main species replacing *C. argus* and *C. maculata* (Yang 2004), especially in southern China, and the scale of the hybrid farming is still expanding.

Currently, the farming of *C. argus* in China is concentrated in Weishan in Shandong Province, Yuanjiang in Hunan Province, Yuhang in Zhejiang Province, and Yugan in Jiangxi Province. In Shandong Province, the farming area is mainly located around Weishan and Dongping lakes, which account for about 78.13 percent of the whole production of the province. Moreover, Luqiao Town in Weishan County, Shandong, is the biggest snakehead breeding–farming base.

Nearly, 99 percent of hybrid snakehead farming areas are located in southern China. Guangdong is the largest producer of snakehead with more than 4000 ha of farming area, including Shunde, Zhongshan, and Nanhai in the Pearl River Delta region. In recent years, Zhejiang has also become one of the main regions where there has been rapid development of snakehead farming. The farming area here reached 2000 ha in 2010, compared with 500 ha in 1990s, mainly concentrated in Xiaoshan, Yuhang, Linghu.

3.6.3 Past Trends

Numerous features, such as strong environment adaptability, ready availability of seed, fast growth, high yields, good meat quality, and easy long-distance transportation, have stimulated snakehead farming. Industrial development of this sector can be roughly divided into three phases: the early exploration phase, the maturing phase of culture technology and industrialization, and the rapid development phase.

3.6.3.1 Early Exploration Phase

Since the 1980s, wild caught snakehead fingerlings were stocked experimentally in ponds and cages, and fed low-valued fish in a few areas of northern and southern China. In 1987, the first batch of *C. maculata* from Hong Kong was introduced into Shunde in Guandong, and showed good growth performance. Within a six-month culture period, this Hong Kong stock gained an average weight of 1 kg. Over the same period, a lot of basic research and experiments on snakehead have been carried out, including nutrition and food, disease control, broodstock cultivation, and so on. Wide experience has been accumulated through culture practices, but, due to some limitations on seed availability and in artificial propagation technology, the development of aquaculture has been slow (Lin 1986; Chen 1997; Yue *et al*. 1999). Annual production was about 15 000 tonnes in China at the end of the 1980s (Zhang *et al*. 2011). Cultivation of *C. maculata* was mainly concentrated in Zhongshan in Guangdong Province, *C. argus* are cultured in Xiaoshan in Zhejiang Province, and in Honghu lake in Hubei Province.

3.6.3.2 Maturing Phase of Culture Technology

In the 1990s came breakthroughs in artificial propagation and in the large-scale production of snakehead fingerlings (Chen 1997; Yue *et al.* 1999; Chen *et al*. 2001). A series of pollution-free technical specifications for culture, based on feeding, water-quality control, and disease prevention and control, were worked out. Based on the above specifications large-scale popularization of high-yielding culture models promoted the industrialization of snakehead farming. A group of villages and towns specializing in snakehead farming sprang up in Shandong, Hubei, Hunan, Guangdong, Jiangsu, Anhui, and other provinces. In Luqiao town, Weishan, Shandong, more than 95 percent of snakehead farmers had mastered breeding technology of the snakehead (Si *et al.* 1999), and between them produced more than 200 000 000 larvae annually, increasing the output value of the larvae to 80 million RMB (6 RMB = 1 US$).

The hybrids *C. maculata* (♀) × *C. argus* (♂) were developed successfully in Shunde, Guangdong in 1994. Hybrids exhibited excellent heterosis in farming. Remarkable progress was made in larval hatching and snakehead feeding around 1996.

Meanwhile, traditional snakehead cultivation not only threatened natural fish resources, caused deterioration of water quality, and resulted in frequent disease outbreaks, but also led to the wasting of water resources and environmental pollution owing to frequent exchange of large quantities of water (Wang 2003). This hindered the healthy and sustainable development of the snakehead farming industry. In 1996–1997, serious germplasm degradation problems brought a heavy blow to the snakehead farming industry in the Pearl River Delta. Problems arose such as high feed-conversion ratio, a slow growth rate, poor water quality, a higher frequency of disease with lower survival rate, as well as higher cost of production, resulting in lower profit margins.

3.6.3.3 Rapid Development of Industrialization of Snakehead Farming

In the twenty-first century, the development on pond farming of the snakehead *C. argus* persisted in what is referred to as an Improved Variety System, a brand known in northern China. A series of cleaner production technologies were applied, such as breeding, pond ecological transformation, composite system construction, water quality regulation, and wetland water circulation, which promoted the rapid progress of industrialization.

Aquaculture in the Weishan Lake area paid particular attention to quality of the produce and efficacy of marketing. Farmers have implemented ponds-wetland circulation ecosystem model at lakeside ponds in the production of *C. argus*. In 2012, the farmed production of snakehead reached 56 202 tonnes in Jining, producing 320 million fry, expanding the farming acreage to 10 333 ha in North China.

The hybrid snakehead was widely cultivated in the Pearl River Delta in 2003, where highly intensive cultivation in ponds was the main mode of farming. With improvements in feed, and greater promotional efforts by feed mills, farmers gradually accepted extruded feeds. With the improvements in fingerling production, and the use of extruded feeds, the industrialization of snakehead aquaculture made great progress in southern China during 2012. It was unexpected to observe that the farmed production of hybrid snakehead yield ranged 75 000 to 112 500 kg/ha compared with other freshwater fish species. This interest in snakehead farming had spurred vigorous development of supporting industries, such as seed stock and formulated feeds.

The snakehead has overcome its negative image as a predatory 'black fish' in aquaculture and has gradually become a favorite species with an annual production of more than 500 000 tonnes. It has been transformed from a special, high-quality species into a conventional freshwater fish on the dining table of the common people.

3.6.4 Culture Environments

Ponds used for snakehead farming are usually 667–2668 m^2, and 1.5–2 m of water depth. The farming conditions require a dissolved oxygen (DO) level above 5 mg/l, pH 7–8, and water transparency of more than 30 cm.

In the case of high-density farming, pond water is prone to become black and smelly, and needs replenishment in time. In general, pond water needs to be exchanged 1/3 times in a week during the early culture period, and 4/5 times every seven to ten days during the high temperature season. Water has to be exchanged at least 10 times during a culture cycle of six months in earthen ponds, and perhaps 20 times in cement pond culture. In addition, making scaffolding shade in the summer, and increasing the depth of water in winter ensures that the water temperature is kept relatively stable.

The breeding period of *C. argus* is generally from May to July. The water must be clean, with an ambient temperature of 20–25°C, water depth 20–35 cm. Quiet and weak light without wind is most suitable for spawning. *C. argus* larvae are cultivated with slow flowing or still water in cages or cement pools. To ensure a relatively stable environment, it is better to install a greenhouse over the pond to prevent direct sunlight and rain.

3.6.5 Culture/Farming System(s)

3.6.5.1 Artificial Propagation

3.6.5.1.1 Natural Breeding

Natural spawning occurs from April to June when water temperatures reaches 20–25°C, in cement or earthen ponds in greenhouses, stocked with aquatic plants to provide the materials needed to build artificial nests, and stocking one male and one female in a pond (Liu *et al.* 1996; Chen *et al.* 2001). After incubation, the fry are fed with live zooplankton collected from rivers, lakes and ponds (Du and Zhou 1962). When fingerlings reach a body length of about 2 cm, they are fed with a mixed diet of zooplankton and surimi and the proportion of the latter is increased gradually. Fingerlings of about 3 cm are transferred to outdoor ponds or cages for the next stage of culture. This model is mainly used in Shandong and other northern areas that are rich in wild *C. argus* resources.

3.6.5.1.2 Mass Breeding

Mass breeding is performed in a batch of foam boxes or net cages with one male and one female per box or cage, using artificial hormones to induce spawning. This model is mainly used for hybrid snakehead breeding in South China, and *C. argus* breeding in a few other regions (Liu *et al.* 1996; Si *et al.* 1999; Chen *et al.* 2001). After incubation, fry are transferred to outdoor ponds with abundant zooplankton. Fingerlings of about 3–5 cm are fed extruded feed.

3.6.5.2 Farming Models

In China, snakeheads are generally cultured in outdoor earthen ponds. Cage and cement ponds are also used in a few farms. At present, snakehead cultivation is mostly a high-yield model, and mainly comprises of ecological farming, and intensive farming models (Wang 2003).

3.6.5.2.1 Ecological Farming Model

The ecological farming model refers to a model where seed density is controlled, stock is fed low-valued fish, and water quality is controlled through stocking bighead carp and silver carp or aquatic plants. In this model probiotics are also used to reduce the incidence of disease and use of medication, to improve flesh quality, yields and profits, and achieve the best environmental and ecological benefits.

In 2012, the traditional farming ponds of snakehead *C. argus* in Luqiao, Shandong was transformed into a system that resulted in zero water discharge by recirculating the water within a pond complex. This has been extended to over 3250 ha of snakehead farms. In such situations, farmers have mastered the technology needed to maintain good water quality with minimal water exchange. The brand of Lake Weishan *C. argus* was recognized as a national geographical indication product. It is an example of ecological farming and branding in the snakehead farming industry of the aquaculture industry of China.

Snakeheads grow fast, a significant proportion of the stock can be sold in May, and the rest before the end of the year. The ecological farming ponds in Weishan town rely on feeding fresh ice fish. The stocking densities used range from 60 000–75 000 ind/ha, when an average yield of 64 485 kg/ha, and a maximum yield of 97 500 kg/ha, with fish of average weight of 1317 g can be obtained.

3.6.5.2.2 Intensive Farming Model

Hybrid snakeheads are usually farmed intensively in ponds and fed with extruded feeds. As the availability of water is limited and its usage is restricted, farming is practiced without any water exchange or with limited water exchange. With water regulation technology, aerator facilities, and the use of extruded feeds, the intensive high-density farming model has achieved success in the Pearl River Delta region since the promotion of hybrid snakehead farming in 2003.

In Guangdong, the fingerlings of hybrid snakehead are stocked in April at a density of 225 000–300 000 ind./ha (Zou and Zhuo 2011). Fish of average weight of 0.45–0.75 kg are harvested in around September and yields of 90 000–112 500 kg/ha are achieved. In Zhejiang a stocking density of 105 000 ind./ha or so is used, and average yields of 51 712 kg/ha are achieved.

The intensive aquaculture of hybrid snakehead has some pros and cons, such as high output, a short farming cycle, a low feed conversion rate (FCR), bigger risks, high-technological inputs, and large investments. There are many animal health and feed companies that deal in chemicals and treatments to maintain good water quality, and to treat diseases. Most of them also provide technical services to farmers.

3.6.6 Main Advances in Culture Technology over the Last Decade or More

3.6.6.1 Production of Snakehead Hybrids

Hybridization of the northern snakehead and blotched snakehead resulted in two hybrids (*C. maculata* ♀ × *C. argus* ♂ and *C. argus* ♀ × *C. maculata* ♂).

Zhongshan fishery technology departments of Guangdong Province attempted hybridization between *C. maculata* (♀) and *C. argus* (♂) in 2000, and developed the hybrid snakehead variety "Huinong No. 1", with many advantages, including fast growth, strong resistance to disease, less reliance on low-valued fish as feed (Yang 2009).

In 2009, Hangzhou Agricultural Science Research Institute of Zhejiang Province successfully developed another hybrid "Hangli No. 1" *C. maculata* (♀) and *C. argus* (♂) which is the first hybrid snakehead variety approved by China National Aquaculture Variety Approval Committee (CNAVAC) (Wang *et al*. 2009).

In 2014, the hybrid snakehead variety "Wuban hybrid snakehead" (*C. argus* ♀ × *C. maculata* ♂) developed by Pearl River Fisheries Research Institute (PRFRI) was approved by the CNAVAC as a new aquaculture variety. This hybrid showed significant heterosis and better growth, lower FCR and better yield, and stronger cold-tolerance (Zhang *et al*. 2011).

3.6.6.2 Extruded Feeds

Since 2000, farmers in the south showed some interest in using extruded feeds. With improvements to the feeds and more promotional efforts by feed mills, farmers gradually accepted extruded feeds (protein: 40–45 percent, fat: 4–5 percent, crude ash: ≤16 percent, water: ≤12 percent). In 2002, the extruded feed market for snakehead was just about 200 tonnes, but reached 220 000 tonnes in 2012. Except for some farming of *C. argus*, using low-valued fish in the north of China, most farmers now prefer to use extruded feed (Figure 3.6.4).

Figure 3.6.4 An example of an extruded feed bag used in snakehead culture.

The promotion of the use of snakehead hybrids and extruded feeds in southern China, not only greatly reduced deterioration of water quality, but also successfully solved the problem of the availability of artificial feeds especially formulated for snakehead. With the development of these technologies and excellent brood-stock, the farming density and unit production of snakehead will be further enhanced. All these successes have not only established a solid theoretical and practical foundation for commercialization and large-scale production of snakehead, but have also laid a firm foundation for the subsequent application and promotion of extruded snakehead feeds.

3.6.7 Markets and Marketing

With an expanding domestic market, the snakehead has become an important commercial fish of high market value. In recent years, market demand for snakehead in Hong Kong, Macao, Japan, South Korea, Vietnam and other regions has increased markedly. Guangdong is the largest producer of hybrid snakehead, and more than 80 percent of its production is sent to Shanghai, Zhejiang, Hubei, and other northern provinces. During the harvest period, more than 300 tonnes of the hybrid in Shunde, Guangdong are sent to market daily (Figure 3.6.5).

The price of snakehead was at RMB 40–60 per kg (6 RMB = 1 US$) in the late 1990s, and the profit margin at farm level was around 33 percent. The high returns have attracted many newcomers to snakehead farming. This has resulted in an oversupply, and a reduction in price with dependence on local live fish markets. The fish price was very low with a large production in 2010, but rose in 2011 and reached the highest point in 2012, but dropped again in 2013–2014.

Since 2010, the market for snakehead has gradually approached saturation. The price has remained at 20 RMB per kg. The market price is high between June and September when there are insufficient supply of commercial-size fish in the market. However, market prices continue to decline even below cost price in northern China because of the import of hybrid snakehead from Guangdong, and farmers have had to choose to stock snakehead fish ponds according to market demands.

Figure 3.6.5 Snakehead at a wholesale market in Wuhan, Hubei Province. (*See color plate section for the color representation of this figure.*)

3.6.8 Constraints

In China, snakehead culture breakthroughs in fingerling production, commercial farming, and extruded feed development have enabled the establishment and popularization of the snakehead industrialization process. Currently, there are some urgent issues restricting healthy and sustainable development of the industry.

In traditional snakehead culture low-valued fish was the main feed, which led to high feed coefficient, food wastage, and deterioration of water quality. Yet it was very common to discharge wastewater directly into common waterways. The discharge of nearly 300 million tonnes of wastewater every year aggravated the level of eutrophication in rivers, lakes and reservoirs, which not only restricted the sustainable development of the aquaculture industry, but also intensified pressures on water resources.

At present, the artificial propagation of *C. argus*, *C. maculata* and hybrid snakehead are inadequate. There are many private-sector hatcheries and nurseries producing hybrid snakehead, but these management systems are not standardized. The high profits of hybrid seed production have resulted in the production of some low-quality fingerlings, and consequently negative economic characteristics, including slow growth and disease have already appeared in some regions (Zou and Zhuo 2011).

As fish prices fluctuate every year, the industry needs a fish trade association, as well as a marketing system to ensure its profitability. More assistance and guidance from the government are sought in establishing effective fish marketing communication channels to ensure a balance in supply and demand, throughout China.

3.6.9 Future Prospects

The conservation of germplasm resources of *C. argus* and *C. maculata* is the basis of the industrial development of hybrid snakehead. Because hybrid snakehead farming expanded rapidly and rather blindly, it is easy for these hybrids to impact on the gene pool of parent stocks.

The standardization of intensive farming technology guarantees the healthy development of the snakehead industry. With strict legal regulations, banned medicines are seldom used in aquaculture. It is still necessary to enhance the environmental awareness of the farmers and encourage compliance with sustainable aquaculture protocols.

Opening diverse markets at home and abroad will be an important factor in the steady development and industrialization of snakehead culture. In Zhejiang Province, some leather producers are attempting to use the skin to produce commercial products, such as handbags and handicrafts. The meat yield of the snakehead is as high as 63 percent, and thus it has a potential for the export of fillet.

It is reasonable to believe that the snakehead will continue to be a promising farmed freshwater fish in China. We expect that the high profit margins will continue to drive the growth in snakehead farming.

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3.7

Mandarin Fish Culture: Status and Development Prospects

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3.7.1 Why is It Mandarin Fish (*Siniperca chuatsi*)?

China has continued to lead global aquaculture production over the last few decades, and its freshwater aquaculture sector has remained a cornerstone of global aquaculture (Wang *et al.* 2015b). Over the years, the Chinese major carps – grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), common carp (*Cyprinus carpio*), crucian carp (*Carassius auratus*), black carp (*Mylopharyngodon piceus*), and round-head bream (*Megalobrama amblycephala*), have dominated Chinese freshwater aquaculture, accounting for nearly 65 percent of the total freshwater aquaculture production in China. These carps continue to contribute to food fish availability and food security, but are generally considered as the 'poor man's' fish. With improving living standards, and a growing middle class in the developing world and in China (Li 2010) which generally has an appetite for high-quality food varieties, one could expect a change in the species profile of cultured species; perhaps significant increases in carnivorous species, which often are purported to have a better taste, and rarities such as puffer fish and Sinipercinae fish (Wang *et al.* 2015b).

Sinipercinae species, freshwater fish indigenous to East Asia, are mostly distributed in China, on the Korean Peninsula, in Japan, Northern Vietnam, and the Amur River along the Russian borderlands (Li *et al.* 2014a). Sinipercinae comprise two genera, *Siniperca* with eight species, and *Coreoperca* with four species. Among them, ten species occur in China, primarily in central and southern China (Yao and Liang 2015). Mandarin fish (*Siniperca chuatsi*), bigeye mandarin fish (*S. kneri*), and spot mandarin fish (*S. scherzeri*) have been farmed in China. They are traditional high-valued food fish, with a good flavor, high nutritional value, little bone in the muscle, and cherished by Chinese people. However, compared with the latter two species, mandarin fish is more widely cultured throughout the country, and is also important in stock-enhanced fisheries in lakes and reservoirs due to its large size, rapid growth, short culture period, ready availability of seed, high market demand, and value (Liu *et al.* 1998; Li *et al.* 2014b; Yao and Liang 2015) (Figure 3.7.1).

3.7.2 Biological Characteristics of Mandarin Fish

Mandarin fish is a demersal species. The fish, with nocturnal habits, often inhabits complex habitats in lakes, reservoirs and rivers. Mandarin fish have good growth potential, a six-year-old individual captured in Lake Biandantang in Zhengjiang Province weighed over 5.5 kg. The growth rate is much faster in artificially controlled conditions than it is in nature. For example, the mean weight of mandarin fish cultured in ponds can

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Figure 3.7.1 Mandarin fish *Siniperca chuatsi*.

reach 900 g compared to about 200 g in a lake, over the same period of time (Li *et al*. 2014a; Yao and Liang 2015). Also, their growth rate showed significant sexual difference in that the growth rate of female was 10–20 percent faster than in males (Chiang 1959; Li *et al*. 1998; He and Xiang 2005).

Mandarin fish in nature mature at two years, and the main breeding season is between April and July, when the water temperature is above 20°C. Spawning grounds of mandarin fish are generally known to be in the littoral zones and water inlets of lakes and reservoirs, especially in sandy or submerged vegetation-covered shallows with flowing water. Spawning time lasts for three–six hours, but very occasionally may last 24 hours.

Mandarin fish have unusual feeding habits. The fish only eat live fish and shrimps, and do not consume dead prey or artificial diets during all lifecycle stages (Chiang 1959; Li *et al*. 2014a; Yao and Liang 2015). In nature it is completely carnivorous, and has been found to capture live fry of other fish species from the first feeding stages (Chiang 1959). Their feeding strategy differs at different stages of their lifecycle, using a cruising search-and-attack strategy in the larval stage, and a hide-and-ambush strategy in the adult stage (Li *et al*. 2014a; Yao and Liang 2015). The diet of mandarin fish is dominated by crucian carp, topmouth gudgeon (*Pseudorasbors parva*), sharpbelly (*Hemiculter leucisculus*), Rhodeinae and shrimps (*Macrobrachium* spp. and *Caridina* spp.) in many lakes in the middle reaches of the Yangtze River (Li *et al*. 2013a, 2014b; Yang *et al*. 2002). The difference in dominant prey fish consumed by mandarin fish in lakes may result from differences in availability and abundance. Mandarin fish is a mouth gape-limited predator which possesses a "predation window" defined by the minimum and maximum size of prey consumed (Claessen *et al*. 2002; Li *et al*. 2013a). The size spectra of a potential prey consumed by mandarin fish is within the predation window set by its mouth gape (Li *et al*. 2013a).

3.7.3 The Value and Significance of Mandarin Fish in Aquaculture

Mandarin fish is a famous freshwater fish in China, and has a relatively high market value. The fish is generally considered to be important as a top order predator in aquatic ecosystems, and it has important significance for regulating the structure of the food web and maintaining ecosystem balance.

3.7.3.1 Economic Benefits

Mandarin fish has been considered as a valuable fish since ancient times. The fish, together with Yellow River Carp (*Cyprinus carpio* var), Songjiang River Perch (*Perciformes* spp.) and Xingkai Lake Culter (*Erythroculter erythropterus*), were hailed as the "four famous freshwater fish" in China (Yao and Liang 2015). The market price of mandarin fish is much higher than many other freshwater fish, e.g. its market price is five to ten times that of Chinese carps. In 2014, the production of mandarin fish was 293 853 tonnes and the output value was

US$ 2.37 billion. Production of mandarin fish accounted for 1.00 percent of the total freshwater aquaculture production, but the output accounted for 2.90 percent of the total output value of freshwater aquaculture of China (China Fishery Statistical Yearbook 2015). Also, the fish has become a new export aquatic product that is exported live to neighboring countries and regions.

3.7.3.2 Optimizing Freshwater Aquaculture Modes

The total freshwater aquaculture production was 29 357 591 tonnes in China in 2014, of which 65 percent was accounted for by grass carp, silver carp, bighead carp, common carp, crucian carp, black carp and round-head bream (China Fishery Statistical Yearbook 2015). These carps, with low market price, were usually cultured in ponds at a high density, creating an oversupply and resulting in environmental problems (Zhang *et al.* 1997). Mandarin fish, with high market value, can be profitable at relatively low yields, reducing the pressure of aquaculture on the environment. Therefore, developing aquaculture of mandarin fish was considered as the important step of adjusting and optimizing the freshwater aquaculture modes in China.

3.7.3.3 Improving Water Quality in Natural Water Bodies

There is a growing recognition of the important role of predators in regulating ecosystems and sustaining biodiversity (Ritchie and Johnson 2009). Furthermore, studies on North American and European lakes have suggested that stocking piscivorous fish has direct and indirect impacts that alter the biota and water quality of lakes through top-down effects (Carpenter and Kitchell 1988; Van Liere and Gulati 1992; Zhang *et al.* 1997). The top-down effects of piscivorous fish in lake systems predict that an increase in piscivorous fish will reduce the biomass of zooplanktivorous and benthivorous fish, leading to a reduction in phytoplankton biomass (Carpenter and Kitchell 1988; Benndorf *et al.* 2002). Stocking piscivorous fish in lakes has become a strategy for water quality management and a widely accepted ecological paradigm (Van Liere and Gulati 1992; Drenner and Hambright 1999).

In China, mandarin fish is considered to be one of the important predators in freshwater ecosystems. However, the natural resources of mandarin fish have declined sharply in the past several decades due to habitat degradation, reduced spawning grounds, overfishing and (or) eutrophication, resulting in small-sized fish species dominating fish communities in many Yangtze lakes (Cao *et al.* 1991). These small-sized fish usually have low market value, and potentially compete for resources with other large or medium-sized commercially valuable fish. In order to utilize the abundant small-sized fish resources, and to prevent populations of small-sized fish from growing excessively, stocking of piscivorous fish, especially mandarin fish, has become an important fisheries activity in lakes along the Yangtze River (Xie *et al.* 2000, 2003; Cui and Li 2005; Li *et al.* 2014b). Mandarin fish stocking is a form of culture-based fisheries in lakes (Wang *et al.* 2015a), which not only channel more energy into large and medium-sized commercially valuable species, but also enable the recovery of the latter populations. In addition, our practices have indicated that stocking mandarin fish has the potential to improve water quality of shallow Yangtze lakes (unpublished data). Based on the above, stocking mandarin fish in lakes may have a positive role for optimizing food web structure and regulating ecosystems.

3.7.4 Development and Status of Mandarin Fish Culture

Experimentation on mandarin fish culture began in 1958 (Yao and Liang 2015). Juvenile mandarin fish were captured from lakes and or rivers and reared in small ponds at that time. From the 1960s to 1970s, mandarin fish culture developed slowly due to limited availability of seed stock. In 1975, artificial propagation of mandarin fish was successfully conducted in the aquaculture farm of Suzhou, Jiangsu Province. In the 1980s, as the technologies of artificial propagation continued to improve, and the technology of larval rearing was developed, and the bottleneck of mandarin fish seed production was settled. Since then, fry and fingerling

Figure 3.7.2 Fry (a) and fingerlings (b) of mandarin fish.

production of mandarin fish has increased rapidly (Figure 3.7.2). According to incomplete statistics, at least 1.5 billion mandarin fish fry and fingerling were produced in 2014. Due to the increasing demand of high-quality mandarin fish fingerlings for grow-out, a number of large-scale grow-out farms have built hatcheries to produce fry and fingerling for their own use.

Now that the key technologies of artificial propagation, larval rearing and commercial fish culture has improved, the production of mandarin fish has increased rapidly. From 1993 to 2014, production increased seventeen-fold, from 17 600 tonnes to 293 900 tonnes (Figure 3.7.3). There were three main culture practices of mandarin fish that were practiced in the development processes; pond, cage, and pen. The development of these types of culture has changed with time. The first record of the production of commercial-sized cultured mandarin fish from artificially propagated seed was in 1975, when 482 individuals were produced in a pond (Yao and Liang 2015). At the beginning of 1990s, pond culture of mandarin fish developed rapidly in Guangdong Province. In 1994, the production reached 18 600 tonnes and the output value was over 1 billion RMB (6 RMB= 1 US$) in Guangdong Province. In the mid 1990s, mandarin fish culture in cages was conducted in reservoirs and lakes in Hubei, Guangdong, Jiangsu, and Anhui provinces. Also, practices of mandarin

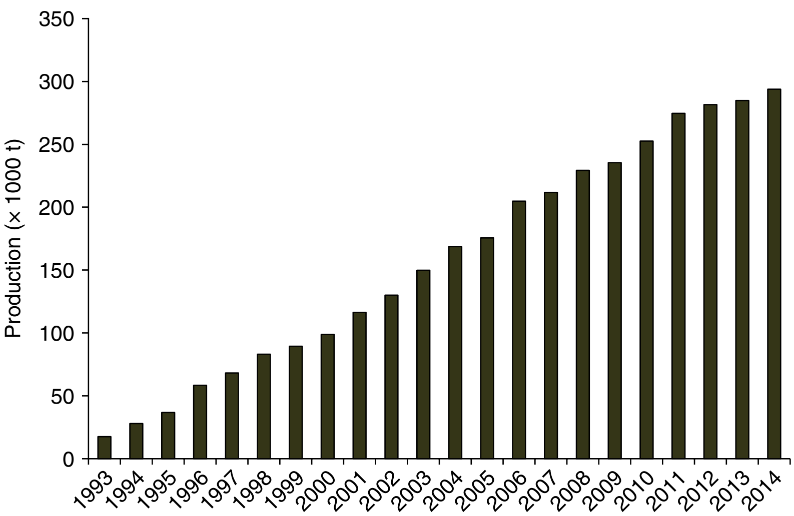

Figure 3.7.3 Production of cultured mandarin fish in China (Chinese Fishery Yearbook 1994–2015).

fish stocking in shallow Yangtze lakes were carried out. At present, artificial stocking of mandarin fish in lakes has achieved success, and has been an important fisheries pattern in China (Xie *et al.* 2003; Li *et al.* 2014b), which has not only increased the profits at relatively low yields and cost, but has also facilitated the control of populations of small fish with low market value, and resolved the conflict between fisheries development and water quality conservation based on the principle of trophic-cascading effects (Carpenter and Kitchell 1988; van Liere and Gulati 1992; Li *et al.* 2014b).

The development of mandarin fish culture differs significantly in different regions of China. The main regions for mandarin fish production is in the middle and lower reaches of the Yangtze River and in southern China, concentrated in Guangdong, Jiangxi, Anhui, Jiangsu, Hubei, Hunan, Zhejiang, and Sichuan provinces, which account for more than 96 percent of the total production (Figure 3.7.4). Annual production in Guangdong province was much higher than in the other provinces above, accounting for at least 32.7 percent of the total production until 2014.

3.7.5 Key Factors for the Success of Mandarin Fish Culture in China

3.7.5.1 Seed Production

The availability of good-quality fry and fingerlings in adequate quantities is considered to be one of the most critical factors for the success of mandarin fish culture in China. Before 1975, fry and fingerlings were wild caught and supply was limited, so the culture of mandarin fish in that period was mainly in small ponds with low stocking density (Yao and Liang 2015). Since the development of artificial propagation, mandarin fish seed has been produced in hatcheries in adequate amounts, and commercial culture has developed with multiple crops per year which has enabled the adoption of high stocking densities.

3.7.5.2 Improvement on Matching Prey Fish Techniques

As indicated earlier, mandarin fish have very peculiar feeding habits, only preying on live fish and shrimp during all life-history stages (Chiang 1959; Li *et al.* 2014a; Yao and Liang 2015). Availability and palatability of prey fish for mandarin fish during all life-history stages is vital for their survival and growth (Li *et al.* 2013a). Mandarin fish start to first feed on the third or fourth day after hatching, therefore it is necessity to provide other palatable larval fish on the third day after hatching. Various kinds of different sizes of live prey fish must be prepared in advance, based on the time of commencement of feeding of mandarin fish. At commencement of feeding, the optimal prey fish provided for mandarin fish are three-day-old fry of bream (*Parabramis pekinensis*),

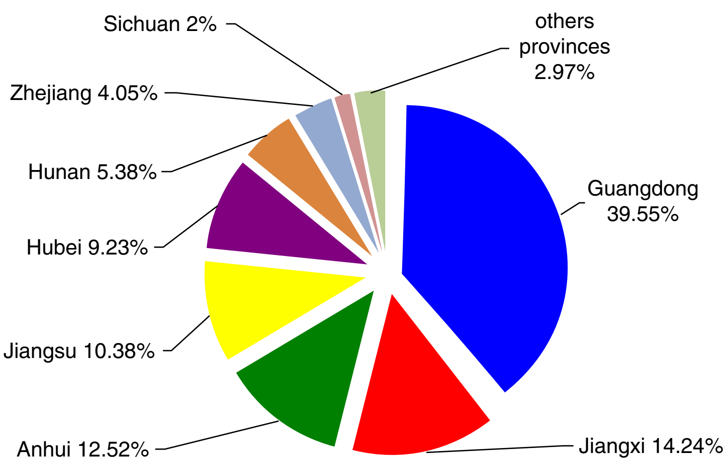

Figure 3.7.4 Mean percentage of mandarin fish production in different provinces in China from 2006 to 2014.

round-head bream (*Cirrhinus molitorella*), *Cirrhinus mrigala*, mrigal or *Labeo rohita*, labeo. After the period of initial feeding, the prey fish size rather than the species is important for mandarin fish. Prey fish with body depth exceeding the gape size of mandarin fish will not be captured. At this stage, more palatable prey fish such as silver carp, grass carp, and/or bighead carp could be used to feed mandarin fish. Improvements in prey fish matching techniques for mandarin fish is one of the key factors for the success of mandarin fish culture.

3.7.5.3 Key Pond Culture Techniques

The techniques for commercial food fish culture of mandarin fish in ponds have improved over three decades of studies and practice. The key techniques of mandarin fish culture in ponds include environmental conditions, stocking parameters, and daily management techniques. Among these, the stocking density is directly related to production. Generally, the stocking density of mandarin fish of 2.5 g is 10 000 to 15 000 individuals per ha. However, a higher stocking density is often used in some practices with the improvement of culture techniques (Yan *et al*. 2016; Zhao 2016).

3.7.5.4 High Economic Benefits and Available Markets

High economic benefits and available markets are two attractive reasons for involvement of investors in mandarin fish farming. In recent years, many owners of mandarin fish farms are investors from other industries. Mandarin fish farming requires high investment for fingerlings, prey fish and pond rent, but the total net benefit per unit area is much higher than for other farmed species, such as traditionally farmed carps, due to the high market price of mandarin fish. In general, the production of traditional carps per unit pond area in China is two to three times compared to that of mandarin fish; but the market price of the carps is only one-tenth to one-fifth that of mandarin fish. Second, the availability of markets has also been one of the key factors contributing to the fast growth of mandarin fish industry. With the advance of living standards in China, more people are demanding quality aquatic products. The increasing requirements for mandarin fish from a growing middle class often results in a short supply, especially during festival seasons. In addition, the rapid expansion of export markets also played a key role in the increase of production in the recent past.

3.7.6 Culture Modes

There are three main culture practices of mandarin fish in China: pond culture, cage culture, and stock enhancement in lakes. Pond culture has been developing rapidly since the success of artificial propagation of mandarin fish and has become the dominant culture model. The important driving forces in the development of pond culture practices include low infrastructural investment, a short culture period, and high economic benefits. Mandarin fish culture in ponds has two modes: intensive culture and co-culture with other aquatic species. Mandarin fish culture in cages was first reported in 1988 in the Fuqiaohe Reservoir in Hubei province (Huang 1988). Experimental results showed that cage culture gave good economic gains, but this culture practice developed slowly, primarily due to higher risks, such as escape of stock, higher technical demands from farmers, and higher costs leading to reduced economic efficiency compared to pond culture. Stock enhancement of mandarin fish in lakes, which is a form of culture-based fisheries (De Silva 2003), began to develop from the beginning of the 1990s in Hubei Province. Since then, this culture practice has been developing very rapidly in many lakes of the middle and lower reaches of the Yangtze River (Li *et al*. 2014a; Wang *et al*. 2015a).

3.7.6.1 Intensive Pond Culture

Intensive pond culture is the dominant practice of mandarin fish culture in China due to the availability of ponds, a short culture period, low infrastructural investment, and high economic benefits compared to cage and lake practices. This culture practice is concentrated in the warmer areas of southern and central China, and is still developing fast.

3.7.6.1.1 Pond Conditions

Intensive pond culture of mandarin fish demands a nearby water source, and the water quality has to conform to the national standards for fisheries. Pond size for mandarin fish intensive culture is similar to around 0.2–1 ha, and 0.3–0.6 ha are considered optimal (Figure 3.7.5). The depth of the pond is about 2 m, and the water depth is maintained at 1.5 m. In general, ponds, with little mud and a sandy bottom are preferred. Prior to stocking, all ponds should be thoroughly disinfected with quicklime (1.5 tonnes used in 1-ha pond) in order to reduce the occurrence of disease during the culture period. In addition, some submerged macrophyte, such as *Hydrilla verticillata*, *Vallisneria natans* are usually planted in the littoral zone around the pond, which act as a shelter and facilitate the predatory habits of mandarin fish, as well as absorbing nutrients from the bottom sediment.

3.7.6.1.2 Fry and Fingerling Stocking

The quality of fry and fingerlings of mandarin fish is vital for the success of mandarin fish culture in ponds. So it is better to choose fry or fingerlings that are directly obtained from hatcheries. Prior to stocking, fry or fingerlings should be immersed in a disinfectant aqueous solution of 3 percent to 5 percent NaCl for ten to fifteen minutes.

Two stocking methods are commonly used in intensive pond culture of mandarin fish: direct-stocking and staggered-stocking. Direct-stocking is when fry of an average length of 3 cm is stocked in ponds, and cultured to marketable-sized fish. This method is suitable for farmers who own a limited number of ponds. In this method, initially, 20 000 000, three-to-five-day-old larvae of mud carp (*C. molitorella*) are stocked per ha, and allowed to grow to a length of 1.5 cm over two weeks, at which point 20 000 mandarin fish fry are stocked. The advantage of this method is that it is simple to operate, it requires a smaller pond area, and saves on investment and labor. The disadvantages are low survival rate due to small stocking size. In contrast, the staggered-stocking method is when fry of 3 cm are first cultivated to large-sized fingerlings, then stocked in ponds and

Figure 3.7.5 An intensive mandarin fish culture pond.

cultured to table-size fish. This method is usually adopted by enterprises and farmers with facilities for large-scale production. The large-sized fingerlings can be cultivated in ponds or cages. In this stage of large-size fingerling cultivation, the stocking density of mandarin fish fry of length of 3 cm was 60 000 to 75 000 per ha or 100 to 150 per m^3 in cages. After about 40 days, most fry reach fingering size of 50 g. Large-sized fingerlings at a stocking density at a rate of 15 000 per ha are transferred in to grow out ponds where prey fish have been prepared. The advantages of this method are low mortality and high economic returns, and the disadvantages are higher technology demand for farmers, more pond space requirement and higher investment costs.

3.7.6.1.3 Prey Fish Feeding

Live small fish and shrimp can be used as prey fish for mandarin fish. Previous studies have documented that *C. molitorella, C. mrigala, L. rohita,* silver carp, bighead carp and crucian carp, can be considered as optimal prey fish for mandarin fish (Li *et al.* 2014b; Yao and Liang 2015) (Figure 3.7.6). Mandarin fish showed apparent size-selectivity in lakes (Li *et al.* 2013a). The ratio of prey fish length to mandarin fish length ranged from 0.12 to 0.53, and the body depth of all prey fish captured was never more than the gape of mandarin fish (Li 2011). Therefore, availability of palatable prey fish is crucial for mandarin fish culture in ponds because prey size that is too large or too small might affect normal growth. Yao and Liang (2015) have listed the size range of palatable prey fish at different growth stages of mandarin fish (Table 3.7.1). Daily food consumption decreased from 70 percent to 7.2 percent of the body weight of mandarin fish7 with the corresponding increase in body weight from 0.5 g to 500 g (Table 3.7.2). In general, the feed conversion ratio of mandarin fish is four to five. As such, the pond area needed for cultivation of prey fish has to be at least four times higher.

3.7.6.1.4 Daily Management

Mandarin fish are sensitive to changes in environmental conditions, especially changes to dissolved oxygen (DO) and ammoniacal nitrogen. Mandarin fish has a high dissolved oxygen (DO) requirement (Yao and Liang 2015). Previous studies have reported that suffocation point of mandarin fish is 3.1 times, 5.1 times and 12.5

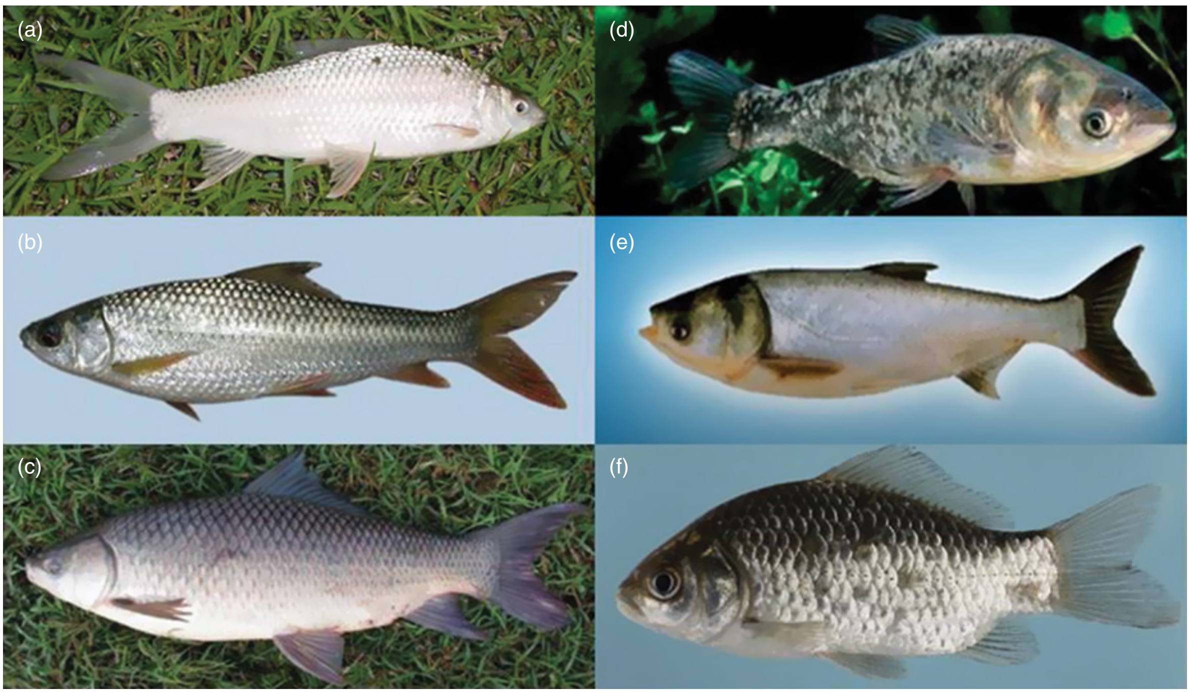

Figure 3.7.6 Prey fish commonly used for mandarin fish pond culture. (a) *C. moliotorella*; (b) *C. mrigal*; (c) *L. rohita*; (d) *A. nobilis*; (e) *H. molitrix*; (f) *C.auratus*.

Table 3.7.1 Size range of palatable prey fish at different growth stages of mandarin fish.

	Total length (cm)					
Mandarin fish	3–10	11–15	16–20	21–25	26–30	31–35
Prey fish	1.5–4.0	3.0–6.0	4.0–7.5	5.0–9.5	6.0–12.0	7.5–14.0

3.7.2 Daily food consumption of mandarin fish at different growth stages.

	Mandarin fish				
Total length (cm)	3	10	17.5	22.5	30
Body weight (g)	0.5	14.5	92.0	190.0	500.0
Daily food consumption (% of body weight)	70%	16.5%	11.0%	7.7%	7.2%

times higher in comparison to silver carp, common carp and crucian carp, respectively (Si *et al.* 1995). So it is necessary to keep dissolved oxygen above 4.0 mg/l in mandarin fish culture ponds. Previous studies had indicated that a safe concentration of ammoniacal nitrogen was 0.052 mg/l under 25°C and at of pH 7.9 for mandarin fish fingerlings (Yao and Liang 2015). However, mandarin fish can grow faster when the concentration of ammoniacal nitrogen is less than 0.025 (Yao and Liang 2015). Other environmental factors, such as pH, water temperature, turbidity and phosphorous, should also be regulated well (Li *et al.* 2013 b).

3.7.6.2 Co-Culture in Ponds

Co-culture of mandarin fish in ponds with other aquatic animals has been an emerging practice over the past ten years. In this practice, mandarin fish is not the main culture species, but plays a major role in controlling abundance of low-valued small fish which may compete for feed with the main farming species. The advantage of this practice is that it saves feed costs, increases production, and increases revenue compared to ponds without mandarin fish.

3.7.6.2.1 Co-Culture with Other Commercial Fish Culture

This practice is usually conducted in ponds which mainly culture species such as grass carp, silver carp, bighead carp, crucian carp, black carp, yellow catfish, *Pelteobagrus fulvidraco*. These species are fed commercial feeds; however, some proportion of the feed is consumed by all kinds of low-valued small fish which may have been introduced accidently into ponds when filling up. Mandarin fish, as a predator, and is stocked to control such small fish. In order to prevent mandarin fish harming the main culture species, its stocking size is strictly controlled, ensuring that the total length of the main cultured species is generally 1.5 times larger than that of mandarin fish. The stocking number can be determined based on the principles that make full use of small fish, and do not require stocking of extra prey fish. The maximal stocking number is not more than 750 fry (3–5 cm) or 300 fingerlings (8–12 cm) per ha under general conditions. In this practice, additional production of about 162 kg mandarin fish can be obtained amounting to about 8100 RMB extra revenue per ha.

3.7.6.2.2 Co-Culture with Crab (Also See Chapter 3.2)

The area of Chinese mitten crab (*Eriocheir sinensus*) farming has increased to around 667 000 ha since 2009 (Zhou and Zhou 2011). An experimental study has indicated that crab was rarely preyed on by mandarin fish (Luo *et al.* 2012). Therefore, stocking mandarin fish into crab monoculture ponds was gradually accepted by farmers, and has become a popular pond culture mode in China (Wu 2014). The mode has been adopted in over 200 000 ha of ponds in Jiangsu Province. Pond size of this practice is about 1 ha, and of which at least 60 percent of the area is covered by submerged plants such as *H. verticillata*. Generally, 9000 large-sized crab seed with an average weight of 10 g are stocked per ha before April, followed by about 400 mandarin fish fingerlings of an average length of 10 cm in June. In the meantime, 450 silver carp and bighead carp fingerlings are each stocked to regulate water quality, as this is a common practice utilized in Chinese crab farming (Wang *et al.* 2016).

3.7.6.3 Stock Enhancement of Mandarin Fish in Lakes

In the past decades, a major conventional fishery practice in many lakes of China has been to overfish piscivorous fish and to stock herbivorous species (e.g. grass carp), and planktivorous species (e.g. bighead carp and silver carp) (Liu and He 1992; Li *et al.* 2010). Such fishery practices often cause a series of ecological problems. Overfishing of commercially important piscivorous fishes induced a dramatic decline of these resources, resulting in small-sized fishes flourishing (Cao *et al.* 1991; Liu *et al.* 2005). Overstocking of grass carp results in a drastic reduction or elimination of submersed macrophytes and consequently, results in an increase in algae and a decline in fish and shellfish dependent on macrophytes (Xie *et al.* 2000). To increase bighead and silver carp production, sewage and fertilizers are used in some lakes, which accelerate eutrophication (Chen 1989). Piscivorous fish stocking can be used as a lake restoration tool to improve water quality by creating a trophic cascade (van Liere and Gulati 1992; Søndergaard *et al.* 1997), also can be profitable at relatively low yields (Liu *et al.* 1998; Cui and Li 2005). Therefore, there has been a shift in fish stocking from common carps to piscivorous fishes, especially mandarin fish, in the past ten years. Mandarin fish has been stocked in many lakes totaling over 133 000 ha in the middle and lower reaches of the Yangtze River (Li *et al.* 2014a). It is well documented that the practice can obtain better economic and ecological benefits (Cui and Li 2005; Li *et al.* 2014a).

3.7.6.3.1 Stocking Sites

In order to prevent possible negative effects of mandarin fish stocking on lake ecosystems, it is vital to ensure that mandarin fish has been previously recorded in this lake. It is suggested that the stocking sites for juvenile mandarin fish should have moderate densities of aquatic plants (Li 2011), because those sites have more available prey fish, and also provide refuge for mandarin fish, which consequently raises the survival rate of juvenile mandarin fish.

3.7.6.3.2 Stocking Size

The choice of stocking size of mandarin fish is an important factor for the success of the practice. Stocking size is tightly related to stocking cost and its potential survival rate. In general, the larger the fry or fingerlings, the higher the survival rate, as well as cost. In natural water bodies, availability and palatability of prey is also vital for the survival of mandarin fish larvae, so species, density, and biomass of prey should be surveyed to determine the stocking size of mandarin fish. If prey is abundant and palatable, 3-cm-long fry are usually suggested; if not, at least 5-cm-long fingerlings are recommended.

3.7.6.3.3 Stocking Numbers

It is generally believed that the stocking number can be determined based on prey and other predators. This is an easy, empirical approach, but with this method it is difficult to guarantee the accuracy of stocking numbers. In reality, there are many parameters which need to be addressed for determining the stocking number, including the bioenergetics model of mandarin fish, the ratio of production to biomass of prey fish, prey energy density, predator energy density, prey biomass, predator biomass, and water temperature, utilization ratio of prey by mandarin fish, survival rate of stocked larvae, and so on.

The above parameters have been investigated by the Group of Fisheries Ecology, Institute of Hydrobiology, Chinese Academy of Sciences since the 1990s, the results of which helped develop an estimation method of rational stocking number of mandarin fish in different water bodies was proposed (Li *et al.* 2014a). The process of estimation method is shown in Figure 3.7.7. First, annual prey consumption of a single mandarin fish larva is determined based on field data and bioenergetics model of mandarin fish built by Liu *et al.* (1998). Second, annual production of prey in a stocked water body is estimated on the basis of biomass of prey and P/B coefficient (Zhang 1998a, b, c). Third, potential fishery productive capacity is calculated. Last, the rational stocking number is determined on the basis of the survival rate of stocked MF larvae and biomass and structure of wild MF population.

3.7.7 Major Challenges to Up-Scaling Mandarin Fish Culture

3.7.7.1 Diseases

Diseases have been one of the important obstacles to sustainable development of mandarin fish culture. Increasing stocking densities used in pond culture practices have resulted in increased disease outbreaks, especially in the past ten years. Three pathogens have been reported to be associated with diseases in mandarin fish culture, including parasites, bacteria and viruses. Parasitic diseases induced particularly by infusorians such as *Trichodina* spp. and *Chilodonella* spp., were commonly observed in the seed cultivation stage, which severely affect larval survival (Gao and Nie 2001). Bacterial and viral diseases usually occur in the grow-out stages. Bacterial pathogens included *Cytophaga columnaris*, *Aeromonas hydrophila* and *Acinetobacter baumannii*. Viral diseases mainly caused infectious spleen and kidney necrosis virus (ISKNV). Rate of loss due to bacterial and viral diseases in mandarin fish farming accounted for more than 60 percent (Huang and He 1999). Outbreaks of disease have been primarily caused by stress-induced factors. Previous studies have revealed that stress factors including high stocking density, the deterioration of water quality, degradation of seed quality, and improper management making the stock susceptible to infectious pathogens (Huang and He 1999).

3.7.7.2 Seed Quality

Increased seed demand has created concerns about seed quality. Seed quality can directly affect survival and economic benefits. Previous studies have indicated that disease-free broodstock sources of mandarin fish are

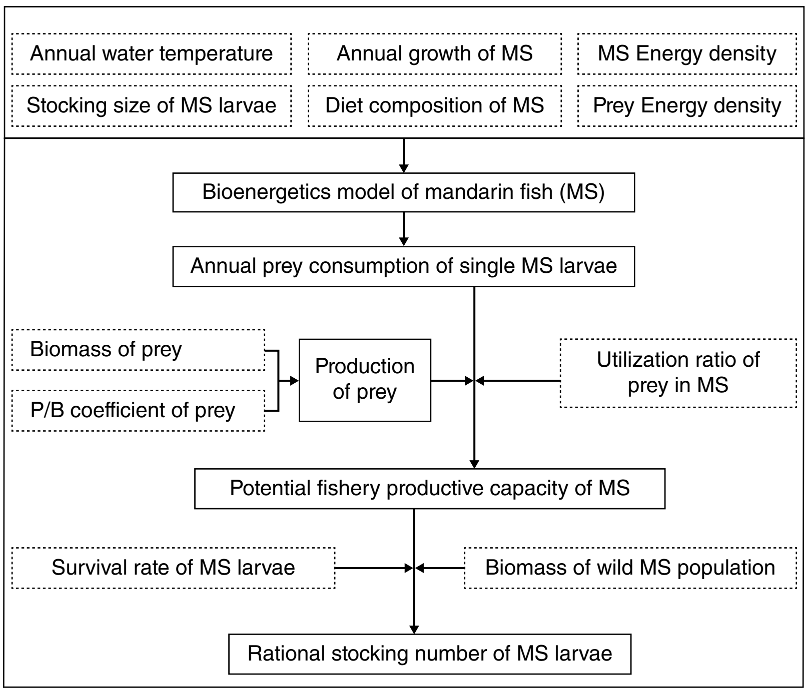

Figure 3.7.7 Flowchart of estimation method of rational stocking numbers of mandarin fish in different water bodies. *Source:* Adopted from Li *et al.* (2014).

vital for their seed quality. For example, comparative studies on viruses of broodstock from the Yangtze River and the Pearl River Delta have been examined and it was found that all broodstock from the Pearl River Delta carried Mandarin Fish virus. Juveniles from the Yangtze River showed stronger resistance to disease, and faster growth compared to those from the Pearl River.

3.7.7.3 Environmental Effects

The environment of mandarin fish culture is not only directly related to its production and quality, but also has a potential impact on the external aquatic environment. Compared to previous years, higher mortality of stocked juveniles and lower survival rate at harvest recently have been observed. These are associated with poorer water quality. Meanwhile, large amounts of effluent from intensive culture ponds are a source of pollution, causing degradation of water quality in lakes and rivers. Wang (2015) reported that effluent from mandarin fish culture ponds had negative effects on water quality, and on the diversity of macrobenthos in the littoral zones of Lake Luhu. Therefore, improvement of the culture environment, and the control of effluents from mandarin fish pond culture systems to minimize external environmental pollution, are a crucial issue in enabling sustainable development of mandarin fish culture. Efforts to minimize environmental pollution, such as the construction of ecological ditches, application of in-situ remediation technology, recommendations on controlling stocking density, and strengthening environmental awareness of farmers, have been attempted for many years.

3.7.8 Conclusions

Mandarin fish have been considered as a valuable food fish since ancient times in China. Currently, mandarin fish farming is in a rapid growth phase in terms of culture area and production, and plays an important role in optimizing the freshwater aquaculture sector. Equally, being an important predator the mandarin fish can regulate the community structure of fish, and improve water quality in large water bodies. The success of mandarin fish farming can be attributed to the breakthroughs in artificial propagation and culture techniques, high economic benefits and available markets, and being able to utilize advantages of natural conditions of large water bodies. Although mandarin fish farming has encountered some problems that could impact on its sustainability, there have been being various studies and pilot projects to support and promote sustainable production modes. Consequently, it is believed that mandarin fish farming will remain as a stable and sustainable development in China.

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3.8

The Success of Yellow Catfish Aquaculture in China: From Rare Wild Fish to Popular Farmed Fish

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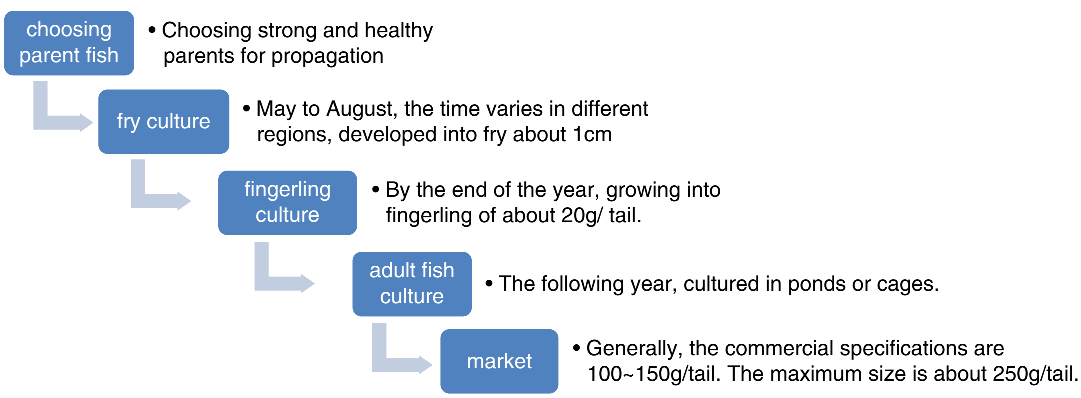
3.8.1 Introduction

Pelteobagrus genus includes five species, namely, yellow catfish (*P. fulvidraco*), vachelli (*P. vachelli*), bearded catfish (*P. eupogon*), gloss catfish (*P. nitidus*) and the intermediate catfish (*P. intermedius*) (Zhu *et al.* 1999). The yellow catfish (Figure 3.8.1) is widely distributed in a range of river basins including the Yangtze River Valley, in China. It is an omnivorous, demersal species with optimal growth temperatures ranging from 25°C to 28°C. Its resistance to low oxygen conditions is poor, requiring dissolved oxygen (DO) concentrations greater than 2 mg/l to satisfy normal development. The characteristics of its flesh are nutrient-rich, with excellent firmness and high elasticity (Ma *et al.* 2015), and its has the highly favorable feature of having no intermuscular bones, making it desirable for human consumption.

Commercial culture of yellow catfish requires a relatively short period of only two years to bring hatched eggs to market-size fish. The fry can be cultivated as large-sized fingerling by artificial propagation within one year, and then intensely fed thereafter to bring them to market size within twelve months.

In 2003, yellow catfish culture in China was only in its infancy, with a yield of less than 50 000 tonnes. With the advancement of fingerling cultivation technology, large-scale aquaculture has gradually developed, generating a steady annual increase in production. The growth rate of male yellow catfish is approximately 30 percent faster than their female counterparts (Liu *et al.* 2007). Since 2007, a focus on the development of an all-male yellow catfish aquaculture, through selective breeding, has greatly improved productivity. Today production is nearing 400 000 tonnes per year. It has become an economically vital component of the freshwater aquaculture industry in China.



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In 2014 in freshwater aquaculture, yellow catfish accounted for 1.19 percent of total annual production in China. Classified as a "special species", it can generate high economic benefits. According to the China Fishery Yearbook, the total production of "special species" was 4 170 000 tonnes in 2013, of which yellow catfish accounted for 290 000 tonnes, or seven percent. Compared to other native carp species, such as grass carp (*Ctenopharyngodon idellus*) and silver carp (*Hypophthalmichthys molitrix*), gross production of yellow catfish could be noted as negligible, but its high market price has created unique opportunities. Currently, the retail value of farmed yellow catfish is 18–21 RMB per kg (6 RMB = 1 US$), and its price fluctuation is dependent on market prices. The price of its wild counterpart is usually 60 RMB per kg.

3.8.2 Current Status of Yellow Catfish Culture

3.8.2.1 The History of Yellow Catfish Aquaculture

At the end of the twentieth century, yellow catfish aquaculture was only in its initial stages of development. Fry were collected from the wild, making it difficult for it to develop into a large-scale sector. High market prices at that time drove the initiative to develop artificial propagation, and large-scale culture. In 1999, yellow catfish were artificially bred for the first time in China, and with this achievement came the foundation of the success of this species in aquaculture (Wang 1999). However, this breakthrough in artificial breeding technology did not immediately result in an increase in production. Problems arose with the larval rearing stage, where lack of knowledge on feeding habits, swimming, and disease prevention inhibited large-scale development (Chen and Zhen 2000). A low fry-survival rate, and inadequate fingerling supply were also limiting factors.

Between 2001 and 2008, yellow catfish aquaculture entered a period of rapid development. Focus was centered on developing good aquaculture techniques. First, large-sized fingerling cultivation technology evolved that provided adequate fingerling for large-scale culture. Second, there was a growing interest from many fish farmers in yellow catfish polyculture in ponds, and also the rearing together with other aquatic species such as culter (*Erythrocutler ilishaeformis*) (Ruan and Chen 2006), mandarin fish (*Siniperca chuatsi*) (Zhang 2003), shrimp (*Macrobrachium nipponense*) (Xu 1995) or soft-shelled turtle (*Pelodiscus sinensis*) (Lei *et al*. 2008) in

Figure 3.8.1 Yellow catfish, *Pelteobagrus fulvidraco. Source:* Photo by Dapeng Li. (*See color plate section for the color representation of this figure.*)

cage culture farming throughout Hubei, Guangdong, Hunan, Liaoning, and other provinces. By this time, much progress had been made in the large-scale culture of yellow catfish, with production steadily increasing from 55 000 to 114 000 tonnes. The development of yellow catfish feed further triggered the expansion.

Since 2008, with the continuous development of aquaculture technology, yellow catfish production increased rapidly. Feed formulae for optimal nutritional requirement have been determined. In addition, disease prevention and control technology have evolved with more specific drugs to kill pathogens, and water quality regulations are being closely monitored. Currently, disease prevention in aquaculture can be effectively controlled. All-male yellow catfish are now easily bred, and skills in culturing large-sized larvae are developed. With the technological developments, alongside good husbandry practices, high stocking densities are being applied to yellow catfish culture, resulting in higher production. The supply of yellow catfish is not only for the domestic market, but has also expanded to the markets of other Asian countries, such as Japan and South Korea.

3.8.2.2 Yields of Yellow Catfish and Main Culture Regions

Since 2003, yearly production of yellow catfish has been listed in the China Fishery Yearbook (2004–2016) due to its elevated share in the market (Figure 3.8.2). Total production in 2003 was 53 800 tonnes, and reached 114 000 tonnes in 2007, with an average growth rate of 15.7 percent per year. Since then, there has been an even faster growth rate, due to advances in breeding and culture technologies, and aquaculture promotion. In 2013, yellow catfish production reached about 296 000 tonnes. All in all, prospects for the yellow catfish industry are looking good with production soaring almost six-fold in the past decade.

The highest production of yellow catfish occurs in Hubei province followed by Jiangxi, Zhejiang, Sichuan, Guangdong, Anhui, Jiangsu, and the Hunan provinces (Figure 3.8.3). According to specific local conditions the characteristics of development of yellow catfish aquaculture are different from region to region. After undergoing long-term exploration and unremitting efforts, Hubei is currently the national leader in aquaculture technology and production practice. The most famous ecologically-sound, healthy culture model has been developed with advances in disease control and prevention in yellow catfish aquaculture, which has encouraged farmers to readily volunteer to invest in yellow catfish culture. Total production in Hubei was 80 100 tonnes in 2013, accounting for 27.1 percent of the national output. In Guangdong Province,

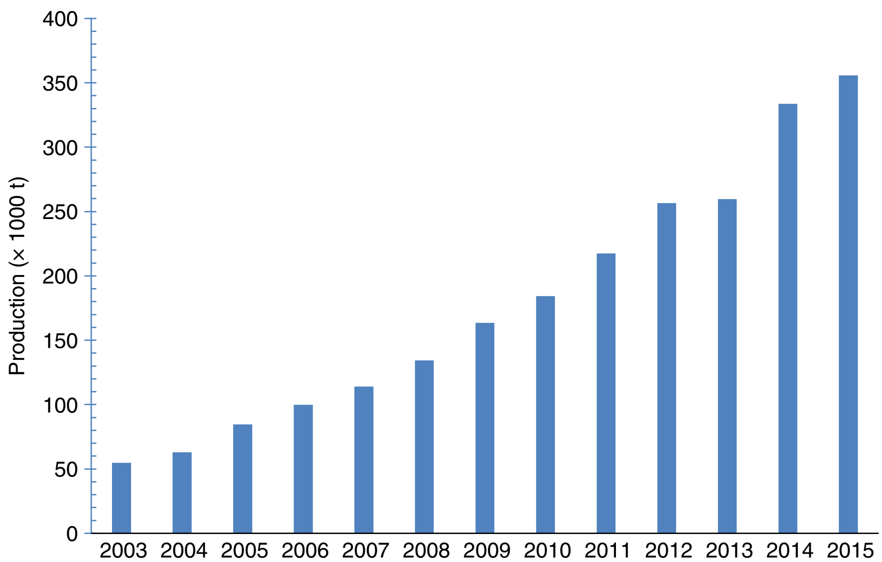

Figure 3.8.2 Annual yield of cultured yellow catfish in China (from 2003 to 2015).

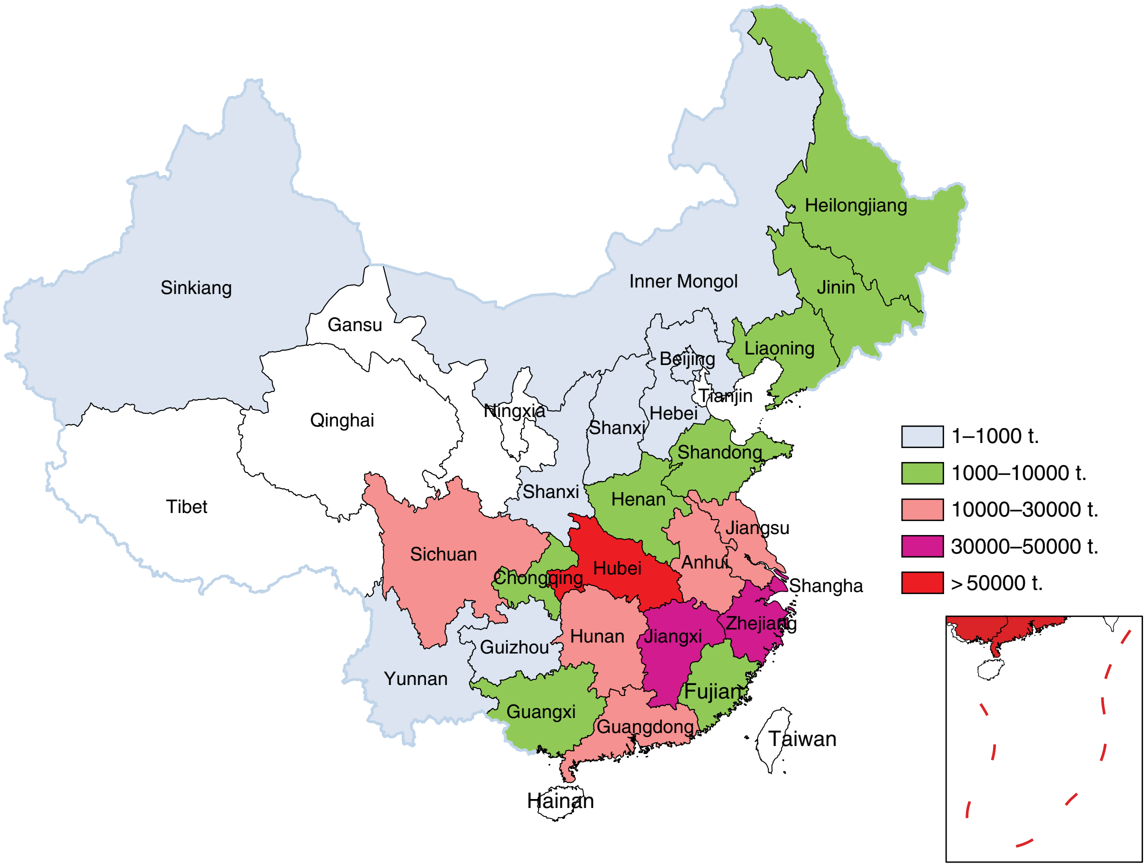

Figure 3.8.3 The production of cultured yellow catfish in different provinces of China in 2013.

high-density culture is very successful, achieving relatively high yields per unit area. In some regions of Guangdong the production can be even up to 2500 kg/667 m^2. The area under yellow catfish culture is highest in Hubei, Jiangxi and Zhejiang. Sichuan Province is in the upper reaches of the Yangtze River with suitable climate, water quality, and superior natural conditions, and where natural seed supply is good. Combined with its local advantages, this province focuses on the breeding technology of yellow catfish. Up to now, it is the most important supplier of fry nationwide.

3.8.2.3 The Main Catfish Culture Models

In China, catfish are cultured in ponds, lakes, reservoirs, rice fields, rivers and other waters. Pond and cage cultures are the main models for catfish production. Currently, pond culture is the most common model, accounting for over 80 percent of production. In large lakes and reservoirs however, cage culture practices were popularized between 2005 and 2011, resulting in a significant increase in areas under cage culture for yellow catfish .

3.8.2.3.1 Pond Culture

Pond culture is divided into two models according to the developmental stages of yellow catfish. One model focuses on fingerling cultivation, the other on commercial-size fish culture. There are differences in culture methods for these two stages.

Fingerling Cultivation Model Fingerling cultivation is a culture process from fry to fingerling, growing to approximately 20 g per individual. With advances in artificial breeding techniques, fingerling cultivation models came into being. Basic requirements for culture habitat include a pond with a flat substrate, adequate water resources, and sufficient acreage (three to five ha). Approximately one month before stocking, a few criteria need to be addressed; ponds need to be drained, the substrate exposed to the sun, and weeds removed from within or around the perimeter. After 15 days, the pond should be filled with water, to a depth of less than 50 cm. There is no need to oxygenate the pond at the same time. Quicklime should be poured into the pond at this stage – this practice kills pathogenic bacteria and harmful organisms, while at the same time adjusting the pH for optimum fish growth. A week before stocking, development of food organisms in the pond are enhanced by adding biofertilizer. Initial ideal feed is considered to be soybean milk, gradually changing to turtle feed, and subsequently yellow catfish crushed diets and pellet diets. In the early and later stages of fingerling development, dietary protein content is about 42 percent and 40 percent, respectively. During the overall growing period, it is necessary to sometimes slowly add water into the pond, and also to oxygenate the system when fish begin to consume crushed diets. One year is generally considered the required time to complete the process of fingerling cultivation.

Table-Size Fish Culture Model Table fish culture is the second stage in growth when fish develop from fingerlings into adults i.e., table-size fish, depending on market demand. Certain parameters for optimum culture are controlled, such as a water depth of two to three meters; dissolved oxygen concentration (DO) greater than 2 mg/l; pH between 6.0 and 9.0; a weed-free pond and perimeter, and good overall water quality. In recent years, the practice of regulating water quality through the construction of circulating water channels, combined with the technology of biological floating beds, has been applied in some regions. Combined with local weather characteristics, there are two methods of pond stocking. In low latitudes, such as Guangdong province, which has a higher temperature in winter, the fingerlings are stocked in early winter and continuously fed on a commercial feed. In this way, cultured fish of a larger size can be marketed earlier. In the higher latitudes, such as Hubei, Jiangxi and Sichuan, fingerlings are not stocked until the end of winter to ensure high survival of fingerlings. At this stage, the protein content of the feeds can be reduced to 38 percent. Stocking density of 10–15 individuals (inds.)/m^2 is widely accepted. In practice, yellow catfish ponds generally contain a mixture of silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*) and grass carp (*Ctenopharyngodon idellus*). Proportions are 200–300 inds./667 m^2 (30 g per ind.), 100–150/667 m^2 (30 g per ind.) and 10–20/667 m^2 (50 g per inds.), respectively. At Gong'an farm in Hubei province, a second economically significant species, the turtle, is cultured in the same pond as yellow catfish; these predate on any weak fish, and improve overall economic benefits. Large-sized fingerlings can be fed on extruded feedstuff. Extruded feed contains a protein content of approx. 38 percent. Approximately 3 percent of the fish body weight is recognized as the optimum daily ration, dispensed in the evening. With careful management, fish can be market ready after eight months.

3.8.2.3.2 Cage Culture

Cage culture of yellow catfish is one of the main monoculture models in China. It is usually practiced in reservoirs, as well as in rivers and lakes (Figure 3.8.4). To prevent the spread of pathogens, cages of yellow catfish are separated from cages culturing other species. Natural flowing water in the culture regions ensures elevated dissolved oxygen (DO) concentrations all year round. There is no requirement for artificial oxygenation intervention or for use of any extruded feeds in this model.

Cages are equipped with hanging weights on the corners, to stabilize the cages and maintain balance. The commonly used net cage size is 5m × 5m, and it consists of three layers (Figure 3.8.5). The first layer of mesh size depends on the size of the yellow catfish. The top edge of this layer is made up of fine mesh gauze, and to a depth of 1 m, preventing feed from floating away which avoids feed waste and subsequent potential environmental pollution. Yellow catfish are cultured in this layer, and the net height is adjusted to 2.5–3m. The second layer is used for culturing large-size silver carp and bighead carp. Based on the filter-feeding habits of

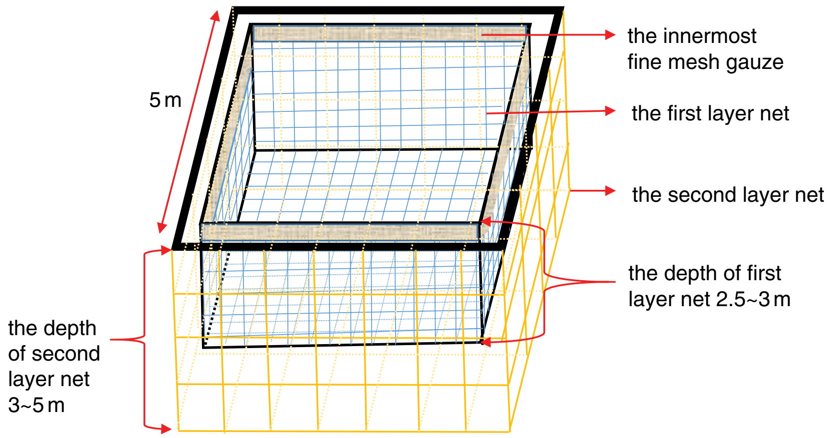

Figure 3.8.4 Schematic diagram of multi-layered cage used in yellow catfish culture.

Figure 3.8.5 Cages for yellow catfish culture located in Qingjiang Reservoir of Hubei Province (photo by Dapeng Li).

these species, they are used to eradicate algae that grow on the net surface, and clean up any residual feedstuffs. The diameter of mesh is about 3 cm, and the depth is 3–5 m. The third layer is installed to prevent fish from escaping; thus avoiding any unnecessary economic loss.

During the culture period, yellow catfish can exhibit significant differences in growth rates. They are therefore sorted into three different weight groups. Mesh sizes also range accordingly, from 2–5 cm for smaller fish, 5–8 cm for medium-sized fish, and 8 cm for market size. Stocking density is approximately 2000–3000 ind./m^2 for the first stage, followed by 1000–1500 ind./m^2 in the second stage and 500–600 ind/m^2 in the third stage. Adult fish are fed twice daily, approximately 2 percent of the body weight.

3.8.3 Main Advances in Culture Technology in the Last Two Decades

After much research over the last two decades, advanced core technology of large-sized fingerling cultivation, and successful artificial propagation methods have been developed. These highly desired advancements are the basis for the robust increase in aquaculture production of yellow catfish.

3.8.3.1 Development of the Breeding Technique

3.8.3.1.1 Artificial Propagation of Yellow Catfish

Artificial propagation is a process promoting the maturation of male and female individuals, and involves artificial insemination and incubation under controlled conditions. The most frequently used method to induce yellow catfish spawning is through injecting carp pituitary gland extract (PG), human chorionic gonadotropin (HCG), and/or luteinizing hormone releasing analogue (LRH) (Wang *et al.* 1989). The expansion of yellow catfish aquaculture, and the consequent increasing demand for fry, prompted rapid development of artificial breeding techniques. A series of breeding methods have emerged. Common procedures are injection of oxytocin agents, natural spawning and fertilization, artificial insemination, or artificial incubation, in large-scale production. In recent years, there are improved reproductive spawning results due to the use of new stimulants.

Parent Fish Cultivation Broodstock to a large extent determine the growth performance of offspring and therefore is the foundation of artificial breeding. In general, two-year-old or older fish are chosen. The reproductive performance of mature fish is enhanced by proper nutritional supplements. In general, two months before spawning, broodstock are fed twice daily, on a ration of 2–5 percent of their body weight. Protein content should not be less than 40 percent. During this period, they are not only fed extruded feedstuff, but also fishmeal. In addition, the water level in the pond is regulated, and water temperature is optimized to promote the earliest maturation of the fish.

Artificial Spawning Healthy and strong mature adult fish can be selected for spawning. The weight of males and females should be at least 180 g and 120 g, respectively. Identifications of male and females, and sexual maturity, are conducted by observing the abdominal outline and genitals on the abdomen. A ratio of 4:1 male to female is used in artificial breeding. During this period, the optimal incubation temperature is between 22°C and 27°C, with a pH of 7.5. The optimal dose of oxytocin for female injection is 200–500 IU HCG+ 5–15 µg/l, and HRH+ 1–3mg/kg DOM for ideal spawning (Zhang *et al.* 2000). The dose for males is decreased by 70 percent from the above level. The base of the pectoral fins is usually chosen as the injection site, where the needle is inserted at 0.3–1.0 cm depth. Two injections can result in spawning, with a time interval of 10–12 hours. Broodstocks are stimulated by slow-flowing water until spawning occurs.

Fertilization Optimal time for oxytocin to exert its ideal effect in artificial spawning ranges between 15–22 hours (Zhang 2014). Artificial fertilization or natural fertilization can be applied to spawning thereafter.

a) ***Artificial fertilization***: Once oxytocin has taken full effect, artificial fertilization must be effected. This involves three steps. First, female eggs are extruded into dry, clean containers (surface water is wiped off the body), meanwhile the testes are removed and blended in a mortar with sperm preservation solution (Formula outlined in Table 3.8.1). Secondly, the prepared testis are put into a container with the eggs and shaken carefully. The third step involves adding two to three liters of water to activate sperm and stimulate fertilization. Fertilized eggs are placed on sterilized fish nests and immersed in hatching jars. Alternatively, the nests may be placed in incubation tanks with an effective re-circling water system, at a density of 8,000 eggs/m^3.
b) ***Natural fertilization*:** After the injection of oxytocin, adult fish are put into the ponds at a ratio of 1:1–1:1.5, female to male. Broodstock should be stimulated with running water, until they are primed and ready for spawning. Complete natural spawning occurs in a specific 'spawning pool'. Once spawning is successfully completed, eggs should immediately be prepared for hatching.

Hatching The spawning pool is located indoors to avoid strong ultraviolet radiation. In general, hatch pool dimensions are 2 × 2 × 1.5 m. Abundant good quality water, with high dissolved oxygen (DO) concentrations (>5 mg/l) are mandatory. Optimal spawning temperatures are 23–28°C. Large-scale production requires a wider temperature range 21–29°C.

Table 3.8.1 Formula for sperm preservation solution.

Chemical	Amount
NaCl	8.00 g
KCl	0.40 g
$CaCl_2$	0.14 g
$MgSO_4 \cdot 7H_2O$	0.20 g
$Na_2HP_4 \cdot H_2O$	0.06 g
KH_2PO_4	0.06 g
$NaHCO_3$	0.35 g
GLU	1.00 g
Distilled water	100 g

Good management during the hatching process is a key component of improving hatchability. The water in the hatching pool should always be exchanged with pond water, filtered through a mesh. Removing opaque unfertilized eggs from the hatching pool will aid in preventing contamination. The use of formalin (50 mg/l or methylthionine chloride water solution every day, or every alternate day, has significant impact on controlling harmful pathogens. Hatching time is dependent on temperature, and ranges from two to three days. Hatching success of yellow catfish is currently above 80 percent.

3.8.3.1.2 Breeding Technology of Yellow Catfish

Improvements in breeding technology have driven the rapid progression of this aquaculture sector. A significant, well-known characteristic of yellow catfish is that males grow faster than females. Achieving fast growth rates, and a high male ratio have improved economic benefits. At present, the main breeding technologies include selective breeding, cross-breeding, cell engineering breeding, genetic engineering breeding, and molecular marker-assisted breeding (Zhang *et al.* 2015).

Selective breeding technology refers to the selection of yellow catfish broodstocks from natural water, with desirable traits for breeding, and the achievement of good growth performance in their offspring. Cross-breeding can produce new varieties with superior genes from parents. For example, the hybridization between yellow catfish *P. fulvidraco* (♀) and darkbarbel catfish *Pelteobagrus vachelli* (♂) result in offspring with attractive color, fast growth and a high resistance to disease and stress.

In recent years, cell engineering breeding of yellow catfish has made a great breakthrough. In 2007, H.Q. Liu, a researcher from the Chinese Academy of Water Ecological Engineering Research Institute, cultivated super-male yellow catfish from females, using a hormonal sex reversal system combined with gynogenesis technology. The characteristics of this method not only shorten the breeding time but also increase the yield of yellow catfish.

Between 2008 and 2010, Liu's team produced approximately 123 000 YY super-males, and 81 000 000 XY male yellow catfish fingerlings. It appears that breeding between YY super-males and YY physiological-females is feasible and fertile (Liu *et al.* 2013).

In April 2011, the new variety of yellow catfish was approved and named the "All-male Release I yellow catfish" by the National Aquatic Primary Variety Approval Committee. In that year, biological technology companies undertook and industrialized the large-scale standardized production of "All-male Release I yellow catfish" larvae. By 2015, the production of these larvae reached 1.5 billion. At present, a healthy industry associated with this particular fish strain is on the rise, including breeding, propagation and promotion, which in turn have accelerated the rapid development of the yellow catfish aquaculture in China.

3.8.3.1.3 Protection of Germplasm Resources

Establishment of Protection Zones of Germplasm Resources The first cluster of protection zones of germplasm resources for yellow catfish was established in Hunan and Hubei in December 2007. These protection zones were named the "National aquatic germplasm resources protection zones of East Dongting Lake carp (*Cyprinus carpio*), crucian carp (*C. auratus*) and yellow catfish (*P. fulvidraco*)" in Hunan, and the "National level aquatic germplasm resources protection zones of Xiliang Lake mandarin fish (*Siniperca chuatsi*) and yellow catfish (*P. fulvidraco*)". From 2008 to 2013, a total of 17 protection zones for yellow catfish were established. They are widely distributed in Hubei, Sichuan, Hunan, Guizhou, Henan, Hebei, Inner Mongolia and Anhui provinces, and provide protection of wild resources (also see Chapter 7.5).

Standards of Yellow Catfish Standards for the production of healthy *P. vachelli* were established in early 2000 and *P. fulvidraco* in 2004. The standard of culture technology in yellow catfish aquaculture was published in 2007. These standards have gradually been updated, and now provide a guide for protecting the genetic diversity and healthy production of yellow catfish.

3.8.3.2 Large-Scale Larval Cultivation Technology

Large-size larval cultivation refers to the breeding process where fish fry are cultivated to a standard size of 20 g per individual. At this early stage, the survival rate is related to the success or failure of yellow catfish larval cultivation. Before the development and success of artificial breeding technology, grow-out was an important step in the culture process. Previously, the survival rate was too low (about 20 percent) to even contemplate implementing large-scale aquaculture. Fish fry cultivation technology gradually advanced over the decades, and survival rates have significantly increased, up to 69.25–95.77 percent (Sun *et al*. 2015).

3.8.3.2.1 Cultivation Conditions

For best management practice, yellow catfish pond area should be at least 0.5–2.1 ha. Pond sediment thickness should be 15–20 cm, to a maximum of 30 cm. Oxygenation should be set to ensure enough dissolved oxygen (DO) is constantly available (no less than 4–5 mg/l). There should always be adequate water in the pond; it should be devoid of weeds, and have a flat substrate, with no cracks or fissures in the cement pool area.

Pond water is initially drained from the pool, and the lining exposed to sunlight (UV rays) for seven days. It is then thoroughly cleaned using quick lime (185–246 kg/ha) or bleaching powder (62–74 kg/ha). After refilling, to a depth of about 20 cm, organic fertilizer is dispersed throughout the pond to encourage the cultivation of plankton, which will be available as fish food. When the rotifer biomass reaches 5000 ind./l (Zhou *et al*. 2013), freshwater is added in order to maintain good water quality and a rich food supply.

3.8.3.2.2 Larval Stocking

On the pond bunds, approximately 1–1.5 m from the pond edge, various crops may be planted. For example, rice may be rooted, or other aquatic plants, attached to the substrate to provide a 'natural-like' habitat for the developing catfish. These attract organic detritus, which can provide a lot of natural food for the growing fish (Ye *et al*. 2014). Before stocking, an oxygen bag containing fish fry is placed on the water surface of the pond. When the oxygen bag temperature is similar to the pond water temperature, the fish are temporarily transferred to a saline solution for two to three minutes for disinfection. Stocking density thereafter depends on pond conditions, but generally it is controlled at a rate of 0.98–1.48 million fry per ha.

3.8.3.2.3 Feeding

There is no need to feed in the first three to five days post stocking. A practice of splashing soybean milk along the pond perimeter is carried out between days 6–13. During the following month, the diet is replaced by soft-shelled turtle feed. At two to three months of development, yellow catfish are given a crushed feed which contains 42 percent protein (this is mechanically fed). Thereafter, they are fed pellets with 40 percent protein, until they reach the end of their larval rearing period.

3.8.3.2.4 Management

In the early stages of cultivation, pond water depth should be maintained at 20–30 cm. As fish fry develop, water depth can gradually be elevated (Xie and He 2014). After two to three months, water depth should be maintained at 1.5–2.0 m. At this stage, surface aerators are necessary, and installed in the middle of the pond to sustain a dissolved oxygen (DO) concentration greater than 4 mg/l. Water color should be observed, and fish activity recorded twice daily, especially morning and evening.

3.8.3.3 Progress in Yellow Catfish Feed Technology

In the early stages of culture, the monoculture feed regime comprised of earthworms (*Pheretima* spp.), grasshoppers (*Acrida cinerea*), barley millet, rice sprouts, and wheat chaff (Ge 1994). In a pond shared with other fish, yellow catfish are not fed on prepared feed, but on a snail (*Cipangopaludina chinensis*) and other natural food (Xu 1995). Subsequently, they progress to fishmeal with vegetables and bran bread.

Studies on artificial feed for yellow catfish have advanced since 2000. During the early period of catfish culture, sinking aquafeed was very popular, resulting in lower feed utilization rate. The feed coefficient of initial artificial feed was as high as 2.7 or so, which hampered the development of catfish feed industry (Peng *et al*. 2000). With the development of the feed industry, the feed coefficient significantly improved. Special feeds for yellow catfish have been developed and the feed coefficients of yellow catfish at present range from 1.3 to 2.0 (Chen *et al*. 2014).

In recent years, Haida, Tongwei, Dabeinong, and other major manufacturers have undertaken the production of formulated feed for yellow catfish (Table 3.8.2). Feed formulation has focused on optimizing growth potential. The raw ingredients of adult yellow catfish feed mainly consist of imported fishmeal, defatted soybean meal, alpha starch, flour, meal, calcium hydrophosphate, L-lysine monohydrochloride, vitamins (A, D3, E, K, vitamin B12), ferrous sulfate, copper sulphate, zinc sulfate, manganese sulfate, allicin and astaxanthin.

With the expansion of cultivation and the maturation of the yellow catfish industry, fish feed is now nutritionally wholesome and characterized by being highly luring, with good palatability, uniform quality, and good water stability with reduced pollution impacts. This has further prompted the large-scale cultivation of yellow catfish. Highly efficient and environmentally friendly feeds have been an attractive trend in national aquaculture.

3.8.3.4 Improvements to Feeding Strategy

The development of nutritionally balanced and environmentally-friendly feed has certainly promoted the possibility of higher stocking densities. Adult yellow catfish prefer feeding in the dark (Yang *et al.* 2006). Specific feeding rhythms have resulted, and are a recognized key in feeding technology. Generally, the daily feeding amounts are divided into a third and two-thirds of the total amounts fed in the early morning and in the late evening, respectively. Successful development of extruded material, and precision feeding technology

Table 3.8.2 The main composition (%) of yellow catfish feed.

Parameter	Proportion
Crude protein	≥40.0
Crude fat	≥3.5
Crude fiber	≤6.0
Crude ash	≤12.0
Calcium	0.7–2.3
Total phosphorus	≥0.75
Lysine	≥1.8
Moisture	≤10.0

minimize feed waste. Thus, under conditions of ensuring highly efficient feeding rates, and following specific growth patterns, stocking densities and optimum yields can be improved. Constant and sufficient aeration throughout the process is critical for a high survival rate. The combined effects of these factors reduce the overall cost of cultivation, and improve the cultivation efficiency of yellow catfish per unit area.

3.8.4 Challenges Confronting Yellow Catfish Aquaculture

3.8.4.1 Disease Prevention and Control

High density and intensive farming has gradually become a popular trend of yellow catfish culture. It is well documented that yellow catfish can be infected by bacterial and parasitic diseases, as well as diseases related to nutrition and metabolism. There is a relatively high incidence of the 'hole in the-head' disease thought to be caused by *Edwardsiella* spp. In addition, there are often outbreaks of hemorrhagic edema disease, induced by the bacterium *Aeromonas hydrophila* during seasons of high temperature. In previous years, the most popular solution to these diseases was drug control. The accumulation of antibiotic drugs in fish tissue will seriously affect food safety, and threaten human health. At present, ecologically sound and healthy water management methods are being developed in various regions. These promotions, however, still need to be enhanced nationwide.

3.8.4.2 Development of the Industry

The development of yellow catfish culture is an important contribution to maintaining the stability of yellow catfish markets. Currently, profits are available for farmers, and there is potential to move into the global market. Yellow catfish is a economically valuable fish. At present, however, yellow catfish are only available in the market as live fish; there has been no yellow catfish processing enterprise in China to date.

3.8.5 Market Aspects

3.8.5.1 Distribution and Marketing

Yellow catfish culture has a good reputation in the domestic market. It is popular among many consumers from various regions. Sale outlets of yellow catfish are widely distributed in Beijing, Shanghai, Chongqing, Shenzhen, Nanjing, and Wuhan.

Yellow catfish are also popular in south-east Asian countries, such as Japan and Korea. It is a good species for export and has huge potential for the export market. In accordance with corresponding laws and regulations in China, some provinces like Zhejiang, Jiangsu and Liaoning, have achieved the exportation of live yellow catfish, which has triggered the rapid development of the farming industry in these areas, and increased economic benefits.

3.8.5.2 Analysis of Economic Benefits

Economic benefits of yellow catfish are higher than the majority of freshwater fish culture in China. From 2012 to 2014, costs of ponds, electricity, drugs, seed and labor were approximately 3.4 RMB per kg fish. Fluctuations in total costs per year are relatively stable (approx. 16 RMB/kg). In 2015, the market price of yellow catfish feed dropped to RBM 7800 per tonne on average, and feed coefficients ranged from 1.1 to 1.8. Total costs were close to 15.1 RMB per kg fish. Between 2012 and 2015, the market price of yellow catfish fluctuated in some major seafood markets (South Central Bridge Market in Suzhou, Baishazhou Market in Wuhan, the Agriculture City in Hangzhou, Tongchuan Market in Shanghai, and other aquatic markets). Although yellow catfish prices have had a downward trend over the past two years, it maintains its high profitability in aquaculture.

3.8.6 Prospects for Yellow Catfish Culture

With the promotion of the 'all-male yellow catfish' breeding technology, and an ecologically healthy and energy-saving production regime, yellow catfish aquaculture certainly has potential for a wider market. Researchers are constantly working on developing better, more environmentally friendly, low phosphorus feeds. Progress in this area is ongoing, and it is now recognized that, with the addition of additives such as vitamin D, phytase and citric acid, inorganic phosphates are reduced. Since 2008, the amounts of inorganic phosphorus have decreased from 2.5 percent to approx. 1.5 percent. Feed producers are now reducing the amount of phosphorus in yellow catfish feed to just 0.5–0.6 percent, and adding phytase at a rate of 1000 IU/kg. It is well documented that nitrogen and phosphorus emissions have decreased by 25 percent and 31 percent, respectively. In addition to these dietary improvements, there are new insights into the molecular mechanisms of sodium-phosphate transporters, which aim at regulating the sodium-phosphate transporter gene expression, to further reduce the emissions of nitrogen and phosphorus in catfish feed.

The technology of all-male catfish farming is advancing. To date, the fourth generation of the "all-male I yellow catfish" strain has been cultivated. The genetic diversity of yellow catfish has reduced by about 50 percent. China's scientists have developed an assembly line for super-male production, which is based on new wild populations, and important indicators such as growth, resilience to disease, and reproductive performance. In addition, with the establishment and back-up of a strong female-bred system, Taguchi orthogonal array analysis is being used, whereby the objective is to produce a high-quality product, at a low cost to the manufacturer. This has resulted in the selection of best performance and the development of a new improved strain known as the "All-male Release II yellow catfish". Compared with "All-male Release I yellow catfish", production of the "All-male Release II yellow catfish" is expected to increase by 10 percent. The most important factor for aquaculture is that this strain has better resistance to disease, and an overall higher survival rate. The advancement of these recent technologies and fish strains is the foundation for better quality seed for large-scale farming.

Acknowledgments

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3.9

Aquaculture of the Paddy Eel, *Monopterus albus*

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3.9.1 Introduction

Monopterus albus, commonly referred to as the rice field and or paddy eel, and/or swamp eel, are small freshwater fish distributed in rice fields, ponds, lakes, ditches, and other shallow water bodies, and are widely distributed in China in every province except Tibet. Research on *M. albus* in China began in 1942, when academics H.W. Wu and C.K. Liu began to observe and study its biology, and discovered the sex reversal trait of *M. albus* (Wu and Liu 1942; Liu 1944; Liu 1951; Liang and Li 1995; Zou 2000). Since then, researchers have focused on biological characteristics, such as age-related growth (Chen 1998; Wang *et al*. 1985; Yang 1991, 1993, 1997; Yang *et al*. 1993), sex reversal (Liem 1963; Chan 1976; Han 1988; Liu *et al*. 1990; Tao and Lin 1991, 1993, 1994; Zhao and Ke 1992; Song *et al.* 1994; Xiao 1995; Teng 2001; Yang *et al*. 2008), feeding habits (Yang *et al*. 1997), reproductive habits (Xu and Zhu 1987; Han 1988; Zhao *et al.* 1990; Yang *et al*. 1994, 1999; Cao 1998), reproductive physiology (Zhou 1990, 1995; Zhang 1994a, 1994b; Zou 2000), etc. Findings from these studies have indicated the rates of growth, feeding in different growth stages and breeding behaviors, and the mechanisms and processes of sex reversal (Liang and Li 1995), all of which have contributed to the gradual development of culture of the paddy eel.

M. albus is a popular food source in China, and wild resources are unevenly distributed; abundant in summer and autumn, and scarce in winter. In order to ensure a year-round steady supply, culture of *M. albus* in many areas of the mid–lower reaches of the Yangtze River were explored in the 1950s. The earliest culture method used concrete pools, with ~20 cm soil on the bottom and aquatic plants, simulating natural ecological conditions for breeding of *M. albus*. However, *M. albus* domestication was not achieved, and its culture stagnated from the 1960s to 1980s. Since the late 1990s, a research team based at Yangtze University began to explore *M. albus* cage-based culture technology in rice fields in Honghu, and other places in Hubei Province. A cage-based *M. albus* culture experiment was conducted by placing large-scale cages (8 m × 4 m × 1.5 m) in rice fields in Daijiayang Town, Honghu City, Hubei Province, in 1998. In total, 100 cages (32 m^2 per cage) were used. A total of 6400 kg of wild *M. albus* was produced in June 1998, yielding 12 000 kg of *M. albus* at the end of 1998, with a sales revenue of RMB 2.4 million (6.0 RMB = 1 US$), and a net profit of more than RMB 70 000. The success of this culture model quickly led to the development of *M. albus* aquaculture. Aquaculture of *M. albus* began to reach a larger scale in 1999, when the yield of cultured *M. albus* reached 2000 tonnes in Hubei Province. As the culture techniques were simple and easily popularized, it spread rapidly to the surrounding areas of Honghu in Hubei province. The yield of cultured *M. albus* exceeded 30 000 tonnes in 2001. Around 2002, experiments of cage-culturing *M. albus* in ponds commenced. The pond-based culture approach rapidly replaced cage-culture of *M. albus*, and was promptly adopted in Hubei Province in 2003.

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This technique gradually expanded to Anhui, Jiangxi and Hunan provinces (located in the middle and lower reaches of the Yangtze River) by 2004.

In order to promote the development of the swamp eel aquaculture industry, most researches focused on the farming technologies (Pan and Li 1999; Cao 2000; Qian 2000; Zhang 2000; Yang *et al.* 2006), reproduction technologies (Zhao 1989; Chen and Cao 1994; Chen 1999; Dong *et al.* 1989; Yang *et al.* 1999), nutrition (Shu *et al.* 2000; Yang *et al.* 2002) and digestive physiology (Bai *et al.* 1997; Yang *et al.* 1997, 2003, 2006, 2007, 2008). These studies have proven the requirements of major nutrients, and revealed the digestive functions. On this basis, formulated feeds have been developed and widely applied, and technologies of cage culture in ponds have been improved.

Currently, cage culture in ponds (CCP) of *M. albus* has become the main model for its culture in China. The culture areas include 18 provinces/cities (Figure 3.9.1), the most important being Hubei, Jiangxi, Anhui and Hunan provinces (Table 3.9.1).

Aquaculture yields of *M. albus* rose from 2000 tonnes in 1999 to 357 991 tonnes, valued at RMB 23.27 billion in 2014 in China, a 179-fold increase over 15 years. Accordingly, *M. albus* has become a major cultivated freshwater species in China.

3.9.2 Culture Techniques and Methods

3.9.2.1 Cage Culture in Ponds (Ccp)

CCP is the main *M. albus* aquaculture technique in China, characterized by simple culture conditions, easy management, and good yields (Figure 3.9.2). At present, *M. albus* yields obtained through CCP account for more than 95 percent of the total production in the country.

Figure 3.9.1 The main areas of *M. albus* culture in China (marked in red).

Table 3.9.1 Trends in the yield (t) of *M. albus* in different provinces in China (2009–2013). Data from the China Fishery Statistical Yearbook.

	Year				
Province	**2009**	**2010**	**2011**	**2012**	**2013**
Shanghai	40	0	9	16	5
Jiangsu	8026	7521	7092	7307	7200
Zhejiang	660	730	911	906	1124
Anhui	29593	36453	38814	40806	43643
Fujian	641	630	781	725	698
Jiangxi	56544	71129	74472	77332	79472
Shandong	678	2112	2483	2453	2083
Henan	1736	1811	1700	1740	2452
Hubei	99620	110694	123835	144398	161837
Hunan	24556	27006	28079	28635	29999
Guangdong	2049	2698	1761	2559	2267
Guangxi	1348	1414	1508	1649	1699
Hainan	369	384	348	352	365
Chongqing	598	542	608	687	746
Sichuan	9866	9377	9429	10510	11409
Guizhou	139	192	248	308	465
Yunnan	477	202	195	275	321
Shaanxi	42	44	137	308	319
Total	237034	272939	292410	320966	346077

Figure 3.9.2 Cage culture in ponds (CCP) of *M. albus*. (*See color plate section for the color representation of this figure.*)

3.9.2.1.1 Requirements for Pond Water and Cages Settings

1) *Water Requirements* A pond area of 1-10 acres (4046.86–40 468.60 m^2) is generally preferred for CCP. A water depth should be around 120–180 cm, and the bottom of the pond should be flat.
2) *Cage Specifications* Generally, ~4–10 m^2 cage size is preferred, as large cages make management difficult, and small cages result in relatively high costs. Cage height should be ~80–100 cm.
3) *Production and Setting up of Cages* Cages are made of knotless polyethylene netting with ~30 meshes (0.3–0.5 cm mesh size). Cages are set up in parallel rows, 3 m apart from each other with a distance of 1 m between cages (Figure 3.9.2) in a row. The optimal ratio of total cage area to pond area should be 40–50 percent. The cages are required to be 50 cm above the water surface to prevent escape of *M. albus*; the bottom of the cages should 50 cm above the bottom of pond to maintain good water quality through efficient water exchange between cages and outside.

3.9.2.1.2 Preparations Prior to Stocking

1) *Soaking of Cages* Cages are soaked in the pond for at least seven days but preferably up to a month. This soaking will enable green algae to grow on the cage surface thereby preventing injury to *M. albus* when stocked.
2) *Cage Layout* Macrophytes are planted early on in the cages. Water peanut (*Alternanthera philoxeroides*) is the most commonly used as its roots provide a habitat preferred by *M. albus*. The area covered by plants in should not exceed two-thirds of the cage area.
3) *Cage Disinfection* Before stocking, the water body and cages should be sterilized to prevent diseases. Possible disinfectants include bleaching powder, strong chlorine, chlorine dioxide or lime. The disinfectant should be distributed evenly across the entire pond, using the following dosages: bleach 10 mg/l, TCCA 2 mg/l, chlorine dioxide 2 mg/l, quick lime 30–50 mg/l. After seven to ten days of disinfection, *M. albus* fry can be stocked.

3.9.2.1.3 Stocking of *M. albus*

1) *Stocking Time* The time of year of stocking impacts on survival and the numbers harvested. Higher survival is recorded when stocking early in the year. For example, stocking of artificially propagated fry in early April can increase yields by four to six times a year, but if stocked in July the yield will increase approximately two-fold. In the middle- and lower Yangtze River areas farms dependent on wild caught fry/fingerlings have to wait until July for the supplies.
2) *Stocking Size* The size at stocking is mostly dependent on the proposed harvesting size. If aiming for a harvest weight of 100 g within one year, the stocking size should be >35 g per fish. If aiming to rear *M. albus* for two years, the stocking size should be ~10–20 g; these young will reach an average weight of 50–60 g at the end of the first year and >200 g after the second year.
3) *Stocking Density* Under normal circumstances, when the stocking density is low, *M. albus* will grow fast and the harvest size will be large, but resulting in low yields per unit area and vice versa. Therefore, a density of 1–2 kg/m^2 is considered appropriate.

3.9.2.1.4 Feed and Feeding Techniques

1) *Types of Feed* In the wild, the diet of *M. albus* consists mainly of small invertebrates; therefore, their aquaculture feed should mainly be animal-based, including small low-valued fish such as silver carp, clams, worms and shrimps. Tests have shown that a rational combination of formulated feed and animal feed will result in improved yields.
2) *Feeding* It is important to wean *M. albus* to formulated feeds gradually. When first stocked it should be provided with an animal feed, in the form of a paste/dough, and over a three-to-five day period, the amount of animal paste reduced and formulated feed proportion increased.

Once weaned to a formulated feed *M. albus* are fed according to four principles (including timing, fixed location, quantitative and qualitative standards). Feeding time is chosen to be at 17.00–19.00 hr every evening, so that *M. albus* can feed after dark. Generally, they are fed only once a day. A relatively fixed feeding point is set up for each cage. The daily ration is estimated to be ~5 percent of total weight of *M. albus* cultured.

3.9.2.1.5 Management

Management includes the following steps:

1) *Regulation of Water Quality* The primary aim is to prevent deterioration of the water quality. In this regard regular and timely water exchange and stabilization of water levels in ponds are encouraged.
2) *Regulation of Water Temperature* The water temperature should be maintained within a range suitable for growth and feeding of *M. albus*. The method is (1) to use low-temperature water, such as well water or river water; (2) to ensure that the planting area with the water plants (for example *A. philoxeroides*) accounts for ~80 percent of the total cage area to shield from the sun, reducing exposure to direct sunlight.
3) *Culture of Water Plants* Using plants in *M. albus* pools has the following effects: (1) prevents sunstroke and to cool; (2) improves water quality through absorption of excess nutrients in the water, and preventing organic matter from polluting pond water; (3) provide habitat for *M. albus*; and (4) to provide thermal insulation. Thus, water plants in the pools are indispensable. The aim of water plant management is to prevent the plants from growing leaves outside the cage, which would allow *M. albus* to escape, while ensuring that the area of water plants does not exceed 80 percent of the cage area. Dead and decaying plants should be removed.
4) *Grading* It is necessary to check *M. albus* growth every month to separate individuals of different sizes.
5) *Prevention and Treatment of Disease* Disease prevention should be conducted mainly through regular water disinfection, and administration of drugs mixed with the feed. Under normal circumstances, water should be disinfected once every 15 days; feed mixed with drugs should be applied once approximately every ten days. Salt, bleaching powder and povidone-iodine should be used to disinfect feed.

3.9.2.2 Soilless *M. albus* Culture in Slow-Flowing Water

Soilless culture using slow-flowing water is a new way of intensively raising *M. albus* that has been developed recently. Compared with the still water soil-rearing method, the characteristics of this method include large culture density, fast growth, high yield, low cost, and convenient harvesting, resulting from using flowing water, which improves water quality and increases the dissolved oxygen (DO) in the water.

3.9.2.2.1 Water Requirements

A water supply maintaining normal physical and chemical characteristics of the culture environment by continuous renewal of water is the most important feature of this technique. Ideally, a daily water exchange of 15 m^3 should be guaranteed for each 100 m^3 of culture. Thus, the following conditions are required: abundant, unpolluted water, low organic matter content, and minimal temperature differences between day and night. Water can thus be divided into the following categories:

i) Reservoir water: generally, the water in reservoirs is very clear, abundant in dissolved oxygen (DO), with low organic matter content, and low numbers of harmful bacteria and parasites; therefore, it is excellent culture water. A water layer ~1 m below the surface should be used, as the temperature of this water layer is constant, with almost no diurnal temperature variation.
ii) Well water: groundwater is one of the preferred water choices for *M. albus* culture. Such water is fresh, with few impurities, almost no harmful bacteria or parasites, but three points should be taken into account: it must be ensured that the water quantity can meet required needs, the water must have

adequate aeration, using a reservoir for equilibrating temperature before use, and the well water should not contain toxic substances.

iii) River water and lake water: the water is rich in dissolved oxygen (DO) due to natural flow, but it generally contains more impurities and organic matter, with a certain turbidity, and might contains more pathogens. If such water is selected for *M. albus* culture, a reservoir should be built for sedimentation and/or for necessary disinfection.

iv) Pond water: As concentrations of organic matter and plankton are very high, this type of water should be avoided.

3.9.2.2.2 Planning and Design of *M. albus* Pools

The culture ponds/raceways are brick or concrete, generally of 1.0 m × 0.5 m × 0.5 m (length × width × height), and the pool walls and bottom are glazed. Flowing water in the form of ponds/raceways are aligned in several rows, with a pool depth of 10–15 cm. A plastic foam board is fixed on the surface of the water. The foam board area accounts for approximately one-third of the concrete pond area, with a thickness of ~3–5 cm. Inlet pipes and drainpipes of PVC of 10 cm diameter should be independent of each other. These are placed horizontally on one side for each row of the concrete raceways, and as high as the pond border. Inlet branch pipes for each concrete pond are installed on top. The total inlet pipe is the same as the total drain pipe in terms of material and bore diameter. The total inlet pipe is placed opposite the total outlet pipe, at the bottom of the concrete pond, in which numerous holes should be provided. The appropriate size for these holes should allow dirt to be discharged smoothly, but prevent *M. albus* from escaping. There should be a certain slope from the inlet to the outlet at the bottom of each pond to facilitate discharge of dirt from the pond. The layout of a flowing-water culture pond is shown in Figure 3.9.3. Reservoir should be constructed in proportion according to the size of the *M. albus* ponds/raceways. Accordingly, for a storage capacity of 100 m^3, the reservoir should exchange 15 m^3 of water every day.

3.9.2.2.3 Preparations Prior to Stocking

After construction of the *M. albus* ponds/raceways, they should be filled with water, allowing them to soak for 15 days, and then the water should be changed completely.

Figure 3.9.3 Soilless *M. albus* culture using slow-flowing water in China.

3.9.2.2.4 Stocking

1) It is generally better to release *M. albus* fry on sunny days in early summer, at an optimal water temperature of 25–28°C. At this time of the year, diurnal temperature differences are small, and *M. albus* transportation and delivery will not be stressful to the fish, and will cause minimal mortality.
2) Stocking density: Stocking density is determined in accordance with the facilities, food sources, the size of *M. albus* fry, and management techniques on each farm. A stocking rate of 3.0–5.0 kg m^2 is the commonest. In farms with better facilities and management stocking rates of 8–10 kg per m^2 could be used. If the size of *M. albus* fry is large, then the number stocked should be relatively reduced and vice versa.
3) Notes on *M. albus* stocking: First, sufficient *M. albus* fry should be placed in each pond each time. Second, the size of *M. albus* fry should be consistent in each pond to prevent cannibalism. Third, the pond should be soaked and disinfected for five to ten minutes using 1–2 percent salt water before stocking, and to eliminate weak or ill *M. albus* to reduce disease incidence during the culture process.

3.9.2.2.5 Feeding

Formulated feed and animal feed, such as worms, should be selected for *M. albus* culture. Animal feed is first minced and mixed with formulated feed at a ratio of 3:7 prior to feeding. *M. albus* fry should not be fed during the first two days after release into pond/raceways, allowing them time to adapt to the new environment. After three to five days of acclimatization, *M. albus* are fed normally. Daily feed consumption should approximate 4–6 percent of *M. albus* weight. They should be fed twice a day, first around 09:00 hr, then around 19:00 hr. The inlet and drain valves should be turned off before feeding, and then turned on again after a period of time.

3.9.2.2.6 Daily Management

M. albus ponds/raceways should maintain a gentle water flow, around 0.05–0.10 m^3/h, and waste should be discharged twice a day (at approximately 09:30 and 19:30 hr, respectively, after feeding is completed). Water flow can be increased appropriately when discharging contaminants. A plastic cover/roof may be constructed over the pond to increase temperatures in cold seasons; a shading net may be used to cover the pond, and water intake should be increased to reduce temperatures in the hot season. The water temperature should be maintained at 25–28°C. Dead and weak *M. albus* fry should be removed to prevent blocking of the inlet/drainage system. The fish are graded into large, medium and small size groups every month to maintain similar-sized groups in every pond/raceway. Disinfectants are applied every 15 days.

3.9.2.3 Cage *M. albus* Culture in Greenhouses

Currently, pond-cage culture of *M. albus* is the commonest in spite of its shortcomings, such as large space requirement, being affected by ambient temperature changes, a short culture cycle, and relatively low yields. This mode of farming is limited to the south of the Yellow River. Recently, the high-density greenhouse (plastic) cage aquaculture technique has been developed, and this approach has the potential to overcome the above shortcomings.

3.9.2.3.1 Design and Construction

The area of each plastic greenhouse is ~300–600 m^2, with an arc-shaped frame structure, a roof height of 2.8–3.0 m, a shed width of 6–8 m, a length of 50–100 m, and a roof covered with thick, colored plastic film. There should be provision to lift the films at both ends of a greenhouse, facilitating ventilation and cooling in summer. The greenhouses are equipped with lights and heating pipes. The greenhouse temperature is increased by circulation of steam in pipes during winter to maintain a constant water temperature of 25–28°C.

Two parallel, long ponds are excavated along the two sides of the greenhouse, and a path of 1.5 m width is provided in the center. The pond depth is about 0.8–1.0 m, and are lined with black polythene film to prevent water leakage. The top edge of the film is 0.5–0.8 m above the pond, and the film is fixed, using a frame made

Figure 3.9.4 *M. albus* cage culture in plastic greenhouses. (*See color plate section for the color representation of this figure*.)

from pipe and wire. The water depth in the pond is maintained at 0.5–0.8 cm. Inlet pipes and drainpipes are independent from each other. Inlet pipes are located on top of one side of the pond, whereas the drain pipes are ~10 cm below the pond bottom. A drainpipe is installed every 10 m and a spillway is installed every 20 m to keep the water level stable (Figure 3.9.4).

Specifications for *M. albus* culture cages are 2 m × 2 m × 1 m (length × width × height). The cages are made of 20-mesh polyethylene mesh. When cages are installed, the cage bottom is maintained ~20 cm above the pond bottom. Cage spacing is ~1 m. *A. philoxeroides* are planted more than ten days in advance of stocking. The water plant area should account for >90 percent of the cage area.

3.9.2.3.2 Stocking

Healthy *M. albus* fry free from injury or disease should be chosen. Fry are disinfected by soaking in 2 percent salt solution before stocking. The entire pond should be disinfected with 2 mg/l bleach 10 days before stocking. The stocking density should be 5–6 kg/m^2.

3.9.2.3.3 Feeding

Feed should be a mixture of formulated feed and fresh animal bait, such as worms and fish. Fresh animal bait and formulated feed are mixed in equal proportion, and delivered in the designated open water area. *M. albus* fry are not fed for the first two days after release into the ponds. After three to five days of acclimatization, *M. albus* are fed normally. Daily feed consumption should be around 8–12 percent of the stock weight. Feeding time should be at approximately 19:00, once every day.

3.9.2.3.4 Management

This culture technique has the following advantages compared to the cage culture techniques in a pond: (1) high culture density, fast growth, low costs, and easy harvesting; (2) all-year-round culture, stocking and commercial harvesting can be controlled effectively, resulting in higher remuneration by avoiding peaks of availability; (3) a survival rate exceeding 90 percent (4) yield per unit area five- to eight-fold and net profit per unit area increased more than five-fold.

3.9.3 Innovations of *M. albus* Culture Technology over the past Decade

3.9.3.1 Improvements of Culture Models

The traditional *M. albus* culture method (CCP) in China was as follows: concrete ponds with bottom soil, still water, and aquatic plants to simulate natural conditions. Although this culture method simulated natural conditions, water quality deteriorated fast. In summer, such ponds warmed up making the stock vulnerable to disease, and causing mortality. In order to overcome these adverse effects, a culture method using embedded cages in rice fields was developed around 1998; and after further improvements, the method of soilless cage culture in ponds was developed. The CCP method had several shortcomings, such as a short culture cycle (only from April to October, even shorter in northern China), resulting from being constrained by natural conditions, and exposure to the elements. In recent years, the method of greenhouse-based cage culture has been developed, which can extend the culture cycle by ~3 months. This indoor culture facilitates management, further improves unit yield and culture efficiency, and culture of *M. albus* can be extended to northern China.

3.9.3.2 Adjustment of Stocking Timing When Wild Fry is Used

Until 2000, *M. albus* culture was based predominantly on wild-caught fry, and the main stocking period was from April to May. During this period, the water temperatures were still low and resulted in a lower rate of injury and suffocation rates during transport. However, *M. albus* suffered from low-temperature stress when transported in water below 20°C, and wild-caught fry had a low survival rate when stocked in early April–May. Studies conducted over three years indicated that the optimum period for fry transportation and stocking is in the summer from late June to July, when the temperature in the middle and lower reaches of Yangtze River is 25–28°C. At this time the survival rate of released *M. albus* fry can reach >95 percent.

3.9.3.3 Development and Use of Formulated Feed

M. albus mainly requires animal feed, feeding on fish, shrimp and worms in the wild. A formulated feed was developed in 2005, thus solving the shortage of feed supply for large-scale *M. albus* culture. In addition, the use of formulated feed may reduce the cost of *M. albus* aquaculture, and reduce deterioration of water quality, allowing for an increase in scale of *M. albus* aquaculture.

3.9.3.4 Artificial Propagation and Fry Rearing Techniques

The bulk of *M. albus* fry used in aquaculture is wild caught. With overfishing and degradation of the natural environment, wild *M. albus* fry resources have become increasingly exhausted. If artificial mass propagation had not been developed there would have been a scarcity of seed stock in a few years, and the industry would have ceased to exist.

M. albus breeding technology is complex because of the following three issues: *M. albus* have sex-reversal characteristics; initially, mature individuals are female and become male after spawning (Zou 1996). Therefore, spawning females are small and have low fecundity, and mass fry rearing is difficult to achieve. Also *M. albus* are cannibalistic, and therefore care has to be taken in mass rearing. Currently, a new technology based on ecological methods, by focusing on improving *M. albus* fertility, artificial propagation, and fry-rearing methods, have been developed and are widely practiced (Zou 1996).

First, *M. albus* sex change is regulated by adjusting density, and a nutrient stress-based approach used for postponing the sex reversal of females for more than a year. The fecundity of such female parents is 3.29-fold higher than from those from the wild of comparable age. Second, development of an eco-breeding technology has solved the problem that artificial spawning methods easily lead to mass mortality of *M. albus* parents; however, it cannot be applied to large-scale production practices as yet. After use of this technique, spawning rates reached 90 percent, hatching rates reached 99 percent, and fry breeding density was up to $1081/m^2$. A gender regulation technology based on the ecological method has also been developed. 'Circulation Gentle-Flowing Grid-Breeding *M. albus* Fry Technology' has solved the problem of cannibalism, increasing the survival rate from 30 percent to 90–95 percent.

3.9.4 Current Problems in *M. albus* Culture

M. albus aquaculture has developed rapidly, and is growing, but there are still some problems hindering its growth. These are summarized below.

3.9.4.1 Rapid Expansion, Affecting Healthy Development of a *M. albus* Culture Industry

M. albus culture is highly profitable. In order to obtain higher returns in a short time frame, many aquaculturists blindly expand the scale of operations, even if they have not mastered key culture techniques, and lack reliable avenues for resourcing fry. Such operations pay limited attention to fry quality, often resourcing fry of a wide size range which leads to cannibalism, and loss of stock. This affects the scale and efficiency of *M. albus* culture.

3.9.4.2 Lack of Consistent Fry Quality and Quantity

At present, *M. albus* artificial propagation technology has not been popularized extensively, and it is still difficult to provide large quantities of seed stock at any one time. As such *M. albus* fry are mainly wild-caught. However, wild-caught *M. albus* fry resources are decreasing gradually, due to environmental degradation and overfishing, making it difficult to meet demand and, thus limiting the development of large-scale aquaculture of the species. Wild-caught *M. albus* are likely to have injuries due to improper fishing methods or long-distance transportation, resulting in low survival rates. High mortality occurs at 7–15 days after stocking.

3.9.4.3 Effects of Unregulated Feeding

M. albus is carnivorous. At present, most culturists mainly provide earthworms, small low-valued fish, and other live bait for *M. albus*, and formulated feeds only account for a small proportion. However, wild animal feed resources are limited, and also often encounter seasonal imbalances of supply. *M. albus* are prone to cannibalism when fed irregularly. Using live feed also helps to introduce enteritis diseases and bacterial Tail rot disease, leading to uneven sizes of mature *M. albus*, and low yields, thus severely limiting the development of large-scale culture.

3.9.4.4 Delayed Disease Prevention and Treatment

Disease is the most common problem in large-scale *M. albus* culture, especially during April–June (the introduction and domestication stage) and from September to October (the culture stage). Some farmers experience mortality rates as high as 60–100 percent, resulting in huge economic losses. Several types of disease occur during the culture cycle of *M. albus*, the most common being bacterial hemorrhagic disease, enteritis disease, unfinished ending disease, big head disease, and skin erosion; in addition, parasitic diseases, such as spiny-headed worm, capillariasis, trypanosomiasis, trematodiasis; black spot disease, fungal infections, and leeches occur (Yang *et al*. 2008 b). If some diseases, such as hemorrhage, tail-rot disease, inflammatory bowel disease or fever, if not prevented or treated timely, could result in high mortality. However, research on these diseases is insufficient, the causative agents or causes of many diseases are unknown, and prevention, treatment methods, and drugs mainly follow recommendations for other fish species. In view of its burrowing behavior and scale-less skin *M. albus* requires specific modes of administration and dose of medication.

3.9.4.5 Lack of Standardized *M. albus* Culture Techniques

The quality of cultured *M. albus* has always been a focus of attention. Although *M. albus* culture is popular in China, the sector is dominated by small-scale farmers, culture units are numerous and scattered, and culture techniques are not standardized. Thus, it is difficult to ensure quality of mature *M. albus* in the market, due to a lack of effective quality monitoring systems. All this affects sales of *M. albus*, and threatens the sustainable development of this industry. It is necessary to study standardized production technology, and formulate technical specifications for healthy *M. albus* culture. Large-scale experiments and demonstrations units in the main *M. albus* culture areas should be developed, in order to ensure that processes are normalized, standardized and pollution-free.

3.9.5 Conclusions and Prospects

Based on existing problems future research should focus primarily on the following aspects:

3.9.5.1 Mass Production of *M. albus* Seed Stock

Artificial propagation of *M. albus* has been listed as a key research topic in some provinces on the middle and lower reaches of the Yangtze River, and some crucial breakthroughs have been made in this regard. It is expected that mass production of *M. albus* seed stock will be solved within a few years through application and dissemination of novel breeding techniques.

3.9.5.2 Diversified Investment Sources

Modern mass production is inseparable from the support of large and medium-sized enterprises, and the same applies to aquaculture production of *M. albus*. As *M. albus* culture has high economic returns, this industry has begun to attract the attention of some companies. In addition, some large aquaculture firms have started to invest in this industry, and investment diversification will be gradually achieved.

3.9.5.3 Scale of Production

At present, intensive factory-like *M. albus* culture has begun to be implemented. With the participation of private investors, and the achievement of investment diversification, as well as large-scale production of artificial *M. albus* breeding techniques, small-scale production will be replaced by intensive, factory-like mass production on a large scale.

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3.10

Aquaculture of the Large Yellow Croaker

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3.10.1 Introduction

The large yellow croaker (also known as the Croceine croaker) [*Larimichthys* = (*Pseudosciaena*) *crocea*] (Figure 3.10.1), endemic to East Asia, was once one of the three top commercial marine fishes of China. The croaker is mainly limited to coastal waters of continental East Asia. It occurs in China and south-west South Korea, including the East China, northern South China and southern Yellow Seas; Taiwan and South Korea lie at the edges of its range so the species is largely endemic to China (Chu 1960; Tian *et al*. 1962; Xu *et al*. 1962, 1984a, b; Huang and Walters 1983; Kawasaki 1987; Kong *et al*. 1987). Fish live down to about 100 m, mostly down to 60 m, over soft muddy or sandy substrate, and adults and juveniles share the same habitats and are typically caught together (Xu and Wu 1962; Yang and Zheng 1962; Kong *et al.* 1987).

Three putative geographic stocks of the croaker were initially identified in coastal waters of China, i.e. the Daiquyang (Taichuyang), Min-Yuedong (Min-Uehtung) and Naozhou (Naochow) stocks (Figure 3.10.2) (Liu and Sadovy 2008; Zhang *et al*. 2011). Classifications were based on morphological characteristics including numbers of gill rakers, lateral branches of the swim bladder, and vertebrae, ratios of eye diameter to head length, depth to length of caudal peduncle, and body depth to length, as well as biological characteristics such as sexual maturity, spawning season, and maximum and average age of samples taken in coastal waters of China around 1960 (Tian *et al*. 1962; Xu *et al*. 1962, 1984a, b). Although there are no similar biological studies conducted in South Korea and Taiwan, the croaker in South Korea is considered to be part of the Daiquyang stock on the basis of its likely migration pattern (Kong *et al*. 1987; Lin 1987) (Figure 3.10.2).

Heavily exploited since the 1950s, wild stocks were so severely depleted by the 1980s that most individuals subsequently sold originated from hatcheries. After peaking at about 200 000 tonnes in the mid 1970s, catches of the croaker in China declined by over 90 percent within two decades; according to most criteria the croaker was categorized as a “threatened” species, and management measures, including restocking, were developed. The extensive government-sponsored mariculture program introduced to address food supply and overfishing in the 1980s, particularly of the croaker, was one of the earliest for marine finfish, not only in China, a nation with a rich and highly successful history in aquaculture, but globally.

Aquaculture in China: Success Stories and Modern Trends, First Edition.
Edited by Jian-Fang Gui, Qisheng Tang, Zhongjie Li, Jiashou Liu, and Sena S. De Silva.

Figure 3.10.1 Adult specimen of the large yellow croaker.

3.10.2 Development of Large Yellow Croaker Culture

3.10.2.1 Starting Phase (1985–1995)

In 1985, in order to protect and restore natural resources of large yellow croaker, the former Ministry of Agriculture, Livestock and Fishery of China, and the former Fujian Provincial Department of Aquaculture determined that the "Artificial propagation of large yellow croaker" as a major scientific objective in Fujian Province. This research project was jointly implemented by Eastern Fujian Fisheries Research Institute, Fishery Technology Extension Station in Ningde region, and Sansha Fisheries Corporation. Wild stocks of large yellow croaker were used to research artificial propagation and cultivation technique.

3.10.2.1.1 Broodstock Collection, Artificial Fertilization and Fry Rearing

The spawning season of large yellow croaker in the Guanjingyang spawning ground is generally from May to June. The project team captured broodstock using drift nets from May to June, 1985, and then chose female fish of around 2 kg and at least three years old, and male fish at least two years old of about 1 kg to practice artificial fertilization, and fry rearing.

The large yellow croaker lives in the middle and lower water depths and when fish are caught and brought to the surface from a depth of 10–60 m, the stomach is regurgitated due to inflation and rupture of the swim bladder. To avoid this, researchers invented an effective method. Briefly, before bringing the fish to the surface, a needle was inserted 1.5–2.0 cm toward the direction of the node at the base of pectoral fin, or inserted about 1 cm above the anus. When the needle reaches the front or rear of swim bladder, the abdomen is pressed lightly, forcing the air in the swim bladder to escape through the needle hole. This technique can effectively keep broodstock alive for follow-up artificial fertilization work.

During 1985–1986, researchers captured 32 large yellow croaker broodstock at Guanjingyang spawning grounds from six batches. In total of 1 570 000 mature eggs were obtained from 24 female broodstock, and 1 115 000 fertilized eggs were obtained through artificial fertilization (Su *et al*. 1997). As it was difficult to capture wild broodstock, in May 1987, the project team selected 20 pairs of broodstock from domesticated large yellow croakers for artificial spawning. Of these 20 pairs, one pair of broodstock spawned with more than 10 000 fertilized eggs, and over 100 fry were successfully nursed, which made a fundamental breakthrough on completing artificial propagation.

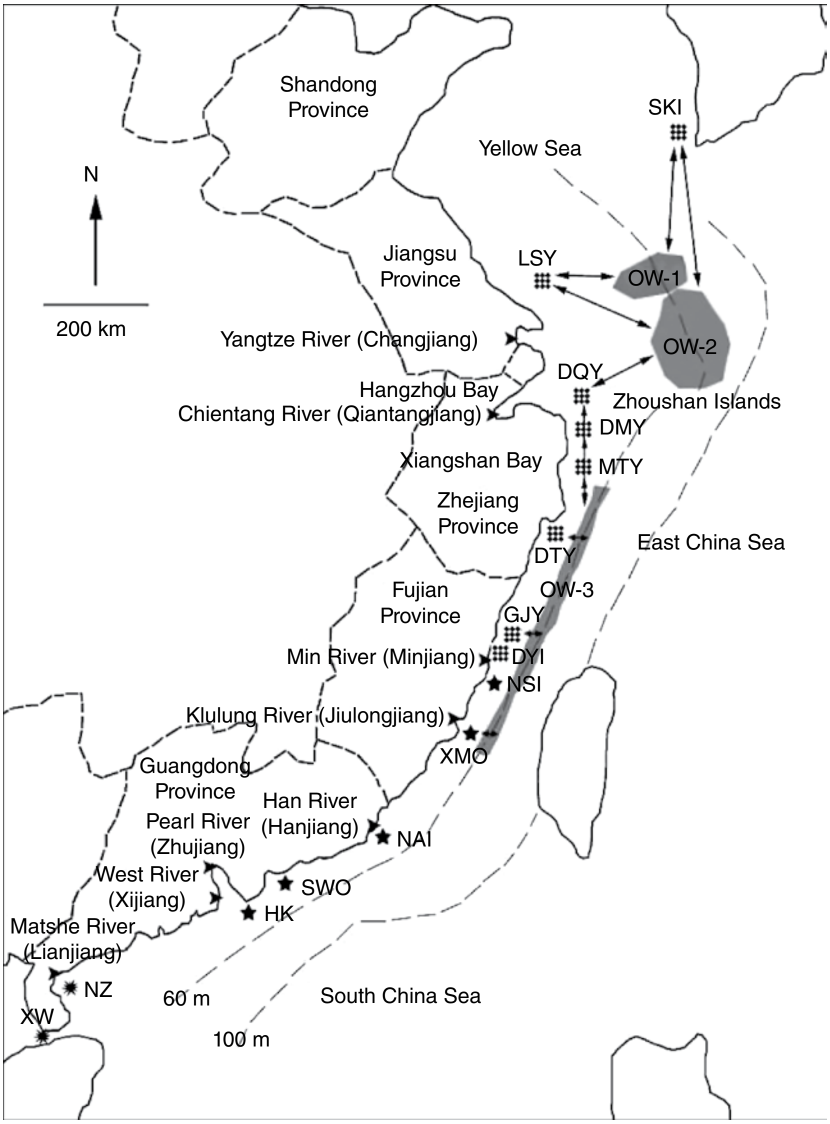

Figure 3.10.2 Geographic distribution, spawning and over-wintering grounds (shading) of the large yellow croaker (*Larimichthys crocea*, Sciaenidae) in coastal waters of China and south-west South Korea (20–36° N and 110–127° E) (modified from Liu and Sadovy 2008). There are three putative geographical stocks along coastal waters of China, the Daiquyang (tiles), Min-Yuedong (5-point starts) and Naozhou (starbursts) stocks. Full names of spawning grounds (n = 15) are given with old names in parentheses. From north to south, these are: SKI, South Korea-inshore; LSY, Lvsiyang (Luszeyang); DQY, Daiquyang (Taichuyang); DMY, Damuyang; MTY, Maotouyang (Miaotouyang); DTY, Dongtouyang (Tongtouyang); GJY, Guanjingyang (Kuanchingyang); DYI, Dongyin island; NSI, Niushan island; XMO, Xiamen (Amoy)-offshore; NAI, Nanao-inshore; SWO, Shanwei (Swawei)-offshore; HK, Hong Kong; NZ, Naozhou (Naochow); XW, Xuwen. OW-1, over-wintering ground in the southern Yellow Sea (32°00′–34°00′N); OW-2, over-wintering ground in offshore northern Zhejiang Province (30°30′–33°00′N and 124°00′–126°30′E); OW-3, over-wintering ground between southern Zhejiang and southern Fujian Provinces (OW-3, 23°30′–29°00′N). Two-way arrows indicated inferred fish migrations.

The effective spread of key technologies, such as broodstock rearing, artificial spawning, and fry rearing of large yellow croakers, made it possible to expand the scale of artificial propagation. In 1990, a million fry were produced through artificial propagation, and the sector was no longer reliant on wild-caught broodstock for fry production. In order to promote the development of large yellow croaker breeding, researchers further studied technologies of broodstock rearing and food organism cultivation in cold seasons, advancing the artificial breeding season of large yellow croaker from late spring and early summer to early spring (January–March).

Based on the success of artificial propagation of large yellow croaker, at the beginning of the 1990s, the Fujian government planned to carry forward commercialization of large yellow croaker artificial propagation. In 1991, Fujian Provincial Department of Aquaculture launched the project on "Development and research on cultivation techniques of large yellow croaker" (1991–1995). Following this project, Fujian Provincial Science and Technology Committee approved projects on "Development and research of artificial breeding technology of large yellow croaker" (1992) and "Research and development of cultivation technology of large yellow croaker along Fujian coast" (1994–1996). Farmers rearing large yellow croaker made significant economic gains. The economic benefits from artificial propagation of large yellow croaker began to come into prominence, boosting commercialization, and stimulated the development of the cage aquaculture industry of endangered large yellow croaker, making it the largest cage culture industry of any marine fish in China.

3.10.2.2 Developing Phase (1995–2000)

With strong support from the Ministry of Agriculture of China, Fujian Provincial Science and Technology Committee, and Fujian Provincial Department of Aquaculture, several projects were approved, such as one on the "Harvest Project" named "Healthful aquaculture technique in earthen ponds for large yellow croaker" (1997–1999) and "Technical research on large yellow croaker breeding industry" (1998–2000); the large yellow croaker breeding industry grew rapidly, and fry output doubled and redoubled year on year. In 1996, there were only 20 hatcheries for artificial propagation of large yellow croaker in Fujian Province. However, since 2000, artificial propagation technology had been introduced to several coastal provinces such as Guangdong, Zhejiang, Taiwan and Jiangsu, and a total of 500 hatcheries were built nationwide, with a total annual fry output of about 1.5 billion. Fujian Province alone has 430 hatcheries, with an output of about 1.3 billion fry (Table 3.10.1), providing sufficient fry resources for the development of large yellow croaker aquaculture industry.

At the beginning of the twenty-first century, large yellow croaker fry cultivated in Fujian Province not only supplied local farms, but also sold to other regions, such as Taiwan, Guangdong, Zhejiang, Jiangsu, Hebei, and Liaoning for rearing tests. The fry were mostly transported in ships with running water, and the survival rate was above 90 percent.

In 1998, Fujian Provincial Science and Technology Committee, united with Fujian Provincial Department of Aquaculture, and launched the project of "Breeding industrialization of large yellow croaker"; established a technical service team on the artificial propagation of large yellow croaker in Fujian Province; and conducted

Table 3.10.1 Trends in the changes in the number of hatcheries (Hatch.) and the total fry production of large yellow croaker, in different regions of Fujian Province from 1997 to 2000.

	1997		1998		1999		2000	
	Hatch.	Fry (x 10^4)	Hatch.	Fry (x 10^4)	Hatch.	Fry (x10^4)	Hatch.	Fry (x 10^4)
Ningde	44	11700	66	46200	183	72900	370	118800
Fuzhou	3	400	6	1500	25	10300	57	10150
Xiamen	4	250	4	200	3	150	3	150
Zhangzhou	3	100	10	300	3	110	–	–
Putian					1	60	2	150
Total	57	12450	86	48200	215	83520	432	129250

Source: From Zhang *et al.* (2002).

research and practices, including "Intensive cultivation and development of fry raising technique of large yellow croaker". In order to transform scientific results into practice as soon as possible, Fujian Provincial Science and Technology Committee, and Fujian Provincial Department of Aquaculture organized cooperation between research institutes and production enterprises, making several breakthroughs in the artificial propagation techniques of large yellow croaker after years of practice and studies. Among the breakthroughs were:

- the cultivation period from fry (ca. 3 cm in body length and ca. 25 g in body weight) to market-sized fish (ca. 350 g) was shortened to 18 months, or even one year at the soonest, from the original two and a half years;
- the maximum survival rate of fry to market-sized fish reached over 90 percent;
- the survival rate of fry to market-sized fish was generally above 50 percent, and resulted in remarkable economic benefits.

From 1997 to 1999, there were 30 000 directly employed and 200 000 indirect employees associated with large yellow croaker culture. Fujian Province drove the development of related industries, such as market-related communications, and transportation, domestic and foreign trade, cage manufacturing, feed processing, service and catering. As estimated, in 2000, the output value of food copepod for fry exceeded 100 million RMB (6 RMB = 1 US$). Large yellow croaker aquaculture became a new economic growth point of the aquaculture industry in Fujian Province. In 1999, there were 2176 hm^2 sea areas occupied by 99 019 sea cages with an annual output of 18 875 tonnes of large yellow croaker aquaculture in Fujian. The total earthen pond area was 522.67 hm^2 with an annual output of 1990 tonnes.

In 2000, in Fujian Province, 300 000 sea cages and 600 hm^2 earthen ponds were utilized for aquaculture, forming the first industrial-scale production, which influenced other provinces, cities and districts, such as Zhejiang, Guangdong, Taiwan, and Jiangsu to follow suit. The development of the industry created huge social and economic benefits, while at the same time other problems, such as quality degradation, contamination of broodstock, and high frequency of diseases began to occur.

Production of large yellow croaker reached 300 000 sea cages in 2000; the aquaculture yield increased up to 70 000 tonnes from 1997 to 2000, creating over 2 billion RMB output value and more than 1 billion RMB of taxes and interests (Table 3.10.2). Aquaculture products were mainly sold to such cities and counties as Beijing, Shanghai, Ningbo, Hong Kong, Korea and Japan.

In 1996, in Xiangshan, Putuo and Yuhuan, Zhejiang Province, researchers successfully conducted artificial propagation of yellow croaker belonging to Min-Yuedong stock reared in sea cages. In 1999, a project on the artificial propagation of large yellow croaker belonging to Daiqu stock was launched, and successfully obtained over 300 000 fertilized eggs, and cultivated about 300 000 fry of 2 mm at the Tunshan Test Base of Zhoushan Fisheries Research Institute in 2000. Following these breakthroughs, the scale of large yellow croaker aquaculture expanded rapidly, and became industrial scale in Zhejiang Province.

Table 3.10.2 Production of large yellow croaker in Fujian Province and its ratio to other sea-cage cultured marine fishes in China (1997–1999).

	Large yellow croaker				Other marine fishes		Ratio of large yellow Croaker to other marine fishes	
		Yield (t)						
Year	No. of cages	Cage	Earthen ponds	Total	No. of cages	Yield (t)	Cages (%)	Yield (%)
1997	30632	3778	415	4193	132730	24461	23.1	17.0
1998	65316	8450	910	9360	185928	36688	35.1	25.5
1999	99019	18875	1990	20865	258324	38930	38.3	53.6

Source: From Zhang *et al.* (2002).

3.10.3 Development and Promotion of Industrialization (2011– to Date)

Since 2000, with the support of the Ministry of Science and Technology of China, the Ministry of Agriculture of China, Fujian Provincial Department of Science and Technology, and Fujian Provincial Department of Ocean and Fisheries, several projects have been conducted. Among these are "Breeding technique for quality improvement of large yellow croaker ", "Cultivation of high-quality and stress-resistant variety of large yellow croaker", "Genetic improvement and aquaculture demonstration of large yellow croaker", and "Standardization of large yellow croaker aquaculture techniques". Moreover, original stock management, disease control, environment monitoring, technical training, and an information network for large yellow croaker were established; "Development Program for Dominant Culture Area of Large Yellow Croaker in Fujian Province" was compiled; and the national original stock farm of Guanjingyang large yellow croaker in Fujian, the Ningde reproduction station of Guanjingyang large yellow croaker, and the Ningde disease control station of aquatic organism were built.

In November, 2011, Zhejiang Province launched "The industrialization of Daiqu-stock large yellow croaker aquaculture", with an annual yield of over 3000 tonnes. Furthermore, Zhejiang Province started large-scale offshore sea cage culture of large yellow croaker, effectively developing ecological aquaculture, and greatly promoting yield and quality.

In October, 2015, the Ministry of Science and Technology of China approved the construction of the State Key Laboratory of Large Yellow Croaker Breeding by Ningde Fufa Fisheries Co., Ltd. This is the first State Key Laboratory of aquaculture enterprises in China.

To date, applied research and farming practice of large yellow croaker have resulted in several remarkable achievements which are enumerated below:

- technical research and industrialization of artificial propagation and new techniques of large-scale aquaculture established;
- two varieties of large yellow croaker were successfully bred;
- the whole genomic map of large yellow croaker was drawn;
- the state-level stock seed farm for large yellow croaker was constructed. The farm has 300 cages with 150 000 m^3 of waters, maintains about 9700 broodstock and 21 000 reserve broodstock, which effectively protect the germplasm genetic resource of large yellow croaker;
- wind- and wave-resistant cages were set up with over 120 000 m^3;
- a service platform for disease control, integrating disease surveillance, warning and forecasting with specialist diagnosis, was established;
- the database on nutritional requirements of large yellow croaker and bioavailability of feedstuff were evaluated, and artificial diets for adult fish were developed;
- "Himeway Yellow Croaker", "Sandu Gulf Large Yellow Croaker", "Xia Pai Large Yellow Croaker" and "Yue Hai Large Yellow Croaker" were designated as popular trademarks of large yellow croaker varieties in China; 12 brands including "Jiu Yang", "Weiers", "Deng Yue", "Wei Er Jia" and "Yu Hui", were identified as the popular brands in Fujian Province; "Zhoushan Large Yellow Croaker", "Xiangshan Large Yellow Croaker", and "Dachen Large Yellow Croaker" (Taizhou) were registered with a geographical indication; Xiangshan County registered such brands as "Xiangshan Harbor" and "Yuanhu";
- two monographs and one handbook on large yellow croaker were published, and are used as tools in training courses for farmers and technicians.

Fry output of large yellow croaker occupied a high proportion in national marine fish culture (China Fishery Statisticsal Yearbook 2014). In 2013, the fry number and annual yield were 1.83 billion and 105 230 tonnes, respectively, accounting for 31.9 percent and 9.4 percent of total fry number and yield of national marine fishes; there were almost 420 000 sea cages for large yellow croaker aquaculture. In addition, the large offshore cages (deep-sea cages) for large yellow croaker aquaculture occupied about 40 percent of sea cages in China. Now, the direct annual value of output of large yellow croaker culture exceeds 10 billion RMB; and the annual foreign exchanges earned by export exceeds US$ 100 million. Floating cages and earthen ponds are the main

Table 3.10.3 Annual mariculture production (tonnes) of the larger yellow croaker between 2001 and 2013.

Year	Nationwide	Fujian Province (Ningde city)	Zhejiang Province	Guangdong Province	Others
2001	76 289	41 191 (27 708)			
2002	83 087	40 638 (28 565)			
2003	58 684	44 430 (30 747)			
2004	67 535	55 324 (41 864)			
2005	69 641	56 122 (43 819)			
2006	69 833	58 669 (40 946)			
2007	61 844	54 142 (37 513)			
2008	71 763	60 846 (39 113)	3 317	7 600	
2009	69 987	58 622 (41 074)	3 365	8 000	
2010	85 808	71 710 (55 452)	3 090	11 008	
2011	80 212	73 214 (56 302)	2 225	4 773	75
2012	95 118	83 505 (65 160)	3 260	8 278	
2013	105 230	96 555 (71 918)	3 275	5 400	

systems of croaker mariculture. Operations today produce up to 105 000 tonnes, with about 91 percent from Fujian, and the croaker ranks the first, by weight, among all marine fishes cultured in China, making up about 25 percent. (Table 3.10.3) (Su *et al.* 2004; Liu 2013).

3.10.4 Current Status and Farming Modes of Large Yellow Croaker Culture

During an almost thirty-year process of exploration, research, practice and development, large yellow croaker aquaculture has stimulated the formation of a long industrial chain consisting of several sectors; fry production, grow-out, processing industry, and logistics. These have driven the development of other related sectors, such as fishing gear production, civil construction, research and development of feeds, technical services, product processing, tourism, and catering. Large yellow croaker is currently the fish with the largest scale of sea-cage culture in China, providing jobs for over 300 000 people, and creating an output value of the industrial chain of more than 40 billion RMB (Liu 2013).

The farming modes of the large yellow croaker include: framed floating sea-cage farming (sea-cage farming for short in the following), earthen-pond farming, subtidal-zone enclosure net farming (enclosure-net farming for short in the following; Figure 3.10.3), deep sea-cage farming, and inner bay-net barring farming. In addition, there are some research institutes working on indoor recirculation farming mode. Whatever the farming mode is, the farming environmental conditions must conform to the ecological habits of the large yellow croaker. Moreover, farming modes should follow the principle of healthful aquaculture, which means the products of large yellow croaker must match the standard of non-polluted food *Larimichthys crocea* (NY5060-2001) (Agricultural Industry Criteria of People's Republic of China 2001). Also, the environmental pollution levels of the farming site should be reduced to a minimum.

Sea cage farming: to date, sea-cage farming is the most important farming mode for large yellow croaker, and it accounts for more than 95 percent of the yield of this species. Sea-cage farming is simultaneously used for the production of large-sized fry for other farming modes of this species. Therefore, it is of significance to choose farming sea areas, distribute sea cages accordingly, protect the farming environment, and increase farming efficiency for the sustainable development of the large yellow croaker farming industry.

Figure 3.10.3 Enclosure net farming of the large yellow croaker (*Larimichthys crocea*, Sciaenidae) in Ningde City, Fujian Province, China. Source: Photograph by Shuqiu Xie.

Earthen pond farming: Compared to sea-cage farming, the environment in earthen pond farming is similar to the natural habitat of wild large yellow croakers. Therefore, large yellow croakers cultured in earthen ponds grow faster, are slender in shape, and are gold in color, tender in taste, and have a low feed conversion ration (FCR). However, some unfavorable conditions can lead to disease occurrence. Such conditions involve poor water conditions in the pond due to infrequent water exchange, water depth being less than 2 m, incomplete dredging and sterilization, or excessive culture time. In the late 1990s, the earthen pond area for large yellow croakers reached 600–700 hm^2 in Fujian province, yielding more than 2000 tonnes. However, in early 2000, due to poor management, most of the earthen ponds were abandoned. Currently, there are only few earthen ponds operating, and these have become a good mode for large-scale fry rearing.

Enclosure net farming: Enclosure-net farming for large yellow croakers started in the late 1990s, in the Dongwuyang shallow sea area, Shajiang Town, Xiapu County, Fujian Province. The sea cages with least depth (used for fingerling breeding) for large yellow croaker farming are 3 m in depth, which have to be placed in areas with a water depth of more than 5 m. It results in the waste of a vast shallow sea area in Dongwuyang, where the water depth is two to three m.

Enclosure-net farming only suits the farming in sea areas with a depth of two to three meters. The enclosure net is 3000 m^2 in area each, whose yield equals that of 100 4 m × 4 m cages. However, routine care requires only two to three staff, even one person on average can be sufficient if more enclosure nets are operated adjacent to each other, resulting in cost savings. Enclosure-net farming is cost-effective, and is more resistance to

Figure 3.10.4 "Marine Venice" nearby Sanduao island, Ningde City, Fujian Province, China. *Source:* Photograph by Shuqiu Xie).

typhoons. The exchange of large amounts of water in enclosure-net regions is efficient, and ensures the elimination of residual feed, thus maintaining good water quality. As a consequence, the survival rate is high and fish are less influenced by disease. With the addition of natural living feed, the cost of feed is lower compared to that of sea-cage farming. Moreover, large yellow croakers farmed in enclosure nets are more consistent in shape, color, meat quality and flavor. Therefore, the price of large yellow croakers from enclosure net farming is two to three times higher than that from sea-cage farming.

Other farming modes: Apart from cage farming, earthen-pond farming and enclosure-net farming modes, there are also inner bay-net barring, storm-resistance deep-sea cage farming, indoor recirculation farming, and so on. Inner bay net barring is currently rare due to the scarcity of suitable sites in inner bays. Storm-resistant deep-sea cage farming, and indoor recirculation farming are promising farming modes, but are still on their way to large scale application.

3.10.5 Potential of the Industry of Large Yellow Croaker Aquaculture

At the end of 1990s, large yellow croaker aquaculture had been industrialized, and became the largest sea-cage aquaculture output of all marine fish species in China; it also had become one of eight dominant exports of aquatic products. At present, there are about 30 000 large yellow croaker farms in China, hundreds of breeding and processing companies, and 300 000 direct employees; in 2013, more than 100 000 tonnes of large yellow croaker were cultivated around the country.

3.10.5.1 Development Potential of Large-Scale Offshore Sea-Cage Culture

Currently, sea-based cage culture in bays has been supersaturated. For instance, in Sanduao waters, Jiaocheng District, Ningde City, Fujian Province, there are more than 320 000 cages, most of which are for large yellow croaker culture. In the mariculture areas of fish rafts and cages, fishery worker households are linked together, stretching tens of square kilometers, forming a human landscape of a “Marine Venice” with unique features (Figure 3.10.3). The first maritime party branch, marine first aid center, marine policy station, marine circuit court, and maritime community in China were established as a result of popularization of large yellow croaker farming (Figure 3.10.4).

Open waters have the potential for large-scale offshore cage culture (Hu 2011). Compared with traditional sea-cage cultivation in bays, large-scale offshore sea-cage farming has advantages: expanding culture areas, being independent of inshore environmental pressures; optimizing cage structure, strengthening resistance against winds and waves; providing a good-quality aquaculture environment, enhancing the quality of product; fewer harmful diseases, favoring rapid growth of stock; higher carrying capacity, improving production efficiency; enhancing technological content, and increasing the status of the industry.

3.10.5.2 Potential of Formulated Feeds in Large Yellow Croaker Culture

Although the annual output reached 105 000 tonnes in 2013 (China Fishery Statistical Yearbook 2014), the usage of formulated feed was less than 30 percent of the total feed used. Thus, the utilization of formulated feed can also provide a development potential for the growth of large yellow croaker industry.

Liao *et al.* (2012) conducted quantitative analysis of cost composition of adult large yellow croaker culture, and a comparative analysis of unit cost-benefit, unit-product income, and their variable coefficients on different production scales and subjects. On this basis, the principal factors influencing the culture cost and economic benefits of adult large yellow croaker were determined to be feed cost, which accounted for 74–84 percent of the total cost; the next were labor cost (7–12 percent), fry cost (4–12 percent), and other expenses (2–7 percent); fixed cost occupied the least proportion of the total cost (1–3 percent).

Research and development of nutritionally balanced formulated feeds for large yellow croaker culture, and the popularization of the use of such feeds, have lead to resource conservation, quality control, convenient operation, high use rate, and have improved overall intensive management. In addition, large yellow croaker cultured using compound feeds is of superior quality to products cultivated using low-valued fish. In the near future, compound feeds will certainly play a more important role in promoting the development of large yellow croaker aquaculture.

3.10.5.3 Cultivating High-Quality Large Yellow Croaker Fry, and Increasing Survival Rates

In 2013, in the whole country, 1 828 000 large yellow croaker fry were produced (Chinese Fishery Statistical Yearbook 2014). In the same year, there were about 200 hatcheries for large yellow croaker in Fujian Province which produced about 1 757 000 fry (accounting for 96.13 percent of the total); and there were 1 332 000 fry produced in Ningde city, accounting for about 72.89 percent of the national total. However, in 2013, the output of large yellow croaker was 105 230 tonnes in China, consisting about 210–250 million market–sized fish, meaning that the survival rate of fry to market-sized fish was only about 30 percent. Such a low survival rate was caused by many factors, mainly covering environment control, management, and fry quality; the latter is one of the key factors; the survival rate of fry less than 10 cm in particular is quite low. Therefore, a technological breakthrough in high-quality fry culture is needed which can effectively increase the survival rate, ensuring efficient and sustainable development of the large yellow croaker industry.

3.10.6 Main Factors Affecting Large Yellow Croaker Aquaculture

In summary, the main problems that have to be addressed include the lack of a standardized management system. Some of the issues which have to be addressed are:

- negative status on germplasm resource protection and popularization of selectively bred varieties – the screening and protection of germplasm of large yellow croaker and the cultivation and creation of improved breeds are basic requirements to achieve high yields, high quality, ecological harmony and product safety;
- usage rate of formulated feeds is less than 30 percent – since the success of artificial breeding of large yellow croaker in 1985, the feed used in the nursing phase has mainly been live foods, such as rotifer, artemia, copepod and cladocera, with unstable yield and quality and high cost; if it these are not properly processed, they may carry pathogens. Micro-encapsulated feeds produced in China were not popular, while those imported were too costly. These factors became major impediments to the expansion of hatcheries.
  - In terms of adult fish culture, industrialized aquaculture of large yellow croaker developed at the end of 1990s mainly used frozen low-valued fish as feed; and the usage rate of formulated feed was less than 30 percent. The mode of large yellow croaker cultured using low-valued fish was difficult to sustain; first, low-valued fish, as feeds, were often spoilt and had a wastage rate of about 60 percent, leading to a waste of resources, and pollution of the culture environment; second, the supply of low-valued fish was unstable, and the shortage of supplies induced price hikes; third, frequently, the improper storage of low-valued fish caused deterioration, and triggered the spread of diseases on large yellow croaker resulting in a decline in quality. About one million tonnes of low-valued fish are estimated to be utilized in Ningde city, Fujian Province for large yellow croaker culture in a year, which greatly stimulates disorderly offshore fishing, severely impacting on fisheries resources.
  - In order to effectively reduce heavy fishing for low-valued fish as feed, to protect offshore fishery resources, to avoid waste of feed during feeding of low-valued fish, and to protect the environment of culture areas, we should actively advocate the development and utilization of formulated feeds for large yellow croaker thereby promoting the sound and sustainable growth of large yellow croaker aquaculture.
- poor disease control network for large yellow croaker – following the expansion of large yellow croaker culture, a lack of scientific planning and layout of culture areas, combined with poor feeds, improper feeding strategies, and unmanageable grow-out environments, have led to frequent occurrences of disease

(Ni and Wang 2009). Large yellow croaker suffer from over 20 diseases, from fry to marketable size, among which the most serious one is parasitic infestation (Wang *et al*. 2012). In the autumn of 2007, infection of *Cryptocaryon irritans* caused heavy mortality (equivalent to 20 000 sea cages of marketable-sized fish) in the Gangyu large yellow croaker culture area, located in Lianjiang District, Fuzhou City, Fujian Province, which resulted in direct economic loss of over 100 million RMB (Economic Information Daily 2007).

- difficulties encountered in complying with environmental conditions expected of modern intensive aquaculture models – Fujian is a province with the largest scale of sea-cage culture in China; and there are more than 500 000 sea cages in the whole province. Ningde city has the largest scale of sea-cage culture in Fujian Province, forming a dozen production areas, centered on Sanduao Gulf and Shacheng Bay, among which Sanduao Gulf is an inner bay with the densest cages for mariculture in the country. In 2012, there were about 320 000 cages in Sanduao waters, about 90 percent of which were for large yellow croaker culture. The Qingshan sea area in the gulf has a concentration of nearly 60 000 cages. There had been an addition of over 40 000 baskets for abalone culture and countless rafts for seaweed cultivation in Sanduao waters in recent years.
  - Narrow channels were left among fish rafts, leading to a retarded flow, deposition of dirt and residues, accumulation of rubbish and wastes. All this lead to eutrophication, culminating in disease, frequent occurrence of anoxic events, low culture efficiency, and a decline in quality and safety of products.

Therefore, we should construct integrated systems for effective and healthful culture and technical demonstration, perhaps achieved by, (1) using water surface resources scientifically; expanding the sea area used; rationally planning the layout of major production areas of large yellow croaker; developing towards the outer bays and abyssal region, and promoting per unit area yield and product quality, (2) optimizing and improving sea cages, enclosure nets, and other culture facilities, and (3) regularizing the management of sea-cage distribution, and strictly controlling excessive and disordered development of cages for large yellow croaker culture.

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3.11

Flatfish Farming

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3.11.1 Why Flatfish?

Flatfish include the families Bothidae, Pleuronectidae, and Soleidae, which belong to the large class of marine demersal fishes with high economic value. Because of their systematic status, rich biodiversity, broad ecological distribution, good taste and special flavor, and high nutritional value, flatfish are highly valued by both researchers and consumers. The ten most commonly cultured flatfish in China are turbot (*Scophthalmus maximus*), Japanese flounder (*Paralichthys olivaceus*), half-smooth tongue sole (*Cynoglossus semilaevis*), summer flounder (*Paralichthys dentatus*), southern flounder (*Paralichthys lethostigma*), stone flounder (*Kareius bicoloratus*), spotted halibut (*Verasper variegates*), barfin flounder (*Verasper moseri*), starry flounder (*Platichthys stellatus*), and Senegal sole (*Solea senegalensis*) (Lei 2005).

Marine finfish culture underwent a stepwise rise from the late 1970s to the early 1980s in the south of China (Lei 2005). In northern China, however, the annual temperature fluctuations of coastal waters vary from 0–27°C, and the long winter is not conducive for farming warm-water fish, and likewise the high temperature in summer is not suitable for farming cold-water fish. Most marine fishes with high economic value cannot complete a full breeding cycle under natural conditions, and only a few species with low economic value were cultured in northern China (e.g. *Chelon haematocheilus*). Thus, in the past commercial-scale culture of fish was not possible in the north.

Developing aquaculture species with fast growth, tolerance to low temperature, and the ability to adapt to the natural conditions of the north became an important goal for marine fish culture in northern China. Once China's reforms began, and economic development surged, consumer demand for high-end fish increased. In response, marine finfish aquaculture developed rapidly in China, with a greater variety of species, using various farming methods. Fish culture in Europe proved that turbot is adapted to low temperature and is a high-quality product. Moreover, the successful culture of left-eye flounder in Japan, and the turbot in Europe, indicated that flatfish could play an important role in aquaculture in China. The scene was set for the introduction of turbot to China, where it could become an important aquaculture species, and the basis of an emerging aquaculture industry in areas conducive to its culture (Lei 2012). In 1992, after many years of exploration, China proposed to introduce turbot from Britain using the new industrial aquaculture mode of

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Figure 3.11.1 View of greenhouse for nursery and on-growing system of turbot.

"greenhouse + deep well seawater". This model enabled the full-cycle operation by industrial aquaculture along the northern coast of China (Figure 3.11.1). Since the beginning of the twenty-first century, the maturity of cultivation techniques for turbot (Lei *et al.* 2012) and left-eye flounder, and advances in artificial feeds and disease prevention and control, have permitted China to develop a successful flatfish culture program, mainly for turbot, left-eye flounder and half-smooth tongue sole.

3.11.2 The Lifecycle of Cultured Flatfish

3.11.2.1 Biological Characteristics of Turbot

Turbot, *S. maximus* is a member of the Family Bothidae and Suborder Pleuronectoibei. The body of turbot is flat and resembles a rhomb and a circle. The eyes are located on the left side of head, the central body is stocky, and the visceral mass of turbot is small. The eye side of the body is snow brown color. The mouth is big, but the lips are short. Dorsal (numbering 57–71), anal (43–52), and tail (20–22) fins are linked together, and pectoral fins (8–0) are not developed (Figure 3.11.2).

Figure 3.11.2 Turbot (*Scophthalmus maximus* Linnaeus).

Turbot is a demersal marine fish native to Europe. Its Chinese name, 'Duobao,' means peace and happiness. One of the salient features of turbot is that it is adapted to life and growth at low temperature. For a short period of time, turbot can live in extreme water temperatures of 0–3°C. The suitable water temperature range for one-year-old fish is 3–23°C, the adaptability to high temperature decreases with age. Water temperature affects survival rate: it decreases if the temperature is above 23–25°C for a long period of time, whereas low temperature does not constitute a life threat under appropriate management conditions. Practice has proven that turbot can live at 3–4°C, and can maintain a positive feeding state at 5°C when it has reached 10–15 cm in length.

Other culture conditions for intensive farming of turbot include clean water with high transparency, pH of 7.6–8.2, illumination of 60–600 lx, oxygen content of 3–4 mg/l, and salinity range of 40 to 10–12‰ (optimal 20–32). The spawning season of turbot under natural conditions is from May to August, with males reaching sexual maturity at two years, and females at three years. Turbot breeds once a year, and is a batch/serial spawner. However, under artificially controlled temperature and light conditions, the age of sexual maturity can occur ~6 months earlier, and mature eggs can be obtained throughout the year.

In short, turbot have a strong tolerance to adverse environmental conditions. Turbot like to cluster together and can congregate in multiple layers with an overlap area of over 60 percent of the body except the head. They cluster feed and exhibit high feed utilization and conversion rates. Thus, turbot is an ideal species for intensive culture in northern coastal China.

3.11.2.2 Biological Characteristics of Japanese Flounder

Japanese flounder, *P. olivaceus* is a member of the Subfamily Paralichthyinae, Family Bothidae and Suborder Pleuronectoidei. The Japanese flounder has an oval body shape, and the two slightly small and protuberant eyes are located on the left side of head (Figure 3.11.3). The eyed side of the body is covered with gray-brown ctenoid scales, and the other side is covered with round white scales. The Japanese flounder has 74–85, 59–63, 12–13, 6, 17, dorsal, anal, pectoral, pelvic and caudal fin rays, respectively.

The Japanese flounder is endemic to North-east Asia and is distributed along China's coastal areas. In China, most capture fishery production of this economically important species occurs in the Yellow Sea and Bohai Sea. *P. olivaceus* is a cold-water benthic fish, with nocturnal behavior. The suitable water temperature range for adult fish is 13–24°C, with an optimum of 21°C. If water temperature is less than 13°C or higher than 23°C, feeding will decrease, and if water temperature is higher than 25°C the fish will stop growing. Long-term culture at 27°C will increase the mortality rate. The Japanese flounder is euryhaline, and can live in high salinity areas offshore, as well as in the low salinity estuarine areas. *P. olivaceus* has a strong ability to tolerate hypoxia, with oxygen concentrations of 0.6–0.8 mg/l being lethal. Under culture conditions, the concentration of oxygen should not be <4.0 mg/l because lower values will reduce food intake and increase incidence of disease. The growth rate of female *P. olivaceus* is significantly higher than that of males. At two years of age, the average body weight of males is approximately 800 g, whereas that of females is at approximately 1200 g.

Figure 3.11.3 Japanese flounder (*Paralichthys olivaceus*).

It takes two and three years for male and female Japanese flounder to reach sexual maturity, respectively. The spawning season of Japanese flounder under natural conditions is from April to June. The gonad of Japanese flounder develops asynchronously, and it is a multiple spawner.

3.11.2.3 Biological Characteristics of Half-Smooth Tongue Sole

The half-smooth tongue sole (*C. semilaevis*) is a member of the Family Cynoglossidae and Suborder Soleoidei. It is a large benthic flatfish that lives in warm water offshore. Because of its large body size and well-flavored, nutritious flesh, the half-smooth tongue sole is an economically important marine fish that is very popular with consumers. This species is widely distributed in China's coastal areas, especially in the Yellow Sea and Bohai Sea. In the Bohai Sea, *C. semilaevis* is mainly distributed in the southern part of Bohai Bay and in the mid-western part of Laizhou Bay. In addition, a small population inhabits the central and southern part of Liaodong Bay. The distribution of this species does not vary greatly seasonally.

The body of *C. semilaevis* is slender and flat and resembles a tongue (Figure 3.11.4). The head and tail are small, whereas the central body is stocky. The visceral mass of tongue sole is small, and the anus is on the eyeless side. The eyes are small and located on the left side of the head, and the distance between the eyes and dorsal fin is about three-sevenths of the head length. The side with eyes has two nostrils, and the mouth, which is bent like a bow, is situated at the bottom right, with a bigger camber on the side without eyes. The lips, which are shaped like a hook, extend backward and coat the jaw, dorsal (123–125 fin rays), anal (92–98 fin rays), and tail (4–6 fin rays) fins are attached together, and do not have pectoral fins. Pelvic fins (8–10 fin rays) are found only on the side with eyes, and tail fins have a sharp caudal end. Three lateral lines are present on the side with eyes, but none on the other side. The number of vertebrae ranges from 56 to 58. This species exhibits sexual dimorphism, as the body length and body weight of mature females are twice and six times greater than those of mature males, respectively. Thus, the half-smooth tongue sole is an excellent animal model for studying the neuroendocrine regulation of sex determination, reproduction and growth in fish (Xu and Chen 2011; Ji *et al*. 2011; Chen *et al*. 2014; Wang *et al*. 2015; Shi *et al*. 2016).

The major external morphological classification of half-smooth tongue sole is based on two points. First, there are three lateral lines distributed in the middle of the body and the base of the fins on the side with eyes. Second, the side with eyes is covered with ctenoid scales, which feel rough if touched backward from tail to head, whereas the other side is covered with round scales that feel slippery when touched in either direction.

Half-smooth tongue sole can withstand a wide temperature and salinity range. The suitable temperature range for survival is 3– 30°C, and that for growth is 15–25°C, the salinity range for growth is 2–33‰. Tongue sole feed on benthic organisms, and their diet includes decapods, stomatopods, bivalves, fish, polychaetes, snails, cephalopods, and sea anemones. In normal conditions, it takes three years for females to reach sexual maturity and two years for males. The ovary weight of individuals with a body length of 560–700 mm is on average 110–370 g, with 92 200 to 259 400 eggs. In contrast, the weight or volume of the mature testis is approximately 1/200–1/900 that of the mature ovary. *C. semilaevis* in the Bohai Sea usually spawn in September or October in the central area of Bohai Bay, Laizhou Bay, and Liaodong Bay, in locations near the

Figure 3.11.4 Half-smooth tongue sole (*Cynoglossus semilaevis*); female fish (above); male fish (below).

estuary at a depth of 10–15 m. The half-smooth tongue sole has been overfished since the 1990s. *C. semilaevis* farming began in 2003, and the industry is developing rapidly. The current aquaculture yield is 8000 tonnes, with an aquaculture production value over 1.5 billion RMB (6 RMB = 1 US$).

3.11.3 Flatfish Farming Industry

The Chinese flatfish aquaculture industry consists of five facets: seed production, nursery, grow-out live fish transportation, and marketing. The techniques for seed production have been developed for a special production system with Chinese characteristics. Seed production can be subdivided into three main components – production of fertilized eggs, rotifer pond culture, and industrialized seedling rearing. In addition, the industry relies on services that provide seed transportation, and suppliers of production materials, such as concentrated *Chlorella*, formulated feeds, probiotics, and nutrition enhancers. The division of labor is clear-cut in seed production related activities and consequently has resulted in increased survival rate of seed and reduced production costs. As an example, in the past the grow-out process for turbot took place in an industrial aquaculture flow-through system. Currently, however, many aquaculture companies use recirculating aquaculture system (RAS), because this system requires less land and water, it reduces pollutants, and improves product quality and safety. The special transportation of live fish from farmers to consumers is now established. In the market, chain franchisers take the fish from the shop to locals, and other areas of consumption.

3.11.3.1 The Role of Flatfish Farming in the Aquaculture Sector

From when turbot was first introduced into China in 1992 until now, its culture has fully developed from industrialized seed rearing to industrialized farming. It has developed into one of the dominant mariculture industries in China, with a production of about 125 000 tonnes and an output value of nearly US$741 million (5.1 billion RMB) in 2015. The flatfish industry has developed at a relatively fast rate, mainly driven by the booming turbot aquaculture business, and it has become one of the pillars of the marine culture industry in northern China. Total flatfish production leapt into first place in 2015 when it reached 10.74 percent of marine finfish aquaculture in China (China Fishery Statistical Yearbook 2015).

To a certain extent, the flatfish aquaculture industry represents the direction of aquaculture development in China. It is developing into a sustainable and healthy mariculture industry in the country, and it set a precedent for industrial aquaculture of cold temperate fish species along the northern coast of China. The aquaculture models known as “Land–Sea Relay”[1] and “North–South Relay”[2] were developed, which led to the push for development of culture of other marine fish species from the north to the south of China. In 2014 the production of flatfish was 195 000 tonnes, which accounted for 10.6 percent of total worldwide marine fish production (FAO 2014). China’s flatfish production has remained the highest in the world for 11 years, accounting for 69.8 percent of the world’s production.

3.11.3.2 Social and Economic Benefits of Flatfish Culture

Annual production of flatfish increased 2.38-fold from 41 583 to 140 455 tonnes from 2003 to 2015 (Figure 3.11.5; China Fishery Statistical Yearbook, 2003–2015), with the accumulated value of about 35 billion RMB (6.00 RMB = 1.00 US$). Thus, flatfish ranked first in 2015, up from fifth place in 2003, in total production of farmed marine fish in China. According to FAO data (FAO 2016), from 2003 to 2014 the annual value

1 “Land-Sea Relay”: Fish are transferred from tanks of RAS to marine cages, or from marine cages to the tanks of RAS for further farming, because the cost of marine cage culture is lower than RAS. In winter, the temperature of natural sea water is low, the fish need to be transferred to RAS.
2 “North–South Relay”: In winter, the temperature in the south is suitable for the growth of flatfish, so flatfish are transferred to the south for further farming. In summer, the flatfish are returned to the north.

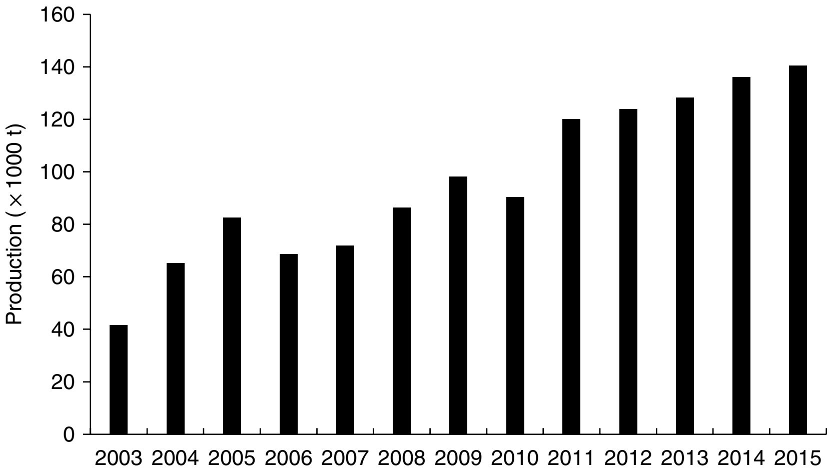

Figure 3.11.5 Production of flatfish in China from 2003 to 2015. *Source:* Data from the China Fishery Statistical Yearbook.

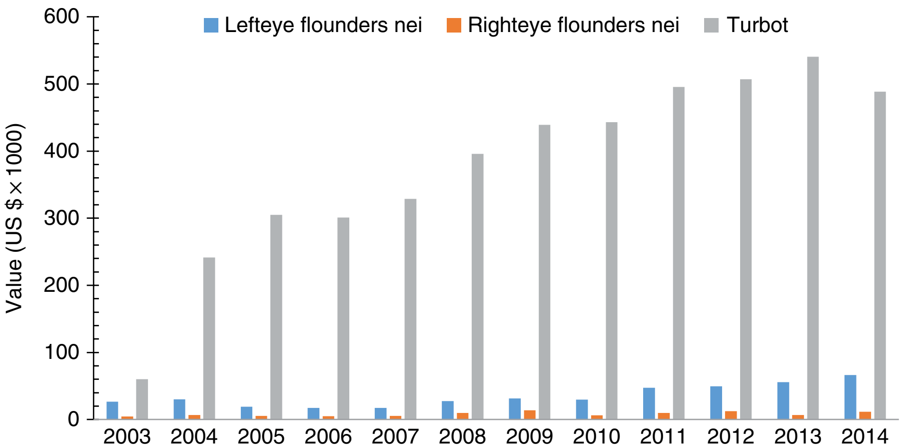

Figure 3.11.6 Output value of turbot, left-eye flounder, and right-eye flounder from 2003 to 2014. *Source:* Data from FAO (2015).

of turbot increased from $60 000 to $488 000, right-eye flounder from $4689 to $11 000, and left-eye flounder from US$ 26 000 to $66 000 (Figure 3.11.6).

The development of flounder aquaculture has turned the coastal areas of deserted saline and alkaline wasteland into booming areas of marine fish culture, provided alternative employment for fishery workers, and overall created employment for up to 200 000 people. Technology for improved marine fish seed production has developed rapidly, and many coastal fishing villages have become prosperous. Since the first decade of this century, a large-scale industry belt for flatfish farming developed along the Bohai Sea ring area and along the northern coast of the Yellow Sea (Figure 3.11.7), which effectively facilitated the economic development of agriculture, the countryside and farmers.

3.11.4 Key Factors Responsible for the Success of Flatfish Farming

3.11.4.1 Seed Production and Hatchery Development

In China, the first attempt to breed *P. olivaceus* larvae was carried out in 1965, and scaled-up culture production was successfully achieved in the early 1980s. By the early 1990s, the whole breeding process,

Figure 3.11.7 Distribution of farms and markets of flatfish in China. Note: black points in the map represent the farms and the arrows represent the distribution of markets, with thick arrow indicating major markets.

including artificial propagation and larval rearing stages, had been systematically established. It included photoperiod and temperature regulation, nutrient enrichment, hormone induction, natural spawning and fertilization, and environmental regulation. These achievements for *P. olivaceus* laid the foundation for industrial farming of flatfish, and the development of large-scale and/or factory propagation of marine fish in China.

S. maximus was first introduced to China by Professor Jilin Lei's research team in 1992. A breakthrough in the artificial breeding of *S. maximus* and the establishment of a new culture system, based on "green house + deep well seawater", resulted in it becoming the highest-yielding flatfish species in China at the end of the twentieth century. Scaled-up breeding production of *C. semilaevis* was successfully achieved in 2002 following the breakthrough in wild broodstock domestication, gonadal maturation, and artificial insemination technologies. RASs using geothermal water for *C. semilaevis* culture further prompted the development of industrial farming in China. The breeding processes for *P. stellatus*, *marbled sole* (*Pleuronectes. yokohamae*), *K. bicoloratus*, *V. variegates*, *V. moseri*, *P. lethostigma*, and *S. senegalensis* were also established.

The artificial propagation technologies for flatfish have greatly improved due to broodstock management, nutrient enrichment, and food conversion processes, as industrial farming in China has developed. The transition from the traditional collection of eggs from wild broodstock to the artificial propagation stage was completed gradually. Similar progress was made in nutrient enrichment and food conversion, which involved switching from using frozen food to adding special nutrient supplements during artificial propagation and larval rearing stages. Applying these improvements reduced the rate of albino larvae from 40 percent to 1 percent and promoted the survival rate of fry from 10 percent to 80 percent. All of these improved technologies allowed for artificial propagation through the year, a low albino rate, and a high survival rate of larvae, which together are crucial for industrial farming of flatfish in China.

3.11.4.2 High-Quality Seed

Having high-quality seed is a key factor for successful farming of flatfish. When flatfish farming first began, broodstock that were not selectively bred, and lack of effective broodstock management programs, resulted in a series of problems, such as slow growth rate, and an unstable male–female ratio. This led to genetic breeding research of all-female *P. olivaceus*, studies on stress tolerance of *P. olivaceus*, and selective breeding of a strain of *S. maximus*, all of which resulted in significant progress. Relevant results are gradually being applied, and high-quality breeding is gradually emerging. "Duobao No. 1" is a new variety of turbot that was cultivated using a breeding technology system which involved traditional family selection and marker-assisted selection. Duobao No. 1 exhibits an increases of 36 percent and 25 percent in average weight and survival rate, respectively, compared to normal turbot. Hybridization between olive flounder and summer flounder resulted in a hybrid with greatly improved growth rate, rate of survival, stress resistance, and reduced dysgenesis (i.e. abnormal development of organs during embryogenesis). All-female *P. olivaceus* have been bred using chromosome manipulation techniques. When the female ratio is over 90 percent, growth is faster than normal by 20–35 percent. In addition, these fish are easy to raise, and have a high survival rate. When farmers use the "all-female egg", they will produce fish as long as the basic methods for common *P. olivaceus* hatching and breeding are implemented; no special measures are needed, and the method is simple and easy to master. At present, use of all-female *P. olivaceus* seed represents more than 50 percent of the national market, and in the last five years this has resulted in newly added output value of more than 2 billion RMB. All-female *P. olivaceus* use has been extended to pond farming in Donggang, Liaoning Province, the coast of Hebei, and cage-culture in Fujian Province.

3.11.5 Success of Culture Developments

3.11.5.1 Culture Systems

In China's flatfish aquaculture program, land-based industrial aquaculture is the main focus, and fish cages and ponds are supplementary. Ten species of flatfish are cultured in China, and they need over 12 months from breeding to reach marketable size. In the natural environment in China, seawater temperature fluctuations are wide in winter and summer, and neither the introduced species (i.e., *S. maximus*, *P. lethostigma*, *P. dentatus*, *S. senegalensis*, *P. stellatus* and *V. moseri*), nor the native species (i.e., *C. semilaevis*, *P. olivaceus*, *K. bicoloratus*, and *V. variegates*) are able to live in the winter or the summer. To address the temperature issue, flatfish aquaculture has been developed in land-based industrial aquaculture systems. Along the southern coast of China, fish can be cultured seasonally in cages when the temperature of coastal waters is suitable for the fish to accumulate fat. The Japanese flounder is adaptable to varying environments, and as such it is mainly cultured in ponds and cages. The body of the half-smooth tongue sole bruises easily and it dwells on the bottom when feeding, so it is suitable for factory farming, but not for cage culture. In 2015, China was home to 7 506 500 m^2 of factory farming, 325 700 m^2 of cage farming, and 7200 ha of pond farming in the counties in which demonstration farming practices of flatfish of the National Technology System for Flatfish Culture Industry, are situated (Guan 2015).

3.11.5.1.1 Industrial Aquaculture (Based on Recirculation Aquaculture Systems (RAS))

Land-based industrial aquaculture can use flow-through systems and RAS. Compared with flow-through systems, RAS are the advanced model, and they save more than 90 percent of resources (including water and land). Through water treatment, RAS reduce natural resource costs, improve the efficiency of the aquaculture system, and protect the environment. With the support of science and technology projects, the RAS used for China's culture of turbot has been significantly improved in recent years. Progress includes process optimization, key facilities and equipment development, system integration, and development of aquaculture management norms. For disease control and management, widely used vaccinations and artificial feeds have led to a healthy farming model for flatfish species.

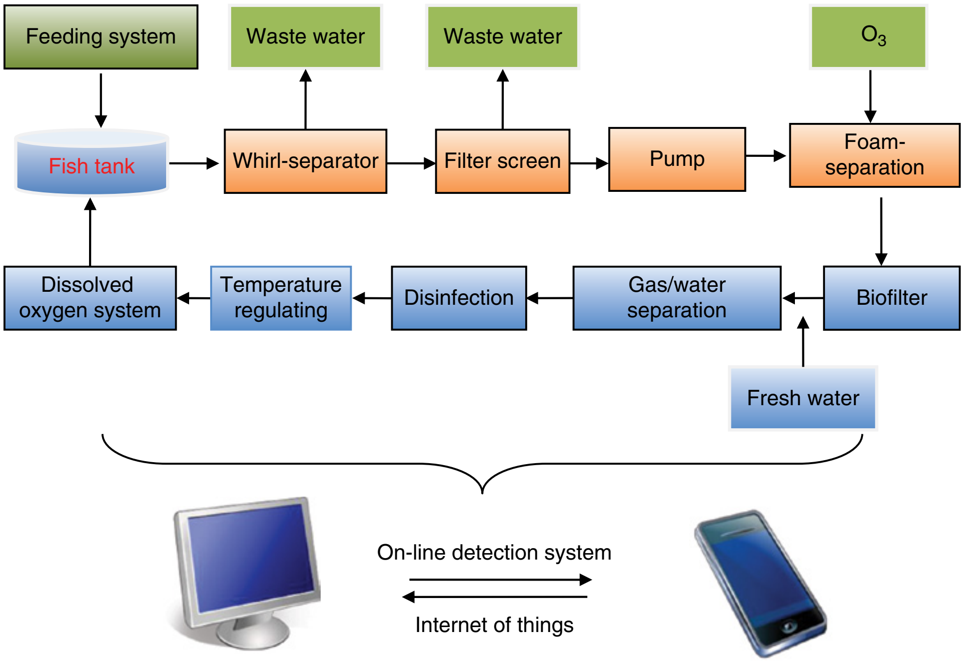

Figure 3.11.8 Schematic representation of an RAS for turbot culture.

An RAS is composed mainly of systems for particulate and organic matter removal, disinfection, aeration, biological filtration, monitoring, and automatic feeding (Figure 3.11.8). An RAS offers highly efficient water treatment that is easily controlled and that occupies a small amount of space. In China, the fry of turbot and tongue sole weigh 5 g, the weight of turbot is 600–750 g (approximately 14–18 months old), and 1000–2000 g tongue sole (approximately 24–36 months old) is the most suitable market size. At present, the culture cycle of turbot is about 10–12 months. The average breeding density is up to 30 kg/m^3, and the survival rate is >95 percent. Feed, energy consumption, and management expenses are the largest part of the production costs (Figure 3.11.9). In recent years, Shandong, Tianjin, Hebei, and Liaoning Provinces, and other regions have built up a large-scale closed aquaculture system to replace the flow-through water system. To date, China has built RAS that cover more than 50 000 000 m^2, promoting sustainable development of the flatfish industry.

In flatfish RAS, the core technology is the stability of the aquaculture water treatment unit, and the efficiency of ammoniacal nitrogen treatment, including physical and biological filtration, and water quality optimization. The role of physical filtration is to remove solid particles from feces and uneaten food, and soluble organic matter suspended in the water. A drum-type, crawler-type microfiltration machine, and foam separator are used commonly. For biofiltration, biofilms are used to remove soluble harmful substances such as ammoniacal nitrogen, and nitrite nitrogen in the water. This is a key step in the process of implementing factory farming because it plays an important role in improving water quality, reducing disease occurrence, increasing culture density and production. Water-quality optimization includes water sterilization, disinfection, temperature control, CO_2 removal, pH and dissolved oxygen control. In the RASs used for flatfish culture, the main sterilization equipment consists of UV and ozone devices. Ozone often is introduced at this stage with foam separation to break down organic matter and purify the water. Oxygen saturation in the RAS can be modified by adjusting the recruitment of liquid oxygen or air.

3.11.5.1.2 Cage Farming

Compared with land-based farming, cage farming offers advantages such as low cost, fast growth, and a high-quality product. As long as the environmental conditions are conducive, cage farming is the best choice for

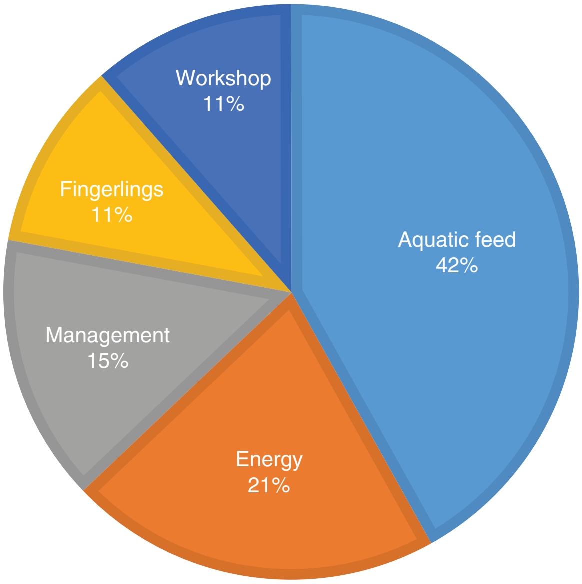

Figure 3.11.9 The proportionate component costs of an RAS.

marine fish farming. In China, experimental studies on flatfish cage farming began in 2000, in the Yuhuan coastal area of Zhejiang Province. Cages (3.6 x 3.6 x 3.6 m) were wood frame structures with a reinforced bottom frame. The average weight of halibut in the experiments reached 0.45 kg, and the survival rate reached 85 percent after ten months of farming. The total weight of halibut in the four cages was 765 kg, and the average yield reached 14.76 kg/m^2. In 2002, the Yellow Sea Fisheries Research Institute successfully tested halibut and turbot cage farming in Qingdao. Cages (6 x 6 x 6 m) were constructed using a steel structure framework, and a bottom platform. Another test of turbot cage farming was carried out in Luoyuan Bay at the Fujian Ningde Fishery technology extending stations. Young turbot were brought from Yantai in Shandong to Luoyuan in Fujian by a live fish carrier. The transport survival rate was 98.3 percent. After three months of farming, the average weight of the turbot increased from 168 g to 556 g, and the survival rate was 95.5 percent. Since these experiments, flatfish fish cage-farming facilities and technology have continuously progressed.

Currently, three main kinds of flatfish fish cage are used in China. The first is an improved traditional cage built using wood or steel pipe frames (Figure 3.11.10). It includes a holding bottle frame made of galvanized steel pipe at the bottom of the cage, and tight ropes in the bottom frame that hold the bottom nets. The bottom nets and the side nets are tensed on the bottom frame, and additional small mesh nets are used to form the bottom platform in order to avoid injury. However, this type of cage is small, with a bottom area of 9 m^2 to 25 m^2, and the stability of the whole cage is poor due to strong ocean currents and sea waves. Thus, the applicability of this cage to deployment in the sea is limited. The second type is the HDPE square floating cage (Figure 3.11.11). The floating pipe and bottom frame are made of flexible HDPE or anti-corrosion steel pipes. This type of cage can resist wind and waves up to level 10, and the bottom area of the cage is 25 m^2. Moreover, it can be used for more than eight years before needing to be replaced. The third type is a submersible cage or sinking cage (Figure 3.11.12). These cages can be submerge in the sea to avoid the effects of currents and waves.

3.11.5.1.3 Pond Culture

A vast number of coastal seawater ponds exist in China. However, many marine fish farming ponds are large facilities with a simple structure, low level of equipment, and provide low yields. Moreover, success of pond culture relies on the weather, which limits sustainable development of the marine fish pond aquaculture industry. Because the winter is long in northern China, pond farming of Japanese flounder and half-smooth tongue sole is restricted to five months in the year. Fish cannot live through the winter in ponds, thus pond

Figure 3.11.10 Bottom frame of improved traditional cage.

Figure 3.11.11 HDPE square floating cage.

utilization and production efficiency are low. These problems point to the urgent need to upgrade the mode and technology of traditional pond farming, in order to increase the efficiencies of pond utilization and production.

A new, environmentally friendly circulating-water pond-farming mode has been developed that is characterized by a low-carbon economy. In brief, a sand and mud sediment pond suitable for the growth of flatfish was selected, and the traditional structure of the mariculture pond was modified by dividing it into small (0.13–0.33 ha) conjoined ponds. These ponds were equipped with independent drainage systems, and effluent treatment systems. Wastewater collected from each single small farming pond was treated (microalgae, probiotics, and substrate amendment) to meet water-quality control criteria, and then returned back to the pools. A cistern was used to replace new water regularly. The effluent is further treated and then let out,

Figure 3.11.12 HDPE circular submersible cage.

making pond aquaculture model a circulating water type (Figure 3.11.13). The main technologies for this cultivation mode include the construction of a circulating water pond aquaculture system, seed production, efficient oxygenation, precision feeding, micro-ecological regulation and control of the aquatic environment, online water-quality monitoring and control, and overwintering and over-summering protocols.

This model has been tested for Japanese flounder and half-smooth tongue sole in Rizhao, Qingdao, and the aquaculture production and breeding benefits were elevated four- to nine-fold. For example, the output of Japanese flounder cultured in circulating water ponds reached 3 kg/m^2, whereas the output of Japanese flounder cultured with traditional monomer pond farming was only 0.3 kg/m^2. In addition to increased production efficiency, land resources were saved and aquaculture waste was reduced. Compared with indoor factory aquaculture, engineered pond farming avoids problems such as abnormal body color, and increases the product quality. At the same time, pond aquaculture can decrease the food coefficient by 30 percent compared with that of indoor industrial aquaculture. In addition, the cost of engineered pond aquaculture is 21.55 RMB/kg compared to 25.6 RMB/kg for traditional pond farming. In terms of production benefits, the output value of engineered circulating water pond aquaculture is \$12.328/m^2, whereas the value for traditional pond farming is only \$1.055/m^2. Overall, engineered pond farming is characterized by high efficiency and high output, which likely will increase the popularity of this new pond farming mode.

The advantages of the engineered circulating water pond farming model are as follows:

- advanced system design, natural ecological environment, sediment conjoined ponds, and wall slope protection, which can improve the safety and operability of the system; a drainage system to ensure adequate water exchange; a system to ensure water quality and recycling;
- improved equipment, including combining the ponds, the drainage system, efficient aeration, and automatic water quality monitoring;
- micro-ecological control of pond-water quality using probiotics, sediment improvers, and microalgae, to effectively control pathogenic bacteria in the water, thereby preventing disease, reducing drug use, and preventing the accumulation of harmful substances such as sediment organic matter, ammoniacal nitrogen, and sulfur; this control also improves conditions on the pond bottom;
- high-quality aquaculture products: the conducive sediment environment, good water-quality conditions, and micro-ecological balance, prevents melanism, thus ensuring that the aquaculture products have the same quality as natural fish, which results in improved market competitiveness;
- high economic benefit: the cultivation mode has high production efficiency (e.g., yield increase of four to nine times that of an ordinary large pond), thus the production cost is greatly reduced, and the economic benefit is notable;

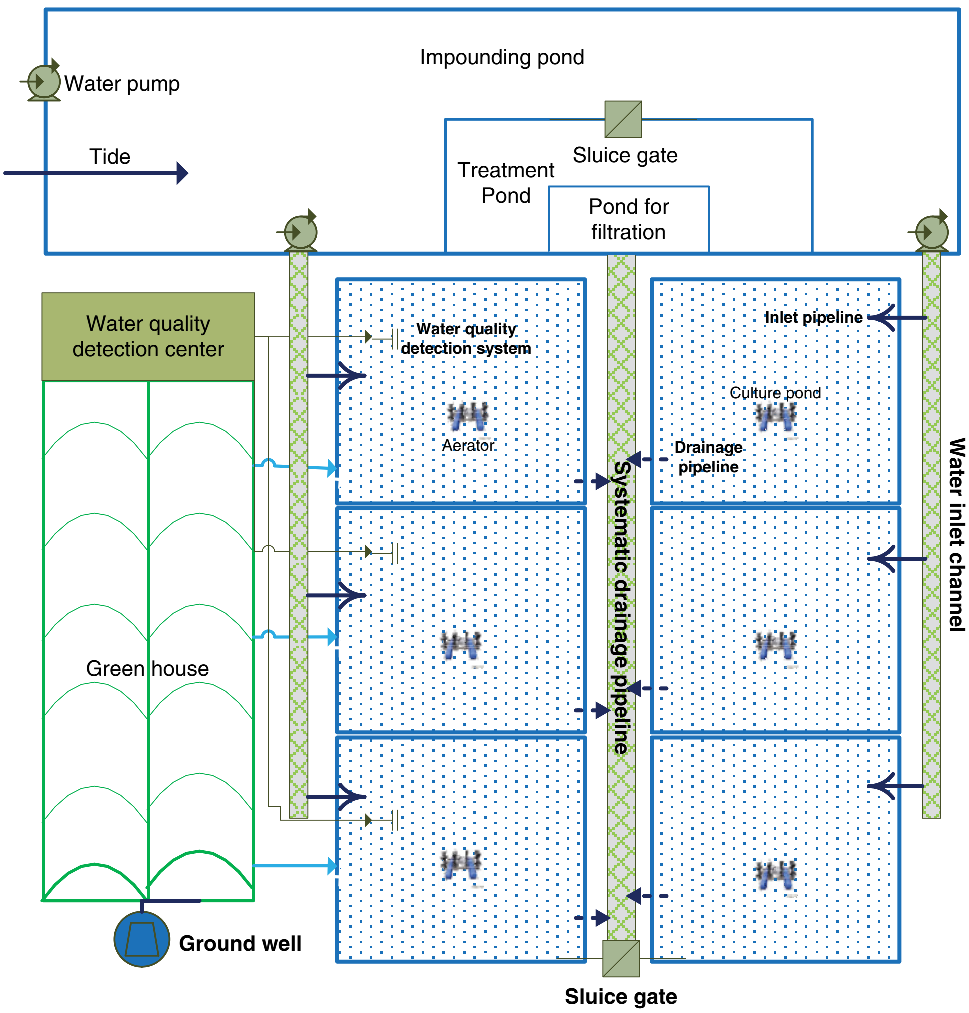

Figure 3.11.13 A circulating water pond-aquaculture system used in flatfish culture.

- environmentally friendly and resource-saving: the efficient farming production reduces use of land resources and water resources. The balance provided by the stable, micro-ecological community ensures that few pathogenic microorganisms are present, and the system has low impact on the environment.

The engineered circulating-water pond aquaculture model can be widely applied in coastal areas of China. This cultivation mode is especially suitable for flatfish, but it also can be applied to other marine fish species. Considering the distribution and structural characteristics of ponds in China, this mode can be applied for flatfish in Shandong, Jiangsu, Hebei, and Liaoning provinces. In addition, this method can be used for grouper (*Epinephelus* spp.), yellow croaker (*Larimichthys crocea*), sea bass (*Lateolabrax maculatus*), and other well-known marine fish farming in Zhejiang, Fujian, Guangdong, and Hainan provinces.

3.11.5.2 Improvement of Feeds

When commercial flatfish farming first began fresh-frozen, low-valued fish was the main food source used. However, high costs, unstable supply, and nutritional inconsistencies of fresh or frozen, low-valued fish could not sustain the high level of production of quality fish. As the scale of marine fish farming expanded, the demand for artificial feeds increased, thus greatly accelerating the pace of development of dietary nutrients and feed processing technology (See Chapter 5.2). Early on, flatfish culture in China (particularly of larval stages) mainly relied on artificial larval micro-diets imported from developed countries such as Japan. This requirement greatly increased the cost of farming, thereby limiting the development of flatfish aquaculture. However, with strong support from the National Technology System for the Flatfish Culture Industry of the China Agriculture Research System, a series of studies were conducted to develop artificial feeds and micro-diets. The generalization and application of the products to flatfish production improved the level of artificial feed use, and provided strong support for development of the marine fish industry. In China, a number of studies on nutritional physiology and nutritional requirements during different growth and developmental stages of turbot have been conducted (Chen *et al.* 2004; Jiang *et al.* 2005; Ma *et al.* 2005; Liu 2010). In addition, the nutritional value of new protein sources has been evaluated for potential use in formulated feeds; these include yeast (Cui *et al.* 2011), soybean meal (Wang *et al.* 2008; Chen 2009), rapeseed meal (Ma *et al.* 2009), and Antarctic krill meal (Kong *et al.* 2012). The application of functional additives such as taurine (Yun *et al.* 2012), and immuno-enhancers such as tombarthite–Y (Cui *et al.* 2011), nucleotides (Peng *et al.* 2013), and probiotics (Pan *et al.* 2012b) have also been tested. These studies provide theoretical and technical support for the commercial development and production of specialized compound feeds for flatfish, which would reduce dependence on imported feeds and decrease feed costs. To date, the amount of artificial feed consumed by turbot in China has reached 20 000 tonnes per year, and up to 90 percent of it was made in China.

3.11.5.3 Government Assistance

The Chinese government recognizes the need for fishery development, and the construction of modern fisheries. Since the Chinese economic reforms, known as "Reform and Opening-up" in 1978, the government has supported many policies related to marine fish aquaculture. Reforms have allowed land transfer to flatfish farmers. The "Preferential Agricultural Policies" and "Preferential Fishery Policies" are gradually being improved, and the institutional environment for industrial development has been optimized.

The Chinese government created appropriate policies to facilitate the successful development of flatfish farming, and include the following:

- establishment of "Specialized Farmer Cooperatives" that have developed many policies;
- implementation of "Micro Credit and Financing" at the grass-roots level;
- the enterprise income tax for "Farming, Forestry, Animal Husbandry and Fishery" was reduced, and a part of the value added tax was exempted.

Shandong and Tianjin provinces have introduced a subsidy policy that could offer a subsidy to farmers who use RASs. It is the responsibility of the Aquatic Product Technology Promotion Department, colleges, and vocational educational institutions to teach farmers about seed production, feeds, disease prevention and control, aquaculture models, and water-quality monitoring.

3.11.5.4 Marketing

The diversification of product circulation, and the continuous expansion of markets played an important role in the rapid development of flatfish aquaculture. China's flatfish products are mainly consumed fresh, but the product circulation radius is large, and the production area and the place of consumption are often separated by long distances. The structure of the value chain is shown in Figure 3.11.14.

Flatfish products are nutritious, taste good, and enjoy a cultural connotation as an auspicious symbol, and as such are popular in China. The market for live turbot has expanded radially from the cities to the countryside, from coastal to inland, and from north to south, including Hong Kong and Macao (Figure 3.11.7). In the beginning, turbot was expensive and viewed as a "noble fish", but today it is cheap and is seen as a "civilian fish". In 2000, the market price of turbot was about 400–500 RMB/kg. With the development of flatfish culture, the market supply increased, and the market price in 2016 for turbot is about 50–80 RMB/kg. In addition

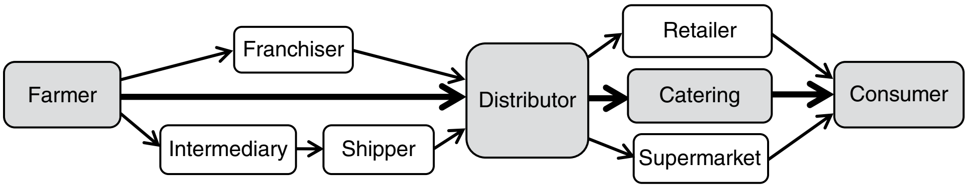

Figure 3.11.14 Schematic representation of the value-chain structure of flatfish production.

to the low price, urbanization, and wide access to multimedia have changed the consumption pattern of flatfish from hotel to home. Moreover, many producers have begun to register trademarks and implement brand marketing. An e-commerce trading platform was constructed, and network marketing is on the rise. All of these factors collectively have increased the market for flatfish products.

3.11.6 Major Challenges to Up-Scaling Flatfish Aquaculture in China

3.11.6.1 Diseases, Drugs, and Chemicals

There is a high incidence of various fish diseases in China's flatfish aquaculture industry. One reason may be that the numerous flatfish species cultured in China (China cultures more varieties than any other country in the world), dilutes the research resources dedicated to each species, and adversely affects the understanding of the characteristics of the farming technology of each single species. In addition, China has the least suitable natural resources for flatfish culture, and it is impossible to accomplish successful flatfish culture without aquaculture models such as the "North–South Relay", "Land–Sea Relay", and "greenhouse + deep well seawater" described above. In contrast, fish production can be accomplished in other countries using only natural seawater.

To achieve sustainable development, disease control measures need to be strengthened. Use of vaccines, and training for standard use of drugs according to national policies and regulations need to be implemented. Current urgent needs for flatfish seed production include development of flatfish vaccines, and new kinds of highly effective disinfectants with low toxicity, less residue, and which can be applied at a lower dosage. Turbot live vaccine (EIBAV1 strain) against *Edwardsiella tarda* is a flatfish-specific vaccine licensed by China's Ministry of Agriculture, and it will be commercially available to the flatfish aquaculture industry in the next ten years. The application of vaccines in fish farming will reduce the use of antibiotics significantly, which will be helpful for fully upgrading the food safety levels of China's marine fish products.

3.11.6.2 Overexploitation of Groundwater and Limited Space for Flatfish Farming

In China today, most turbot and half-smooth tongue-sole are still raised in flow-through aquaculture systems, which use large quantities of water. This scenario results in overexploitation of groundwater in flat fish-producing regions, which leads to lowering the water table, lack of water, and high cost of water and electricity. The rapid development of the coastal economy, tourism, shipping traffic, real estate development, and other industries translate to growing demand for space along coastlines and harbors, thus marine and land areas available for offshore cage culture and pond culture have greatly decreased. Moreover, with the Chinese 2015 national "water pollution prevention plan", groundwater exploitation, offshore aquaculture, and pollutant emissions, will be regulated more closely, and space for flatfish aquaculture will be greatly compressed.

3.11.6.3 Seed Quality

Good quality seed is a prerequisite of successful aquaculture. Seed-based rearing of flatfish is moving forward with advances in the modern seed industry. However, many enterprises that produce flatfish seed strive for quantity over quality, and to date very few improved varieties are available for use in China. Excellent germplasm is the most basic requirement for healthy and stable development of fish culture. Artificial propagation and selective breeding research have only recently been carried out, and a lot of improvements are expected in the ensuing years. National investment to advance the availability of high-quality germplasm of marine fish is needed, and China should strengthen the construction and management of the flatfish seed production center. Technology related to broodstock culture, biological bait cultivation, artificial insemination and hatching, and breeding also should be improved.

3.11.6.4 Small-Scale Farming, Decentralized Operations, and Lack of Coordination

Flatfish farming is mainly on a small scale, although 0.5 ha farms account for only about <10 percent of the total flatfish farming area. In 2012, the average turbot farm size was 0.24 ha, and average production was 23.9 tonnes. In Europe, turbot farming is dominated by large-scale operators because it is difficult to be profitable there if production is <100 tonnes per year. In China, flatfish farming lacks the professional cooperatives that are present, for example, in Japan and Korea, and which lead to strong competition among farmers. Moreover, small-scale farmers do not have the ability to make technical improvements, and invest in expensive facilities, which makes it difficult to ensure the quality of fish products, and achieve sustainable development.

3.11.6.5 China Needs to Strengthen Industrial Aquaculture under the Slow Pace of Market Expansion and Consumption Transformation

Traditionally, the main buyers of flatfish, which are considered medium- and high-grade fish products, have been caterers (restaurants). However, household consumption patterns are still in their infancy. In addition, consumers of Chinese flatfish generally want fresh fish, which requires long-distance transport and distribution, resulting in high costs. These disadvantages are the main constraints of the flatfish industry. Traditional consumer attitudes, narrow circulation and distribution channels, and the lack of positive publicity have resulted in a slower expansion rate of the Chinese flatfish market relative to the rate of development of the aquaculture industry at large. The whole industry faces pressure to maintain high-speed sustainable development due to the low price of farmed flatfish.

The key factors necessary to further expanding the flatfish industry are developing aquaculture products, improving the processing industry, and promoting the market transformation from raw materials into processed products. Therefore, the key tasks that need to occur are as follows:

- develop industrial associations and professional cooperatives, which could lead to expansion of enterprises and other industrial organizations. These could play a role in organizing and coordinating farmers, so that farmers can produce under standard conditions in order to provide improved raw materials to the processing industry;
- reinforce market expansion in processing flatfish products. Obviously, only processed products can be sold in far-away markets, but development of processed flatfish products will continue to stimulate the aquaculture industry. This would require the transformation of the market trend from selling only fresh fish, to selling both raw materials and processed products. Producers and processers should use modern electronic networks, and strengthen cooperation with hotels, supermarkets, print media, e-commerce, and other businesses institutions to establish and improve marketing channels.

3.11.7 Ensuring Sustainable Flatfish Farming Sector

The sustainable development of China's aquaculture industry is affected by factors such as economic instability, high risks inherent in breeding, lack of processing industries, and water scarcity. Therefore, there is an urgent need to establish a sustainable aquaculture system in China.

3.11.7.1 Market Consolidation and Expansion

A stable market plays a key role in promoting the development of an industry. Although Chinese flatfish have a large potential consumer market, various means to expand on a large scale need to be explored. The following approaches are needed to consolidate and expand the market:

- focus must be given to marketing of regional brands and the establishment of a diversified marketing system to actively expand the market. It is important to involve aquaculture producers from major producing sites. Chambers of commerce, aquaculture producer cooperatives, and big enterprises should cooperate to act as leading units. They must charge fees, and establish marketing funds for print media, electronic media, and other platforms to increase products publicity. This approach should result in increased consumption of products in inland areas, which subsequently will aid in the economic betterment of families in the producer areas;
- increase development of the domestic aquatic-products traceability system. During the entire process of the industrial chain from aquaculture sites to the table, simple and economical methods are generally employed to obtain the relevant information. However, application of technology through the industrial chain provides quick sampling, effective integration, and seamless packaging. Such a process can detect any changes or spoilage inside the packaging, and alert the relevant entity about potential problems during the transportation and distribution of aquatic products. Such a system would provide real-time monitoring of quality and would serve as an information and record-keeping system for consumers and management agencies;
- promote development of the processing industry, guide the transformation of consumption patterns, and expand the consumer market for flatfish products. Attention needs to be paid to research and development of processed products, and the development of flatfish products and the innovation of the e-commerce marketing model need to be encouraged. As an example, the production line of chemical-residue free turbot, and other marine products, processing organization has been formed in China, which has led to increased capacity for chilled product processing.

3.11.7.2 Organization of the Industry

A good and an effective industrial organization would not only strengthen the self-discipline of the industry, and reduce market risks for fish farmers, but it would also serve as the link between industry and government. In countries such as Norway and Japan, mariculture professional cooperatives play an important role in connecting the government and farmers, and they alleviate unfair competition and non-normative farming. In China, mariculture professional cooperatives and mariculture associations have been established in some farming areas. The cooperatives are economic organizations consisting of fish farmers and stakeholders, whereas the associations are organizations designed for industry cooperation, with the primary goal of making a profit. The degree of industrial organization can be strengthened following the model of "large-scale farmers lead the small-scale" and "the national key leading enterprises lead the farmers."

3.11.7.3 Low-Cost Aquaculture Systems

The main aquaculture mode for marine flatfish aquaculture is "greenhouse + deep well seawater", which requires large quantities of water, and leads to shortages of underground water resources, environmental pollution, fish diseases, and other problems in some flatfish-producing regions. These problems have already begun to stunt the sustainable development of the flatfish industry. It seems clear that the only choice for the industry to follow in the future is the use of recirculating aquaculture (RAS). Compared with flow-through aquaculture, recirculating aquaculture has significant advantages, including reduced land and water use, pollutant reduction, and improved product quality and safety. The impetus of technological and economic development of the flatfish aquaculture industry, which occurred much earlier than for other marine species, provided a solid foundation for the development of recirculating aquaculture for marine fish in China.

Industrialized aquaculture of flatfish will be a symbol of how the mode of aquaculture can be transformed in China, leading to an upgraded system of fish aquaculture.

Today, research and development of low-cost RASs is a key goal in China. Few fish species are suitable for industrial aquaculture, and they mainly consist of flatfish, salmon, and grouper. Compared with flow-through aquaculture, the fixed investment required for flatfish recirculating aquaculture is quite large. One RAS generally costs at least 600 000 RMB. However, in China about 60 percent of flatfish aquaculture producers are small scale, with farming plants <2000 m^2, and thus it is difficult for farmers to make such an expensive investment. Furthermore, proper management of RASs is very important, and poor managers cannot make the system run efficiently. Therefore, improving the management skills of fish farmers is also important for improving the practice of recirculating aquaculture.

3.11.8 Conclusions

Although the development of flatfish farming in China began only 20 years ago, it has played an extremely important role in the history of marine finfish aquaculture in China. The development of flatfish farming has effectively promoted “the fourth wave of marine aquaculture development in China” represented by marine fish. From the time turbot was introduced into China in 1992 until now, numerous breakthroughs in breeding technology have been achieved, and the “greenhouse + deep well water” model was developed as a new industrial aquaculture mode. New varieties of turbot were studied, and the new concept of industrial fish aquaculture was recognized both inside and outside the industry. Industrial aquaculture represented by turbot expanded rapidly to coastal cities of northern and southern China. In addition, flatfish farming was the forerunner of marine finfish aquaculture, representing the development direction of modern aquaculture in China. At the beginning of the development of flatfish farming, industrial aquaculture was the main production mode, and turbot was the main farmed species. Today, industrial aquaculture has been enhanced by advanced culture modes with highly standardized facilities and engineering. In addition, turbot is the most successful model of aquaculture breeding in China.

With the strong support of the China Agriculture Research System, flatfish farming continues to develop in China. Studies focused on selective breeding, the development of new varieties of seed, nutrition requirements and artificial feeds, disease prevention and control, facilities and equipment, processing and quality control, logistics and marketing, and intelligent management of the “Internet of Things”[3] will continue to be research goals. The high-end model of industrial aquaculture will be rapidly improved based on the core “four modernizations of aquaculture”, which are equipment engineering, technology modernization, industrial production, and management industrialization. The end goals are sustainable and healthy development of flatfish farming, and the production of more and better flatfish for China and the world.

3.11.9 Author Contributions

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3 “Internet of Things”: a proposed development of the internet in which everyday objects have network connectivity, allowing them to send and receive data.

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3.12

Rabbitfish – an Emerging Herbivorous Marine Aquaculture Species

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3.12.1 Introduction

At present, carnivorous fish species such as seabass (*Lateolabrax japonicus*), large yellow croaker (*Pseudosciaena crocea*), grouper (*Epinephelus coioides*), flat fish species, plaice and flounder, cobia (*Rachycentron canadum*), seabreams, red drum (*Sciaenops ocellatus*), yellow drum (*Nibea albiflora*), yellow tail (*Seriola quinqueradiata*) and pompano (*Trachinotus ovatus*) account for a large proportion of Chinese marine aquaculture. Cultured herbivorous marine fish species are very limited, and principally include microalgae feeders such as mullet (*Mugil cephalus*), milkfish (*Chanos chanos*), redlip mullet (*Liza* spp.), and macroalgal feeders such as rabbitfish (*Siganus* spp.) and butterfish (*Scatophagus argus* spp.).

Compared to carnivorous species, the herbivorous marine teleosts feature in a short food chain, have a low requirement of protein and lipid, and a high efficiency of plant protein utilization. In addition, a large number of valueless and remnant seaweeds, or their derivatives, can be used to feed herbivorous marine teleosts (Xu *et al.* 2011). Thus compared with other fish species, herbivorous marine teleosts possess obvious advantages in energy transformation and resource utilization. Moreover, herbivores commonly have high nutritional quality, and low culture costs. Thus, they provide opportunities because their production can be profitable and there is good market demand, and also offer a favorable basis for aquaculture development (Ding *et al.* 2014). Furthermore, the breeding of herbivorous species has also been recommended by the Food and Agriculture Organization of the United Nation (Tolentino-Pablico *et al.* 2008). In summary, the development of novel herbivorous species and their specialized aquafeeds is becoming an important direction for future research. Finally, as a typical marine teleost consuming macroalgae, rabbitfish has been proposed as a promising herbivore for aquaculture along the south-east coast of China.

3.12.2 The Taxonomic Status, Geographical Distribution, and Feeding Habits

Rabbitfish are perciform fish of the family Siganidae. They are widespread along the tropical and subtropical Western Indo-Pacific coast and the eastern Mediterranean Sea. Up to now, 27 species belonging to the genus *Siganus* have been documented, and of these, 13 species have been recorded in China, principally distributed in the South and East China Sea and Taiwan Strait (Ma 2006; Froese and Pauly 2000).

Rabbitfish are small fish preferring shallow, warm waters, and commonly inhabit ledges, corals, kelp beds, mangrove swamps, coastal areas, and estuaries. The natural food for rabbitfish includes filamentous green

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algae, brown algae, diatoms and sea grasses. However, rabbitfish also consume other food types and can be easily weaned on to formulated feeds.

Rabbitfish are eurythermic and euryhaline. Their optimal water temperature is 22–29 °C and the environmental salinity should be above 5% (14–32% optimal). They have a strict requirement for dissolved oxygen (DO) which must be above 5 mg/l. DO value below 2 mg/l may result in death, which may be one of the main reasons for mass mortality of rabbitfish in summer (Chen and Li 2005).

3.12.3 Commercial Value and Aquaculture of Rabbitfish

The flesh of rabbitfish is delicate and with an excellent flavor, it is devoid of fine bones, rich in long-chain polyunsaturated fatty acids (LC-PUFA), and/or highly-unsaturated fatty acids (HUFA), and high in nutrition value. Rabbitfish are marketed commonly at 50–150 g and there is high market demand. Rabbit fish are high priced in southern Fujian, Guangdong and Hong Kong (Zhuang and Song 2008). It is reported that there are about 14 rabbitfish species of commercial value, among which 10 are becoming promising aquaculture species in South-east Asia, the Middle East, Fiji, and southern China.

In China, the principal cultured rabbitfish species include *S. canaliculatus* (or designated *S. oramin*), *S. fuscescens* and *S. guttatus*, which are mainly distributed in south-eastern coastal waters of China such as Guangdong, Guangxi, Fujian, Hainan, and Taiwan (Figure 3.12.1). In addition, rabbitfish has been rated as one of "the important marine species with developmental potential" in Guangdong and Fujian provinces. According to the data from FAO (2014), the yield of rabbitfish is above ten tonnes per year in Singapore, while 14 748 tonnes per year in Philippines, which accounts for 5.7 percent of the yearly global gross output (Ren 1998). In recent years, the output of rabbitfish in Xiamen, Fujian Province was up to 1000 tonnes, and large outputs of rabbitfish has also been reported in Zhuhai and Raoping in Guangdong Province. Rabbitfish is characterized by multiple dietary resources, and can adapt to diverse culture modes. Recently, artificial

Figure 3.12.1 Rabbitfish *Siganus canaliculatus* (above) and *S. fuscescens* (below).

propagation of rabbitfish has been developed, and this has facilitated the expansion of its culture in south-east China (Zhao *et al*. 2007; Liu *et al*. 2009).

3.12.3.1 Culture Practices

At present, the main methods of rabbitfish culture in China include pond and cage culture. Cultures have developed from a monoculture mode to a polyculture mode. In the latter mode, the common species used include sugpo prawn (*Penaeus monodon*), mud crab (*Scylla paramamosain*), milkfish (*C. chanos*), black bream (*Sparus latus*), Japanese croaker (*Nibea japonica*), large yellow croaker and grouper (*Epinephalus* spp.) (Zheng 1999; Shen and Chen 2003). In rabbitfish polyculture, several benefits exist: rabbitfish can play a role as a scavenger, preventing algal blooms; it is beneficial in attenuating environmental pollution, contributing to disease prevention, increasing the usage ratio of net cage and enhancing the unit output. Thus, polyculture mode for rabbitfish is practicable with high economic returns (Feng *et al*. 2007; Hu *et al*. 2008). In aquaculture, rabbitfish juveniles are sourced mainly from the wild. However, success in artificial propagation of *S. guttatus* provides a basis for expanding rabbitfish farming in China (Zhao *et al*. 2007; Liu *et al*. 2009).

3.12.3.2 The Development of Rabbitfish Feeds

In nature, rabbitfish ingest seaweed and grow slowly, at about 150–250 g per year. Indoor growth experiments have demonstrated that rabbitfish fed formulated feeds can gain about 200 g within two months. In a growth trial, the rate of average weight gain of rabbitfish fed the seaweeds *Gracilaria lemaneiformis* or *Enteromorpha prolifra* was only 24.1–25.8 percent of that fed formulated diets, or 31.3–33.5 percent of that fed frozen, low-valued fish (Table 3.12.1) (Xu *et al*. 2011, 2014). However, feeding rabbitfish with seaweeds can increase the contents of semi-essential amino acids and n-3 LC-PUFA, and enhance the anti-oxidative capacity (Li *et al*. 2015; Xu *et al*. 2014). Combining the advantages of seaweed and ingredients commonly used in formulated feeds, there is potential to develop effective, low-cost formulated feeds for rabbitfish (You *et al*. 2013; Zhu *et al*. 2013). In addition, the incorporation of seaweed into formulated diets can facilitate the recycling of low-value seaweeds and seaweed that is washed ashore in the coastal areas of China, promoting the development of seaweed farming which is helpful for repairing and improving the coastal environment, and also stimulates the healthy and sustainable development of marine aquaculture.

Table 3.12.1 Mean (±SD) of a number of parameters representative of the growth performance of *S. canaliculatus* maintained on different diets for eight weeks.

	Dietary group			
Parameter	**Formulated feed**	**Raw fish**	***G. lemaneiformis***	***E. prolifra***
Initial body weight/g	7.51 ± 0.11	7.55 ±0.06	7.39 ± 0.05	7.45 ± 0.04
Final body weight/g	26.66 ± 0.59[a]	22.40 ± 0.18[b]	12.24 ± 1.63[c]	12.03 ± 0.33[c]
Weight gain/%	255.38 ± 2.55[a]	196.72 ± 0.50[b]	65.85 ± 0.71[c]	61.58 ± 5.30[c]
SGR (%/ week)	2.27 ± 0.02[a]	1.81 ±0.02[b]	0.90 ± 0.01[c]	0.86 ± 0.06[c]
Survival rate/%	100	97	100	100
Condition factor	2.63 ± 0.02[a]	2.18 ±0.06 0.03[b]	0.96 ± 0.03[c]	0.89 ± 0.01[c]
Hepato-somatic index/%	2.72 ± 0.06[a]	2.22 ± 0.03[b]	1.28 ± 0.04[c]	1.14 ± 0.05[c]
Viscero-somatic index/%	13.89 ± 1.1	12.18 ± 0.46	13.65 ± 1.11	13.63 ± 0.72

Data on the same row with different superscripts are significantly different ($P < 0.05$).
Source: Modified after Xu *et al*. (2014).

Table 3.12.2 Growth parameters (mean ± SD) of *S. canaliculatus* fed diets with different ratio of seaweed for eight weeks.

	Dietary seaweed (*Enteromorpha prolifera*) level/%					
Parameter	**0% (control)**	**5%**	**10%**	**15%**	**10%+NSP**	**15%+NSP**
Initial body weight/g	23.14 ± 0.12^{ab}	23.30 ± 0.33^{a}	22.99 ± 0.13^{ab}	22.64 ± 0.25^{ab}	22.29 ± 0.03^{b}	22.74 ± 0.10^{ab}
Final body weight/g	56.17 ± 1.14^{a}	50.45 ± 1.25^{ab}	49.05 ± 1.16^{b}	48.63 ± 0.56^{b}	52.18 ± 1.34^{ab}	49.92 ± 2.05^{b}
Weight gain/%	142.80 ± 0.07^{a}	116.44 ± 0.02^{ab}	113.32 ± 0.04^{b}	114.87 ± 0.04^{b}	134.11 ± 0.06^{ab}	120.47 ± 0.08^{ab}
Feed conversion ratio	1.35 ± 0.07^{ab}	1.46 ± 0.09^{ab}	1.56 ± 0.04	1.48 ± 0.04^{ab}	1.28 ± 0.02^{b}	1.44 ± 0.04^{ab}
Protein efficiency ratio/%	231.66 ± 0.11^{ab}	215.17 ± 0.13^{ab}	200.68 ± 0.05^{b}	211.67 ± 0.16^{ab}	244.08 ± 0.03^{a}	217.26 ± 0.06^{ab}
Survival rate/%	91.67	94.45	91.67	94.44	97.22	95.84

Note: NSP: non-starch polysaccharide enzymes. Data on the same row with different superscripts are significantly different ($P < 0.05$).
Source: Modified after Zhou *et al.* (2013).

Table 3.12.3 Growth parameters (mean ± SD) of *S. canaliculatus* fed diets with fish oil (FO) or different ratio of soybean oil (SO) for eight weeks.

	Dietary groups			
Parameter	**FO**	**SO23**	**SO45**	**SO67**
Initial weight (g)	11.86 ± 0.05	12.15 ± 0.16	12.09 ± 0.09	12.23 ± 0.09
Final weight (g)	41.33 ± 0.33^{c}	46.85 ± 0.85^{b}	50.04 ± 0.8^{a}	45.11 ± 0.62^{b}
Weight gain (%)	248.43 ± 4.23^{c}	285.63 ± 3.66^{b}	313.96 ± 7.57^{a}	268.79 ± 4.23^{bc}
Daily weight gain (%)	2.35 ± 0.02^{c}	2.44 ± 0.02^{b}	2.57 ± 0.03^{a}	2.36 ± 0.02^{bc}
SGR (%/ week)	2.23 ± 0.02^{c}	2.41 ± 0.02^{b}	2.54 ± 0.03^{a}	2.33 ± 0.02^{bc}
Feed conversion ratio	1.23 ± 0.01^{a}	1.18 ± 0.01^{b}	1.10 ± 0.01^{c}	1.24 ± 0.02^{a}
Protein efficiency ratio (%)	2.48 ± 0.02^{c}	2.61 ± 0.02^{b}	2.81 ± 0.01^{a}	2.51 ± 0.04^{c}
Condition factor (g/cm^3)	2.72 ± 0.18	2.76 ± 0.17	2.84 ± 0.06	2.72 ± 0.12
Hepatosomatic index (%)	1.43 ± 0.11	1.19 ± 0.08	1.34 ± 0.08	1.25 ± 0.09
Viscerosomatic index (%)	8.27 ± 0.35	8.55 ± 0.37	8.93 ± 0.31	9.08 ± 0.35

Note: FO: diet with fish oil as dietary lipid. SO23, SO45, SO67 respectively means diet with 23%, 45% and 67% of dietary fish oil was replaced by soybean oil. Data on the same row with different subscripts are significantly different ($P < 0.05$).
Source: Modified after Xu *et al.* (2012).

In recent years, research and development on formulated diets for rabbitfish has made major advances. Studies have shown that the optimum protein and lipid requirement for rabbitfish is 29–34 percent and 6–9 percent, respectively (Wang *et al.* 2010; Zhu *et al.* 2013). Fish meal in these diets can be partly replaced by soybean meal and seaweed meal alternatives. The percentage of seaweed meal substitution can reach up to 5–15 percent (Table 3.12.2), while fish oil can be replaced by vegetable oil alternatives, such as soybean oil, with above 67 percent in rabbitfish formulated diets (Table 3.12.3) (Xu *et al.* 2012; Zhou *et al.* 2013; You *et al.* 2014a, 2014 b). The inclusion of plant derivatives can reduce the cost of formulated feeds, significantly.

Moreover, rabbitfish possess many important features in LC-PUFA biosynthesis. It is the first marine fish demonstrated to have the ability to biosynthesize LC-PUFA from C 18 PUFA precursors (Li *et al.* 2008). In addition, rabbitfish is the first marine fish characterized with the dual functional Δ6/Δ5 fatty acid desaturase (Fad) and also the first vertebrates characterized with the Δ4 Fad (Li *et al.* 2010). All these features make rabbitfish a good model for investigating the regulatory mechanisms for LC-PUFA biosynthesis in marine teleosts. These data are theoretically and practically important for replacement of fish oil (FO) with vegetable oil (VO) in aquafeeds, cost reduction of formulated feeds, and healthy and sustainable development of marine aquaculture.

3.12.4 Challenges Confronting the Development of Rabbitfish Culture

The development of the rabbitfish culture sector is significant for promoting healthy and sustainable development of marine aquaculture in China. However, there are still some problems with the rabbitfish culture industry. These are:

- artificial propagation of rabbitfish: Rabbitfish fry in aquaculture are currently sourced from the wild, and thus the output and quality cannot cater to the requirements for the sector to develop fast. Although artificial propagation of *S. guttatus* and *S. fuscescens* has succeeded, the survival rate of fry is low, and there is a need to improve fry to fingerling survival;
- cultivation of improved varieties of rabbitfish: Wild rabbitfish show strong stress responses to environmental disturbances, such as high temperatures and low salinity. It is necessary to develop new varieties of rabbitfish capable of high salinity tolerance and greater stress resistance;
- research on aquaculture mode and technology for rabbitfish: Compared to other herbivorous teleosts, there is still a huge gap between the culture mode for rabbitfish and other popular carnivorous fish species in skills, infrastructure facilities used, disease prevention and control, and overall management, all of which require more studies and investment. In the future, we should take full advantage of the feeding habits and ecological merits of herbivorous fish species, enhance investigation on polyculture mode and emphasize the significance of integrative ecological benefits.

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3.13

Soft-Shelled Turtle Culture

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3.13.1 Soft-Shelled Turtle: An Emerging Aquaculture Species

Reviewing the last three decades of aquaculture development, it is not difficult to find that one of the most important contributions to this development comes from the emergence of dozens of new high-valued and marketable species such as soft-shelled turtle, crucian carp, mandarin fish, large-mouth black bass, crab, freshwater giant prawn, among others. Soft-shelled turtle culture over the last decade or more has emerged as one of the most successful among these.

Based on ancient records (Ding 2001; Lin 2005), soft-shelled turtle (*Pelodiscus sinensis*) was considered a nutritive food due to its high nutritional and medicinal values and its use for these purposes can be traced to the early Zhou Dynasty approximately 3000 years ago (Wu *et al.* 2002; Somfai-Relle 2005). However, the commercial farming of soft-shelled turtle did not begin until the mid 1980s when the greenhouse culture system was successfully established and practiced in Zhejiang Province (Sun *et al.* 1994), and spread nationwide. Currently, 26 provinces, municipalities and autonomous regions have developed soft-shelled turtle culture, and the provinces of Zhejiang, Hubei, Jiangsu, Jiangxi and Anhui rank as the top five producers. Zhejiang province is the biggest turtle producer with almost 45 percent of the national output (Figure 3.13.1).

Over past three decades, soft-shelled turtle culture in China has shown a gradual increase in production, from about 945 tonnes in 1992 to 355 000 tonnes in 2014, with production almost stabilizing since 2011 (Figure 3.13.2); i.e. over the 22-year period the cultured soft-shelled turtle production averaged an annual growth of 32.6 percent.

Soft-shelled turtle culture is considered as an aquaculture practice that yields high economic gains. It has been estimated that soft-shelled turtle culture was worth 25 billion RMB (6.0 RMB = 1 US$) in 2014. A small-scale farm that stocks 30 000–50 000 turtles, on average, earns 100 thousand RMB, and there are more than 100 thousand of such farms in China (He 2000; Haito *et al.* 2008; He *et al.* 2015). The emergence of soft-shelled turtle culture diversifies the lists of important cultured species in China, and offers farmers an opportunity for livelihood improvement.

3.13.2 Development Overview

Over past three decades the development of soft-shelled turtle has generally been fast. During this period, the supply chain of the soft-shelled turtle culture industry has been developed including hatchery production of fingerlings, grow-out farming, feed manufacture, product processing and marketing. All these developments led to turtle culture becoming an important component of Chinese aquaculture. The period of development

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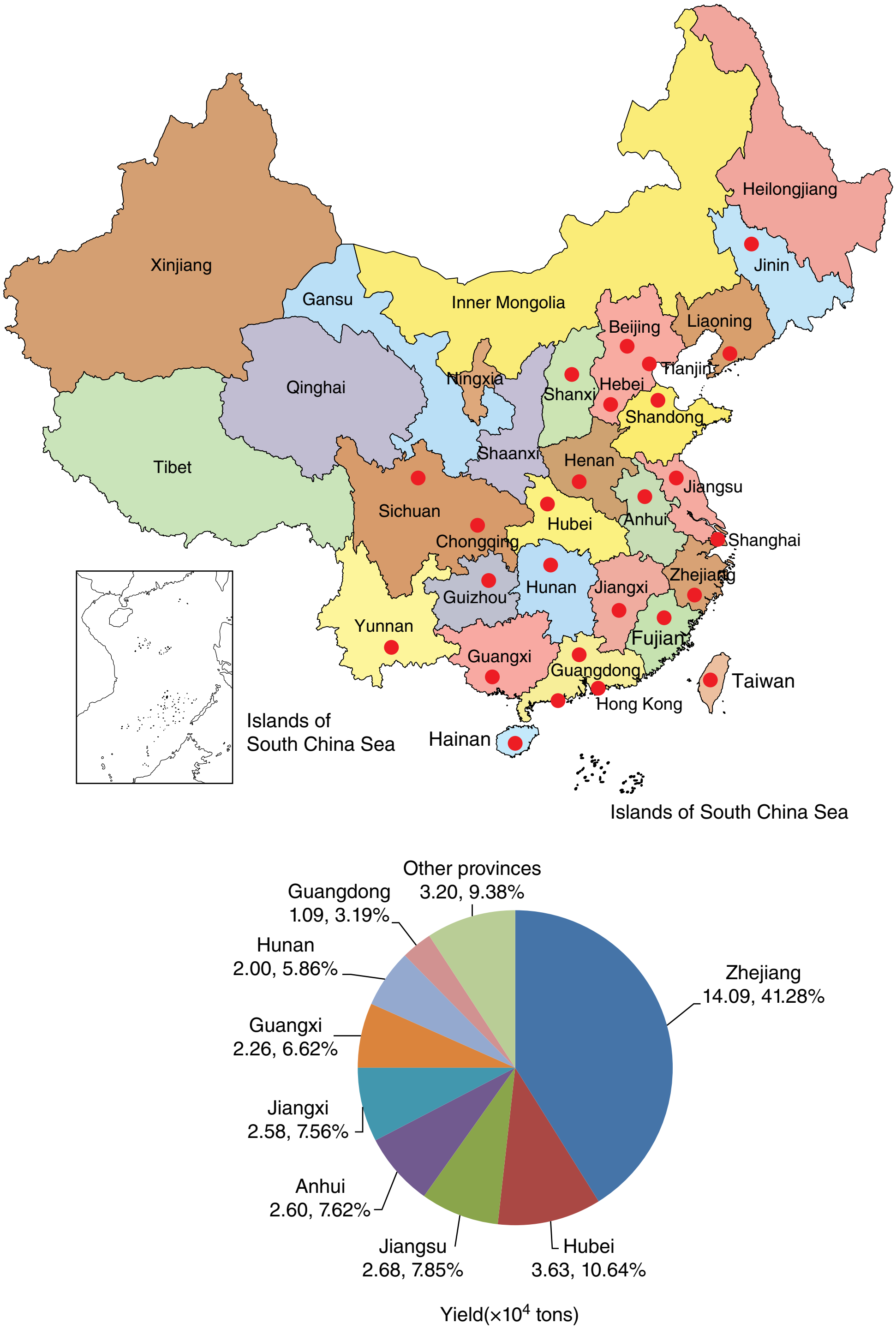

Figure 3.13.1 Distribution of soft-shelled turtle in China. The production values in 2014 are used in the lower diagram.

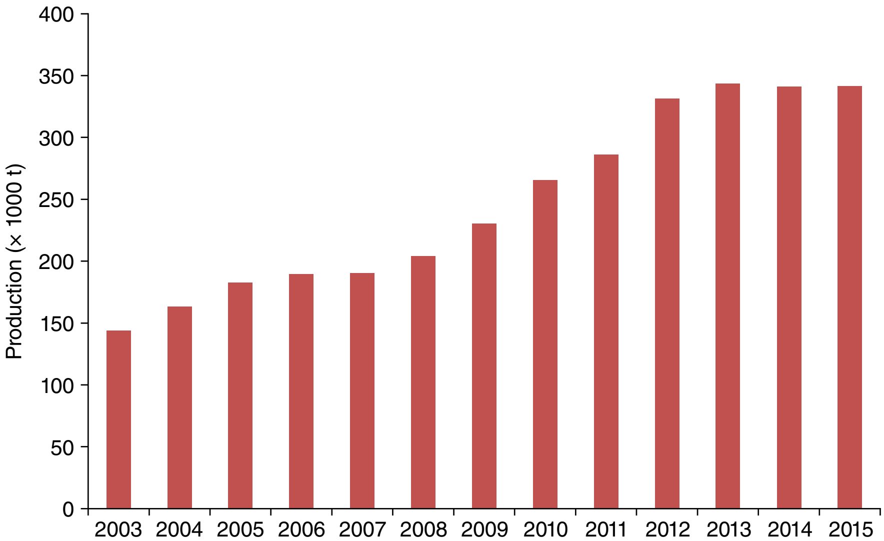

Figure 3.13.2 Annual output of farmed soft-shelled turtle in China.

can be broadly categorized into three phases; initial phase, fast-adjustment phase and restructure cum upgrade phase.

3.13.2.1 Initial Phase

The period from the mid 1980s to the mid 1990s could be described as the initial phase. The most remarkable feature of the phase was the successful development and practice of greenhouse culture. Greenhouses were designed to keep the water temperature at 30±2°C for optimal growth of soft-shelled turtle, enabling year-round growth and eliminating the turtle's half-year hibernation in nature. This enabled a shortening of the culture cycle from three to four years under natural conditions. to ten to twelve months, and also resulted in an average yield of 2.5–3.0 kg/m^2 (He *et al.* 2015). As an advanced and a practical cultural system, the greenhouse culture model was extensively popularized nationwide by fisheries research institutes, and technical extension stations. The rapid popularization of this culture model, however, resulted in a shortage of seed stock which were primarily wild caught. Although artificial propagation was begun to try and meet seed requirements, the shortage did not substantially improve, because of the high price of artificially propagated seed at 10–15 RMB/indiv. during this period. However, this high seed cost did not impact on the demand from farmers because of the shortage of marketable turtles, which as a result commanded a price of about 200–300 RMB/kg. In this phase soft-shelled turtle production increased from 945 tonnes in 1992 to 17 400 tonnes in 1995, increasing 3.3 times annually (He *et al.* 2015).

3.13.2.2 Rapid-Adjustment Phase

The period from the mid 1990s to the early part of the twenty-first century could be classified as the rapid-adjustment phase. From the mid 1990s, a large amount of industrial and commercial capital was invested in soft-shelled turtle culture in the pursuit of higher profits. During this phase, a seven-fold increase in output from 17 400 tonnes in 1995, to 140 000 tonnes in 2004 occurred within the space of ten years (He *et al.* 2015). Such a rapid expansion of soft-shelled turtle culture also gave rise to many problems.

Fingerlings from local hatcheries were unable to meet the demand for increased numbers of seed stock, and therefore, about 60 percent of needs had to be imported from the Taiwan region, and some south-east Asian countries (Wu and Zheng 2007). The import of fingerlings fulfilled the immediate needs, but brought new diseases such as hole disease, skin fester disease, red neck disease and red abdominal shell disease, which prevailed and caused heavy economic losses. At this time, the market price of cultured turtles fell dramatically from an average of 200–300 RMB/kg to 40–50 RMB/kg because of public concerns on the greenhouse environment, medicines used for disease control, and product quality and safety. Many farmers and companies who had old, poorly run facilities had to close and became bankrupt (Wu and Zheng 2007).

These problems forced the culture practices to be changed and adjusted through a series of improvements and innovations. Not only greenhouse culture but also some new models, such as pond culture, and the two–phase culture of pond integrated with greenhouse and polyculture, began to develop. These changes lowered the cost of farming, improved the culture environment, and resulted in good quality produce. The physical nature of greenhouse facilities were also improved, resulting in low construction costs, roof made of light material, better ventilation, and single-pool layout. Based on a series of studies, feeds specific for each stage of soft-shelled turtle development were produced, and used instead of eel feed at the initial phase. The culture of soft-shelled turtle began to shift from output-oriented to one that brought about environmental integrity, quality, safety, and reasonable economic returns.

3.13.2.3 Restructure-Cum-Upgrade Phase:

In the early years of this century, because of the pressures of production costs, marketability, environment and quality safety, soft-shelled turtle culture had to be restructured and upgraded, to bring about significant improvements of the production and market chains for sustaining development. A new type of greenhouse featured with lightweight roof, single-pool layout, and the systems used clean energy and became the mainstream type. In addition to the nationwide practice of pond culture, and two-stage culture of greenhouse integrated with pond polyculture systems have been innovated and improved of turtle with fish, and/or white-leg shrimp, freshwater giant prawn, the turtle-rice integrated cultivation, the grading of pond culture (He 2000, 2001; He *et al.* 2015; Zhang and Wu 2000), all of which have contributed greatly to upgrade traditional turtle farming.

The artificial propagation and selective breeding of improved strains have been fundamental to recent developments in soft-shelled turtle culture. During this phase, a dozen geographic populations of soft-shelled turtle have been collected, nursed and conserved, which have made it feasible to establish the system of propagation and selective breeding of fingerlings of different quality. Currently, one national breeding center, and about 30 native or fine-strain farms, and lots of local fingering hatcheries have been established. Selective breeding programs have enabled improvements in the quality and quantity of fingerling production, and consequently in 2014, 590 000 000 soft-shelled turtle fingerlings were produced (China Fishery Statistical Yearbook 2015), most of which were from selected strains.

The control of water quality, product quality, and effluent were also key issues that have been addressed over this period. Many actions were taken to deal with these issues through the comprehensive adoption of new types of greenhouse, disposal facilities, use of good-quality fingerlings, proper farming models, and monitoring of culture environment and product quality and safety. The aforementioned efforts have restructured and upgraded culture practices. The annual output of soft-shelled turtle in 2014 was 355 000 tonnes, a 1.5-fold increase compared to 140 000 tonnes in 2004 (He *et al.* 2015).

3.13.3 Principle Farming Models and Practices

The innovation and upgrading of farming systems and the technology created have contributed most to the developments in soft-shelled turtle culture in the last three decades. Although many different models may be identified according to the different facilities and species, in general, there are five models that can be classified and described. These are:

- greenhouse culture;
- pond culture;

- integrated greenhouse and pond culture;
- polyculture (turtle, fish, crustaceans etc.);
- turtle-rice integrated cultivation.

3.13.3.1 Greenhouse Culture

As a cold-blooded species, soft-shelled turtle is impacted by the water temperature in its growth, propagation and feeding. It grows well under the optimum temperature of 28–32°C, stops feeding at 15°C or below, and hibernates at 10°C or below (He *et al.* 2004; Xu 2013). The culture period from 3–4-g fingerlings to marketable size of above 500 g usually lasts three to four years, with two to three overwintering periods under natural conditions in central and eastern parts of China. Approximately 10 percent mortality may occur during overwintering. This longer culture cycle increases overwinter mortality and culture risks.

The greenhouse culture model began in the mid 1980s in Zhejiang. Between 1985 and 1988, the model and technology were developed and successfully practiced, with an average yield of 2.5–3.5 kg/m^2, average individual size of above 400 g after 10–12 months' culture in greenhouses (Wang 2007). Encouraged by the success, the model was quickly extended and practiced nationwide.

Although many factors contributed to its success, the most important one was maintaining the water temperature at the optimum range of 28–32°C, which allowed soft-shelled turtle to grow round the year. It is this model that makes large-scale soft-shelled turtle culture profitable and feasible. However, with the rapid development of soft-shelled turtle culture, some problems were encountered that hindered its popularization. The problems which arose from poor lighting, insufficient ventilation, with two or three levels of pools (Xu 2000) made feeding and other routine operations difficult, finally resulting in the deterioration of water quality and disease emergence.

To overcome these problems, a new type of environmentally friendly greenhouse was designed. The new greenhouse was had a translucent roof, good ventilation, and single-pool layout, with flexible pool size, the use of clean energy from renewables for thermal heating/solar heating, and disposal ponds (Figure 3.13.3).

A typical greenhouse is of 500–1000 m^2, laid out in singly or in pairs (He *et al.* 2015). Upgrading greenhouse design and structure brought about a significant improvement in performance, higher yields, a decline in disease, less pollution, as well as improved quality and safety. This model usually yields 10–12 kg/m^2 of mean weight of 400–500 g after 10–12 months' culture, at a stocking density of 25–35 fingerlings/m^2 of body weight of 3–4 g. The model is suitable not only for large-scale farms, but also for small-scale farms and local farmers, and therefore has become the primary model used in central and central-east regions of China. A farmer who manages 1000 m^2 of greenhouse with a stock of 25 000–30 000 fingerlings, can earn 50 000–100 000 RMB yearly.

Figure 3.13.3 New greenhouse (left, light-shed plastic ceiling; right, shows solar energy heating equipment).

3.13.3.2 Pond Culture

The pond culture model is usually defined as the completion of all stages of the lifecycle in ponds until marketable size is reached. The model began to be adopted in the mid 1990s, with fingerling stocked in grow-out ponds with a view to improving quality, and obtaining a higher market price (He 2000). Although the model is disadvantaged by a longer production cycle, overwinter mortality and potential risks, it has been widely adopted, driven by technological improvements, fingerling availability, and incentives of market requirements for improved quality. Under this model, the ponds (usually 2000–5000 m^2) have to be designed to prevent escape by providing a 50–60 cm high fence, and water depth of 2–2.5 m (Figure 3.13.4).

Stocking fingerlings once at the beginning of a culture cycle and harvesting after three to four years was a conventional farming operation, but it also resulted in some problems. In a three-to-four-year period the survival over two to three overwintering periods, and the wide range in individual sizes of turtles is difficult to predict, and results in a lowered pond utilization efficiency and management. In order to overcome these problems, a graded culture process was introduced and widely practiced in Zhejiang (He 2000; Wang *et al.* 2005). Under this approach, it is usual to stock 4–5-g fingerlings from July to August, at a density of 50–80 fingerlings/m^2 of and then to grade yearly. The first grading is carried out in the winter–spring season when the fingerlings are 75–125 g, and the stocking density reduced from 50–80 fingerlings of the initial stocking to ten ind./m^2 for the second-year culture. The second grading is done in the third year of culture, with the stocking density of two to three ind./m^2, an average size of 250–400 g is maintained.

Graded culture is a substantial improvement on pond culture, and makes it profitable for both large-scale and family-run farms. Farmers can manage the culture cycle more effectively during the different phases, which enables effective utilization of pond space, and provides better economic returns. As an example, in Zhejiang, the Yuhang Benpai Soft-shelled Turtle Association, which has a membership of over 100 family-run farms, has adopted the graded culture approach covering 733 ha of ponds, and achieved an average yield of 6.95 tonnes, and a profit of approximately 45 000 RMB/ha.

3.13.3.3 Two-Phase Culture in Ponds and Greenhouses

The model of two-phase culture in ponds and greenhouses has been developed since the mid 1990s and is widely practiced, especially in the central, central-east and southern parts of China. The main characteristics of the model are that the whole culture cycle is divided into two stages; large-sized fingerlings are cultured in

Figure 3.13.4 A pond culture facility (shows the fencing on the far side and structures provided for the turtles to bask in the sun). (*See color plate section for the color representation of this figure.*)

a greenhouse and the marketable soft-shelled turtles cultured in ponds. This model shortens the culture cycle substantially, and results in a better product quality (He *et al.* 2015).

The propagation season of soft-shelled turtle in the main culture regions in China is usually from May to August. Fertilized eggs are laid at night in sand beds that are 30–40 cm, and collected next day (Figure 3.13.5). Eggs are then collected and placed in trays and moved into a hatchery when hatching occurs in about 45–50 days at a temperature of 30–32°C (Xu 2000). Hatchlings are stocked at a density of 25–30 ind./m^2. After several days of training to feed, hatchlings are fostered in a greenhouse for the first stage of culture, until the following July when the water temperature reaches above 25°C. The second stage commences when the fingerlings are 400–500 g (Figure 3.13.6). In this stage the same pond improvements are needed as in the pond culture model, and the soft-shelled turtles are transferred from greenhouse to ponds and maintained at a density of 2–2.5 ind./m^2. Young turtles grow to an average size of about 750 g in four to five months, the total yield usually reaches 10–12 tonnes, and profits of 75 000–120 000 RMB/ha can be obtained.

3.13.3.4 Turtle-Rice Integrated Culture

Turtle-rice integrated culture began in 2001 (He 2001). The model combined the traditional rice-fish culture system with greenhouse culture. Several thousand hectares of rice paddy are used in turtle-rice model. For

Figure 3.13.5 Fertilized eggs collected, selected, and arranged in hatching trays.

Figure 3.13.6 Two-phase culture of greenhouse and pond.

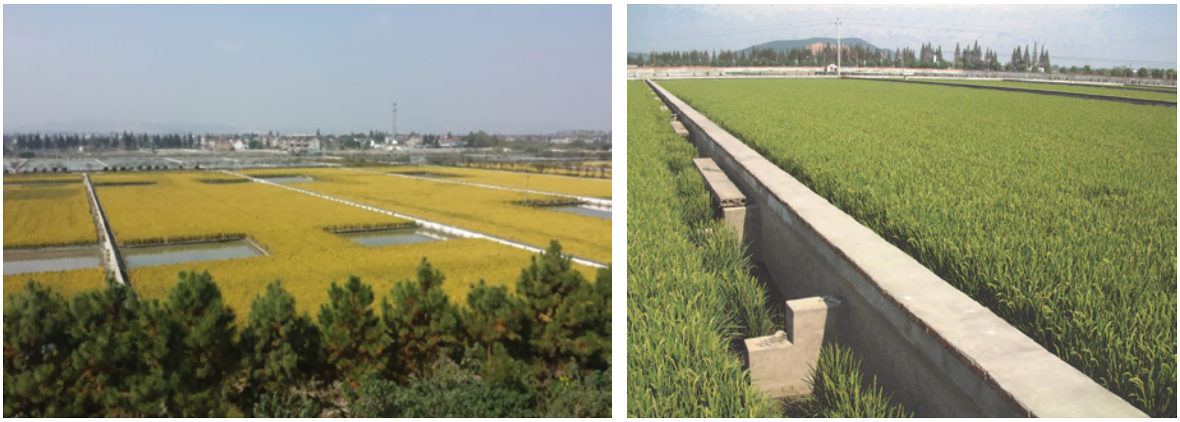

Figure 3.13.7 Turtle-rice integrated cultivation (left), and rice rotation in ponds (right).

example in Zhejiang, there are more than 1300 ha of rice paddies in turtle-rice culture at present (Figure 3.13.7; He *et al.* 2015).

Use of large-sized fingerlings is crucial for the success of this model. Fingerlings hatched in July to August are fostered in greenhouses for about 10 months, and grown to a size of 400–500 g, then transferred into the rice paddy the following May to July, when the water temperature is around 25°C and rice plantation is green. Construction of field earthworks is a basic improvement for the rice-turtle cultivation. The field dike should be reinforced, heightened, and be fenced with suitable materials such as plastic plate/aluminum plate, and/or brick wall to a height of 50–60 cm (Xu 2013; He *et al.* 2015). A feeding platform should be installed on one side of the dike, and pits 1.0–1.2m deep amounting to 5–10 percent of the total paddy area should be provided for turtles to shelter, especially when rice paddies are drained and dry.

Although the planting of the rice crop and the stocking of soft-shelled turtles may differ according to the situation, such as the size of the paddy plants and size of turtle juveniles, the predominant approach in rice-turtle culture is one crop of rice and stocked with 300–600 turtles of 400–500 g each. In spite of the availability of good levels of natural food organisms in the paddy, it is still necessary to provide supplementary feed. This practice can expect to harvest about 500 kg of rice, and a net yield of 150–200 kg of soft-shelled turtles, with a gain of approximate 10 000 RMB. The practice also reduces the use of over 44 percent of chemical fertilizers, and 50 percent of pesticides compared to the levels used in rice monoculture (He *et al.* 2015).

3.13.3.5 Polyculture

Polyculture is typical of traditional Chinese aquaculture, and also widely adopted in soft-shelled turtle culture during the pond culture stage. Although there are many species suitable for this system, the main species include fish such as silver carp, bighead carp, yellowtail catfish, crustaceans, such as firewater giant prawn (*Macrobrachium rosenbergi*), river shrimp, crab and white-leg shrimp (Table 3.13.1).

Stocking different species based on their habits enables full use of the water column and available natural food organisms, and the species can benefit from each other. For example, silver carp and bighead carp clean water through filtering plankton, crab and shrimp clean the bottom organic matter by feeding on feed residues, and turtles feed on crustacean molts, as well as dead fish and/or dead shrimp.

Turtle-fish polyculture was started at the initial stage of pond culture during the mid 1990s (Ge 1997; He 2000) and has become common in China. In this model, the recommended stocking densities of aquatic species are listed in Table 3.13.2. Typically, soft-shelled turtles at 350–500 g are stocked at a density of two to three ind./m^2, 300–600 individuals/ha of 400–500 g silver carp, 450–750 ind./ha of bighead carp and 1250–1500 ind./ha of 100-g crucian carp. Compared to turtle-fish polyculture, turtle-shrimp polyculture is a recent development with the initial purpose of controlling shrimp disease. It is a very popular model in some areas, especially in Zhejiang

Table 3.13.1 Common aquatic species poly-cultured with soft-shelled turtle.

Category	Species
Fish	Silver carp (*Hypophthalmichthys molitrix*); bighead carp (*Hypophthalmichthys nobilis*); crucian carp (*Carassius auratus*); common carp (*Cyprinus carpio*); grass carp (*Ctenopharyngodon idellus*); tilapia (*Tilapia mossambica*); mandarin fish (*Siniperca chuatsi*); yellow catfish (*Pelteobagrus fulvidraco*); bluntsnout bream (*Megalobrama amblycephala*); loach (*Misgurnus anguilli caudatus*); eel (*Anguilla anguilla*); Japanese sea perch (*Lateolabrax japonicus*)
Crustaceans	Chinese Mitten Crab (*Eriocheir sinensis*); river shrimp (*Macrobrachium nipponense*); freshwater giant prawn (*Macrobrachium rosenbergii*); red swamp crayfish (*Procambarus clarkii*), white-leg shrimp (*Penaeus vannamei*)

Table 3.13.2 Recommended stocking densities (SD: ind./ha) of aquatic species in soft-shelled turtle–shrimp polyculture model.

Parameter	Silver carp	Bighead carp	Crucian carp	White-leg shrimp	River shrimp
Size (g)	400–500	400–500	100	7mm	1.0–1.5cm
SD	300–600	225–750	1125–1500	450 000–900 000	450 000–600 000

Figure 3.13.8 Soft-shelled turtle polyculture with shrimp.

where approximately 10 000 ha of ponds have already adopted this model (He *et al.* 2015). In this model, soft-shelled turtles of 350–500 g are stocked at a lower density of 3750–4500 individuals/ha, with shrimp of 5–6 mm body length at a density of 600 000–750 000 larvae/ha, and the stocked animals are fed. In addition, several dozen silver carp and bighead carp are stocked for the purpose of water-quality control.

Good results can be obtained from polyculture practice of turtle-fish and turtle-crustacean. Typically, total yields of 12 tonnes soft-shelled turtle and 1.5 tonnes fish per ha in the turtle-fish model, and 4.5 tonnes soft-shelled turtles and 2.25–4.5 tonnes shrimp and 1.5 tonnes fish in turtle-shrimp-fish model per ha could be achieved, with an approximate overall gain of 150 000 RMB/ha. As a result, the polyculture model has become standard practice (Figure 3.13.8).

3.13.4 Soft-Shelled Turtle Feeds

Feed is the main component of production costs in soft-shelled turtle culture, therefore, improving feed conversion efficiency and reducing feed production costs are issues focused on by the sector. Feeds for soft-shelled turtle juveniles costs 12 000–14 000 RMB/t, usually contain 46–48 percent crude protein, and average feed conversion ratios of 1.2–1.5 are registered. The cost of the feed accounts for about 50–60 percent of the total cost of production of juveniles.

At the initial phases of soft-shelled turtle culture in the early 1990s, there were no specific feeds, and turtles were fed eel feed. With the rapid advancement of turtle culture and huge markets for feeds, attention has been paid to the development of specific feeds. Nutrition requirements at different growth stages, substitutes for fish meal in feeds, economic and environmentally friendly feed formulations, as well as improved technologies of manufacture have drawn the attention of researchers and manufacturers. A typical initial powdered feed formula contains 48–50 percent crude protein which is gradually reduced to 47–48 percent and 45–46 percent for small-sized fingerlings and grow-out, respectively (He *et al.* 2004). In order to lower feed costs for soft-shelled turtle culture, protein content has been reduced by 1–3 percent in all feeds (Wu and Zheng 2007; Tang 2013), and high-cost white fishmeal has been partially replaced by fresh brown fishmeal and plant protein sources (Gao 2003; Wu 2009). The success of extruded feed development in recent years has been considered a remarkable advance in soft-shelled turtle feed, which has brought a series of improvements not only in feed production, but also in the culture practices and management (He *et al.* 2015).

Extruded feed has advantages over traditional powdered feed because of the improved water stability, labor savings and lower costs. Improved water stability lessens feed residue and deterioration of water quality. Quantities of soybean and cereals may be used as both plant protein sources and feed binders in extruding, and α-starch which accounts for 20–25 percent of raw ingredients mainly used as a binder in traditional feed is not used in extruded feeds due to its lower efficacy. A typical recommended formula of main ingredients for juvenile soft-shelled turtles is given in Table 3.13.3, and the extruded feed processed based on the formula reduces the cost of raw ingredient effectively (Zhang 2013; Wu *et al.* 2014). Soft-shelled turtle of average size of about 500 g stocked in turtle-shrimp polyculture ponds at the end of July can reach a body weight of 800 g by early October with extruded feed, with a feed conversion ratio of 1.5–1.7 (He *et al.* 2015).

Table 3.13.3 Main ingredients in a referenced typical feed formula (in percent dry weight) for juvenile soft-shelled turtle.

Ingredient/ proximate composition	Content (%)
Fishmeal	48
Wheat meal	22
Meat and bone meal	8
Corn protein powder	6
Yeast meal	6
Wheat gluten meal	3
Soybean meal	2
Fish oil	2.5
Extruded soybean	1.5
Moisture	9.53
Crude protein	46.1
Crude fat	6.96
Crude ash	12.1
Ca	3.62
P	1.71

3.13.5 Fingerling Production

High quality and availability of fingerlings are the important factors for the sustainable development of soft-shelled turtle industry. In nature, soft-shelled turtle reaches sexual maturity at two to three years of age in southern China, or three to four years of age in central and eastern China. In controlled environments the age of sexual maturity can be shortened to two years using greenhouse cultivation and pond culture models (He 2000).

The key to artificial propagation of soft-shelled turtle is the selection and cultivation of brood turtles. In general, the weight of female and male brood turtles should be more than 1.25 kg and 1.5 kg, respectively, and the ratio of female to male is about 6:1. After careful nurturing, the females may lay 50–100 eggs, three or four times each year. As spawning sites, sand beds of 30–40 cm thick, with a top shelter should be set on one side of the pond where flooding does not occur. Soft-shelled turtles lay eggs at night. The eggs can be collected the following day, transferred into trays, and kept in a hatching room maintained at 30–32°C and relative humidity of 80–85 percent (Figure 3.13.5). The humidity of sand is about 7–8 percent and the total hatching temperature is about 37000°C days. The eggs will usually take about 45–50 days to hatch, which may be longer or shorter depending upon the hatching temperature. The weight of hatchlings is related to the size of the egg, and the proportion of egg weight and juvenile turtle is about 1 to 0.7.

Since 2000, maintaining brood stocks and the production of improved strains of soft-shelled turtles are carried out at a centralized governmental facility. The task of the genetic and breeding center is to collect germplasm of soft-shelled turtle from different areas, and breed improved varieties. The stock and fine-strain farms are to preserve and culture brood turtles, and the propagation bases are to provide materials to small hatcheries that have currently been established all over the main turtle culture regions (Figure 3.13.9). For example, by 2014 in Zhejiang Province, a national genetic and breeding center, 13 provincial farms have been established that maintain improved strains, as well as 18 large-scale propagation bases and hundreds of small hatcheries, with a total output of about 200 000 000 high-quality fingerlings.

A germplasm bank for soft-shelled turtle has been established with material collected from different geographical locations which include 302 000 individuals of the Taihu populations, 81 000 individuals of Yellow River populations, 248 000 individuals of Japanese strains, 58 000 individuals of Qingxi black turtle, and 35 000 individuals of other strains (He 2014). As the morphological characteristics of some populations are similar, some rapid and accurate molecular differentiation methods such as PCR–RFLP (Zhang 2015) and HRM–SNP (Zhang *et al.* 2015) method have been established to assist identification of the different populations/strains (Figure 3.13.10).

The breeding programs for the Qingxi black turtle and Japanese strain began in 1993 and 1995, respectively. The breeding method for the Japanese strain is selective breeding, assisted with molecular detecting method for the main goal of improving growth performance. The technical route is five-step-selective breeding based on its culture environment and growth stages (Figure 3.13.11). After continuous selection with the selective intensity of about five percent, the genetic and growth performance of Japanese strain were fixed down after five generations of breeding (Figure 3.13.12), and its growth rate increased by more than 25 percent compared with others (Zhang *et al.* 2011). As the first fine soft-shelled turtle strain, Japanese strain was authorized as a new breed certificate by the Ministry of Agriculture of China in 2008. Because of its better growth performance and disease resistance, the Japanese strain has been widely introduced to all turtle culture areas in China, North Korea, Thailand, South Korea, and Taiwan, and has become a main species in the industry. According to preliminary statistics, over 100 000 000 juveniles of the Japanese strain are propagated each year in Zhejiang Province (Zhang *et al.* 2012).

Black soft-shelled turtle has a high consumer demand, and therefore commands a high market price among all soft-shelled turtles. The breeding programs for this turtle selects for black abdominal color over growth. The black abdomen feature is genetically stable after five successive generations (Xue *et al.* 2009). Currently, there are only two selectively bred soft-shelled turtle strains. One of the main reasons for this is the five-generation, 10–15 year breeding cycles (He 2014). Due to the better performance of the new strains, the genetics and breeding of turtles have attracted more attention among researchers, as well as from prospective farmers. In this regard, intraspecific hybridization between different populations, and heterosis are being investigated.

Figure 3.13.9 The propagation base of soft-shelled turtle.

For example, a hybrid soft-shelled turtle named as “Zhexinhuabie”, an offspring of Japanese strain and Qingxi black turtle (Figure 3.13.13), with obvious belly color differences from its parents and better growth performance, and disease resistance has been developed (Meng *et al.* 2013).

3.13.6 Water-Quality Control and Disposal

Although soft-shelled turtle as an amphibious reptile is adapted to a wide range of environments, it mainly lives in water. The water-quality conditions not only have a direct influence on its growth, but also are closely related to product quality and safety, and the surrounding environment.

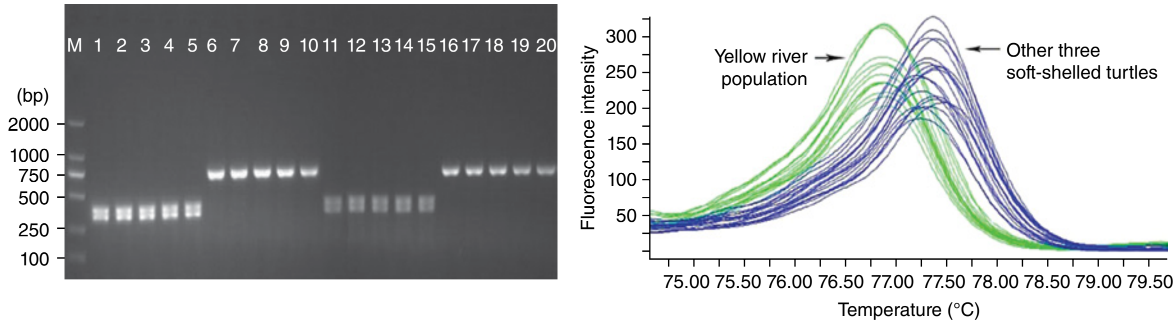

Figure 3.13.10 PCR–RFLP (left) and HRM–SNP (right) identification method for four soft-shelled turtles (1–5, 6–10, 11–15, and 16–20 represent Taihu population, Taiwan population, Japanese strain and Yellow river population, respectively).

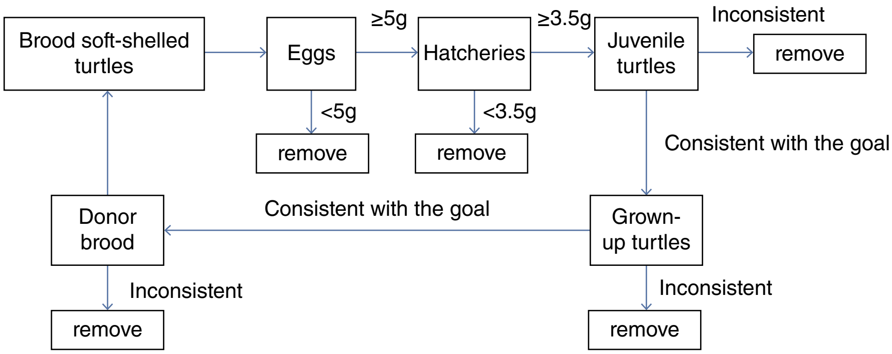

Figure 3.13.11 Five-step selective breeding procedure for soft-shelled turtle.

Figure 3.13.12 Dorsal view of Japanese strain (left), and ventral view of Qingxi black turtle (right).

Figure 3.13.13 Ventral view of hybrid soft-shelled turtle and its parents (from left to right shows Japanese strain, Qingxi black turtle, and its hybrid offspring).

The industrialization of soft-shelled turtle culture began from greenhouse intensive culture. The structure of the early greenhouses was such that it inconvenienced operations of water-quality control and disposal. The current feed conversion rate is generally as high as about 1.2–1.5 in the greenhouse model, but protein retention is only about 30 percent. The major proportion of the protein in feed is discharged into the water in the form of residue and excrement, which accelerates deterioration of water quality. Total ammoniacal nitrogen and COD concentrations of water in a pool may reach 100mg/l and 300 mg/l, respectively. Such high levels stress soft-shelled turtle, and culture systems should therefore resort to frequent water exchange, which, however, in turn pollutes the environment (Sun 2014). Greenhouses have been upgraded to incorporate water disposal facilities. Also, improved light permeability, and the provision of aeration have helped the breakdown of organic material. In addition, planting of aquatic plants, such as duckweed, water hyacinth or vegetables in pools, covering an area less than one third of the pools, have enabled further improvements in water quality.

For effluent collection and final disposal of the sludge, disposal pools are constructed. The water in the disposal pools is recirculated. Disposal pools accounts for 20–30 percent of total greenhouse area, and are usually divided into multi-grade pools with depths of 2–2.5 m. The first grade pools are used for sedimentation, the secondary ones often have aquatic plants, and are stocked with filter-feeding fish (i.e. bighead carp, silver carp) or omnivorous fish (i.e. tilapia, crucian carp), and are aerated. The disposal procedure is shown in Figure 3.13.14. The research and monitoring results have shown that the total phosphorus, total

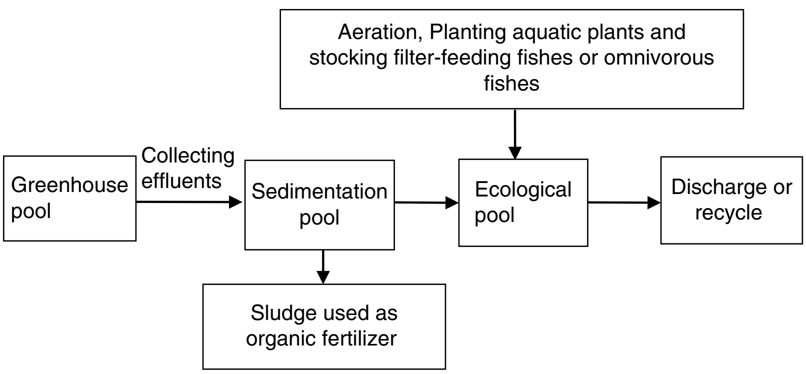

Figure 3.13.14 Recommended disposal procedure for the effluents from soft-shelled turtle greenhouses.

nitrogen, COD_{Cr}, ammonia and BOD can be reduced by 75–88 percent, and suspended solids by 97 percent (He *et al.* 2015).

The nutrient absorption capacities from the effluent differ between different plants. Water hyacinth absorbs ammoniacal nitrogen, nitrite nitrogen, COD and phosphorus up to 71.5 percent, 88.1 percent, 68.5 percent, and 90.7 percent, respectively (Yuan and Liu 2001). The eco-ditch technology system which combines *Eichhornia crassipes*, *Bacillus subtilis* and water snail (*Margarya*), to purify effluents from greenhouses reduce the total nitrogen concentration by 75 percent, ammoniacal nitrogen concentration by 91 percent, total phosphorous by 83 percent, and COD_{cr} by 62 percent, and raised the dissolved oxygen content by nearly four times and maintained the pH at a neutral level (Wu *et al.* 2012).

3.13.7 Marketing and Processing

Soft-shelled turtle is a traditional high-valued food item, and also used as a medicinal material as described in the pharmaceutical book, *Compendium of Materia Medica*, written 600 years ago during the Ming Dynasty (Wang 1992). It is known that soft-shelled turtle is rich in protein, indispensable amino acids, docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA), trace elements, B vitamins, folic acid, and other functional factors such as polysaccharide, collagen, taurine and Vitamin B17, and so on (Zhang *et al.* 2013). Proximate analyses of Taihu, Japanese and Taiwan strains of soft-shelled turtle, and Qingxi black turtle, indicate that the crude protein, moisture, crude fat and crude ash contents averaged 18.3–19.9 percent, 79.4–80.0 percent, 0.66–1.14 percent, and 0.93–1.07 percent, respectively (Zhang *et al.* 2008). The crude protein content in eggs and skin are 23 percent and 29 percent, which are higher than that of muscles in soft-shelled turtle, and the content of collagen in skin is the highest (Wang *et al.* 1997; Fang 2010).

The amino acid composition of the proteins are in line with the Food and Agriculture Organization of the United Nations/World Health Organization (FAO/WHO) standard, and the amino acid scores (AAS) of protein in the legs are above 100 (Chen *et al.* 1999; Wang *et al.* 2005). The amount of highly unsaturated fatty acids account for 32.69 percent of total fatty acids, among which DHA and EPA accounted for about 8.30 percent and 6.97 percent, respectively (Zhan *et al.* 2000). It is also rich in trace elements such as iron, chromium, zinc, copper, manganese in muscles (Jiang *et al.* 1996).

Soft-shelled turtles have good marketability in China due to the traditional belief in its high nutritional and medicinal values. Some research have shown that soft-shelled turtle is helpful in improving immunity, promoting blood circulation, stimulating metabolic activities and enhancing the ability of resistance and anti-aging effects (Song *et al.* 2012). Its main markets are in China, Japan, Korea, and other South-east Asian countries. The main marketing channels are wholesale markets, supermarkets, retail stores and online sales, and the average commodity specification is about 0.5–1.0 kg/individual and turtle is mostly marketed live.

The price varies according to its culture mode, sex, strain, and other specifications. In general, the prices of pond-cultured and turtle-rice model-cultured soft-shelled turtles are higher than those from the two-phase culture of pond and greenhouse, and turtles from the latter are sold at a higher price compared with those from greenhouses. The 2016 price of pond-cultured soft-shelled turtle was approximately 60–70 RMB/kg; greenhouse culture mode was approximately 40–50 RMB/kg. The price of a male soft-shelled turtle is about 10 percent higher than that of a female with same specifications.

There was no registered trademark for soft-shelled turtle until the end of 1990s, when quality and safety became a consumer concern. So far, more than 200 trademarks of soft-shelled turtle have been registered in China (He 2012). The sale of a soft-shelled turtle with a brand can be traced to its origin, and its quality and safety guaranteed. The registration of soft-shelled turtle brands is not only beneficial for traditional marketing, but also plays a fundamental role in online sales, which are gaining in popularity.

The major processed products of the soft-shelled turtle include ready-to-eat foods, packaged ready-to-eat soft-shelled turtles, gutted, and with a moderate amount of condiments, cooked and vacuum packed and heath care products, which mainly include crude soft-shelled turtle powders, soft-shelled turtle protein peptide powder, and soft-shelled turtle peptide (Wang *et al.* 2014). The processing scale of soft-shelled turtle is relatively small due to the high cost of purchasing soft-shelled turtle raw materials, and the relatively limited market for such finely-processed products.

3.13.8 Conclusions and Prospects

Soft-shelled turtle culture has generally developed fast over the past three decades, and now has become one of important segments of Chinese aquaculture. Although there are many factors responsible for this success, the diversification of culture models, improved fingering production, environment and product-quality control, environment-friendly extruded feed use, and marketing, have been the dominant contributions. The innovations in culture practices based on the facilities and conditions have made soft-shelled turtle culture suitable for farmers who have different resources at their disposal; the fine fingerling breeding system supplies sufficient high quality fingerlings to meet the culture requirements; the monitoring and controlling of the environment and product quality promote consumer acceptance and marketability; and the extension of extruded feed reduces the production cost and water pollution.

Based on the views of the development strategy, it is expected that more and more greenhouses will be built or upgraded with lightweight roof, good ventilation, clean energy, and disposal facilities which will significantly reduce effluent discharge. Moreover, greenhouse culture will be mainly used for the cultivation of large-sized fingerlings for pond culture and turtle-rice culture, which are generally considered to be environmentally friendly culture models, and can greatly improve product quality and safety. The polyculture of turtles integrated with different species in ponds is expected to be more intensively adopted for improving product quality, providing an effective approach to utilizing natural resources. The improved strains and high-quality fingerlings will predominantly be bred with the help of the established turtle breed systems which could provide a reasonable utilization and conservation of germplasm resources.

The idea of "the nutrition and quality-oriented market, and the market leads the production" will be acceptable to producers, and this will guide them to pay more attention to product registration. With the emerging marketing forms of online sales, high-quality products with trademarks are expected to revitalize the market.

As a traditional and yet an important emerging species, soft-shelled turtle has already become a high nutrient food for ordinary consumers, and it is expected that turtle culture industry will further develop in a more sustainable way, with the help of innovation and the extension of culture technologies under the guidelines of a sustainable development strategy.

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3.14

Hard-Shelled Turtle Culture

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3.14.1 Introduction

Turtles are ancient reptiles, which have been living on earth for 250 million years, and are called "living fossils". Turtles are of high value as pharmaceuticals, food, in scientific research, and the shells are used for making ornaments and jewelry accessories. Traditions of eating turtle for health, and for its medicinal values were recorded in the *Shennong Ben Cao Jing*, a Chinese book on agriculture and medicinal plants written around 2800 BCE (Zhang 1994). Turtles are long-lived animals, their shell protects them from external damage and predation by other animals. Turtles are the only one of the "four spirits" (dragon, phoenix, turtle, kirin) in Chinese traditional culture that exists in reality.

Turtle resources were once very rich in China. Turtles were exploited for food and pharmaceutical materials. However, the long reproductive cycle, five to six years to reach maturity, and low fecundity of turtles lead to slow population expansion, and so the species could not keep pace with exploitation. The resources of all species of turtles declined towards the 1980s. At present, most Chinese turtle species are listed as endangered or critically endangered status by the International Union for Conservation of Nature (IUCN). As such, culture of selected species of turtles such as the Chinese three-keeled pond turtle (*Mauremys reevesii*), Chinese stripe-necked turtle (*M. sinensis*), Asian yellow pond turtle (*M. mutica*), Chinese three-striped box turtle (*Cuora trifasciata*), and Yellow-margined box turtle (*C. flavomarginata*) are encouraged in order to meet the demands for human food and pharmaceuticals, as well as to replenish depleted wild populations.

3.14.2 Aspects of Biology of Chinese Turtles

3.14.2.1 Morphology

Turtles are specialized groups of reptiles, and their external morphology can be divided into five parts: head, neck, torso, limbs and tail, like other animals, but the torso is enveloped in two shells, the carapace and the plastron which develop from their ribs and act as shields. The head of the turtle is rather small, slightly triangular, and the mouth is terminal, devoid of teeth, but with horny ridge-covered jaws to cut and chew food. Turtle beak shapes differ depending on the species, and can be beak-shaped, streamlined, saw tooth, herringbone, and ∧-shaped. The nostrils are located at the front end of the snout. The eyes with upper and lower, moveable eyelids are located bilaterally on the head, rounded and slightly prominent. Turtles have no external auditory canal, but the eardrums are placed behind the eyes.

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Based on the manner of retracting the necks into the shell, sideways or backwards, turtles are divided into two groups. All Chinese turtles retract their necks backwards, under their spines. The carapace and plastron are made up of bone and scutes – the bones include backbone and ribs, the scutes being made up of horny scales.

The limbs of aquatic living turtles are flat and their feet are webbed. Some turtles live most of their life in water and their feet are fully webbed; some turtles are semi-aquatic, their feet are semi-webbed.

3.14.2.2 Behavior

Aquatic turtles often live in rivers, lakes, ponds, and other aquatic environments. They spend most time in water in daylight, but must breathe air at regular intervals. Turtles prey on small animals and/or plants, such as insects, worms, small fish, shrimps, snails, leaves, and seeds. They can endure starvation for several months.

Turtles are poikilothermic animals. The temperature greatly influences their behavior. Turtles hibernate when the water temperature goes below 10°C in November until April.

3.14.2.3 Reproduction

Most Chinese turtles reach maturity at more than five years after hatching. Females reach maturity later than males. The mature turtles mate in water or on land, but mainly in water. Mating can be observed all round a year, and the sperm could remain dormant, deposited inside the female for years before fertilization (Gist and Congdon 1998).

Female turtles usually lay their eggs at night or at dawn in moist sand on land. For example, the egg-laying process has been observed for *M. mutica* (Zhao *et al.* 2008). Six stages were observed: selecting a nesting site; excavating a pit; excavating egg chamber; laying eggs; covering the nest; and re-entry into water. Fertilized eggs hatch after 50–70 days. The temperature and humidity affect the incubation time, survival rate, quality of the hatchlings (Guo *et al.* 2010). The sex of turtles is determined by the temperature at hatching (Zhu *et al.* 2006).

3.14.3 Chinese Turtle Species Cultured

Mainly native turtle species are cultured in China (Figure 3.14.1), such as Chinese three-keeled pond turtle (*M. reevesii*), Chinese stripe-necked turtle (*M. sinensis*), Asian yellow pond turtle (*M. mutica*), Chinese three-striped box turtle (*C. trifasciata*) and Yellow-margined box turtle (*C. flavomarginata*). Non-native species are also cultured, such as the Red-eared slider (*Trachemys scripta elegans*), Western painted turtle (*Chrysemys picta bellii*), but not very commonly. Total production of cultured turtles in 2014 reached 36 226 tonnes, and required over 80 000 000 larvae (Figure 3.14.2).

3.14.3.1 Chinese Three-Keeled Pond Turtle

M. reevesii is the most widely distributed turtle species in China. It is known variously, in different regions as golden turtle, grass turtle and mud turtle, etc. The wild resources of *M. reevesii* have been exhausted, and it been listed as endangered by the IUCN.

Artificial culture of *M. reevesii* began in the 1980s. The culture developed fast in the 1990s with the development of artificial propagation, and associated hatchery technologies. Middle and lower reaches of Yangtze River are the centers of aquaculture of this turtle, mainly in Hubei, Hunan, Anhui, Jiangxi, Zhejiang, Jiangsu, and Guangdong provinces.

3.14.3.2 Chinese Stripe-Necked Turtle

Chinese stripe-necked turtle, also called Taiwan grass turtle, is widely distributed in southern China and Vietnam. The flesh of this turtle is rich in protein and vitamins and is considered to be delicious. The shells

Figure 3.14.1 Major species of turtles cultured in China (a. Chinese three-keeled pond turtle (*M. reevesii*), b. Chinese stripe-necked turtle (*M. sinensis*), c. Asian yellow pond turtle (*M. mutica*), d. Chinese three-striped box turtle (*C.trifasciata*) e. Yellow-margined box turtle (*C. flavomarginata*)).

are used for pharmaceuticals. The main culture regions are Zhejiang, Fujian, Taiwan, Guangdong, Guangxi, Hainan provinces. Total production of this turtle is slightly less than Chinese three-keeled pond turtle. It is also listed as endangered by the IUCN.

3.14.3.3 Asian Yellow Pond Turtle

Asian yellow pond turtle, also called stone turtle or well-smelling turtle, is widely distributed in Guangxi, Guangdong, Hainan, Fujian, Anhui, Zhejiang, Jiangsu and Taiwan provinces of China, as well as in Vietnam and Japan. Two major geographic populations, classified as the southern and northern populations, have been identified. The two populations are different in head color and body size. The southern population is distributed in Vietnam and Hainan Island in China, and now cultured in Guangdong, Guangxi and Hainan provinces. The northern population is distributed in mainland China and on Taiwan Island, and mainly cultured in Zhejiang, Jiangsu, and Anhui provinces. Several million Asian yellow pond turtles are produced every year (Cai *et al.* 2014). It is also listed as endangered by the IUCN.

3.14.3.4 Chinese Three-Striped Box Turtle

Chinese three-striped box turtle, also called golden coin turtle, is distributed in southern China and northern Vietnam. It is very highly valued for its economic and pharmaceutical functions, and by far the most expensive turtle species. It is raised in some turtle farms in Guangdong, Guangxi, and Hainan provinces, but these total no more than 100 000 turtles. It is listed as a critically endangered species by the IUCN, and the Chinese government classifies it as a second-tier protected animal (for example pandas are classified as a first-tier protected animal).

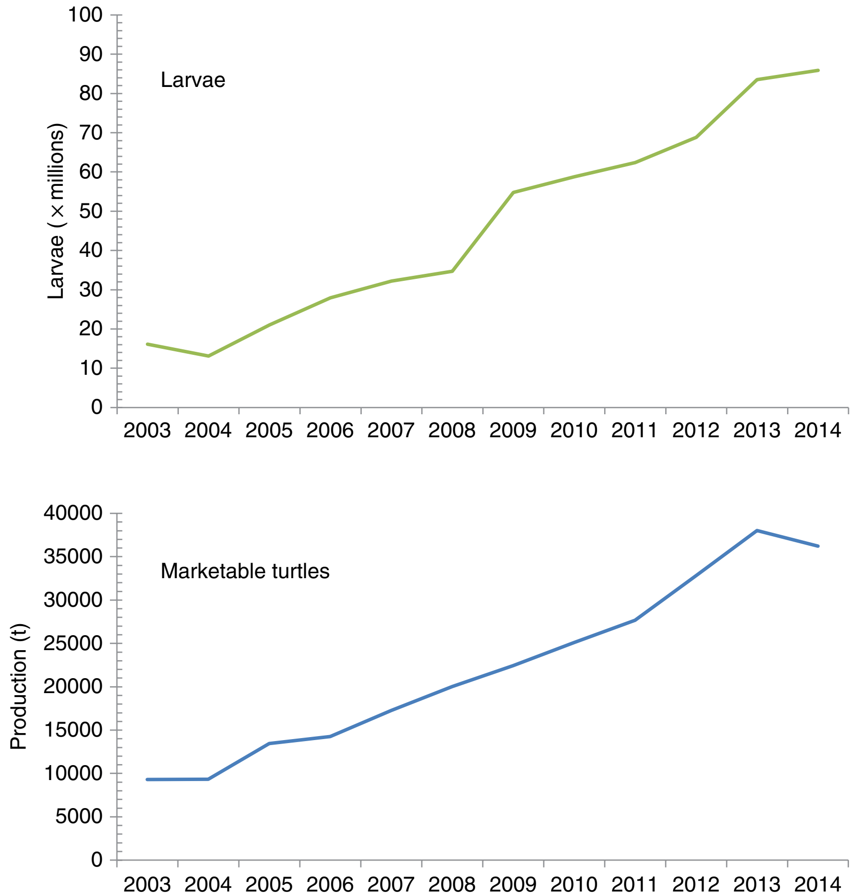

Figure 3.14.2 Trends in the production of larvae and market-sized, hard-shelled turtle in China from 2003 to 2014 (China Fishery Statistical Yearbook 2004–2015).

3.14.3.5 Yellow-Margined Box Turtle

Yellow-margined box turtle, also called snake-eating turtle. Its carapace is highly domed, like a hemisphere. It spends more time on land than in water, though it is amphibious. It is distributed mainly in central, east and southern China, in addition to Taiwan and Japan. Golden turtle powder is used in the treatment of many diseases, in accordance with traditional Chinese medicine. Yellow-margined box turtle is of low fecundity, so the total number is not large.

3.14.4 Aquaculture Models

There are various turtle culture models in China (Figure 3.14.3), depending on the intensity and the value of the overall facilities. The Chinese three-keeled pond turtle and Chinese stripe-necked turtle are relatively low-valued species, and are usually cultured in ponds along with fish. The Asian yellow pond turtle, Chinese three-striped box turtle, and Yellow-margined box turtle are high valued, and are usually cultured in cement pools planted with vegetables or flowers.

Figure 3.14.3 Major culture models of turtles in China. a. (top left) earthen culture pond; b. (top right) large cement culture pond; c. (bottom left) smaller cement pools; d. (bottom right) multi-layered cement tank system. Every unit is divided into water, with a land and sand area. The sand area is used for laying eggs.

3.14.4.1 Pond Culture

Pond culture (Figure 3.14.3) together with fish is the major model used for Chinese three-keeled pond turtle and Chinese stripe-necked turtle. Square ponds, usually with two parts – water covering three-quarters of the pond and a land area in the remaining quarter. The water area is usually 2–2.5 m deep, and the land area is covered with fine sand 20–30 cm thick and 1 m wide. A wall 60 cm high, with a smooth internal surface, must be built to prevent escape.

Turtles like clean water. They are very sensitive to water quality, and fertilization is not effected unless under optimal water-quality conditions. Fishes cultured together with turtles are those that can help improve water quality, such as silver carp and bighead carp to control the plankton, common carp and crucian carp to clean residual feed.

The turtle-fish mixed culture model has some advantages. First, air breathing turtles do not compete for oxygen in the water with fish. Further, turtles move frequently in and out the water, which can increase the oxygen content of water. Second, fish can feed on residual feed and plankton. Three, turtles are predators, which can clean moribund or dead fish. This model fully utilizes the water area of the pond, and the turtle and fish benefit from each other.

3.14.4.2 Cement Pool Culture

Cement pools are usually used to keep high-valued turtles, the Asian yellow pond turtle, Chinese three-striped box turtle, and Yellow-margined box turtle (Figure 3.14.3). For safety, the pools are usually built indoors or in a yard, and a monitoring system installed. The pools can be as large as 100 m^2, and as small as several square meters, depending on the quantity of turtles and size of the farm size. The pools are 1 m in depth, containing 40–50 cm water taking up three-quarters of the area. The other quarter area is for the turtles to move around and to lay eggs. Sheds are installed to provide shade. Pools can be built on one floor or over several floors (Figure 3.14.3).

3.14.5 Value Chain of the Turtle Culture Industry

The complete value chain for turtle culture consists of larval production, culture, feed production, product manufacturing, trade, and consumption. At present, such a vertically integrated chain is not developed. For Chinese three-keeled pond turtle and stripe-necked turtle, there are professional corporations for larval, feed and commercial turtle production, and cultured turtles are carried live to meat markets, or factories for processing. But for the Asian yellow pond turtle, three-striped box turtle, and other cultured turtles, such an industry chain has not been formed, only breeding farms and several feed production factories are functional at present. Asia is the major market for turtles and their products, and Hong Kong, Taiwan, and southern China are key regions. Turtles are consumed in the form of meat, used as ingredients into pharmaceuticals (traditional medicine), and shells are used for ornaments and jewelry. The flesh of turtle is delicious and nutritious. The shells of turtles are used to produce Chinese traditional medicines, such as kidney and other ailments. Asian people like to keep turtles at home as pets, because they are perceived to be symbols of luck and longevity.

3.14.6 Sustainable Development of Turtle Culture

An assumption is made is that the sustainable and fast development of turtle culture relies on progress in technology. In fact, research and generalization of technology in the areas of efficient reproduction, culture and germplasm identification, provide the basis for sustainable turtle culture.

3.14.6.1 Promotion of Artificial Propagation Techniques

In the wild, turtles often find it difficult to get food. Most Chinese turtles are low fecund animals, because of the long maturation time, and produce only a few offspring per year. In artificial culture environments, the provision of nutritious food regularly promotes the laying of a higher number of eggs, and a higher fertilization rate (Zhu *et al.* 2001a, b; Wei *et al.* 2004, 2010). Temperature and humidity are key factors that influence hatchery production (Zhao *et al.* 2009a, b; Guo *et al.* 2010, 2014).

Furthermore, the sex of turtles is determined by the incubation temperature (Zhu *et al.* 2006), and in hatcheries the temperature is controlled to produce more females to facilitate population expansion. In nature, turtles lay eggs in soil or sand, and leave them to hatch naturally; but in hatcheries, vermiculite, a mineral which helps to maintain temperature and keep humidity levels stable, is used to hatch turtle eggs (Guo *et al.* 2009), when the hatching and survival rate of young turtle are improved significantly. Selecting high fecund strains is another approach for elevating production rate.

3.14.6.2 Promotion of Culture Techniques

Turtles can adapt to natural or artificial environments well, but in hatcheries, turtles, when reared in high density and/or poor environments, are prone to disease. To minimize such occurrences, culture techniques and several culture models, have been developed and introduced as standard processes for turtle culture (Zhu *et al.* 1999, 2010, 2014; Huang *et al.* 2015). The establishment and generalization of standard criteria have elevated the technical level of the whole industry, and promoted the development of turtle culture.

3.14.6.3 Germplasm Identification

Many species of turtles are cultured in China, including both native and foreign species. Several books have been published with colored photographs to enable precise identification for research, production, and conservation (Shi *et al.* 2011; Zhou and Li 2013).

Turtles move slowly, and do not migrate long distances. The widely distributed species formed many isolated geographical populations, and significant genetic diversity occurs between some populations. With the developments in molecular techniques, DNA tools have been used to identify germplasm of turtles. Molecular and hybrid trials have proved the hybrid origin of many new species, such as *C. galbinifrons serrata* (Shi *et al.* 2005), *M. iversoni* and *M. pritchardi* (Parham *et al.* 2001; Parham and Shi 2001), and *Ocadia philippeni*, *O. glyphistoma*, and *Sacalia pseudocellata* (Stuart and Parham 2007). DNA markers are also used in population identification of turtles (Zhu *et al.* 2005, 2008; Zhao *et al.* 2015).

3.14.6.4 Protection of Wild Resources

With environment degradation and over exploitation, wild turtle resources have become almost extinct in China. To protect turtle resources, the government listed some species of turtles as national or provincial protected animal status, and set up wildlife refuges, where all activities of catching or fishing are banned. On the other hand, artificially propagated turtles have been released to replenish wild counterpart populations for the recovery of wild resources, which are the basis of sustainable development of turtle culture.

3.14.7 Constraints of Turtle Culture

Turtle culture is a newly developed industry, and is just beginning to flourish. But there are constraints that need to be resolved.

3.14.7.1 Development of Compound Feeds

The food of turtles in the wild is varied and wide ranging, but few studies have been conducted on the nutrient requirements of turtles. Compound feeds for turtles are produced on the basis of other aquatic feeds, and not specifically for turtles. Such feeds often result in nutritional imbalances, favoring heavy accumulation of fat, which in turn reduces the reproductive rate and impacts on general health. As a result, in most farms broodstock are still fed on natural food items, such as fresh or frozen fish, shrimps, fruits, and vegetables. If the turtle culture industry were to develop fully, the problems associated with compound feeds will have to be resolved.

3.14.7.2 Processed Products

At present, consumer markets of turtles are not fully mature. Most turtles from large-scale culture are slaughtered for fresh meat, and pharmaceutical materials. High-valued turtles are sold mostly as pets, investments, and a small portion for producing high-valued health products. Mass consumption products are still lacking. For sustainable development of turtle culture, processed products must be manufactured for the populace (Cai *et al.* 2014).

3.14.8 Future Prospects

Turtles are highly valued for food, pharmaceuticals, and the shell is used to make ornaments and jewelry. Turtles are traditionally eaten by Asian people, so turtle culture has future prospects. The industry chains of

Chinese three-keeled pond turtle and stripe-necked turtle are stable and intact, though lacking processed products for mass consumption. For Asian yellow pond turtle, three-striped box turtle, and other high-valued turtles, the industry is in its infancy. By developing the science and technology for culture of turtles, popularizing mass consumption of turtle products will provide an impetus for the industry.

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Section 4

Alien Species in Chinese Aquaculture

4.1

Crayfish (*Procambarus clarkii*) Cultivation in China: A Decade of Unprecedented Development

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4.1.1 Introduction

China, in spite of its rich fauna and flora, has depended to varying degrees on alien species in its desire to fast forward aquacultural development and enable the provision of aquatic food for a growing population. The general importance of alien species and their contribution to aquaculture production in China were reviewed by Liu and Li (2010). It is conceded that there is a general notion that alien species in aquaculture have impacted negatively on biodiversity. However, more often than not the contribution of such species to food fish availability is not acknowledged; indeed there are instances where aquaculture sectors in certain nations have been built around alien species, a case in point being the Chilean salmon industry (Gajardo and Laikre 2003). The pros and cons of alien species in aquaculture versus food security and biodiversity have been addressed many a time and we do not consider it is necessary, and/or appropriate to dwell on this controversial issue at present (Beveridge *et al.* 1994; Bartley 1996; Beardmore *et al.* 1997; De Silva *et al.* 2004, 2006, 2009; Diana 2009; De Silva 2012). However, it is important to point out that crayfish (*Procambarus clarkii*) is one of the first species to be introduced into China, and as far as the authors are aware that there are no records of any negative impacts of it on biodiversity.

Crayfish is native to the northern United States, and was introduced into Japan, and then into China in 1929 (Wu and Gao 2008). After nearly a century, this species is currently mainly distributed in the Yangtze River basin, and is becoming an increasingly important aquaculture species in the country. In recent decades, due to its unique taste and well-flavored meat, crayfish has become one of the favorite aquatic products in China, especially in the provinces along the Yangtze River, the harvesting periods often being associated with number of festivities.

"Xuyi Crayfish Festival" in Jiangsu Province and "Qianjiang Crayfish Festival" in Hubei province, which are both annual events organized by local governments, have enhanced the crayfish consumption culture in China, and have promoted the development of local county economies. In the wake of soaring market demand, the Chinese crayfish aquaculture industry has developed in leaps and bounds in the past decades.

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4.1.2 Aquaculture of Crayfish in China

4.1.2.1 Evolution of Crayfish Aquaculture in China

In the early 1970s, farmers in the Yangtze River basin attempted to culture crayfish, but did not attain industrial scale on account of a lack of technology and consumer demand. In 2001, farmers in Qianjiang County, Hubei province, initiated the rice-crayfish rotation farming model (Tao and Zhou 2014). This farming practice successfully solved the problem of fallow paddy fields in winter, and provided an avenue to increase the income of farmers.

After more than ten years' development, China has synthesized various methods to develop workable strategies for cultivating crayfish in specific environments, such as rotational rice-crayfish culture, continued rice-crayfish culture, lotus-crayfish culture and pond polyculture.

4.1.2.2 Recent Developments

4.1.2.2.1 Trends in Production and Value of Crayfish in China

Crayfish aquaculture production in China increased from 44 570 tonnes in 2003 to 723 207 tonnes in 2015, which is equivalent to a 117 percent increase per year. Overall, China predominates global crayfish production, and its contribution to global crayfish production increased from 57.1 percent in 2003 to 91.9 percent in 2015 (Figure 4.1.1). Furthermore, the total value of crayfish produced in China increased from 151 600 000 US$ in 2003, to 344 240 000 million US$ in 2015 (Figure 4.1.2) (RMB 6 = US $1). As such, the importance of crayfish aquaculture in China to global crayfish aquaculture, and the predominance of Chinese contribution to the former are evident.

4.1.2.2.2 Farming Area Distribution in China

Crayfish is mainly cultured in provinces along middle and lower reaches of Yangtze River (Figure 4.1.3). Hubei province dominates crayfish aquaculture, and is referred to as the crayfish basket of China, with a

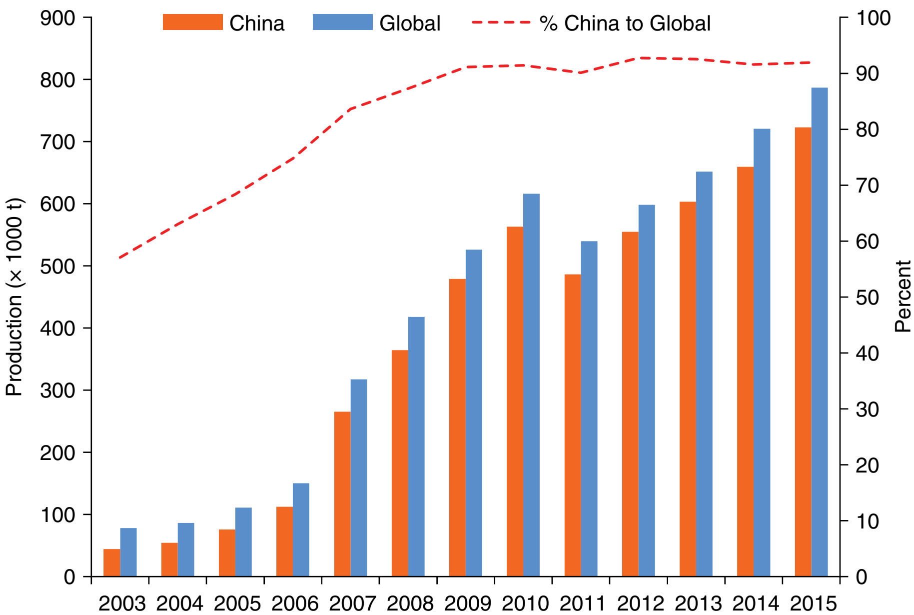

Figure 4.1.1 Trends in crayfish aquaculture production in China, and its percent contribution to global crayfish production from 2003 to 2015. *Source:* Data from FAO (2016).

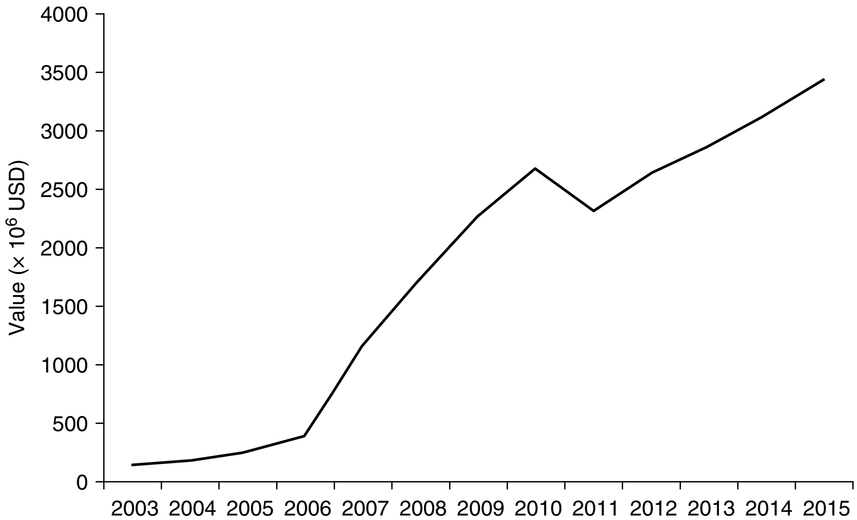

Figure 4.1.2 Trend in crayfish aquaculture value in China from 2003 to 2015. *Source:* Data from FAO (2016).

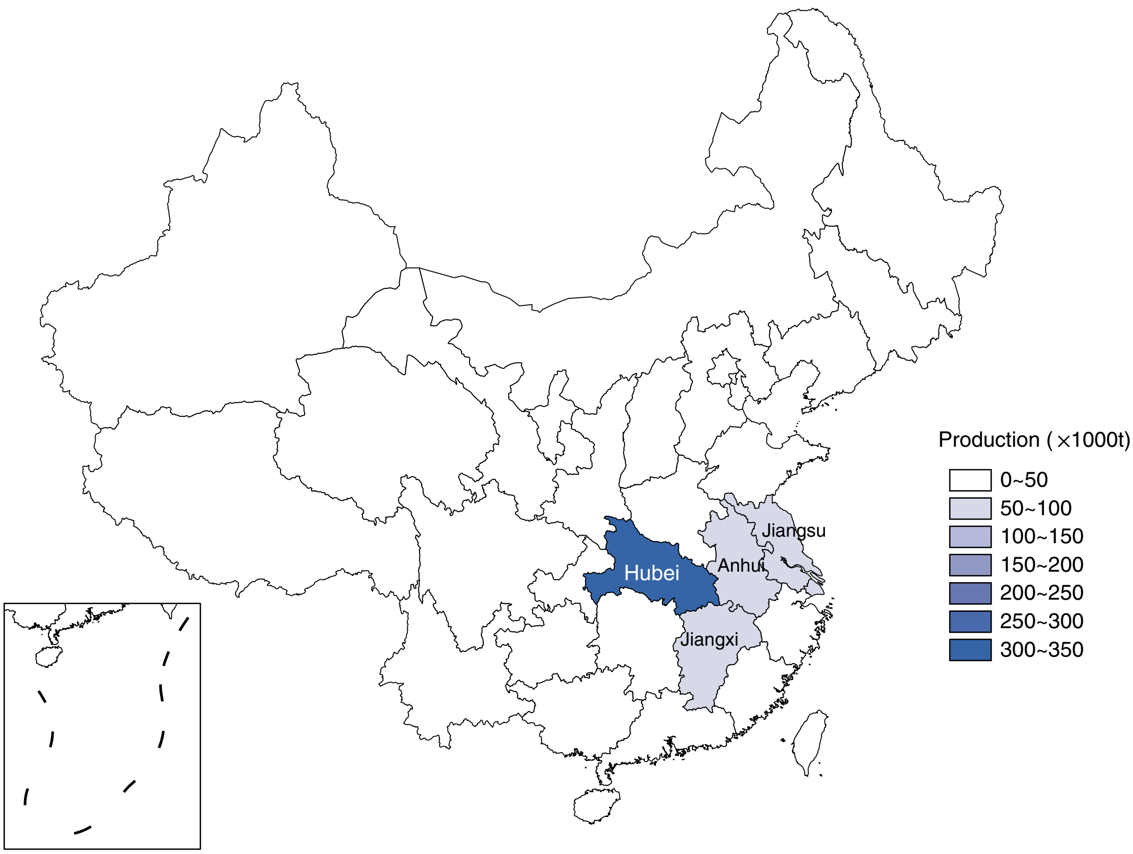

Figure 4.1.3 Average crayfish aquaculture production (t) over the last five years (2011–2015) in the different provinces. *Source:* Data from China Fishery Statistical Yearbook (2011–2016).

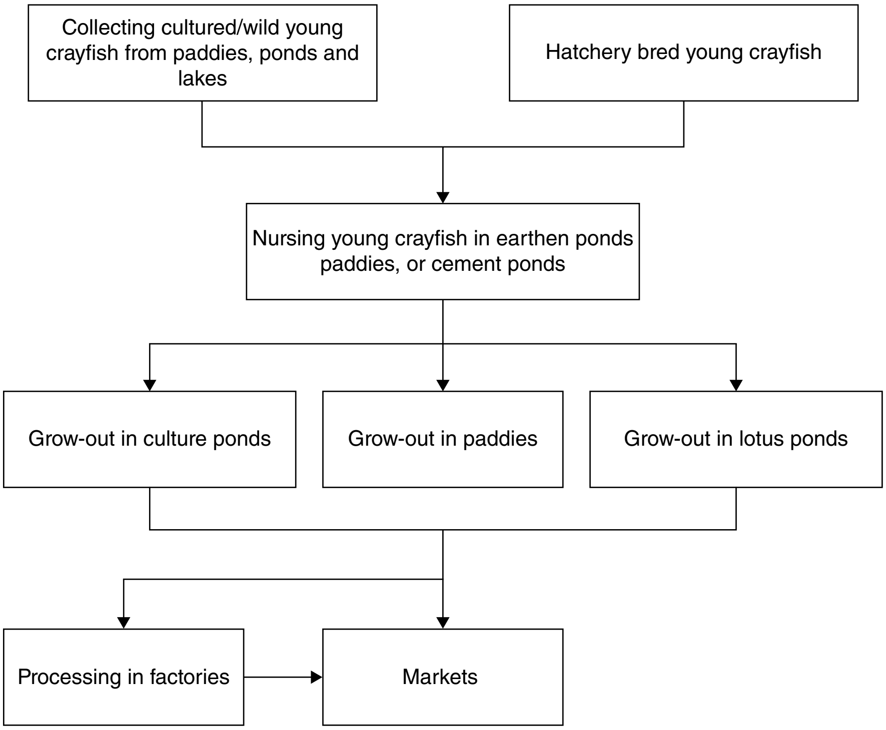

Figure 4.1.4 Value chain of crayfish farming in China.

production of 433 053 tonnes in 2015, which accounted for 60.0 percent of total crayfish aquaculture production in China. In other words, more than 55 percent of crayfish consumed globally is cultured in Hubei Province, China. The other provinces which make significant contributions to crayfish production are Anhui (13.4 percent), Jiangsu (12.5 percent), Jiangxi (8.5 percent) and Hunan (2.4 percent) province (China Fishery Statistical Yearbook 2016).

4.1.2.2.3 Production Chain in China

China has developed a value chain of crayfish from production to market. This sector can be divided into four major components, including hatchery, nursery, grow-out and processing (Figure 4.1.4). In general, crayfish hatcheries are functional between July and September; crayfish nursery rearing occurs between September and October; grow-out is between April to June. Vertically integrated crayfish farming operations are popular, such as, for example, all the lifecycle stages are cultured as units of a single management enterprise, in the same physical location. Normally, grow-out famers buy young crayfish and/or broodstock once, and then operate crayfish hatchery and nursery in their own farms.

4.1.3 Farming Systems and Practices

4.1.3.1 Rotational Rice-Crayfish

Rotational rice-crayfish culture is an extensive farming practice. Normally, the paddies are constructed on the lowlands, adjacent to lakes or rivers where there are pre-existing populations of crayfish. Crayfish paddies require good-quality water sources, and soils that retain water. Paddy sizes vary from 1 ha to a few ha; larger paddies harbor more natural food organisms, such as snails, a favored food item of crayfish, and therefore facilitate their growth. Levees should be well built to ensure that water will be held, and also to discourage burrowing by the crayfish. A channel of 1–1.5 m width and 0.8 m depth, accounting for 3–6 percent of total paddy area should be constructed around the rice-growing area. Fencing should be built around the paddy to prevent escape of crayfish.

Around 10–15 days prior to stocking, farmers use quicklime, 300–750 kg/ha to eradicate unwanted aquatic animals. Following the above, inorganic and/or organic manure are used to enhance the growth of food organisms, such as macroinvertebrates. A combined group of submerged macrophytes (e.g. *Elodea canadensis*, *Vallisneria natans*, *Ceratophyllum demersum*) with a coverage rate of more than 50 percent should be transplanted in the channel for maintaining water quality and providing refuge for molting crayfish during the growth cycle.

Crayfish is stocked between August and September, that is approximately one month before the rice harvest in the Yangtze River Basin (Figure 4.1.5a). In general, two stocking strategies are practiced. In the widely used strategy, crayfish broodstock of 300–450 kg/ha is stocked. The stocking size of crayfish should be more than 35 g/ind. The sex ratio of female to male is around 3:1. In the second strategy, young crayfish that become dislodged from females are stocked at a density ranging from 150 000 to 2 250 000 ind./ha.

Crayfish is polytrophic, consuming all kinds of living plants and animals, as well as microbially enriched detritus, such as crop detritus (Huner 1994). In the paddy, the rice stubble provides excellent substrate for many food items such as periphyton and invertebrate animals. In order to provide more animal feed for crayfish, lights are used to attract and trap insects that fall into the water, and provide an additional food source. In the winter, little supplementary feed is used in crayfish culture. Between February to March in the following year, fertilizers are used to enhance the growth of food organisms for crayfish. Living forages such as

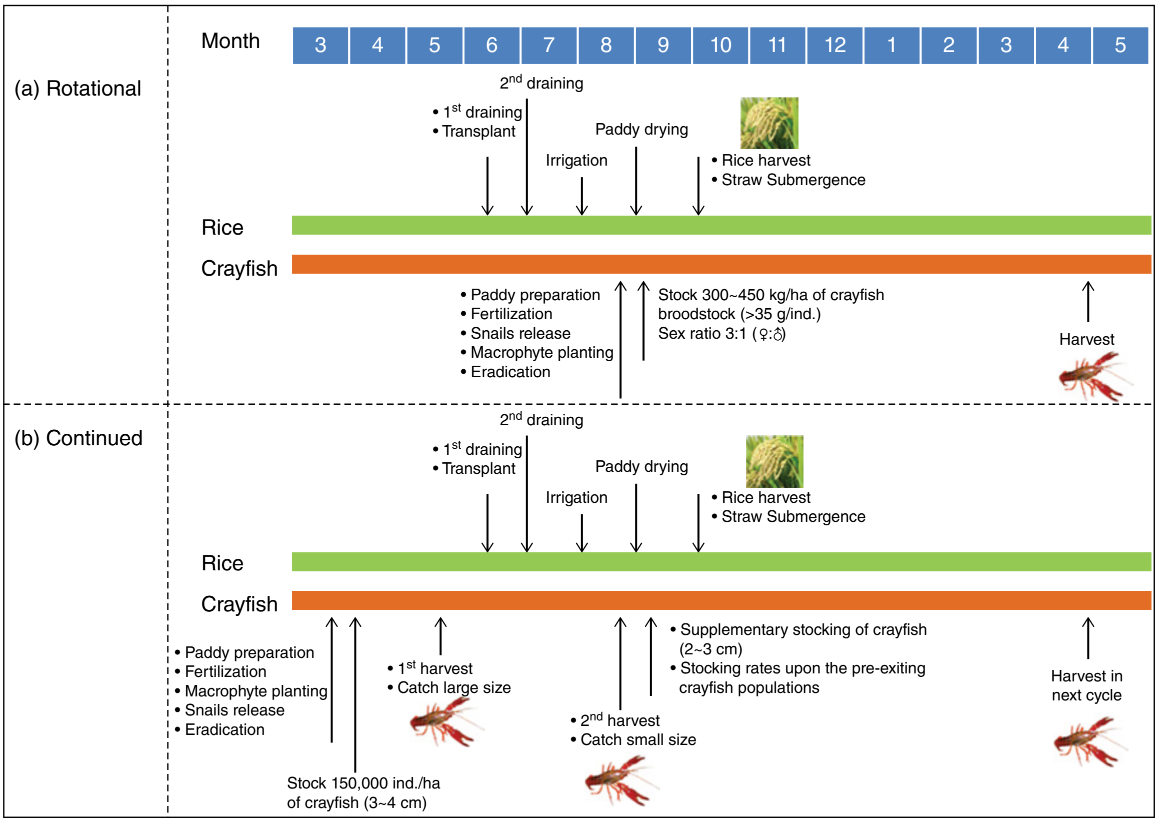

Figure 4.1.5 Crop calendar of rotational rice-crayfish culture model (a); and continued rice-crayfish culture model (b).

macrophytes and animal food organisms (e.g. snails) are also used when available. In addition, rapeseed meal and/or soybean meal are used at a rate of approximately 15–22.5 kg/ha.

4.1.3.2 Continued Rice-Crayfish Culture

Continued rice-crayfish culture is an intensive integrated farming practice. Crayfish and rice are co-cultured concurrently in the paddies. Overall, in such a culture cycle, one crop of rice and two crops of crayfish are harvested per year resulting in an increased production efficiency as well as significantly improved economic viability.

Prior to rotational rice-crayfish culture, a wider and deeper channel of 3–4 m width and 1–1.5 m depth is constructed around the paddy levees. A cross channel of 1–2 m width and 0.8 m depth is constructed in the rice growing area. In total, the channels in the paddy account for around 10 percent of the paddy area. In the channel, macrophytes are transplanted covering more than 50 percent of the channel area. Snails are stocked in the channel at a recommended density of 750 kg/ha (Tao *et al.* 2013).

Figure 4.1.5b depicts the details of stocking, planting and harvesting of the continued rice-crayfish culture system in a whole culture cycle. In this farming practice, there are two stocking strategies. In the first, young crayfish of total length of approximately 3–4 cm is stocked at a density of 150 000 ind./ha between April and May (Figure 4.1.5b). When young crayfish are readily available, the first stocking method is widely used because the crayfish can be harvested after about two months. For the second type, crayfish broodstock of 300–450 kg/ha is stocked between August and September, and the crayfish is harvested in the next rearing cycle. Typically, crayfish may be cultured through a few generations in the paddies without supplementary stocking, on the premise that farmers should be good at population management that ensure sufficient broodstock for next rearing cycle.

In general, Chinese freshwater aquaculture almost always utilizes models incorporating principles of polyculture; not only as a means of increasing productivity, but also as a way of improving the utilization of feed resources, both allochthonous and autochthonous, which in turn reduce nutrients in the effluent (Wang *et al.* 2015, 2016). The majority of rice-crayfish farm holders stock high-valued, carnivorous, mandarin fish (*Siniperca chuasti*) of average body length of 5–8 cm at densities ranging from 300–750 ind./ha in the channels. These fish are expected to forage on the naturally recruited wild fish. It is also very common practice to stock silver carp (*Hypophthalmichthys molitrix*) and/or bighead carp (*Aristichthys nobilis*) of average weight range from 50–100 g/ind. at a density of 450–900 ind./ha to facilitate maintenance of water quality.

Supplementary forages and feeds are provided to crayfish in the channels. From April to December, organic manures and chemical fertilizers are used once a month at a rate of about 1500–2250 kg/ha to facilitate the production of natural food items, including plankton, periphyton and invertebrates. Macrophytes (e.g. *E. canadensis*), at a rate of about 2250 kg/ha, are used once per month. Rapeseed (*Brassica junica*) stubble, pea (*Pisum sativum*) stubble, potato vine (*Solanum tuberosum*). Every unit is divided into water, with a land and sand area. The sand area is used for laying eggs, and other vegetation are also used as green manures, plant food and substrates. Wheat and/or corn seed that are available locally, are used during crayfish culture (Zhang and Zhou 2014); the daily feed ration is about two to three percent of body weight. Overall, crayfish are fed in rotation; feeding of two or more diets results in higher weight gain owing to the diverse nutrition provided by various forages and food types (Dong *et al.* 2016).

In the wake of the fast-growing developments of the crayfish industry, traditional feeds such as macrophytes, grains, crop residues, animal residues, and low-valued fish are not able to meet the demand of large-scale culture. In recent years, feeds formulated exclusively for crayfish have been widely accepted and used by famers in China (Cai *et al.* 2010; Wang *et al.* 2012). The optimum protein level and total phosphorus level for crayfish formulated feeds range from 33.4–38.0 percent, and 1.8–2.0 percent, respectively (Li 2012). Formulated feed is provided twice a day at 06:00–07:00, and 17:00–18:00, a little earlier than the two observed feeding peaks (08:00–10:00 and 19:00–22:00) (Xu *et al.* 2012). The recommended daily ration ranges from 2–5 percent of body weight. Feed is used sparingly when the water temperature is below 12°C.

Table 4.1.1 Details on the stocking, harvesting and economic benefits of rotational rice-crayfish culture (RCC), and continued rice-crayfish culture (CCC).

		Stocking		Harvest		Benefit (RMB/ha)			
Farming practice	**Area (ha)**	**Biomass (kg/ha)**	**Size (g/ind.)**	**Yield (kg/ha)**	**Size (g/ind.)**	**Total revenue**	**Net profit**	**County/ Province**	**Authority**
RCC	3.3	375	35	1500	20–25	43 920	24720	Qianjiang, Hubei	Tao *et al.* 2014
CCC	3.3	375	35	3000	20–25	97 920	70 470	Qianjiang, Hubei	Tao *et al.* 2014
RCC	47.7	157.5	1	1275	25	18 868	12 825	Guichi, Anhui	Xi and Cao 2012
RCC	69.9	225	20–25	1500	17–20	24 070	15 750	Guichi, Anhui	Xi and Cao 2012
RCC	4.1	127.5	20–25	750	20	10 976	7455	Nanqiao, Anhui	Xi and Cao 2012
RCC	3.3	90	25–33	300	25	5455	3600	Nanqiao, Anhui	Xi and Cao 2012
RCC	66.7	300	25–33	1125	20–25	16 867	12 000	Quanjiao, Anhui	Xi and Cao 2012
RCC	13.3	142.5	22–29	750	20–25	12 030	7650	Dongzhi, Anhui	Xi and Cao 2012
RCC	7.2	150	25–33	765	20–25	11 111	9000	Taihu, Anhui	Xi and Cao 2012
RCC	33.3	300	1	1575	17–20	22 523	15 000	Huaining, Anhui	Xi and Cao 2012
RCC	2.0	450	22–33	3750	17–20	60 000	37 500	Panji, Anhui	Xi and Cao 2012
CCC	4	750	6.3	2700	25	149 850	59 745	Kaihua, Zhejiang	Ge 2016
CCC	—	60	8	1620	—	51 140	21 680	Ruichang, Jiangxi	Liu *et al.* 2017
CCC	8	—	—	1500	—	57 000	44 010	Ezhou, Hubei	Ma *et al.* 2016
CCC	7.3	—	—	1575	—	68 700	51 000	Ezhou, Hubei	Ma *et al.* 2016
CCC	15.3	—	—	1875	—	83 400	51 360	Ezhou, Hubei	Ma *et al.* 2016

Table 4.1.1 summarizes economies of rotational rice-crayfish culture (RCC) and continued rice-crayfish culture (CCC) in major producing provinces in China. Overall, integration of crayfish culture with rice can be more profitable than crayfish monoculture or rice cultivation. In rice-crayfish culture a number of expenses such as land lease, labor, electricity, water and so on are common, and therefore shared between the two. The total revenue of RCC and CCC is 5455–60 000 RMB/ha (average: 22 582 RMB/ha; 6 RMB = 1 US$), and 51 140–149 850 RMB/ha (average: 84 668 RMB/ha), respectively. The net profit of RCC ranges from 3600 to 37 500 RMB/ha (average: 14 550 RMB/ha) and the net profit of CCC ranges from 21 680 to 59 745 RMB/ha (average: 49 711 RMB/ha). Economies of scale show that larger units are more successful than smaller ones.

4.1.3.3 Pond Culture

Crayfish pond culture is an intensive farming practice compared to rice-crayfish culture. However, and in general, crayfish monoculture is rarely practiced in China because crayfish itself do not utilize the water column fully and the food sources thereof. Therefore, in order to make full use of food resources, most stakeholders adopt to co-culture mitten crab, mandarin fish, yellow catfish and carps (e.g. bighead carp, silver carp, crucian carp, etc.) in polyculture systems. Polyculture of crayfish and mitten crab can achieve better efficiency under appropriate habitat conditions (Yu *et al.* 2012; Xiong *et al.* 2012). Details for the crayfish-mitten crab-finfish pond polyculture system are shown in Figure 4.1.6.

In crayfish polyculture systems, macrophyte transplanting should be a priority. Macrophytes do not only help maintain water quality and provide refuge, but also provide food itself, as well as substrate for many food items (Wang *et al.* 2016 a, b). The most commonly transplanted species include submerged macrophytes

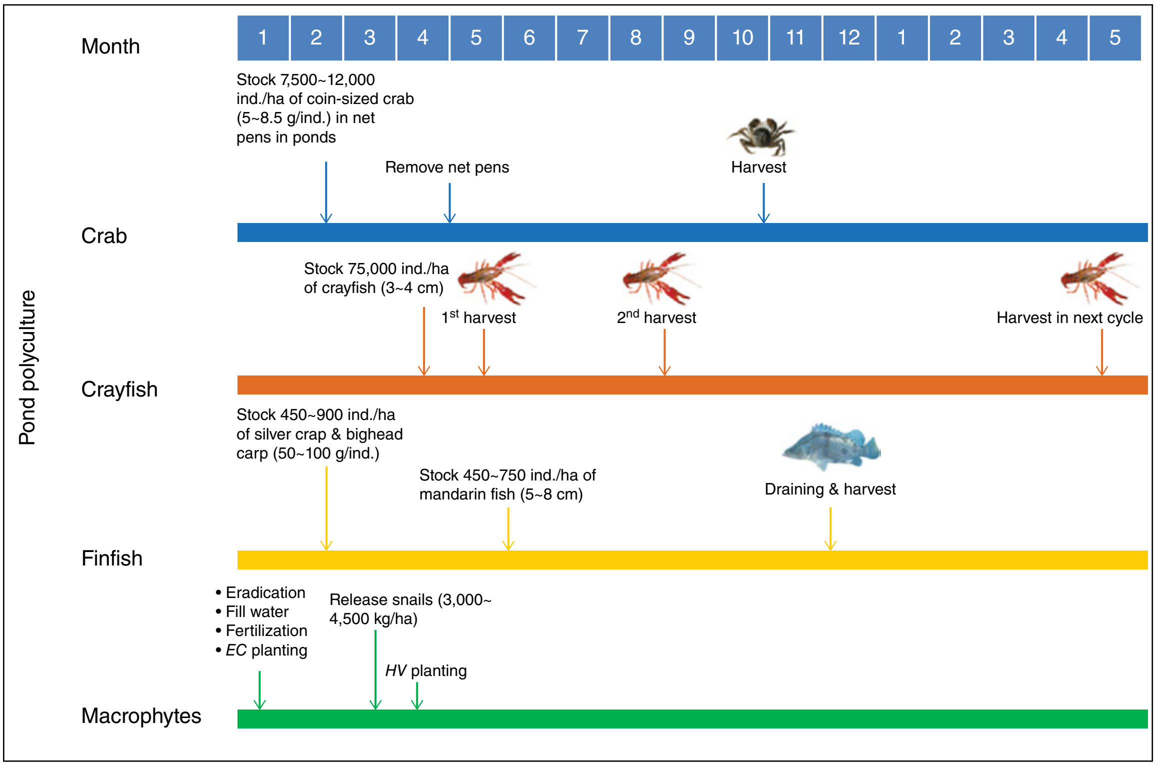

Figure 4.1.6 Crop calendar of crayfish-mitten crab-finfish pond polyculture system (EC = *E. canadensis*; HV = *H. verticillata*).

(e.g. *E. canadensis*, *H. verticillata*, *C. demersum*, *V. natans*, etc.), floating plants such as *Alternanthera philoxeroides*, and emergent plants, such as, for example, reed (*Phragmites australis*) and cattail (*Typha orientalis*). In general, a combination of the above species is widely adopted, but in varying combinations and proportions. Macrophytes with five to ten pieces of stem are planted evenly at an intervals of 0.5–0.6 m on the bottom of the ponds (Wang *et al.* 2016a).

In recent years, aquatic vegetables such as water spinach (*Ipomoea aquatica*) have been used in conjunction with the culture of crayfish with a view to maintaining water quality, and providing forage (He *et al.* 2011).

Prior to stocking mitten crab, it is very common to use quicklime (1050–1500 kg/ha) to eradicate unwanted fish, crayfish and/or other aquatic animals. Mitten crab is stocked in a temporary net pen of about 20–30 percent of total pond acreage around the Chinese spring festival. Mitten crab can adapt to the culture environment in grow-out ponds, and be raised in a relatively small area in a pond. Between April and May, when macrophytes and snails outside the net pen reach a certain coverage and biomass, the net pen is removed, and mitten crab released into the pond. Farmers harvest and count mitten crab in the net pen, to determine the quantity and survival rate after winter. Based on data from the above measures, farmers can make their stocking and feeding plan accurately. The stocking details of mitten crab are given in Figure 4.1.6.

Farmers stock young crayfish (total length: 3–4 cm) at a density of 75 000 ind./ha between April and May. This stocking strategy permits the crayfish to be harvested after around two months. Mandarin fish of total length ranging from 5–8 cm is stocked at a density of 450–750 ind./ha between May and June. Other high-valued species such as yellow catfish, and/or snakehead could also be stocked driven by the market price. Silver carp and bighead carp (average weight: 50–100 g/ind.) are stocked at a density of 450–900 ind./ha when fish fingerlings are available.

In the early stage between March and June, formulated feed, snails and low-valued fish are used to feed crayfish and mitten crab. In the mid stage between July and August, more fresh macrophytes, wheat, and corn seed are used to prevent deterioration of water quality caused by feeding large amounts of high-protein food types. In the latter stage between September and October, formulated feeds, snails and low-valued fish are the main dietary inputs. Feeds are broadcast twice a day, in the morning and afternoon, by hand in the shallow area around the pond. The feeding rate in the morning and afternoon account for 30 percent and 70 percent of the daily feed, respectively.

Co-culture of crayfish with mitten crab and/or fish can be more profitable than crayfish monoculture. As the case in Honghu City, Jiangsu Province, an average of 2318 kg/ha (range: 1530–4444 kg/ha) of crayfish; 659 kg/ha (range: 265–1025 kg/ha) of mitten crab; 924 kg/ha (range: 721–1048 kg/ha) of finfish were harvested in a rearing cycle. In regard to cost–benefit analysis, the total cost (e.g. land lease, fencing, depreciation, crayfish seed, mitten crab seed, fish fingerling, feed, electricity charges, etc.) ranged from 17 519 RMB/ha/cycle to 22 257 RMB/ha/cycle (mean 20 252 RMB/ha/cycle); the net profit ranged from 22 876 RMB/ha/cycle to 52 405 RMB/ha/cycle (mean 37 765 RMB/ha/cycle) (Xiong *et al*. 2008).

4.1.3.4 Lotus-Crayfish Culture

Regular fertilization and feeding in fish ponds result in nutrients being deposited in pond mud (Yang *et al*. 2002). Removing pond mud is labor intensive and expensive. Alternatively, aquatic macrophytes may utilize nutrients in mud through co-culture with fish. The co-culture of lotus and fish has been practiced in China for a few decades. In recent years, large numbers of lotus ponds have been used to culture crayfish, driven by its soaring market (Figure 4.1.7).

In a lotus pond, a rectangular and cross channel (4–5 m width and 1–1.5 m depth) should be constructed around the lotus growing area, and in the lotus growing area, respectively (Tao *et al*. 2012). Fencing should be built around the pond with a view of preventing escape.

Figure 4.1.7 A typical lotus-crayfish farming system; farmer used long net trap to harvest crayfish in Honghu City, Hubei Province, China.

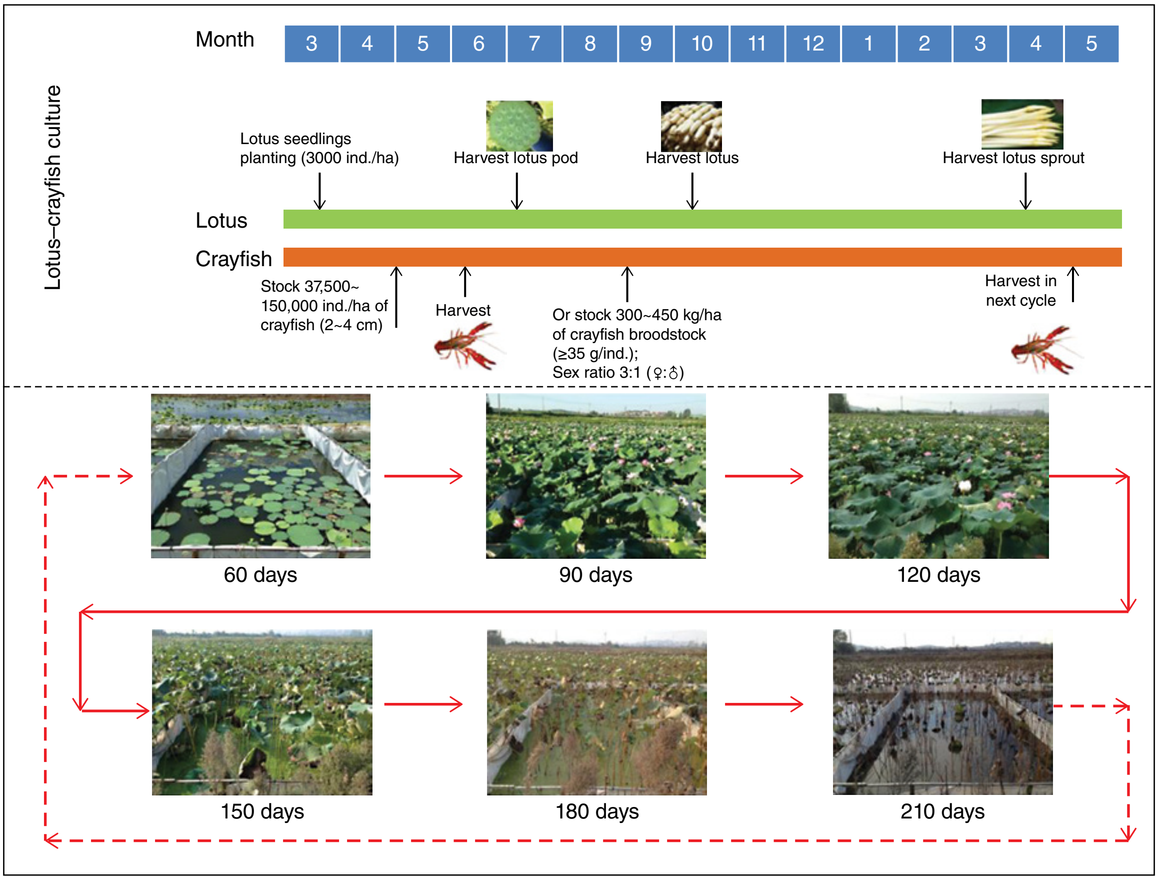

Figure 4.1.8 Crop calendar of lotus-crayfish culture system.

Prior to lotus planting, approximately 22 500 to 30 000 kg/ha of manure or chemical fertilizer is used. Lotus is planted between March and April, evenly at an interval of 3.5–4 m in the pond and each bunch including three to four lotus seedlings. In total, 3000 lotus seedlings are planted per hectare (Figure 4.1.8).

Prior to stocking crayfish, it is very common to use quicklime (1500–2250 kg/ha) to eradicate unwanted fish, crayfish and/or other aquatic animals. In general, there are two stocking strategies in this practice. In the widely used strategy, young crayfish (mean total length: 2–4 cm), at a rate of 37 500–150 000 ind./ha, are stocked between April and May. In the second strategy, crayfish broodstock of 300–450 kg/ha is stocked. The stocking size of crayfish should be more than 35 g/ind. The sex ratio of female to male is around 3:1.

As in the example in Xinghua City, Jiangsu Province, a farmer that operated 6.4 ha of lotus pond from 2008 to 2011 harvested an average of 23 348 kg/ha of lotus, and 2370 kg/ha of crayfish each year. In regard to cost–benefit analysis, the total cost (e.g. land lease, fencing, depreciation, crayfish seed, feed, electricity charges, etc.) ranged from 35 922 RMB/ha/cycle to 40 484 RMB/ha/cycle (mean 37 172 RMB/ha/cycle); the net profit ranged from 49 859 RMB/ha/cycle to 61 219 RMB/ha/cycle (mean 57 469 RMB/ha/cycle) (Feng *et al.* 2012).

4.1.4 Harvest and Transportation

Crayfish is harvested almost exclusively with long trap nets from April to May. The general design is a long cuboid body with two cones in the ends (Figure 4.1.9a). Typically, the length of this net trap ranges from 10 m to 20 m. There are 10 to 20 funnel-shaped entrances (Figure 4.1.9b) at the two sides of the cuboid. At the two

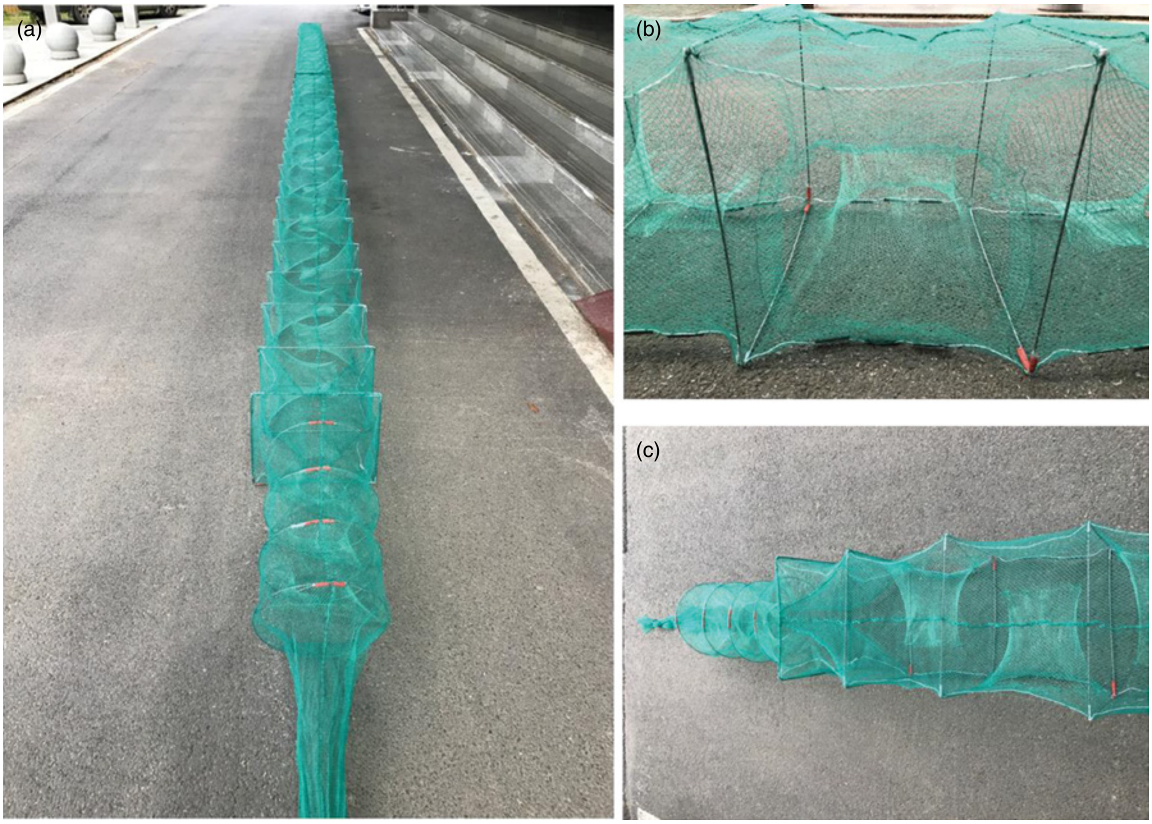

Figure 4.1.9 (a) A typically long net trap using for harvest crayfish in China; (b) entrance; (c) cone-shaped collection mesh bag.

ends of the cuboid, there are two cone-shaped crayfish collection mesh bags (Figure 4.1.9c). The net trap is made of polyethylene net of 2.0 cm mesh.

Traps are set so that the end is above the water surface to facilitate checking and provide access to air for the crayfish. Trap densities have ranged from 15 to 45 ind./ha, and more traps are set when market condition demands. Traps are set in the night and hauled early morning. Farmers rarely bait traps due to the high population densities in farming systems.

Crayfish are normally transported in open plastic boxes. The boxes are convenient and effective in protecting crayfish from physical damage associated with moving and storing them vertically during long term transportation (Figure 4.1.10). In order to enhance survival rate among broodstock, young crayfish and marketable-sized crayfish, the bottom of the box is covered with a layer of macrophytes to retain moisture during transportation and associated aerial exposure. It is very common to equip the transport vehicles with air-conditioning, or systems of equivalent function.

4.1.5 Conclusion

The crayfish farming industry plays a vital role in inland aquaculture in China, and is in a fast-growing phase in terms of soaring consumer demand, farming area and production. This species will also continue to be an important aquatic export commodity for China.

Figure 4.1.10 A crayfish harvest transported to a restaurant is sorted out according to size. Consumers pay different prices based on average size for a dish.

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4.2

Development of the Culture of the White-Legged Shrimp, *Penaeus vannamei*

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4.2.1 Introduction

4.2.1.1 Why was *P. vannamei* Introduced into China?

In the early 1990s, an outbreak of White Spot Syndrome Virus (WSSV) was common to all shrimp-producing nations in Asia, and almost devastated the established *P. monodon* culture. Most countries in the region, including China decided to introduce *P. vannamei* as an alternative species, and perhaps inspired by the availability of disease resistant seed stocks, commonly referred to as "specific pathogen free – SPF", it took root in most Asian nations.

4.2.1.2 The Status of *P. vannamei* in China

P. vannamei is one of the three productively farmed shrimp species in the world. *P. vannamei* was first introduced into China from the United States in 1988 (Zhang 2001). About five to seven years after its introduction, the culture area and production of *P. vannamei* have ranked top in the world for both production and value for many years. The production of *P. vannamei* in China was 43.14 percent of the world total in 2013.

Shrimp production in China was 2 780 000 tonnes in 2013, and accounted for 6.12 percent of the total amount of aquatic products. Production of *P. vannamei* was 1 430 000 tonnes, which in turn accounted for 51.42 percent of total shrimp production (China Fishery Statistical Yearbook 2014). Seawater *P. vannamei* production was 810 000 tonnes, accounting for 75.15 percent of total cultured marine shrimp production in China in 2013 (Figure 4.2.1).

P. vannamei is an important export aquaculture species for China (Zhang 2001). According to customs data; the general trade export volume and exports of aquatic products was 2 847 000 tonnes, worth US$ 16.05 billion in 2014. The general trade exports of shrimp, mainly *P. vannamei,* accounted for 13.71 percent, and ranked top among farmed species (Figure 4.2.1b).

China is also a big consumer of *P. vannamei*, and the bulk is used to meet domestic market demand. Chinese domestic consumption of shrimp products was about 1.15 million tonnes in 2010, accounting for 85 percent of total farmed shrimp, leaving only 15 percent for export. However, by 2013 China became a net importer of shrimp due to heavy domestic demand (Cui 2014).

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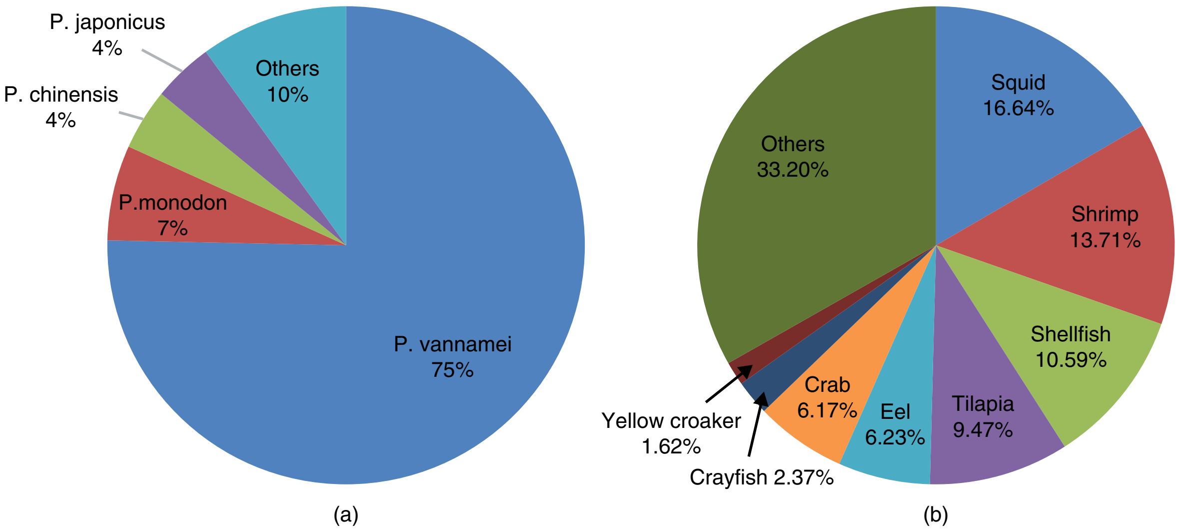


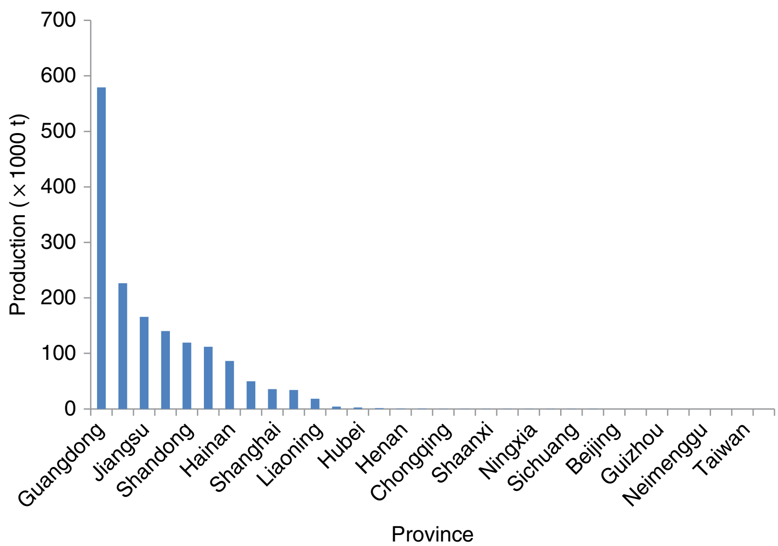
Figure 4.2.1 Maricultured shrimp in China and the relative proportions of cultured aquatic products exported from China in 2014. *Source:* Data from China Fishery Statistical Yearbook (2015).

4.2.2 Overview of the Development of *P. vannamei* Culture in China

4.2.2.1 Current Distribution Range of *P. vannamei*

The southern coastal provinces are the main mariculture regions for *P. vannamei*. In 2014, the top three productions centers were Guangdong, Guangxi and Hainan provinces, which collectively accounted for 648 000 tonnes, or 75 percent of the total mariculture *P. vannamei* production in China (China Fishery Statistical Yearbook 2015). As the domestic market expands, the production in seven north-eastern coastal provinces, especially Fujian, Zhejiang, Jiangsu, Shandong and Liaoning, also increased by 6 percent, to 228 000 tonnes (Figure 4.2.2).

Figure 4.2.2 Production intensities of farmed *P. vannamei* in the different provinces of China in 2014. *Source:* Based on data from China Fishery Statistical Yearbook (2015).



Chinese freshwater culture of *P. vannamei* also developed rapidly through out many provinces (Luo *et al.* 2000; Zhang 2001), and even spread to Xinjiang Province in the plateau region. Freshwater culture production of *P. vannamei* amounted to 701 000 tonnes in 2014, accounting for 47.14 percent of the total cultured (Liao *et al.* 2005). The top three provinces Guangdong, Jiangsu and Zhejiang accounted for 66 percent of the total freshwater culture production of *P. vannamei* in China.

The combined farmed production (freshwater and marine) of *P. vannamei* was predominant in seven provinces, viz. Guangdong, Guangxi, Jiangsu, Fujian, Shandong and Zhejiang, and amounted to 1.429 million tonnes in 2014 (Figure 4.2.2), accounting for 90.6 percent of the total. Production in Jiangsu grew significantly, due to the rapid growth of its freshwater aquaculture, while the ranking of Hainan dropped significantly, mainly because the mariculture area of Hainan was gradually shrinking, and instead Hainan will be gradually transformed into a Chinese seed breeding base for *P. vannamei* due to favorable environmental conditions, unique geographical location, climate and clean water.

4.2.2.2 Development Trends

The development of *P. vannamei* culture in China can be divided into an initial phase, a fast development phase, an adjustment phase, transformation, and upgrading phase.

4.2.2.2.1 The Initial Phase (1988–1999)

When *P. vannamei* was introduced into China in 1988, Chinese shrimp culture was mostly dominated by the two indigenous species *Fenneropenaeus chinensis* in northern China, and *Penaeus monodon* in southern China. The development of *F. chinensis* and *P. monodon* greatly boosted the economic development of coastal areas, and led to the simultaneous development of seed production, feed developments, cold storage and processing, and other related aspects of the value chain (Zhang *et al.* 2003). These later provided a solid foundation for the rapid development of *P. vannamei*. The farmed shrimp output in the world reached 560 000 tonnes in 1988, and Chinese cultured shrimp production was over 180 000 tonnes, accounting for 32.1 percent, and since then, Chinese cultured shrimp production has retained its top rank both in terms of production and value, globally.

In 1993, the outbreak of WSSV resulted in a sharp decline in shrimp aquaculture production. Cultured shrimp aquaculture production had decreased to 55 000 tonnes in 1994 from over 220 000 tonnes in 1992, and started to recover slowly until 1995 (Figure 4.2.3a).

As a suitable, direct solution was not available to combat the WSSV outbreak(s), and as in most Asian countries that were culturing shrimp, Chinese farmers began to seek alternative varieties, and turned to *P. vannamei*. However, post-larvae (PL) production of *P. vannamei* on a large scale was still difficult, and shrimp culture technology was still at an exploratory stage.

Some trial cultivations were successful in Shandong, Tianjin, Jiangsu, Guangdong and Guangxi, proving that *P. vannamei* was fast growing, had good adaptability and was disease resistant. In 1998, *P. vannamei* broodstock from Hawaii were imported to resolve the problem of deterioration of broodstock selected from farming ponds (Wyban 2002; Zhang *et al.* 2003). Furthermore, Shenzhen Tianjun Industrial Co., Ltd., in cooperation with a marine biotechnology company in the United States introduced both SPF broodstock and seed breeding technology of *P. vannamei*, which was the first successful introduction of SPF post-larvae (PL).

4.2.2.2.2 The Fast Development Stage (2000–2003)

After exploration, accumulation of experience, and absorption of foreign seed production technology, Chinese researchers broke through key technology on nursery rearing, which made large-scale seed production possible. This enabled the Chinese *P. vannamei* industry to move into a fast development stage. After 1999, the area of *P. vannamei* culture in Guangdong, Guangxi, Hainan, Shanghai, Jiangsu and other provinces (cities, districts) expanded rapidly; for example, the area of farmed *P. vannamei* in Qinzhou city, was only 1.33 ha in 1999, but increased to 1400 ha by the end of 2000. The total area of *P. vannamei* culture in Guangdong, Guangxi, and Hainan provinces was 22 000 ha, about 40 percent of the shrimp culture area in China in 2000

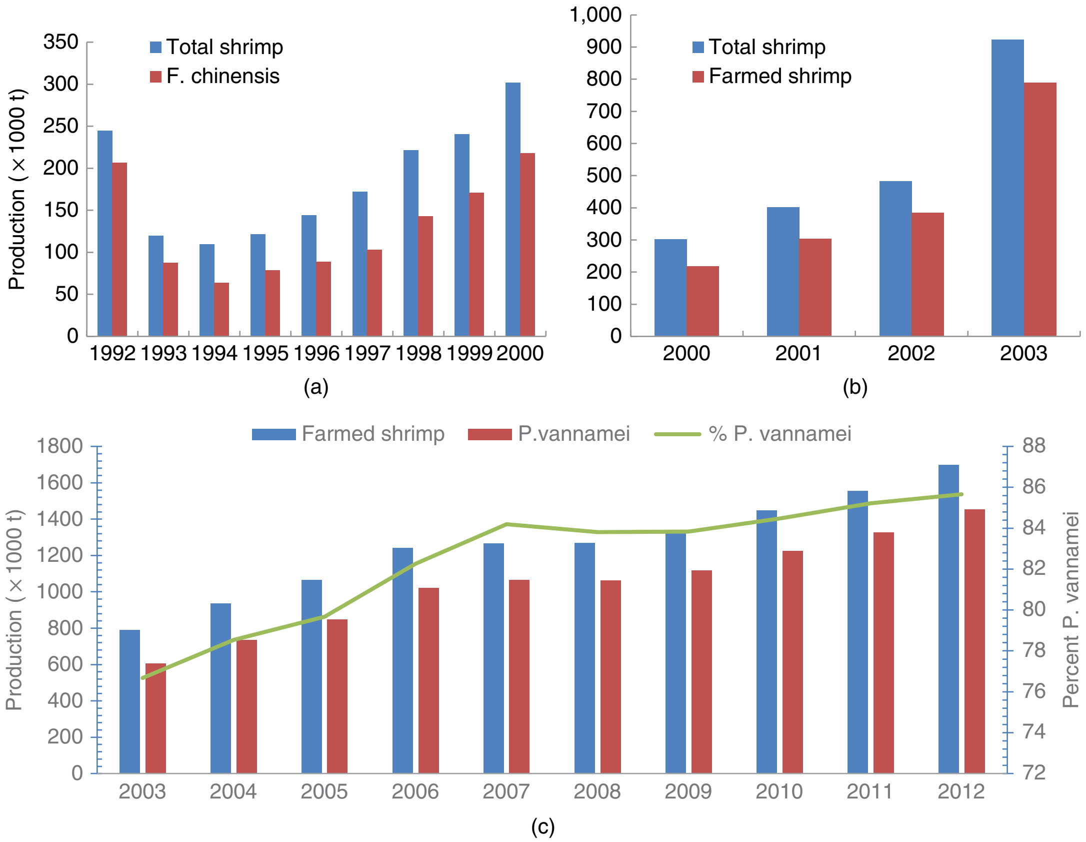


Figure 4.2.3 Trends in production of *Fenneropenaeus chinensis* (1992–2002) and *P. vannamei* (2003–2012) in China. *Source:* Based on data from China Fishery Statistical Yearbook (1993–2013.)

(Huang 2002). Due to its disease resistance and success of large-scale seed production, *P. vannamei* replaced those traditionally cultured shrimp species by 2001, and revitalized the shrimp industry (Hu *et al.* 2001). In the early part of first decade of this millennium a breakthrough in freshwater culture of *P. vannamei* was made (Gan *et al.* 2000) which promoted a rapid spread of shrimp culture inland. Consequently, *P. vannamei* culture spread to all provinces, except Tibet. After only a few years' development, Chinese shrimp culture production progressed leaps and bounds, in 2003 reaching 789 000 tonnes an increase of 105 percent what it had been in 2002 (Figure 4.2.3b). *P. vannamei* accounted for 63 percent of mariculture shrimp production, and 43 percent of freshwater shrimp production in 2003 when the *China Fishery Statistical Yearbook* started collating data for *P. vannamei* separately. Since 2003, freshwater aquaculture production of *P. vannamei* has accounted for about 50 percent of the total.

With the promotion of *P. vannamei* culture in China (Liao *et al.* 2005), culture technology and culture models also developed, mainly in the following aspects:

(a) improvement on stocking density and yield per unit area, such as a culture experiment carried out in Qingdao city in 2003, in which stocking density was increased from less than 0.5 million to 1.5–2.1 million/ha and yield to 22–24 t/ha;
(b) the popularity of the use of aerators. Farmers gradually introduced improvements which resulted in an increase in DO levels, and jet aerators were preferred with at least eight aerators/ha;
(c) the model of elevated ponds was promoted and innovated by applying mulch, and a whirlpool central sewage technology, which greatly reduced disease (Lin *et al.* 2003);

(d) extensive and semi-intensive culture models gradually decreased, while intensive models were further developed, such as factory farming with water circulation and high-density stocking, polyculture of fish and shrimp, and introduction of winter shed culture (equivalent to greenhouse agriculture), thereby enabling three crops per year;
(e) a variety of freshwater culture models to suit local conditions were promoted, which enabled freshwater *P. vannamei* culture to rapidly spread inland (Chen *et al.* 2000).

Under the dual impact of the disease situation, and quality and safety problems, the Chinese government together with practitioners in the industry began to examine internal problems, and made a series of measures to adjust and improve the industry, which led the Chinese *P. vannamei* industry to enter the adjustment phase.

4.2.2.2.3 The Adjustment Stage (2004–2006)

During this adjustment period, Chinese aquaculture production of *P. vannamei* still maintained an upward trend (Figure 4.2.3c), but policies and culture technologies changed. To further improve veterinary regulations, and make Chinese veterinary management reach international standards, the Ministry of Agriculture issued a series of corrective measure to monitor use of veterinary drugs.

After years of effort, Chinese aquatic product quality and safety standards, and the technical regulations system provided quality assurance for shrimp export, resulting in a surge in Chinese shrimp exports. Chinese shrimp exports to the US in 2002 grew 73.4 percent over that in 2001, and over 37.1 percent of that in 2003 (China Fisheries Yearbook, 2002–2004). In 2004, the United States implemented shrimp anti-dumping sanctions against China and another five countries, which resulted in a loss of US$380 million to the Chinese shrimp industry (https://www.ictsd.org/bridges-news/bridges/news/china-launches-wto-dispute-against-us-shrimp-duties). With the continuous improvements in the Chinese economy and living standards, there has been a concurrent growing demand nationally for aquatic products, especially high-quality products such as shrimp. This demand made the *P. vannamei* industry to shift from an export-oriented industry to a domestic one, with continued economic viability.

Under the influence of adjusted national policy and market changes, culture patterns of *P. vannamei* began to change. The use of antibiotics was curtailed and the use of illegal drugs completely banned in shrimp culture. Beneficial microorganisms and other ecological products, and ecological techniques such as polyculture of fish and shrimp were encouraged and adopted successfully during this phase. The adjustment made the industry embark on the road to green, environmentally friendly, and pollution-free ecological culture models.

4.2.2.2.4 Transformation and Upgrading Stage (2007–)

Chinese annual output of *P. vannamei* was over one million tonnes and still shows steady growth, but the growth rate has slowed down at this stage (Figure 4.2.3c) due to limitations in area available and the yield.

At this stage, WSSV still existed, but outbreaks of new diseases, such as EMS (Early Mortality Syndrome), *Enterocytozoon hepatopenaei* (EHP), vibriosis and so on, occurred in southern China – the original shrimp producing area. This resulted in a drop in the success rate of farming, and for example, the success rate was only ten percent in Guangxi in 2015; this in turn induced farmers to turn to the northern coastal areas such as Shandong, Liaoning, and inland areas of freshwater aquaculture for shrimp farming. In the latter areas, an initial success rate and consequent rapid developments began to be impacted by emergence of disease. The industry urgently needs transformation and upgrading, and in these regards some efforts have been made.

In 2009, the Ministry of Agriculture launched a "national shrimp industry technology system", to solve key issues in the application and popularization of science and technology for industrial development, to promote efficient, sustainable and healthy development of the industry, by bringing together the domestic talents on technology, and promotion to integrate technical studies that could lead to the development of the following:

- ecological farming technology;
- ecological breeding technology;

- feed fermentation technology; and
- factory farming technology.

4.2.2.3 Culture Models

There are many culture models that have developed over the years for *P. vannamei*. The culture models in early years were accompanied by the application of aerators, use of high stocking densities. Due to the disease problems in later stages, intensive model were further developed, such as film pools, winter shed culture, freshwater culture and polyculture of shrimp and fish, and attached importance to reducing disease and increasing success rate.

Diversification of culture models to suit different environmental conditions and economic conditions were important reasons for the fast development of the Chinese industry of *P. vannamei*. Each culture model evolved with changing situations, improvements and updates to aquaculture facilities, and the development of culture technologies. Based on the current status, culture models can be categorized into extensive, semi-intensive, intensive, and factory models.

4.2.2.3.1 Extensive Culture Model

Extensive culture model mainly relies on the tides for water exchange. The extensive culture model of *P. vannamei* was evolved from those used for other shrimp species. In this model pond size could be up to 6 ha located in coastal areas, built by damming with canals and sluice gates.

In the late 1990s, as artificial propagation of seed production of *P. vannamei* began to be developed and extended, farmers started annexing post-larval (PL) rearing facilities to the model. Improved practices included removal of weed fish (unwanted fish and other aquatic animals) using “tea cake” prior to filling up ponds, increasing the stocking density to about 450 000 to 670 000/ha, use of post-larvae of about 3 cm, and using formulated feeds. The model is still largely subject to the elements, and production cannot be guaranteed. However, due to its low cost, this culture model is generally economically beneficial.

4.2.2.3.2 Semi-Intensive Culture Model

Semi-intensive model is used mostly in northern China, and is the next-step development from extensive culture, with better environmental conditions, small investment. The main characteristics of this model are:

(a) coastal ponds rely on tides for water exchange, and as such it is difficult to dry and clean the ponds completely, after years of culture this can lead to environmental degradation and make the shrimp prone to bacterial diseases;
(b) the ponds are large and can exceed 1.3 ha, with a water depth of about 1 m;
(c) many ponds are placed together to form large culture areas, where inlet water and effluent mix, this could result in relatively easy spread of diseases across the whole area of ponds;
(d) ponds are equipped with a small number of aerators; two to three sets/0.67 ha generally.

The average production, restricted to a maximum of one cycle, ranges from 4.5 t/ha to 6 t/ha (production is usually for first cycle).

4.2.2.3.3 Intensive Culture Model

In the intensive models shrimp are cultured at a high density (600 000–3 000 000 ind./ha), and require more inputs, in particular energy and a high level of management. Common intensive models include the ordinary earthen ponds model, and winter-shed pond model (Figure 4.2.4).

(a) ***The ordinary earthen pond model***
The model is an improvement from semi-intensive culture model (Figure 4.2.4a). Pond area is generally about 0.67 ha with a water depth of 1.5–2.0 m, equipped with relatively complete systems for drainage and inlet of water, and generally use 7–15 units/ha of aerators, most of which are water tanker aerators and/or

Figure 4.2.4 Intensive culture models of *P. vannamei*: (a) ordinary earthen ponds model; (b) the high intensity pond model; (c) big shed pond model; (d) big shed model.

submersible aerators. The density of post-larvae (PL) stocked is between 600 000 and 900 000 ind./ha, which vary according to pond conditions and facilities. Generally, there is zero water exchange in the early period of culture, adding more water in the middle term, and a small amount of water exchange in the late period. Production of this model can generally reach 7.5–8 t/ha, over one cycle.

(b) ***High-ground pond model***

In this model, ponds are located above the tide, and are equipped with central drainage, and use water filtered through sand and ponds have lot of aerators (Figure 4.2.4b). The position of the pond is the biggest difference between the elevated pond model and the extensive model, and also is the biggest advantage of the former.

The high-ground pond model is a high-density intensive culture model requiring large investment, which can provide high yields, is prone to fewer diseases, and has a high success rate but is associated with high risks. High-ground ponds can be divided into three types; cement slope ponds, cement ponds and plastic lined ponds.

Cement slope ponds have a sandy bottom. After prolonged use, cement slopes tend to crack and cause water leakage. Because feed, shrimp excrement, biological debris, and other organic matter are deposited on the bottom the sandy bottom it is difficult to clean, and over time this brings about gradual deterioration of the pond environment.

Cement ponds with a cement slope and cement bottom often minimizes the problem of sediment accumulation and consequent deterioration of pond bottom. The construction of cement ponds make them sturdy and facilitates sewage discharge and management. The high capital costs in the construction and leakages with time are problematic, however.

The biggest advantage of plastic-lined ponds is easiness to clean. Sediment contamination in aging ponds is a potential trigger for diseases. Plastic-lined ponds with bottom and central sewage system are not only conducive to removing accumulated organic matter, but make general cleaning and disinfection easier. High-pressure water jets are generally used to clean the bottom of the pond. The next culture cycle starts after disinfection and exposure to sunlight (Figure 4.2.4b).

Due to good shrimp culture technology and scientific management of high ground pond model, its production can reach 15–25 t/ha.

Due to its high production and high efficiency, the high-ground pond model originated from Guangdong, Guangxi, Fujian and Hainan, and then was quickly extended to the whole country, and continuous improvements are brought about to enhance production and facilitate management. Some of these are as follows:

(a) miniaturization – currently, ponds of 0.067–0.13 ha with a water depth of 1.8–3 m are used;
(b) in the early stage, the ponds were of cement slope and sandy bottom, which tended to accumulate sediment in the center and cause disease; now most new ponds are lined with plastic film and are cemented throughout;
(c) the introduction of a central sewage discharge system is undoubtedly a very important technological innovation, which greatly reduce disease;
(d) multi-layer aeration technology is currently used;
(e) successful application of beneficial microorganisms, biological floc, polyculture of shrimp and fish and so on, have made the high-pond model popular and helped the industry to return to healthy culture practices.
(f) In the early stage, water was directly pumped into ponds from sea or manhole without disinfection measures, and sewage was directly discharged into sea. Due to the promotion of pollution-free culture, a reservoir and disinfection are necessary for the model, and furthermore, sewage treatment ponds are becoming increasingly popular now.

(c) ***Winter shed model***

The winter shed model is essentially an enclosed high-ground pond model that helps maintain water temperature to enable shrimp to safely overwinter, prolong culture time, and improve culture efficiency. The model is the equivalent of the "greenhouse" agriculture model. Building materials mainly include stents, wire, plastic film, etc. Stents can be of wood, and steel, and must be strong enough for people to move for management and maintenance. Plastic film should be clear colorless film, which is firmly connected to the stent, in order to avoid leaks or being damaged by wind (Figure 4.2.4c). The model permits shrimp culture throughout the year, making it possible to stagger sales seasons in accordance with market prices, it can therefore increase both production and economic benefits. Depending on the size of the shed, the model is divided into a big-shed model and a small-shed model, and the characteristics are compared in Table 4.2.1.

(d) ***Super-intensive culture***

Large-scale farming and super-intensive culture, is a modern culture model. The model provides a suitable growth environment for shrimp by regulating water temperature, and providing dissolved oxygen (DO), light and food, and other factors through mechanical, electronic, chemical, biological, automation, and other modern facilities.

Table 4.2.1 A comparison of the characteristics of big and small shed ponds used in *P. vannamei* culture.

Big shed model	Small shed model
• Distributed in Guangdong, Fujian and Guangxi provinces; pond size: 0.4–0.67 ha; 150–180 cm Depth; total area ~15 000 ha; 5–10 % water exchange/day	• Distributed in Jiangsu provinces; pond size 400–600 m^2; 50–70 cm depth; total area ~1500 ha; 10–30 % water exchange/day
• Highly aerated; three culture cycles	• Two culture cycles in spring and autumn
• Stocking density: 2 250 000–4 500 000/ha	• Stocking density: 700 000–1 000 000/ha
• Yields: 37.5 t/ha, some can reach 75 t/ha	• 7.5–9t/ha
• Possibilities of uneven temperature distribution; of stratification	• Stratification unlikely to occur
• Slow algal growth could occur	• Very unlikely

In aquaculture, large-scale farming is roughly divided into three forms: flowing-water farming, semi-closed recirculation farming, and closed-system farming. At present, the mainly flowing-water culture and semi-closed recirculation culture are used in China.

Due to the serious situation of diseases, shortage of land and a deteriorating environment, factory farming will be an inevitable trend of farming of *P. vannamei*. large-scale farming has the following advantages:

(a) effective in preventing the spread of diseases;
(b) increase production and improve utilization of land to ease the issue of land shortage;
(c) has comprehensive water-treatment facilities, which can eliminate the adverse effects caused by water pollution;
(d) full controllability, leading to high success rate, fast growth, and short culture cycle, and;
(e) provides the ability to farm through the year, and obtain three cycles of growth.

Factory farming of shrimp in China began with nursery rearing in waste pearl nursery ponds in 1999, and was then developed rapidly because of its high production rate and good economic returns. Now the model is available throughout China, but its popularity is limited due to its high costs.

4.2.2.4 Scientific and Technical Development and Innovations

4.2.2.4.1 Establishment of Seed Propagation Technology of *P. vannamei*

The artificial propagation of *P. vannamei* was developed through the period 1988 to 1993, when the lifecycle was successfully closed (Zhang and Yu 1993). Further research in the following years lead to large-scale seed production and opened the doors for large-scale culture of *P. vannamei* (Chen *et al.* 2000; Yu *et al.* 2001; Zhang *et al.* 2002). Post-larvae (PL) production (93.39 x10^9) in 2001 was 60 percent more than that (58.37 x10^9) in 2000, and that (562.84 x10^9) in 2002, and increased six-fold over that in 2001 (China Fishery Statistical Yearbook 2003).

4.2.2.4.2 *P. vannamei* Culture in Freshwater

Technical specifications and the culture model for freshwater pond aquaculture of *P. vannamei*, were initially developed through work conducted in Guangxi Institute of Fisheries (Gan *et al.* 2000). This stimulated the development of other appropriate technologies for a variety of freshwater culture models, including coastal low-salinity aquaculture, coastal freshwater aquaculture, inland freshwater aquaculture, and aquaculture in inland saline waters. A number of modes of such culture practices occur in China (Fang *et al.* 2004), dictated primarily by the availability of inland saline water and are briefly summarized in Table 4.2.2.

4.2.2.4.3 Shrimp and Finfish Polyculture

Polyculture of shrimp and finfish came into being when there was no fast and effective method to cure white spot syndrome virus (WSSV), Taura virus, or EMS (early mortality syndrome). The technology originated from practice, and its wide application is the result of continuous improvement and active promotion by many (He *et al.* 2009, 2014).

Polyculture of shrimp and fish attempts to establish a multi-species balanced ecosystem dominated by shrimp or fish. This technology can effectively reduce deterioration of water quality, reduce feed wastage, inhibit the spread of pathogens, and improve the rational use of water resources and provide increasing economic benefits.

The main species in polyculture of fish and shrimp are divided into two categories; filter-feeding fish, such as silver carp and bighead carp together with omnivorous fish such as tilapia, and carnivorous fish, such as clarias (family Clariidae and the mostcommon genus is *Clarias*) pomfret (family Bramidae and common genus is *Brama*). A wide variety of polycultures of shrimp and fish with different operations have been developed depending on local climate conditions, access to sea water, and pond conditions in different regions in China. The following briefly describes two commonly practiced fish polyculture models.

Table 4.2.2 Brief description of the different modes of inland/freshwater culture of *P. vannamei*.

• Coastal low salinity aquaculture In estuaries, with access to fw, when saline water is pumped into ponds and diluted with fw; farmers may use small ponds to hold post-larvae (PL) up to 20 days, whilst gradually diluting the medium to the appropriate salinity: reduces the impact of marine pathogens on shrimp and promotes the growth of shrimp
• Coastal freshwater pond aquaculture In some inland cities of coastal provinces, *P. vannamei* is cultured in abandoned fish ponds with diluted seawater; the salinity is kept low from 2‰ down to no more than 1‰ in the late term
• Inland freshwater aquaculture In the mid-west China, freshwater ponds are used for culture *P. vannamei*; disease occurrence is low compared to coastal culture; greenhouses are used for only one cycle/yr – for the winter period cycle; seawater required for post-larvae (PL) is made from industrial salt; post-larvae (PL) are generally shipped from Guangdong, Guangxi or Hainan by air; harvested shrimp is small – generally no more than 60 shrimp/kg, but command a high price, and economic benefit is considerable.
• Inland saline aquaculture Usually extracts saline groundwater blended with fresh water; has wide distribution in Shandong Province and Tianjin city; in China there is an estimated 33 million ha of saline land; saline land aquaculture of *P. vannamei* has good prospects.

(a) ***Polyculture of P. vannamei and tilapia***

Tilapia cultured with shrimp can effectively improve the water quality and improve shrimp culture efficiency. In this polyculture practice, 600 000–7 500 000 post larvae (PL) of 0.8–1 cm per ha are stocked together with 3000–6000 tilapia, when shrimp have grown to about 2.5 cm. In order to avoid tilapia consuming shrimp feed, and to improve feed conversion ratio, the tilapia are fed before the shrimp, followed by other culture management measures that are consistent with monoculture of shrimp.

In recent years, tilapia in some polycultures are segregated in a net enclosure at the center of the pond. The netted area is about one-fifth of the pond area, and the mesh is adjusted to let shrimp in and prevent fish moving out. In this method, water circulation is adjusted with aerators so as to move left-over feed, feces and dead shrimp into the enclosure for tilapia to clean up. Results show that this method can achieve a 10 percent higher success rate and 0.75–1.5t/ha more production.

(b) ***Polyculture of P. vannamei and grass carp***

When water salinity is less than 5‰, grass carp can be used for polyculture. In this model, 600 000–750 000 post-larvae (PL) of 0.8–1 cm per ha is combined with 450–750 grass carp of 1 kg, when shrimp have grown to about 2.5 cm. In the culture process, grass carp can be fed or not, but if dead shrimp or sick shrimp are found, grass carp feeding must be stopped in order to let the grass carp scavenge on them. This polyculture mode is popular in the Pearl River Delta region, because large grass carp are welcomed by the markets of Macau and Hong Kong, and command a high price.

4.2.2.4.4 Selective Breeding of New Varieties

Aquaculture of *P. vannamei* developed rapidly since breakthrough of large-scale artificial propagation in 2000. Most broodstock are selected from farmed stocks. Over a few generations this process has led to degradation of the germplasm and genetic diversity.

Consequently, China has to import broodstock every year at a high cost. According to official statistics, over 100 000 pairs of broodstock are imported annually at a cost more than US$ 10 million. In 2005, the Guangxi Institute of Fisheries introduced shrimp which came from five geographical populations in order to establish the most diverse germplasm bank for *P. vannamei*. In 2012, after six generations of successive breeding, "Guihai No. 1", a high-yielding new variety of *P. vannamei*, was bred, and got official approval from the National Aquaculture Variety Approval Committee in December, and had been designated as the top most aquatic variety in Guangxi.

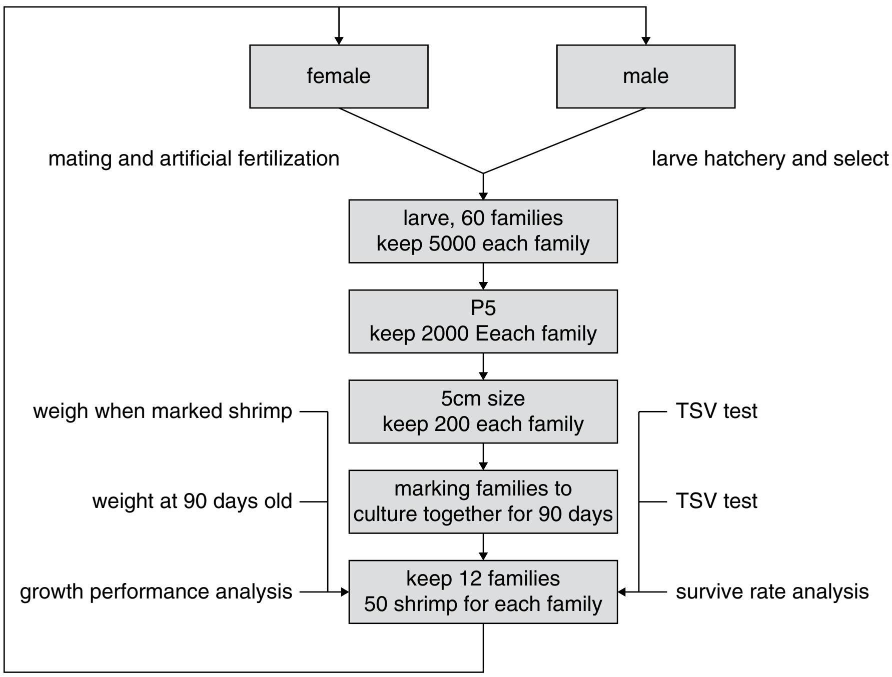


Figure 4.2.5 Steps taken to selectively breed "Guihai No. 1"

Due to the advantages of "Guihai No. 1" such as fast growth, strong adaptability, high survival rate, high production rate, being suitable for high-density and growing on to a large size, "Guihai No. 1" has been accepted by many hatcheries and farmers, and extended to Guangxi, Jiangsu, Fujian, Guangdong, Hebei and Shandong provinces, and even Vietnam.

Chinese selective breeding studies on *P. vannamei* use family selection. The family selection method is to establish families for systemic selection, and excellent families of each generation obtained from selection can either be parents of the next generation or used as broodstock to directly produce post-larvae (PL) for culture. For example, the breeding route of "Guihai No. 1" is shown in Figure 4.2.5.

So far, in addition to "Guihai No. 1", there are four new domestic varieties approved by the committee in China: "Kehai No. 1", "Zhongke No. 1", "Zhongxing No. 1" and "Renhai No. 1." (Wang 2014). Optimization of the performance and application of new varieties will help the *P. vannamei* culture industry in China to gradually reduce its dependence on foreign broodstock, and will enhance its ability to resist risks.

4.2.3 Markets and Trade

4.2.3.1 Export Markets

Chinese shrimp export volume has increased significantly since *P. vannamei* became the dominant cultured species of shrimp in 2001. Although EU bans kept China out of the European market between 2002 and 2004, China adopted a series of industry adjustments, and explored other export markets which kept the shrimp export volume increasing. In 2006, shrimp export volume reached 270 000 tonnes. In 2007, the United States, China's largest export market, implemented a withholding of all consignments of Chinese shrimp for testing, which resulted in shrimp exports plummeting until 2010, when the shrimp exports began to recover. In 2011, shrimp exports amounted to 305 000 tonnes (Figure 4.2.6). In 2012, Chinese shrimp exports showed signs of decline, which could be attributed to strong competition from Thailand, India, Brazil, and Ecuador.

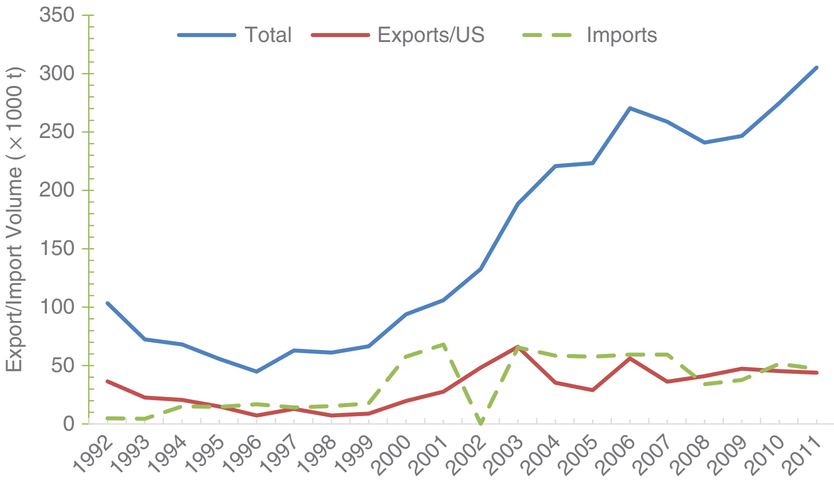


Figure 4.2.6 Total volume of shrimp exports, and that to the USA from China, and imports to China for the period 1992–2011. *Source:* Data from UN Comtrade Database: http://comtrade.un.org/.

The United States, Japan, and the European Union are still the main shrimp importing countries or regions in the world, and they are also the main market of shrimp exports for China. In recent years the production and export volume of *P. vannamei* generally increased in China, but the export volume in some of the country's major markets declined. For example, the US is the main export market of China (Figure 4.2.6). In 2011, Chinese shrimp export reached 305 000 tonnes valued at US$ 2.19 billion, up 11 percent and 21.7 percent, respectively. This was possible because the Chinese shrimp export market was diversified and was able to export to others.

In order to deal with trade problems and meet the changing demands of importing countries, China adjusted its product structure by introducing new processing technologies, and made great strides in processed shrimp products, especially processed shrimp products with high added value, all of which resulted in significant growth. In 2011, the share of processed shrimp products reached 39.7 percent, and highest record was 74.3 percent in 2006 (Figure 4.2.7a). Processed shrimp products, such as breaded shrimp and frozen cooked shrimp, have become major export products.

4.2.3.2 Import Markets

Chinese shrimp imports showed a huge growth in 2000 when shrimp imports reached 577 000 tonnes, a 330 percent increase compared with 1999. During the period from 2001 to 2003, shrimp import volumed maintained a modest growth, and then declined in 2004 when the shrimp industry began to turn to the domestic market due to export trade issues. Shrimp import volumes fell to 34000 000 tonnes in 2008, and then began to rise in 2009 due to improvements in the export situation, and an expanding domestic shrimp market (Figure 4.2.6). In 2013, shrimp import volumes exceeded shrimp export volumes and China became a net "shrimp-importing country" from a "shrimp-exporting country". Shrimp imported into China mainly originates in Vietnam, Ecuador, Thailand, Indonesia, Malaysia and India.

Chinese shrimp imports were mainly frozen shrimp. Since 2000, the proportion of frozen shrimp imports has accounted for more than 80 percent of total shrimp imports (Figure 4.2.7b). This is attributed to two factors: Chinese consumers prefer live shrimp or frozen shrimp to processed shrimp products; and the second is that part of the imported shrimp is for re-export after processing.

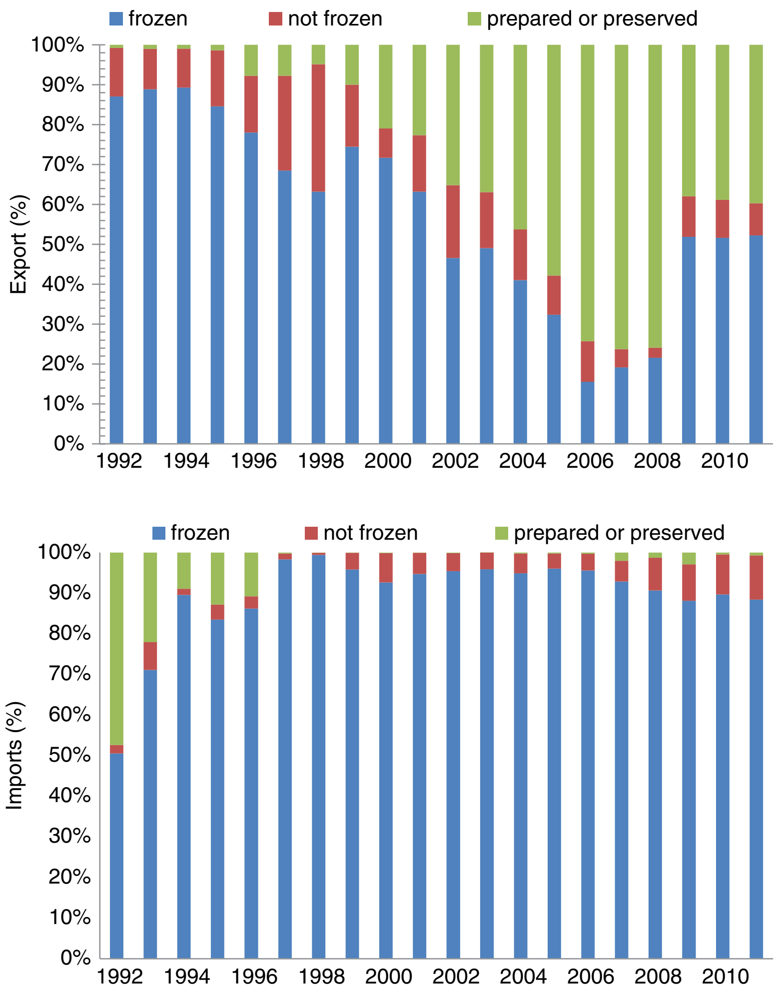


Figure 4.2.7 The percent composition forms of shrimp exports from China, and imports to China.

4.2.4 Constraints

4.2.4.1 Germplasm Degradation and Dependence on Imported Broodstock

P. vannamei aquaculture in China requires a large quantity of post-larvae (PL) every year. For example, in 2013, 613.4 billion post-larvae (PL) were produced (China Fishery Statistical Yearbook 2014), which meant the shrimp industry required at least 200 thousand pairs of broodstock. China is dependent on importing broodstock at a high price. Moreover, the broodstock market is chaotic. A lot of degraded broodstock from farming ponds are used for producing post-larvae (PL), which results in slow growth, disease, high feed-conversion ratios, and uneven size of shrimp.

4.2.4.2 Lack of Standards on Production and Sale of Post-Larvae

As the sector grew very fast, hatcheries tended to use poor quality broodstock. The situation was exacerbated by using high stocking densities of larvae, elevated temperatures, and high levels of antibiotics, to meet the demands for post-larvae. These practices resulted in slow growth and a low survival rate, with farmers compelled to rely on low quality post-larvae (PL), with consequent lost in productivity and narrowing of profit margins.

4.2.4.3 Disease Occurrence

Disease is always the biggest threat to shrimp culture, although the development of technologies, such as the high-pond model, freshwater aquaculture, and polyculture of shrimp and fish, have eased the situation to a certain extent. With the continuous expansion of the culture area (ha) of *P. vannamei* and increase use of high stocking densities, disease outbreaks have become more frequent. In addition, new diseases keep emerging, the latest being EMS, which has brought huge losses to *P. vannamei* industry since 2009 (Hu *et al.* 2001; Lai *et al*. 2015).

4.2.4.4 Aging Ponds and Rate of Adoption of Advanced Aquaculture Models

After many years of culture, there are a large number of aging ponds in urgent need of renovation. In addition, the current aquaculture model for shrimp is mostly small scale and low-cost retail, and the adoption of advanced aquaculture models is slow due to the prohibitively high investment costs, which puts it out of reach of a large number of retail farmers. This limits the development of the Chinese *P. vannamei* industry.

4.2.5 Prospects

In the final analysis, the root cause of the current plight of the *P. vannamei* aquaculture sector in China is that the farmers have conducted a one-sided pursuit of production and have neglected the environmental carrying capacity; currently the farming model(s) use excessive high-density stocking, high energy consumption, have high emissions and high pollution, but have low efficiency. This model can result in short-term development of the industry and the appearance of prosperity.

Fortunately, both the government and farmers are aware of the seriousness of the problems, and are actively seeking transformation and upgrading, so we can expect the following trends in the next few years.

(a) Demand from the domestic market will continue to expand, and shrimp imports will continue to increase, shrimp prices will continue to remain high;
(b) coastal areas of the shrimp farming area will shrink, the mainland farming area will continue to expand;
(c) diseases cannot be eradicated in a short time. This is still the biggest factor affecting shrimp yield, and new diseases may appear;
(d) more ecological farming models will be used, and large-scale farming technology will make major advances, and the area under large-scale farming area will be greatly increased (Fang *et al.* 2004);
(e) seed production will adopt ecological nursery methods, and seed prices will rise accordingly because of rising costs;
(f) more attention will be paid to environmental protection, and waste-water treatment in order to reach the standards that will be the basic requirements of shrimp farming.

We have reason to believe that the industry of *P. vannamei* in China will eventually embark on a green, healthy and sustainable development path through these series of reforms.

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4.3

Channel Catfish Culture

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4.3.1 Introduction

Channel catfish (*Ictalurus punctatus*) is the most numerous catfish species in North America. Since the 1980s, it has become the main species of freshwater aquaculture in the United States. Pond-based culture is the principal mode of farming, mainly in the southern states such as Mississippi, Louisiana, Arkansas and Alabama (Xue *et al.* 2013). Channel catfish were introduced to China from the United States by the Fisheries Research Institute of Hubei Province in 1984. Artificial reproduction was successful in 1987 (Chen 1988). Three strains of channel catfish, totaling approximately 600 000 'tails', were imported from the United States in 1997 by the National Aquaculture Technical Extension Center, and placed in Xiaotangshan (Arkansas strain), Wuhan (Mississippi strain), and the Taixing in Jiangsu provinces (Texas strain). Unfortunately, catfish placed at Xiaotangshan did not survive. Further introductions occurred in 1999, with roughly 700 000 fish placed in Datong Beijing, Nanhui Shanghai and Taixing Jiangsu. In 2004, approximately 440 000 fish were introduced by the Chinese Fishery Association Channel Catfish Chapters. This latter instalment involved many institutions which are in Yuanjiang, Hongze, Taixing, Minqing, Nanchang, Wan'an, Yudu Poyang and Ganzhou (Li 1994).

4.3.2 Development of Channel Catfish Aquaculture in China

Phase I (1984–1997): In the early stages of this 13-year period (Figure 4.3.1), artificial reproduction of channel catfish was successfully carried out. Once established, a rapid spread in aquaculture followed. It spread from Hubei to Hunan, Guangdong, Guangxi, Jiangsu, Liaoning, Jiangxi, and other provinces. Pond culture of channel catfish was undergoing experimentation and exploration, and the challenge of optimizing and producing quality aquaculture feed was also ongoing. The geographical span in China of channel catfish aquaculture was still limited and decentralized, and resulted in less than 10 000 tonnes total annual yield, mainly in the Hubei and Guangdong provinces. Live catfish was the main product in the market, with high price due to low yield overall.

Phase II (1998–2003): In this period the development of the channel catfish industry began and 'cage culture' was on the rise (Figure 4.3.1). The development of the channel catfish industry involved several stages, commencing with breeding, developing nutritionally optimal feeds, quality controlled aquaculture management and marketing. Small quantities of processed products were successfully exported to the United States. The yield of channel catfish aquaculture increased continually over this period. In 2003, yields reached

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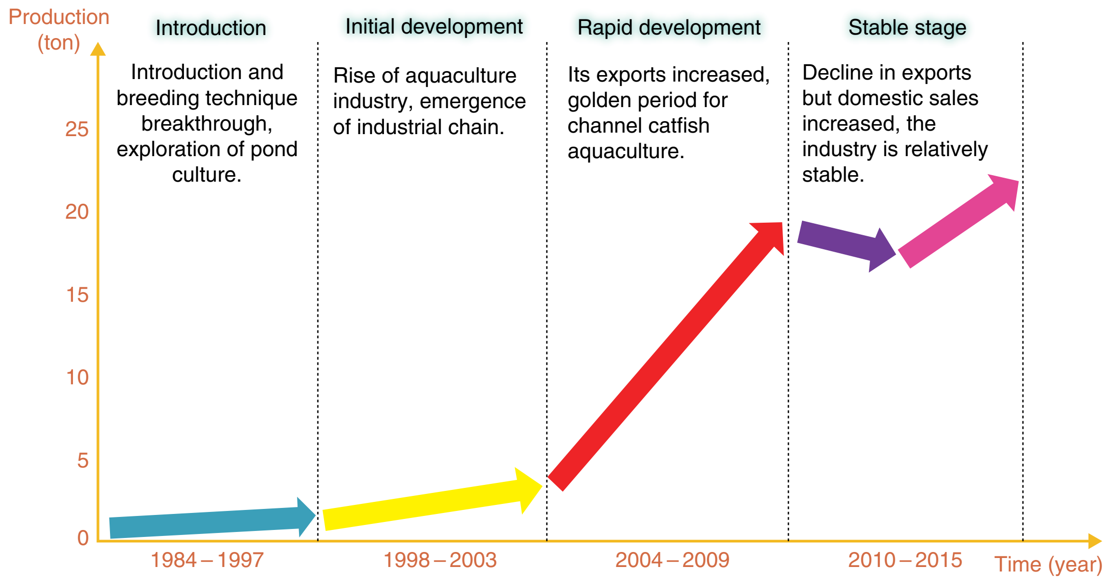

Figure 4.3.1 Schematic representation of the development phases of the channel catfish culture industry in China.

45 500 tonnes, with fresh fish mainly being sold to the domestic market. In that same year, however, export volume of processed channel catfish products reached 326 tonnes (Li *et al.* 2012).

Phase III (2004–2009): Channel catfish industrialization gradually matured and developed over this period. In 2008, channel catfish aquaculture developed and expanded rapidly and the yield reached 224 500 tonnes. Channel catfish processing plants were built in Hunan, Jiangsu, Shandong, Guangdong, Hubei, Guangxi and other provinces. Frozen commodities were exported to the United States, and exports reached 17 000 tonnes in 2008.

Phase IV (2010 to the present): The channel catfish industry in China has been relatively stable in this period, with only slight fluctuations in the production volume over the last five years. The price of raw fish processing is high inside China. Processing enterprises for export are witnessing significantly high cost pressures, which have resulted in a decrease of yield and market demand; only 6 568 tonnes were exported in 2011. By 2011, the yield of Channel catfish aquaculture had begun to decline, with only a 205 000-tonne yield. The price of channel catfish was showing volatility in the domestic market. Lowest prices dropped to only RMB 9 per kg (6 RMB = 1 US$), while the highest price rose to RMB 28 per kg. The market demand for fresh channel catfish has increased in recent years, particularly in the southwest of China including Chengdu, Chongqing, and Guiyang. Increased market demand has pushed up the price to a certain degree, promoting industrial recovery (Xiao 2014). In 2013, the aquaculture yield of channel catfish increased to its maximum historical yield of 247 399 tonnes.

4.3.3 Status of Channel Catfish Aquaculture and the Fisheries Economy

4.3.3.1 Status of Channel Catfish Culture

Currently channel catfish culture has been extended to more than 20 provinces in China, essentially covering the whole country (Xia 2010) (Figure 4.3.2).

The yield of channel catfish in China reached 247 399 tonnes in 2014, increasing by 10.38 percent from the previous year, and accounting for almost 1 percent of the total national freshwater aquaculture production (24 817 311 tonnes). The top five provinces with the greatest yields are Sichuan (56 854 tonnes), Hubei

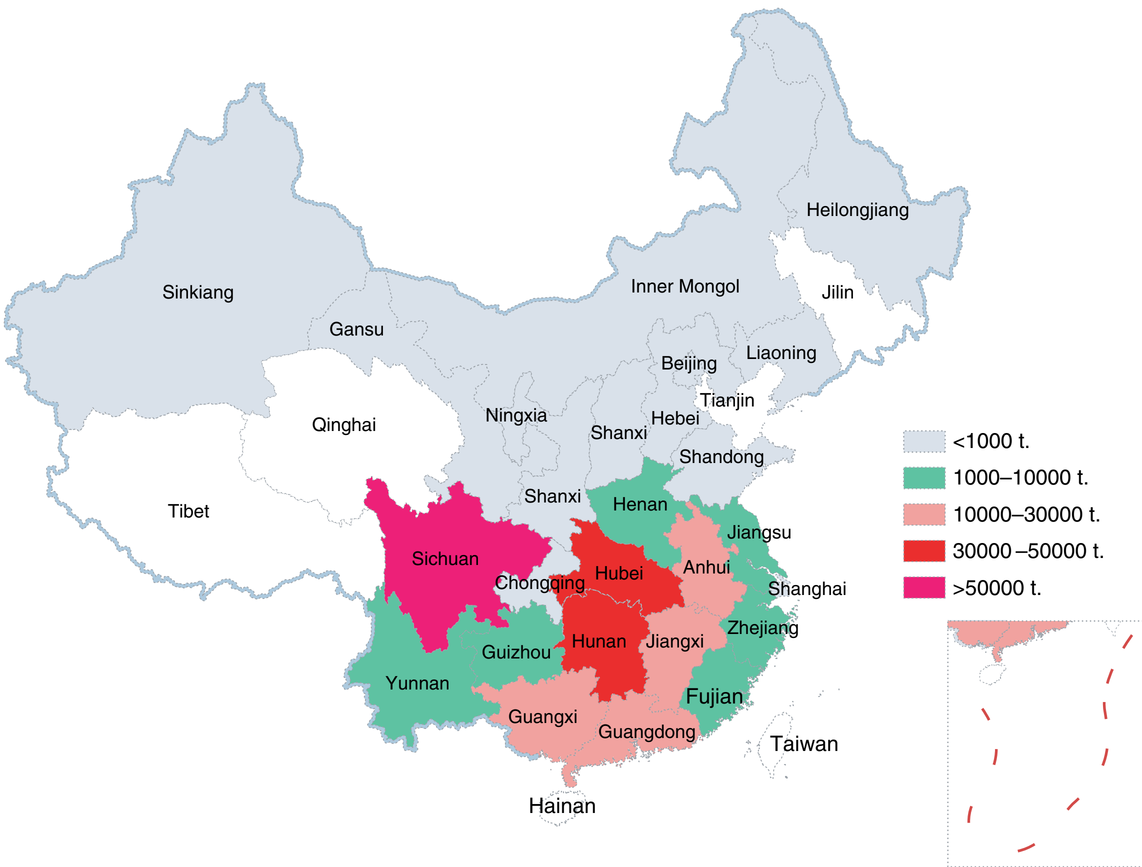

Figure 4.3.2 The distribution of channel catfish aquaculture in China. The mean production values are from 2008 to 2013.

(47 640 tonnes), Hunan (37 674 tonnes), Jiangxi (29 527 tonnes) and Guangdong (17 636 tonnes), respectively (China Fishery Statistical Yearbook 2013).

According to customs statistics, the export of channel catfish fillets reached 8305 tonnes in 2013, which was a significant increase (117.18 percent) compared with the previous year. This is equivalent to the value of 20 762 tonnes of fresh fish, which would account for 13.84 percent of the total national output (an increase of 95.87 percent). Domestic consumption is approximately 130 000 tonnes, of which fresh consumption is approx. 120 000 tonnes, and the processed products 10 000 tonnes (Xiao 2014) (Table 4.3.1).

Table 4.3.1 Channel catfish production and exports from 2003–2013 in tonnes, together with values of export in US$ from 2007–2013.

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Culture (t)	45552	62618	101096	170766	204929	224471	223233	217303	205177	224132	247399
Export (t)	326	1500	1747	12000	5900	17000	16600	9170	6534	3823	8305
Export value ($ million)	na	na	na	na	23.11	65.19	65.39	41.72	51.36	26.42	40.47

na = not available. *Source:* The data are from the 2014 China Fishery Statistical Yearbook; the export volumes are based on statistics of the Department of Customs.

Table 4.3.2 A comparison of selected parameters on channel catfish culture in the United States and China and indigenous catfish species in Vietnam.

Parameter	The United States	China	Vietnam
Species	Channel catfish	Channel catfish	Streak catfish and Mekong catfish
Source	Native species	Alien species	Native species
Breeding conditions	Good	Good	Excellent
Cultivation status	Developed technology	Developing technology	Developing technology
Feed prices	Intermediate	High	Low
Annual processing rate	97%	15–30%	95%
Processed products	Fish fillet,	Fish fillet, single	Fish fillet,
Processing equipment technology	Mature	Developing	Developing
Processing cost	High	Intermediate	Low
Food safety management	Standardized	Conditional standards	Conditional standards
Market	Domestic	The United States and Domestic (fresh)	The United States, the European Union and others
Brand	Independent brands	OEM	OEM and own brand
Processing requirements	Mature markets and large demand	Immature market and large potential demand	The immature market and small potential demand

Source: Modified from Xiao (2014).

In 2013, the output value of channel catfish reached RMB 4.45 billion, accounting for 0.95 percent of the GDP of freshwater aquaculture that year. Total exports reached US$40.47 million, increasing by 53.18 percent from 2012 (China Fishery Statistical Yearbook 2013) (Table 4.3.2). For instance, channel catfish cultured in the Qingjiang Reservoir in Hubei Province were mostly sold to the United States in the 2000s. The export value of fish from this reservoir in 2006 reached RMB 75 million, and produced a profit of RMB 18.5 million. The average income of aquaculture farmers was over RMB 30 000 per year (Hu and Peng 2008). In recent years, although the profits from channel catfish farming have decreased, profits are still approx. RMB 1500–2000 per tonne, amounting to an income of RMB 25 000 per ha. Channel catfish-shrimp polyculture farming is popular in Zhejiang, which can bring more than RMB 2460 profit per ha (Fan *et al.* 2008).

The channel catfish aquaculture industry has promoted the development of other processing enterprises. After many years of industrial development, a number of leading enterprises have been established in the Qingjiang reservoir area, and these companies have played a leading role in the successful development of the channel catfish industry. The Gaobazhou Aquatic Products processing company, which was founded in 2001, has more than 30 employees, with total assets of RMB 12 million. In 2004, the production of channel catfish was more than 800 tonnes with an output value reaching RMB 10 million (Hu and Peng 2008).

4.3.3.2 Channel Catfish Seed Production

In 2013, 1.5 billion catfish fry were produced, with an equivalent output value in the range RMB 2000–3000 million. The main location of channel catfish fry production is in Jiayu County in Hubei Province. There are 72 breeding facilities in Jiayu with nearly 80 000 broodstock. Fry production in Jiayu accounts for nearly 70 percent of the national total channel catfish fry production.

Fry production depends on market requirements on the yield and the export quantity of channel catfish. When the market is good, more fish are cultured, which leads to a greater demand for fry, and vice versa. In

2013, there were 200 000 adult breeding fish in Jiayu, producing 0.8–1 billion fish fry. In the early life stages, 10 000 fry can be sold for a total of RMB 500, while later, as mature adults, they can individually reach a value of RMB 30–50.

In the late 1980s, the initiation of artificial propagation of channel catfish was a success. Over the past few years, however, some issues have occurred such as germplasm degradation, germplasm variation and an increase in disease occurrence.

In order to solve these issues including inbreeding, germplasm degradation, and slow-growth rates, the government has invested and set up National Channel Catfish Improved Variety Bases in Sichuan, Hubei, and Anhui. The provincial departments of aquaculture have also established a series of Provincial Improved Variety Bases such as the breeding farm in Jiayu county of Hubei Province. The farm covers an area of 70 ha with the pond area of 47.5 ha. The farm has received four batches of brood fish from the USA. To date, the farm has utilized 30 000 channel catfish adult broodstock and has 50 000 reserved breeders *in situ*. In 2013, approximately 0.8–1 billion fry were produced in Jiayu.

The breeding platform and germplasm bank of channel catfish were established with the cooperation of enterprises and research institutes. In 2007, a channel catfish breeding project was carried out by the National Fisheries Extension Center, and the Yellow Sea Fisheries Research Institute of the Chinese Academy of Fishery Sciences. After six years of research, they succeeded in breeding a channel catfish named "Jiang Feng No.1" (Ocean and Fishery 2014). Under the same culture conditions, the average weight of an 18-month-old "Jiang Feng No. 1" increased by 22.1 percent compared with any other artificially spawned fish, and 25.3 percent greater than wild channel catfish. The success of this new variety brings a sustainable, healthy and efficient development to the channel catfish industry.

4.3.3.3 Grow-Out Culture Models

Channel catfish can be cultured in ponds and other freshwater systems such as rivers, lakes and reservoirs. It is an important species for high-density flow-through pond and cage culture. At present, pond and cage culture have become successful farming models for adult channel catfish in China.

4.3.3.3.1 Pond Culture

Pond culture of channel catfish in China can be mono- and or polyculture practices. In monoculture, stocking density is 12 000–18 000 fish per ha, combined with a very small number of silver carp and bighead carp, is popular in China. In the polyculture model, silver carp, bighead carp, tilapia, mudfish, or shrimp are cultured with catfish. Other suitable species for polyculture are white shrimp (Fan *et al.* 2008), dace (*Leuciscus* spp.) and bream (Xu *et al.* 2004) and trout (Wu 2008). For example, a polyculture pond stocked with 21 000/ha channel catfish and 375 000/ha white shrimp, in March and April of the first year, will produce on average of 11 752.5/kg/ha at the beginning of the second year, which equates to an average value of RMB 384 150 and a profit of RMB 134 250 per ha, including income from the white shrimp. The cultured channel catfish are mostly exported to North America (Zhang *et al.* 2007).

4.3.3.3.2 Cage Culture

Regions of South China, such as Sichuan, Hubei and Anhui, possess abundant lakes, and reservoirs, and are rich in water resources. Cage culture in lakes and reservoirs has become a major (Figure 4.3.3), and a preferred, model of catfish farming in China. Due to higher quality of fresh water in lakes and reservoirs, the quality of fish cultured in cages is much better, and these command double the price of pond-cultured fish. Fish cultured in reservoir cages are the main resources for processing for export. Qingjiang Reservoir of Hubei is the principal base of channel catfish cage culture, with 180 000 m^2 of cages. The annual yield has exceeded 10 000 tonnes in Qingjiang Reservoir. For example, the "cow-shape" mountain reservoir, a cage culturing test zone in Hengyang, Hunan province, stocked with 18 000 channel catfish fry and 500 silver carp and bighead carp fry in 10 cages. After 286 days, there was a total output of 13 728 kg of commercial fish, i.e. 1 372.8 kg per cage. The yield of channel catfish was 1246.8 kg; mean weight was 792 g. Considering

Figure 4.3.3 Cage culture in Qingjiang Reservoir of Hubei Province.

overall economic benefits, the value of a single cage was RMB 13728, including RMB 3896 net profit (Luo *et al.* 2008).

With the development of culture technology, reservoir cage culture has become an ecologically friendly, healthy, and intensive farming method. In general, there is an outer cage around the inner culture cage. Filter-feeding fish and omnivorous fish are stocked as "signal fish" between the cages, simultaneously the main fish cultured are in the inner cage. "Signal fish" eat excess feed and remove fouling organisms adhering to the cages. It is recommended to build a floating island of 3–100 m^2 outside the cage, for aquatic plants such as water celery (*Vallisneria americana*) and water lily (*Nymphaea tetragona*) (Wu et al. 2010). This practice provides added benefits of aquatic plants in the water column, and creates a more natural aquatic habitat, which contribute to lowering carbon emissions and improving water quality.

According to the principles of polyculture and cage culture, in the RuanLing Hunan Province, small cages in the upper reaches are stocked with fish such as channel catfish, and large cages in the lower reaches are stocked with a combination of omnivorous fish (such as bream, carp and silver xenocypris). The omnivorous fish and filter-feeding fish make full use of feed waste and excreta of the channel catfish. At the same time, the aquatic plants in cages absorb nitrogen, phosphorus and other substances from the water, reducing the risk of eutrophication. Under these conditions, each ecological cage harvests omnivorous and filter-feeding fish averages of 1250 kg, and aquatic plants of 700 kg, increasing the revenue to RMB 12330 (average RMB 1541 in each small cage), which brings significant benefits (Deng and Luo 2013).

4.3.3.3.3 Flowing-Water Culture in Concrete Tanks

Culture Conditions In these systems, the water is generally from a natural source and temperature is kept 15–30°C. Three polypropylene carbonate (PPC) inflatable tubes are fixed on the bottom of the pond with cement. These tubes have a series of holes at regular intervals, which are connected to an aerator. This system can provide oxygen as needed, and assist in maintaining dissolved oxygen (DO) concentrations at ≥7mg/l. Two water pumps are used interchangeably, with the intake pump connected to an intake pipe. Three intakes pipes are used to maintain a continuious water supply through 24 hrs; they are located on the west side of each pond. An outfall is located on the east side of the pond at 1–1.2 m water level. The water in the pond is always fresh and flowing. The color of the water is pale green, and transparency is around 30 cm.

The tanks are treated prior to use by disinfecting with potassium permanganate and generally stocked at a rate of 40–60 individuals per m^3 in the concrete tanks, with fry of average weight of 200–300 g.

Daily Management Channel catfish are fed floating pellets (specific food mix), three times a day at 10:00 hr, 16:00 hr, and 22:00 hrs. Each feeding period should last approximately 30 min. If the feed is consumed before 30 min, then the quantity of food should be appropriately increased. Fish are generally most active at night. With the growth of the fish, feed particle diameter should be increased from 3 mm to 5 mm, and then to 10 mm later. With inclement weather, such as continuous rainy days, the feed intake is relatively poor because of low dissolved oxygen (DO) and reduced activity. In such situations, feed volume is based on the previous day's feeding regime. The intake pump is only used to exchange water during the early rearing period, generally from April to June. At this time, the exchange of water and oxygen should be carried out simultaneously, keeping dissolved oxygen at ≥7mg/l. Waste and extra food are removed promptly and regularly from the bottom of the pond with a suction hose.

Disease Prevention Disinfectant drugs are sprinkled into the breeding pool periodically, and a microporous plastic bottle containing drugs is also immersed in the water as a disinfectant. Medicinal feed is also given regularly to the fish. Key ingredients, including allicin and diallyl thiosulfinate, are known for their strong antibacterial activity against a wide range of gram-negative and gram-positive bacteria. As soon as a disease occurs, water is disinfected, and a monitored medicinal feed program must be administered in order to eradicate the disease (Chen 2009).

4.3.3.4 Control of Culture Processes

To improve the quality of aquatic products, and promote the healthy development of aquaculture, national and provincial administrations have implemented a series of measures. According to the "National Product Quality and Food Safety Specialist Rectification Action Plan" deployed in September 2007, the Ministry of Agriculture carried out special campaigns for limiting aquatic drug residues, and promoted pollution-free culture. Provinces, such as Hunan, Jiangxi and Hubei, compiled and issued a series of regulations specifically for channel catfish aquaculture.

Not only should the management of product quality and safety occur during the processing and terminal product management, but it should also be implemented throughout the entire production chain, including breeding, production, processing, storage, transportation and sales. The goal of the breeding enterprise and of farmers is to ensure sufficient quantity and cheap fresh fish for processing. HACCP (Hazard Analysis Critical Control Point) is an assurance system for food safety, and a popular management tool of channel catfish aquaculture. Through the implementation of HACCP guidelines, channel catfish can be cultured in ponds and cages according to standard contamination-free and food-safety protocols (Yu *et al.* 2007, 2008). Under the control of culture processing, culturing channel catfish is environmentally friendly and sustainably developing (Liu and Zhang 2013).

4.3.4 Improvements on Feeds

The quality of cultured fish is closely related to the quality of feed. Since the end of twentieth century, many studies have investigated the quality of channel catfish feed in China. Research examined the energy, protein, lipid, carbohydrate and vitamin requirements of the fish. According to the American Soybean Association, the representative dietary formulae recommended showed positive responses but, however, needed a practical improvement for adoption for channel catfish feeds (Dai and Zhou 2005). In addition, the impacts of feed additives on the growth of channel catfish have also been studied, such as specific research on the introduction of phytase (Yang *et al.* 2011), carnitine (Wang 2009) and fermented herbal extracts from traditional Chinese medicine (Liu *et al.* 2010). These new measures aim at promoting more efficient nutrient digestion and absorption, which can reduce the quantity of nitrogen and phosphorus excretion to the environment.

4.3.5 Innovative Technologies

4.3.5.1 Molecular Breeding and Genomics Research

In order to establish a core breeding population, "Channel Catfish Multiple Characters Breeding Projects" were implemented by the National Fisheries Extension Center (Bian 2008). These projects collected and conserved 216 individuals from five different groups of channel catfish germplasm available across China. First, they focused on enriched genetic diversity of channel catfish based on the breeding populations. Second, the project constructed G0 and G1 genealogy traits, with 155 and 82 individuals, respectively, by using 'multiple characters compound breeding technology', which is based on targeted mating and electronic chip labeling.

Later, breeding varieties (lines) were developed. Two high-performing families were screened through the evaluation of economic gain and growth performance. The results after one year of culture indicated that there are quite significant differences in growth and resistance among various hybrid groups of channel catfish. Using the Best Linear Unbiased Prediction (BLUP) method for evaluation of genetic techniques, two best hybrid groups were chosen. They both had excellent growth performance and resistance compared to all other strains tested. Weight and survival rates increased by 20.22 percent and 7.36 percent, respectively. Third, this project also launched research on reproductive biology and genetics. Three patents were successfully acquired, aquatics industry standards and technical regulations developed and a platform for the "Channel Catfish Genetics and Breeding Analysis and Management System" established (National Fisheries Technology Extension Station 2011).

Channel catfish has become a good model for genomics research, as well as offering great possibilities for the screening of genetic phenotypes and quantitative trait loci (QTLs). Genetic research on channel catfish began in 2005. Initial work was mainly focused on the development and application assessment of polymorphic genetic markers. Several types of molecular markers were tested, including RFLP, mtDNA, RAPD, AFLP, SSR, EST and SNP. The study of SSR markers made great progress during this genome research. Breeding populations studied were from variant hybrid groups including Yidu, Fujian, Liaoning, Hunan, and Hubei. The results showed that genetic diversity was relatively low in domestic breeding populations (Liang *et al.* 2007), but the study on microsatellite marker loci of the cultured populations in Yidu City of Hubei Province had a high genetic diversity. These populations could be used as good breeding material.

4.3.5.2 Challenge to Exports and Transition Dilemma

Since early 2000, channel catfish products have been exported to the United States. In May 2003, the sale of catfish from Vietnam (known commonly as striped catfish, basa catfish etc., *Pangasianodon hypophthalmus*) was judged to be dumped by the United States (Nguyen 2010; De Silva and Nguyen 2011). This brought an opportunity for China to export channel catfish products. After that, exports to the US commenced rapidly. The export volume of processed channel catfish was only 326 tonnes in 2003, but this volume increased to 12 000 tonnes in 2006. Under the influence of the US trade sanctions, the export volume of channel catfish product was reduced to 5900 tonnes in 2007. In 2007, the United States implemented automatic detention of Chinese channel catfish imports when drug residues were detected, which lead to a sharp drop in exports into the US from China. Between 2008 and 2009, the export volume of channel catfish from China rapidly regained strength globally. Sales of fresh channel catfish increased after 2009 domestically and the price rose rapidly. Under the influence of technical barriers on channel catfish processing enterprises in the United States, and a substantial appreciation of the Chinese currency, the export of catfish from Vietnam to the United States increased greatly after 2008, while exports of channel catfish from China fell into a period of depression, and export items hit a downward trend.

Because of the influence of the trade barriers, the export of channel catfish was blocked, and volume fell sharply in the late 2000s. Channel catfish aquaculture declined sharply, with farmers choosing to rear alternative species. Some even sold off parent catfish as commercial fish, leading to a shortage of seed in 2010. This resulted in a sharp rise in commercial fish price, reaching more than RMB 20 to RMB 22 per 500 g. The highest price reached was RMB 34 per kg; which was due to its popularity in the domestic market. Hubei, Jiangsu, Anhui, Hunan and Jiangxi that were important export provinces for channel catfish began to focus on the domestic market, due to high local prices. Driven by the attractive domestic market, fresh fish from producing provinces such as Hubei, Hunan, Jiangxi, and Anhui were then transported to other markets, especially in Chengdu, Chongqing and Guiyang (Cui and Xiao 2012). "Hot pot" became a very popular dish in which channel catfish is the main ingredient. Consequently, the demand on channel catfish in these areas evoked the enthusiasm of channel catfish culture. Fresh channel catfish weighing 50 tonnes was sold in Guangzhou market daily. Followed closely by Xi'an, Xining, Taiyuan and Shijiazhuang and other small consumer markets, the consumption in these areas is around 40 000 tonnes every year (Xiao 2014).

4.3.5.3 Challenges Confronting the Channel Catfish Industry

Germplasm degradation affects the quality of fish seed, and has become a problem in most areas of China. Therefore, the broodstocks need to be replaced. In 2007, the last channel catfish was introduced to China from the United States. These strains will be eliminated in the next few years due to serious degradation of the broodstocks. The degradation results in slow growth, an altered physical appearance with a shorter, wider and thicker body shape, decreased disease resistance, and decreased feed-conversion efficiency. At present, the main culture modes of channel catfish are pond and cage culture. The poor quality of produce is thought to result from the differences in individual farmers' technology, management systems, feed quality, and even seed quality. In addition, fish medication is not always administered correctly by farmers, which results in increasing drug residue problems. In 2009, there was a loss of RMB 202 million, caused by channel catfish diseases (Deng *et al.* 2010). Compared with aquaculture in natural waters, the water quality of pond farming has deteriorated, leading to increased harmful substances in the water. Fish grown in such conditions can lead to poor muscle quality. Although the quality of channel catfish cultures in cages is good, cage culture will be eliminated from lakes and large and medium-sized reservoirs when the new fisheries policy in China is implemented (see Wang *et al.* 2017, and Chapter 7.4 for details).

The main reasons for epidemic diseases in the culture process in China have been the absence of standard culture technology, high-density farming, poor culture environments, and the pursuit of high yields. The recognized scientific culturing method allows for a channel catfish density of 128–160 tails at 910–1210 g per ha in ponds, or 100–120 tails/m^2 in cages.

The protein content in feed is 38–40 percent for fry and fingerling, 36–38 percent for broodfish, and 32–36 percent for grow-out fish. Feeding should be performed under weak/poor light conditions (Cai and Xiao 2013). Because of regional differences and the lack of basic technology, some areas cannot strictly implement scientific feeding and breeding standards, resulting in low yield and economic loss.

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4.4

Status and Trends of the Tilapia Farming Industry Development

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4.4.1 Introduction

Tilapia are endemic to the African continent, found in freshwater and saline sea areas along the Atlantic coast of the Middle East, and in Israel and Jordan as well. Tilapias have many favorable traits for aquaculture, such as, for example, high growth rate, wide-ranging food habits, high disease resistance, lack of intramuscular bones, convenience for processing, short culture period and reproductive cycle, and suitable for high-stocking-density culture practices (Wang *et al.* 1998; Wang 2008; El-Sayed 2006). The 1976 FAO Technical Conference on Aquaculture held in Japan, recommended that tilapia are highly suitable for farming as an alternative to alleviate poverty and provide quality animal protein in rural areas (FAO 1976). Tilapia as food fish are also important because they are an animal protein source that is affordable to most poor communities in developing countries, and this fish plays an irreplaceably important role in food security and poverty alleviation (De Silva *et al.* 2004; Charles *et al.* 2010). The major tilapia farming countries and regions are China, Egypt, Indonesia, Brazil, the Philippines, Thailand, Bangladesh, Vietnam (Figure 4.4.1), accounting for 34.45 percent, 17.06 percent, 15.93 percent, 6.36 percent, 5.78 percent, 3.40 percent, 2.74 percent, 2.22 percent of global production, respectively. Global tilapia production increased from 2 550 000 tonnes in 2004 to 5 220 000 tonnes in 2012, at an annual average growth rate of 9.36 percent (Figure 4.4.2). In 2014, global tilapia production was estimated to be about 6 480 000 tonnes, of which aquaculture production reached to 5 770 000 tonnes, and the rest was from capture fisheries (Figure 4.4.2). Over 135 nations and regions in the tropics, sub-tropics and temperate zone farm tilapias (FAO 2014). Tilapia, along with carp and catfish (including *Pangasius*) account for most of the global increase in aquaculture production, and represent about 60 percent of total aquaculture production in the world in 2015 (FAO 2016).

Mozambique tilapia was initially introduced into Taiwan from Singapore in 1946 (Li 2005; Yang 2015), and translocated onto mainland China from Thailand in 1956 and Vietnam in 1957 (Lou 2000). China started to farm tilapias on a large scale after the introduction of Nile tilapia in 1978. In 1983, Blue tilapia (*Oreochromis aureus*) was introduced into China, and after that China began to farm the AuNi hybrid tilapia (*Oreochromis niloticus* ♀ × *Oreochromis aureus* ♂). In recent decades, production of quality strains such as Genetically Improved Farmed Tilapia (GIFT) has been driven by strong demand from domestic and overseas markets. With the progress of culture technology, and abundant low-cost labor resources, tilapias have been developed into a dominant farmed and export-oriented species in China.

As a major component of the Chinese aquaculture industry, tilapia farming also has driven developments in other sectors such as feed manufacture, processing, and live fish transportation. Learning from farming experiences and technologies of traditionally farmed species, tilapia farming in China has been transformed from introduction to commercialization, from extensive to intensive farming. Mature tilapia farming

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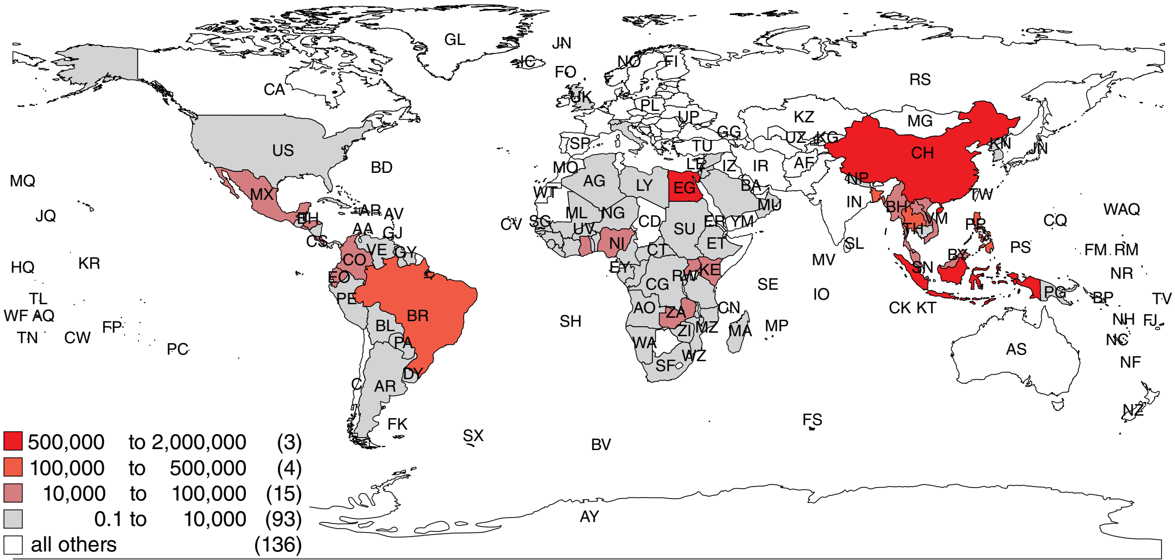

Figure 4.4.1 Distribution map of world's tilapias farming countries and production volume. *Source:* Based on data from FAO FishStatJ version 3.01, http://www.fao.org/fishery/statistics/software/fishstatj/en.

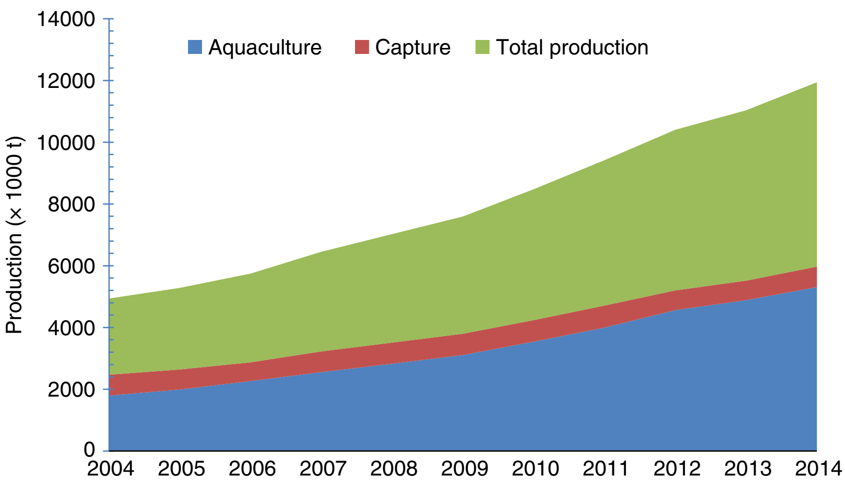

Figure 4.4.2 Global tilapia production volume from 2004 to 2014. *Source:* Based on data from FAO FishStatJ version 3.01, http://www.fao.org/fishery/statistics/software/fishstatj/en.

technologies and systems have accumulated and developed based on local conditions. Driven by the export trade, other sectors closely related to tilapia farming also have developed. The major tilapia farming in China now is intensive, which is based on monoculture and polyculture in ponds, cages, in ponds close to mountains or hills (water *source:* rain) and reservoir farming. The industry differentiation is more refined, i.e. development of specialized commercial feeds for different growth stage of tilapia, development of processing techniques and utilization of processed wastes.

Tilapia production volume has increased from 707 thousand tonnes in 2002 to 1 658 000 in 2013, with an annual growth rate of 8.1 percent. In 2013, the production volume accounted for 5.9 percent of the total freshwater aquaculture production of China. Tilapia is the sixth major farmed freshwater species in China, following grass carp (5 070 000 tonnes), silver carp (3 851 000 tonnes), common carp (3 022 000 tonnes), bighead carp (3 015 000) and crucian carp (2 594 000 tonnes) (China Fishery Statistical Yearbook 2014). In 2013, the global farmed tilapia production was 4 850 000 tonnes (FAO 2014), and that in China was 1 658 000 tonnes (China Fishery Statistical Yearbook 2014), accounting for 34.2 percent of global production. Tilapia is not only the fastest growing freshwater farmed species in the country, but the most successful introduced species. It has effectively promoted the fast development of the aquaculture industry in China, and even in the world, and some sources regard tilapia as the most important farmed fish species of the twenty-first century (Shelton 2002).

Conventional freshwater fish (including the Chinese major carps, common carp, crucian carp, and Chinese bream) farming mainly caters to the needs of the domestic market, which has been leading the development of the aquaculture industry in China. In 2014, for instance, the farmed production of the above seven conventional fish accounted for 75.8 percent of the total freshwater fish aquaculture production, and for 67 percent of freshwater aquaculture production (China Fishery Statistical Yearbook 2014). The introduction of tilapia has effectively increased profits and incomes of farmers, and enriched market supply of aquatic products. The main producing areas are situated in south of China, and tilapia yields can reach up to over 15 tonnes per ha, and generate a net profit of more than 30 000 RMB (Yang 2010; 6 RMB = 1 US$). Increasingly, tilapia has been taking the place of cod and other marine products in Western cuisine, and has become the third major internationally traded farmed commodity after salmon and shrimp. In 2013, China's total exports of tilapia was 403 600 tonnes (China Fishery Statistical Yearbook 2014), its most important exported farmed species.

Initially, tilapia farming was scattered and small-scale, mainly catering for the domestic market. As the farming and processing technology developed, together with the rise of export trade, tilapia farming became more intensive, large-scale and ecological. Chinese-farmed tilapia products gradually entered the international market. Farmed-tilapia product exports began to boom in the mid 90s (Dai *et al.* 2014) the export value rose from US$ 50 million in 2002 to US$ 1.53 billion in 2014, with an average annual growth rate of 33 percent. As the world's largest producer and supplier of tilapia with low price and quality products, China provides a large amount of high-quality animal protein for the world. As of 2014, there were 97 export destinations, and the export value into the five major countries (listed later) accounted for 75.6 percent of total tilapia export value. Exports to the United States, Mexico, Côte d'Ivoire, Iran, and Israel were 53.1 percent, 13.1 percent , 3.3 percent, 3.0 percent and 3.0 percent, respectively.

4.4.2 Major Tilapia Farming Areas

Tilapias are warmwater fish. They can survive in temperatures of 16–40°C, and the optimum temperature for growth is 24–32°C (Wang and Tsai 2000). In China, tilapia is farmed in 29 provinces and cities, except Qinghai and Ningxia (Figure 4.4.3), but can be farmed on a large scale under natural conditions in five provinces in the south of China, viz. Guangdong, Hainan, Guangxi, Fujian, and Yunnan. Tilapia production volumes in major production areas from 2009–2014 are shown in Figure 4.4.4. In 2013, the tilapia farming production in these areas accounted for more than 95 percent of the total in China.

4.4.3 History of Tilapia Farming in China

Taiwan was the first Chinese province to introduce tilapia. In 1946, Mozambique tilapia (*Oreochromis mossambicus*) from Singapore, named "WuGuo Tilapia" was introduced (Liu 1998). The mainland first introduced Mozambique tilapia in 1956, from Vietnam. In subsequent years, Mozambique tilapia was extended to southern China. Mozambique tilapia farming was gradually phased out in view of its tendency to stunt, slow growth rate, and darkish appearance. Since then, China has repeatedly introduced tilapias from other countries (Table 4.4.1). In 1966, Taiwan introduced Nile tilapia (*Oreochromis niloticus*), and in 1969 male Nile

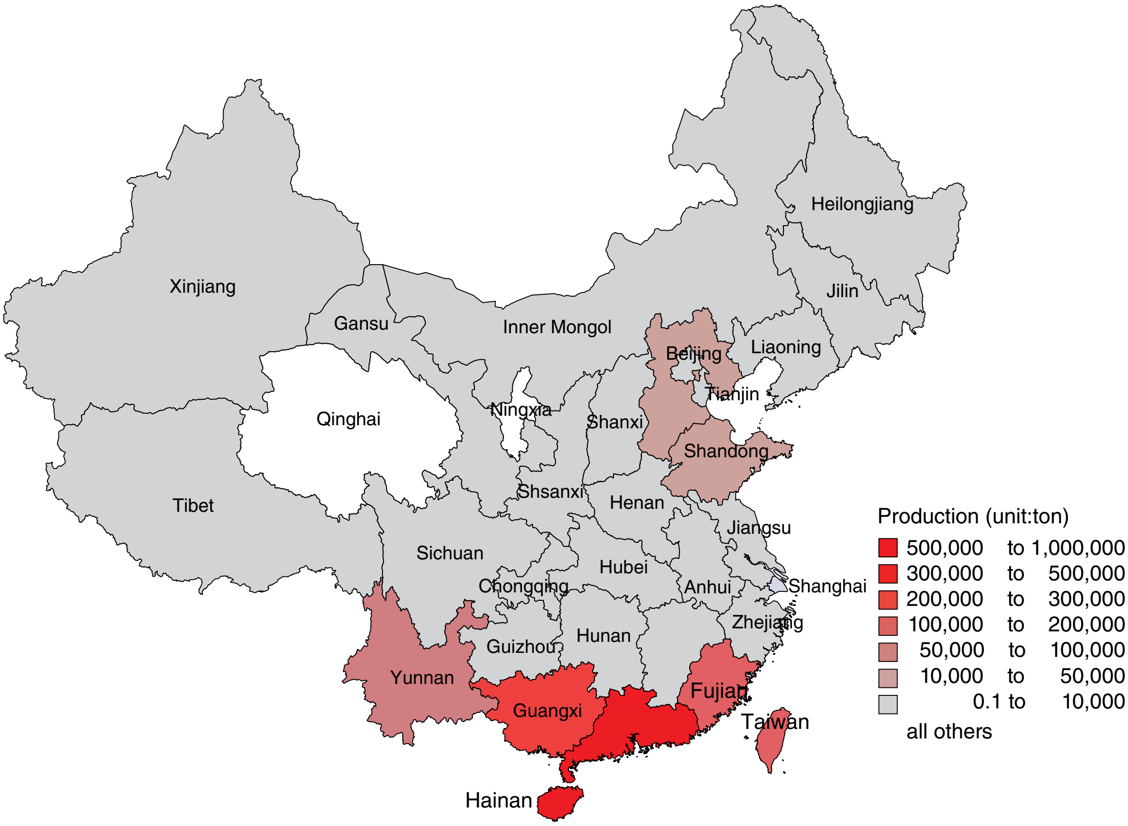

Figure 4.4.3 Major tilapia farming areas and production volume distribution. *Source:* Based on data from China Fishery Statistics Yearbook (2015).

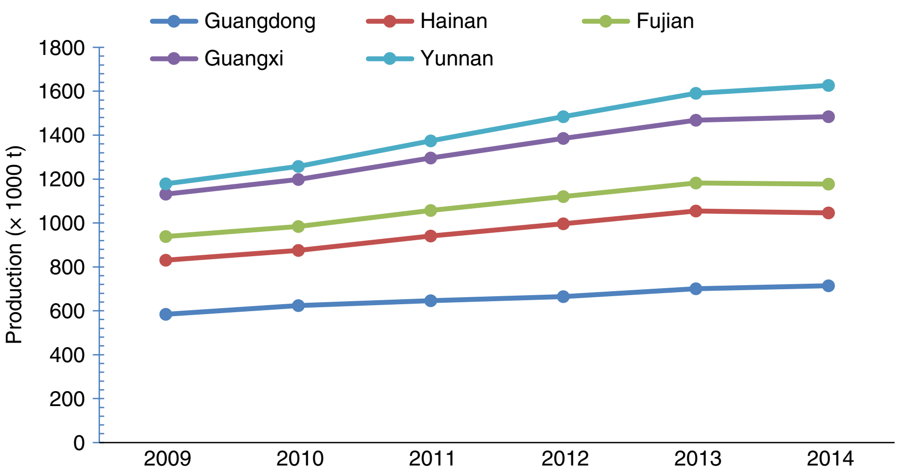

Figure 4.4.4 Trends in tilapia production volumes in major farming areas from 2009–2014. *Source:* Based on data from China Fishery Statistics Yearbook (2010–2015).

Table 4.4.1 Fact sheet of important introductions of tilapias to China.

Year	Species or strain	Place of origin	Introduction and domestication Unit
1946	*Oreochromis mossambicus*	Singapore	Taiwan
1956	*O. mossambicus*	Vietnam	Ministry of Agriculture, P. R. China
1978	*O. niloticus*	Upstream of Aswan Dam within Sudan along the Nile river	YRFRI of CAFS
1983	*O. aurea*	Introduced from USA and the original place is Israel	FFRC of CAFS
1988	*O. niloticus*	Downstream of Aswan Dam within Egypt along Nile river	Xianghu Fish Farm in Hunan province
1994	GIFT strains of *O. niloticus*	International Center for Living Aquatic Resources Management (ICLARM, Philippines)	Shanghai Fisheries University (Now: Shanghai Ocean University)
1999	*O. aureus*	Fishery Research Center, Ministry of Agriculture and Land Reclamation, Egypt	FFRC of CAFS
1999	*O. niloticus*	Fishery Research Center, Ministry of Agriculture and Land Reclamation, Egypt	FFRC of CAFS
2006	GIFT strains of *O. niloticus*	WFC	FFRC of CAFS
2010	Red Tilapia	WFC	FFRC of CAFS

tilapia and female Mozambique tilapia were cross bred and a new hybrid FuShou tilapia (Li and Cai 2008) was produced. In 1978, the Yangtze River Fisheries Research Institute (YRFRI) of the Chinese Academy of Fishery Sciences (CAFS) introduced Nile tilapia obtained from the upper Nile River, a species of which the growth performance was much better, and this introduction triggered tilapia farming in China. The Freshwater Fisheries Research Center (FFRC) of CAFS introduced *O. aureus* from Auburn University, Alabama, in 1983. Male *O. aureus* were crossbred with female Nile tilapia and a high proportion of male hybrid AuNi tilapia characterized by uniform size and fast growth rate were obtained. Hybrids were used to improve farming yield, and resulted in a high proportion of males in the hybrid AuNi tilapia farming model in China, which greatly promoted the rapid development of the tilapia farming industry.

In addition, different strains of Nile tilapia were also introduced into China in 1973, 1981, 1993, and 1985. In 1994, a genetically modified strain of Nile tilapia, known as GIFT (Genetically Improved Farmed Tilapia) was introduced. In 1995, Nile tilapia (53 individuals) from Sudan were introduced again. In 1998, 3000 individuals of the original species of Nile tilapia from Egypt were introduced directly from the country of origin. In 2006, the FFRC of CAFS introduced 60 families of the latest generation of GIFT from the World Fish Center, Manila, Philippines (WFC). These GIFT fish constituted the base population for breeding programs, and 120 families were designed for each generation (PIT tagged), when quantitative genetic analyses were carried out to perform family selection. At present, the main farmed species or strains are AuNi tilapia, GIFT and red tilapia. The farming area of GIFT, AuNi tilapia, red tilapia and other species or strains accounts for about 60 percent, 30 percent and 10 percent, respectively of total tilapia farming areas (Yang 2015).

Five development periods can be recognized for tilapia farming in the Chinese mainland (Li *et al*. 2007; Yang 2015):

(1) **Start-up and exploratory period of industrial development (1956–1978):** In this period, Mozambique tilapia was the main farmed species. However, in view of the previously mentioned unfavorable traits of

this species, Mozambique tilapia farming was not popular among farmers. During this phase, other tilapia species, such as Nile tilapia strains and *O. aurea*, continued to be introduced into China.

(2) **Introduction and extension period of new varieties (1978–1985):** During this period, Nile tilapia, FuShou tilapia (*O. mossambicus* ♀× *O. niloticus* ♂) and Mozambique tilapia coexisted, and large-scale tilapia farming commenced. Rural households were contracted to farm tilapia, and private tilapia hatcheries in southern China were rapidly established. Meanwhile, China also stepped up research on tilapia breeding and improvement of farming techniques, all of which contributed to and stimulated tilapia farming.

(3) **Technological innovation period (1985–2000):** In this period, scaled-up tilapia selective breeding farms, hatcheries and nurseries, and grow-out farms gradually sprang up. Nile tilapia almost completely replaced both Mozambique tilapia and FuShou tilapia. Meanwhile, AuNi tilapia farming development kept a rapid pace. In view of the significantly higher growth rate of male tilapia, all male tilapia grow-out farming gradually became predominant.

(4) **Peak development period (2000–2009):** With the rapid development of the tilapia industry, more and more enterprises and research institutions joined in the R&D chain. Scientific research achievements, advanced biotechnology and traditional genetic breeding methods were combined and applied to improve farming performances. New improved tilapia strains or hybrids with Chinese characteristics such as New GIFT tilapia (2005), “XiaAo No. 1” tilapia (2006), “JiLi” tilapia (2009) were successfully bred and distributed to different regions of China. Nutrition studies lead to the development of nutritionally wholesome feeds for different growth stages. In this period, the GIFT strain bred by the World Fish Centre (WFC), and a new strain of GIFT tilapia bred in China gradually replaced the AuNi tilapia as the major farmed strains, and the farming area of these two new strains accounted for about 60 percent of total tilapia farming area.

(5) **Period of industrial development (post 2009):** In this period, the Central and Provincial Governments set up special funds to standardize pond size and farming practices. Consequently, widening and deepening of ponds resulted in around 30 percent increase in average yield per unit area. But after 2009, due to the expansion of farming area as well as an expansion in farming practices geographically and increased stocking densities, streptococcus infection of tilapia resulted in significant damage to the industry. In recent years, the emergence of new tilapia-farming countries, together with associated increases in product quality standards, and with the absence of an established domestic market for tilapia products, led to a downturn in price, and a fluctuation in the geographical tilapia farming area that changed with market demands. At the same time, frequent low-temperature periods, typhoons and other extreme weather conditions were also confronted by the Chinese tilapia farming industry, impacting on profits and market supply. “LuXiong No. 1” Nile tilapia strain (2012) and “ZhongWei No. 1” GIFT tilapia (2014), were bred in this period. The AuNi tilapia farming area increased slightly in this period than that in previous years, but GIFT remained the dominant farmed species.

4.4.4 Tilapia Farming Environment

With developments spanning nearly half a century in China, tilapia farming is mainly conducted in the Pearl River basin, and is conducive for semi-intensive, high-stocking-density intensive farming in enclosed ponds, cages and semi-enclosed nets in reservoirs, lakes, rivers, as well as in indoor recirculating systems. It is noteworthy that, due to the ease and speed with which they adapt to new environments, tilapias as an exotic species are bound to affect the local ecosystems through competition with native species for food, and impacting on the amount of available light in the water column (Gu *et al.* 2014). High-stocking-density intensive tilapia farming is carried out in closed ponds. When cultured in cages and semi-enclosed nets in reservoirs, lakes, rivers and other natural water bodies, phytoplankton and zooplankton are utilized, resulting in reduced impact on the environment. At present, tilapia can overwinter and establish populations in natural water bodies in Guangdong and Hainan provinces only; elsewhere it is not able to establish long-term stable wild populations to pose a threat to native fish. However, they may to some extent cause certain negative impacts on fish catches, biodiversity, on the structure and function of ecosystems, and on the growth of native species in the local watersheds in subtropical and tropical areas. For instance, in the main rivers of Guangdong Province, such as the Pearl River (and its large tributaries, including the Xijiang River, Beijiang River, and Dongjiang River), Hanjiang River, Jianjiang River, and Tanjiang River, populations of *Oreochromis* spp. have become established due to their ability to overwinter and reproduce in natural waters (Gu *et al.* 2012a, b). And recent investigations found that tilapia (mainly *Tilapia zillii*, *O. niloticus* and *O. galilaea*) have become the main fish groups in some areas of Jiulong River in Fujian Province, which may affect the biodiversity and native fish resources (Fang 2015). However, in recent years, because of all-male tilapia culture, the impacts on the natural ecosystems have been considerably reduced (Ridha 2013). Tilapia farming in indoor recirculation systems is the trend in China, resulting in improved production efficiency, and reduced production costs.

4.4.5 Tilapia Farming Systems

In China, tilapia farming systems vary due to farming conditions in different regions. The main tilapia farming areas in China are currently distributed in the southern regions of China, such as Guangdong, Hainan, Guangxi, Fujian, and Yunnan provinces (see also Figure 4.4.1). In the northern areas such as Shandong, Beijing and Liaoning provinces, tilapia farming has also been developing rapidly in recent years. Tilapia farming also occur in regions where heat is produced from electricity generation facilities or geothermal resources. Currently, monoculture and polyculture with tilapias as dominant species are the most important farming models. Unique farming models also exist in some regions in accordance with local geographical and natural resources, such as stocking a certain amount of high-economic value fish species in tilapia ponds, obtaining three-crops-in-two-years farming model, three-crops-in-one-year farming model, large-size overwintering fingerlings farming model, and northern overwintering farming through the utilization of geothermal resources (better for balanced market supply of tilapias).

4.4.5.1 Pond Farming Systems

There are no special requirements for tilapia pond farming systems, apart from an adequate and a reliable water supply. However, standardization of pond construction is necessary to increase farming output (Figure 4.4.5). Generally, pond area ranges from 0.066 to 0.66 ha while around 0.66 is ha is optimal. Water depth ranges from 1.5 m to 3.5 m. The pond bottom should be flat with minimal silt. Before stocking, pond clearing and disinfection should be carried out. Seed of 3 cm body length, are generally stocked when the water temperature stabilizes at 18°C. The stocking density is 30 000–37 500 individuals per ha, while for deep ponds equipped with aerators, 37 500–45 000 per ha can be stocked.

4.4.5.2 Cage Farming Systems

Cage farming of tilapias has the following advantages: running water, high stocking density, high survival and growth rates, and high yields. Tilapia are highly suitable for cage farming because they can adapt to high stocking densities in cages, and are tolerant of low dissolved oxygen (DO) and resistant to diseases, but also can feed on the algae attached to the nets. Cages are installed in reservoirs, lake branches, bays or ponds with an area of above 0.67 ha with the characteristics of leeward exposure to the sun, a wide water surface, small waves, and fertile water with plankton. A flow velocity of 0.05–0.2 m/s is preferred. Perennial water depth should be 3–4 m and above. The bottom should be flat and the cage should be above 0.5 m of the bottom. Filter-feeding fish can be raised in or out of tilapia cages, thereby taking full advantage of the space and the natural live food organisms available within, and outside, the cages, and on cage netting, to increase growth and production. It also helps reduce the impact of tilapia feed residues on water quality. For instance, in Yunan

Figure 4.4.5 Standardized tilapia farming ponds in Guangdong province.

Province tilapia farming is conducted in double-layered cages: tilapia are farmed in the inner small cage of 5 m × 5 m × (4–6) m, mesh size of 0.4–4 cm; silver carp, bighead carp, crucian carp, and other fish are stocked in the large outer cage of (10–22) m × (10–22) m × 10 m, and mesh size of 6 cm. This farming model can effectively control the carrying capacity of inner cages. There is no feeding for outer cages, in which the fish mainly feed on tilapia feed residues and feces, plankton in the water, and algae attached to the nets.

4.4.5.3 Paddy Field Farming Systems

Paddy fields used for tilapia farming should meet the requirements of an adequate water supply, inlet and outlet structures, and be free from the effects of drought and floods, have a strong water retention capacity, an abundance of sunshine, fertile soil, good water quality, and low acidity. The dike should be heightened and reinforced. Ditches, pits, inlets and outlets should be excavated. For paddy-field tilapia farming, stocking time should be early in the year with fingerlings bred in the same year. Generally, tilapia should be stocked seven to ten days after transplantation of seedlings, when these turn green. Stocking large-sized overwintered fingerlings bred in the previous year needs to be done about 20 days after seedling transplantation. Fingerlings should be first stocked into the pits, then the tilapia can swim slowly through the ditches to rice fields for food, and gradually adapt to the environment. Usually the stocking density of fingerlings of 4–6 cm is 4500–6000 individuals per ha. Tilapia are also polycultured with a small amount of grass carp and silver carp. Usually before the rice harvest, fish ditches should be dredged, then slowly drained making the fish swim into the fish pits. A dip net can be used to collect the tilapia in pits. Yields generally can reach 1500–2250 kg/ha.

4.4.5.4 The Farming System in Ponds and Small Reservoirs in Mountain Areas

These systems are common in Guangxi and Fujian provinces. Generally, the ponds and small reservoirs in the mountain areas built for irrigation purposes are suitable for tilapia farming. On the one hand, these water bodies play an important role in flood control and improving agricultural production, and on the other hand, in view of an adequate water supply and abundant natural live food organisms, it can provide a suitable environment for producing large-sized, high-quality tilapia. In general, AuNi tilapia or GIFT (over 95 percent males) are stocked in these waters. The stocking density varies with the area and water depth. For ponds or small reservoirs in mountain areas in Guangxi with maximum water depth exceeding 10 m, and an area less than 67 ha, the common stocking density (50 g/ind.) is 7500 –15000 ind./ha. A certain amount of freshwater carp, such as silver carp, bighead carp, grass carp, and crucian carp can be stocked into the waters to fully utilize the nutrients. The yield can exceed 15 tonnes per ha. The effluent from intensive farming in small ponds and reservoirs in mountain areas can be used for crop irrigation. These systems can reduce environmental degradation, improve ecological and economic benefits. The disadvantage is difficulty in pond clearing and harvesting.

4.4.5.5 High-Stocking-Density Farming in Flow-Through Systems

Fish ponds are constructed on the bottom of dams of many medium and small reservoirs impounded for irrigation and hydroelectric power generation in some regions of southern China. By setting inlet, outlet, aerators, automatic feeders, cages, automatic fish screens, fish crane platforms, and electric fish cranes, a suite of standardized operational procedures is established. Fish are harvested using a large cage to trap, then transfered into small cages for overnight exercising, and after that are automatically screened to retain large-sized individuals that are lifted by an electric crane to the shore. In this form of industrial farming and management, the survival rate during transportation can be improved. The flesh is firm. Wastewater can still be used to irrigate farmland. There is a high water utilization rate, the production cycle is short, and the production volume can increase by two to ten times than that for conventional farming.

4.4.5.6 Recirculating Farming Systems in Wetlands

These systems consist of ponds and constructed wetlands for water purification. In tilapia ponds, water spinach (*Ipomoea aquatica*) are also cultivated in five percent of total pond area on artificial floating beds. Production tests showed that water spinach could yield up to 7315–13 923 kg/ha, which directly removed the nitrogen and phosphorus from water up to 27.45–52.35 kg/ha and 28.35–53.85 kg/ha, respectively (Yang 2015). Promoting the use of biofilms facilitates sufficient exchange between surface and bottom water, and the energy consumption is low. *Elodea nuttallii* and *Typha angustifolia* can be selected as purification plants for constructed wetlands, and the planting areas accounting for 40 percent and 30 percent of total wetland area, respectively. Small amounts of submerged plants and floating-leaved plants such as *Vallisneria natans*, *Hydrilla verticillata* and *Trapa natans* covering 30 percent of total wetland area can be beneficial. Also, certain amount of snails can be stocked. Wastewater from farming areas is discharged into constructed wetlands to be purified, and then the purified water flows into the farming areas through ditches.

4.4.5.7 Tilapia Farming in Brackish Waters

Tilapia are euryhaline. At present, the main species or strains of tilapia used for brackish farming are the Nile tilapia, AuNi tilapia, red tilapia, JiLi tilapia (New GIFT strain ♀ × *Sarotherodon melanotheron* ♂), MoHe tilapia (*O. mossambicus* ♀ × *O. hornurum* ♂) and so on. Salinity-tolerance varies for different tilapias, among which Nile tilapia can be farmed at salinities below 15‰. China has a vast area of shallow seas, beaches, seaside fish ponds, in which tilapias can be farmed. Red tilapia, JiLi tilapia and MoHe tilapia can be farmed at salinities of 20‰ or higher. Tilapia farmed in brackish waters are free of earthen smell and are high-quality, and welcomed by farmers and consumers. At present, tilapia farming in brackish waters is carried out in Hainan, Guangdong, Guangxi, Jiangsu, Shandong, Hebei, Liaoning, and other coastal areas (Yang 2015). Tilapia fingerlings for brackish water farming are produced in freshwater, and transferred to water of 18‰ or less.

Tilapias can be monocultured in brackish water ponds at a stocking density of 45 000–75 000 fingerlings/ha of 3–5 cm. They also can be polycultured with other fish, shrimps, crabs, shellfish, and so on. Tilapia as the dominant species or minor species can be polycultured with *Penaeus vannamei*. When farmed as the dominant species, first *P. vannamei* (1–2 cm in body length) are stocked at a density of 300 000– 600 000 ind./ha, then after 15–20 days, or when the shrimp grow to 5–6 cm in body length, tilapia fingerlings (4–5 cm in body length) at a density of 450–750 ind./ha are introduced. During the farming period, only the tilapia are fed (3–6 percent of body weight/day) with compound feeds. Feeding is adjusted according to the weather, the water quality and fish behavior. Dissolved oxygen content in pond should be maintained above 7 mg/l. After 3–4 months, the average size *P. vannamei* can reach 25 g, and after 5–6 months, the average size of tilapias reach 0.6 kg. Tilapia can also be polycultured with *Mugil cephalus* and *Liza* spp.

4.4.6 Advances in Farming Technology Over the Last Decade or More

Large-scale farming of tilapia in China started in 1978, when Nile tilapia was introduced. After 30 years of effort, China's tilapia farming industry has developed rapidly and the production volume, value and exports value all rank topmost in the world. Tilapia farming has created a large number of employment opportunities in rural areas, and promoted the development of China's rural economy, and increased farmer incomes. Reviewing the course of the development of China's tilapia farming industry, it is not difficult to find that science and technology have played a crucial role in upgrading and revolutionizing the tilapia farming industry.

4.4.6.1 Progress of Breeding Technologies

Since tilapia were introduced to China, as at the end of 2014 seven new strains including Aulia tilapia (*O. aureus*),Nile tilapia (*O. niloticus*), FuShou tilapia (*O. mossambicus* ♀× *O. niloticus* ♂), GIFT strain of Nile tilapia, "New GIFT" tilapia, "XiaAo No. 1" tilapia, and "ZhongWei No. 1" GIFT tilapia (quantitative genetics, BLUP analysis and family selection), have been developed by applying the techniques and methods of traditional selective breeding, family selective breeding and population selective breeding for several generations. Parental purity is the key for breeding hybrid tilapia with high proportion of male progeny (Xia 2004). The recent newly bred varieties include AuNi hybrid tilapia (*O. niloticus* ♀ × *O. aureus* ♂), "JiLi" tilapia (New GIFT strain ♀ × *Sarotherodon melanotheron* ♂, suitable for marine culture) and JiAo tilapia (New GIFT strain ♀ × *O. aureus* ♂). The hybrids are characterized by fast growth, strong resistance to disease, and low-temperature-tolerance. Tilapia that produce a high proportion of male progeny have alleviated problems such as slow growth, small size, easy propagation, and seed germplasm degradation caused by interspecific and intergeneric crossbreeding. Also farming hybrid tilapias and male tilapias will reduce the potential extent of the damage caused by exotic species on original ecological systems in China, and also improve the farming yield and profits. At present, national tilapia fine breed farms and extension systems have been established in many provinces (Figure 4.4.6), for subsequent selective breeding programs, conservation and provision of quality seed for hatcheries.

4.4.6.2 Tilapia Seed Production: Transition from Traditional to Industrialized

Traditional tilapia seed production was similar to that of the Chinese major carps: stock male and female broodfish in a pond for natural propagation, collect the hatchlings using a scoop net, and then rear the fry for a certain period. By this method it is often difficult to collect all the fry in a pond, and cannibalism can impact on seed quality and production efficiency. In addition, this traditional breeding method is easily impacted by the weather, with features of a short production season, low productivity, uneven seed size, and being unable to meet the demand of a growing farming sector. With the continuous expansion of tilapia farming, more and

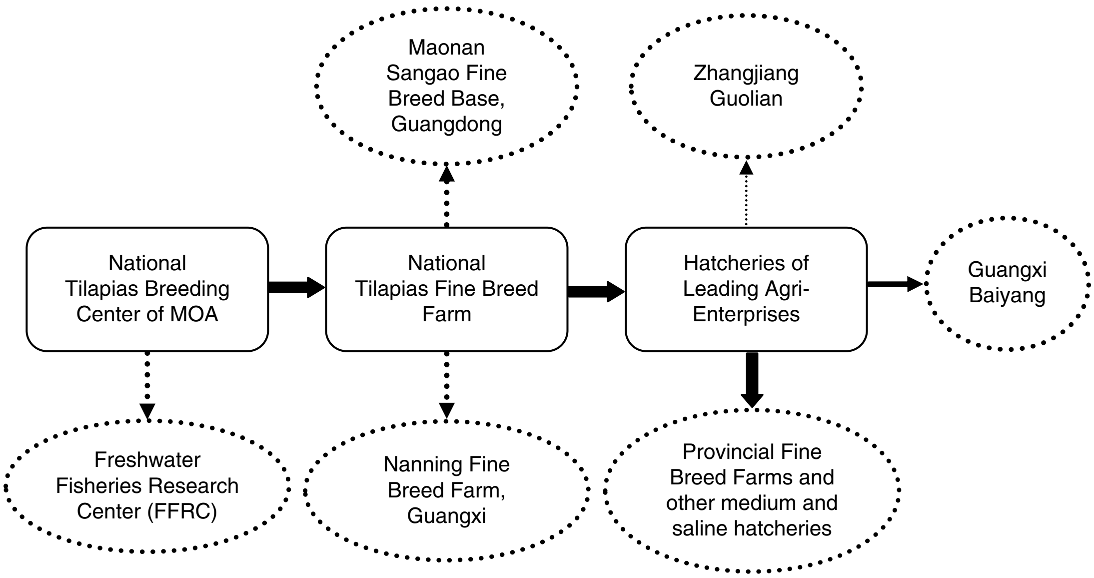

Figure 4.4.6 Framework of tilapia breeding systems.

more hatcheries attempted to apply industrialized breeding technology, and after several years of exploration, the current technology matured.

Industrialized breeding of Tilapia generally comprises filtering and heating devices, incubation and collection devices, broodstock mating in cages, artificial egg collection, and flow-through incubation facilities, conducted under controlled temperature, and other environmental conditions. Tilapia fingerlings are characterized by uniform size, a high survival rate and a high proportion of males. Full-year supply of quality tilapia fingerlings can be achieved according to production needs, and are capable of responding to extreme weather events. Currently, large-scale seed production is widely applied in large hatcheries in Guangdong, Hainan, and Guangxi provinces. The number of tilapia fingerlings produced reached to 102.874 billion in 2013 (China Fishery Statistical Yearbook 2014), which is sufficient to meet the needs of the tilapia industry.

4.4.6.3 R & D Progress on Nutrition and Feeds

In the 1980s, there were no special tilapia feeds in mainland China, and tilapia were fed commonly available fish feeds. From the late 1990s, along with further research on tilapia nutritional requirements, special feeds production began. Tilapia feed production enterprises are mainly distributed in Guangdong, Hainan, Guangxi, and Fujian provinces. There are two kinds of tilapia feeds: floating extruded feeds, and sinking pellet feeds. Currently, the FCR (feed-conversion ratio) of floating extruded feeds and sinking pellet feeds are around 1.2 and 1.5, respectively. In recent years, the national annual output of tilapia feeds stabilized at around 1 500 000 tonnes, priced at 4500 RMB/t and 3800 RMB/t for extruded feeds and sinking feeds, respectively.

The nutritional requirements of tilapia have been a focus of the studies on tilapia nutrition and feeds. The carbohydrate requirement of GIFT and AuNi tilapia is reported to be 38–45 percent, while phosphorus requirement of GIFT and AuNi tilapia ranges between 0.73–0.96 percent and 0.61–0.90 percent, respectively; iodine and cobalt requirement of juvenile of Nile tilapia are 0.5–2.0 mg/kg and 0.29 mg/kg, respectively. Efficient and environmentally friendly aquaculture feed technologies have been developed which cater to the main farming areas, and the typical farming models (Yang 2010).

Compound tilapia feeds for different growth stages can be produced by feed enterprises, based on locally available, low-price, and quality ingredients. The common tilapia feed formulations for three growth stages are listed for reference (Tables 4.4.2–4.4.4).

4.4.6.4 Disease Prevention and Control

In recent years, with the deterioration of the farming environment, the frequency of disease occurrence has increased, and consequently product quality and safety are threatened. In the initial stages of development tilapia farming was mainly extensive, and gradually shifted to intensive pond culture, coexisting with other

Table 4.4.2 Common feed formulation for tilapia of body weight of 0–50 g.

Ingredients	% by mass
Fish meal	3
Soybean meal	27.5
Rapeseed meal	31
Wheat	5
Barley	16
Rice bran	8
Mineral premix	1
Vitamin premix	0.1
Monocalcium phosphate	1.5
Choline chloride	0.5
Soybean oil	2.5
Bentonite	2
Zeolite powder	1.9

Table 4.4.3 Feed formulation for tilapia of body weight of 50–250 g.

Ingredients	% by mass
Fish meal	1
Soybean meal	20
Peanut meal	5
Wheat	31
Barley	9.5
Rice bran	16
Mineral premix	8
Vitamin premix	1
Monocalcium phosphate	0.1
Choline chloride	1.25
Soybean oil	0.5
Bentonite	2.75
Zeolite powder	2

Table 4.4.4 Feed formulation for tilapia of body weight of above 250 g.

Ingredients	% by mass
Fish meal	1
Soybean meal	20
Peanut meal	5
Wheat	31
Barley	9.5
Rice bran	16
Mineral premix	8
Vitamin premix	1
Monocalcium phosphate	0.1
Choline chloride	1.25
Soybean oil	0.5
Bentonite	2.75
Zeolite powder	2

forms, such as cage farming, flow-through farming, recirculating aquaculture, and multi-species polyculture have come to predominate. Good Aquaculture Practices (GAP) are also strictly followed. Consequently, there are few disease problems, and drug use is also gradually declining.

Currently, on aspects of tilapia disease prevention and control, the strategy has gradually shifted from relying solely on drug usage to focusing on prevention and control with a combination of drugs, immunization and treatment, and use of disease-resistant strains.

4.4.6.5 Progress in Processing Technology

In 2014, 46 percent (6 700 000 tonnes) of tilapia were marketed for direct human consumption live, fresh or chilled, which in some markets (such as Asia) are often the most preferred and highly priced (Fan 2011). The rest of the production for edible purposes was in different processed forms, with about 12 percent (1 700 000 tonnes) in dried, salted, smoked or other cured forms, 13 percent (1 900 000 tonnes), and 30 percent (about 4 400 000 tonnes) in frozen form (FAO 2016). A large proportion of farmed tilapia (global production about 3 950 000 in 2011) is marketed in filleted form, and the fillet yield in this species is about 30–37 percent (FAO 2014). In China, tilapia are the main species of freshwater aquatic products processed, and the volume accounts for about 50 percent of the total. The tilapia processing industry in China began in the late 1990s, and developed rapidly. Tilapia processing capacity and volume increased from approximately 40 000 tonnes in 2002 to 600 000 tonnes in 2012, an increase of 15 times with an average annual growth rate of 136 percent (Chen and Li 2014). It is estimated that there are more than 200 tilapia processing enterprises, mainly concentrated in the main tilapia farming areas, among which there are more than 170 export-oriented tilapia processing enterprises. The annual processing capacity exceeds 2 000 tonnes, but the actual annual processing volume is only about 600 000 tonnes (Chen and Li 2014).

In the early stages, there were only two processed product forms: frozen tilapia and frozen tilapia fillets. There is a low-tech input for processing frozen whole fish, and market price and benefit are both low. In recent times, the forms of processed tilapia products have been diversified according to consumer demands in the international and domestic markets. Currently, processed tilapia products can be divided into four major categories: (1) frozen whole tilapia; (2) frozen tilapia fillets; (3) chilled fillets; (4) tilapia products such as breaded tilapia fillets, smoked tilapia fillets, pickled, and canned tilapia products.

With the rapid development of China's tilapia industry, researchers have been making concerted efforts to improve the processing techniques, develop new products and improve quality control technology based on pre-processing, processing, and post-processing stages. In recent years, the common technologies have been increasingly used in tilapia processing industry, include composite chromogenic technology, cold sterilization technology, modified atmosphere packaging, and ice-temperature storage technology, rapid freezing technology, anti-freezing and moisture-retention technology, liquid smoking technology, canned food processing technology, enzymatic hydrolysis processing technology, low-carbon and energy-saving processing technology, high-value-added utilization technology of processing by-products, and by-product recycling and utilization technology. A series of a whole set of tilapia processing techniques and quality control systems with independent intellectual property rights have gradually been developed. At present, Chinese tilapia processing enterprises are actively applying the "HACCP Management System" and other quality control standards, and 21 related tilapia-product processing techniques have been developed, such as frozen tilapia fillet processing technology, frozen breaded tilapia fillets processing technology, modified atmosphere packaging, and ice-temperature storage technology for tilapia fillets.

The conversion rate in tilapia fillet processing ranges from 30 percent to 37 percent, resulting in considerable quantity of processing by-products. Of these by-products, the gills, guts, viscera, scales, skin, fish bones, head, lower jaw flesh, brain and eyes account for 2.50 percent, 2.53 percent, 10.94 percent, 2.96 percent, 3.83 percent, 9.18 percent, 11.61 percent, 8.65 percent, 0.04 percent, and 0.83 percent, by wet weight, respectively. In addition, there are also fins and blood. In China, these by-products are mainly processed for livestock and poultry feeds, or directly used as fertilizer, which to some extent reduces the impact of tilapia processing by-products on the environment. As these by-products contain various functional active substances, in recent years research on high-value-added utilization of tilapia processing by-products has been initiated. Tilapia processing by-products can be processed into fish oil and fish meal, and besides that into value-added gelatin, collagen, collagen peptides, functionally active peptides, seasonings and biological enzymes. Active calcium products are also developed by processing the skin, bones, viscera, and other by-products (Figure 4.4.7).

4.4.7 Marketing and Markets

At present, China is the world's largest consumer of fresh tilapia (Yuan 2013). Total annual consumption of fresh tilapia is above 600 000 tonnes accounting for nearly 50 percent of China's annual production (Chen 2011; Fan 2011). As the demand for tilapia in the international market continues to grow, it is likely that the export volume will increase, and the proportion available for domestic consumption will decline (Dai 2014b). In order to maintain a balance between the two markets, counter-season stocking is encouraged, whilst avoiding a large amount of fish flowing into the market in the harvesting season. Selling of tilapia products from the South to the North of China is also encouraged, to balance regional market supply, avoid concentration of sales in the main farming areas, and expand marketing areas. Factors affecting consumption of tilapia include consumer age, education level, and the degree of preference for aquatic products, household income, marketing methods, and external environmental factors (Liu *et al.* 2014). Along with education of the nutritional value of tilapia, and the promotion of cooking styles, awareness of tilapia in China has gradually been strengthened. There are also recreational fishing activities in some areas to attract anglers to promote consumption.

4.4.8 Major Factors that Influenced China's Success in Tilapia Farming

4.4.8.1 Availability of Suitable Vast Farming Areas

Tilapia is a widely accepted freshwater food source. It is capable of living in brackish water, and capable of surviving in shallow waters of lakes, rivers and ponds. Tilapia have a strong ability to survive in water with low

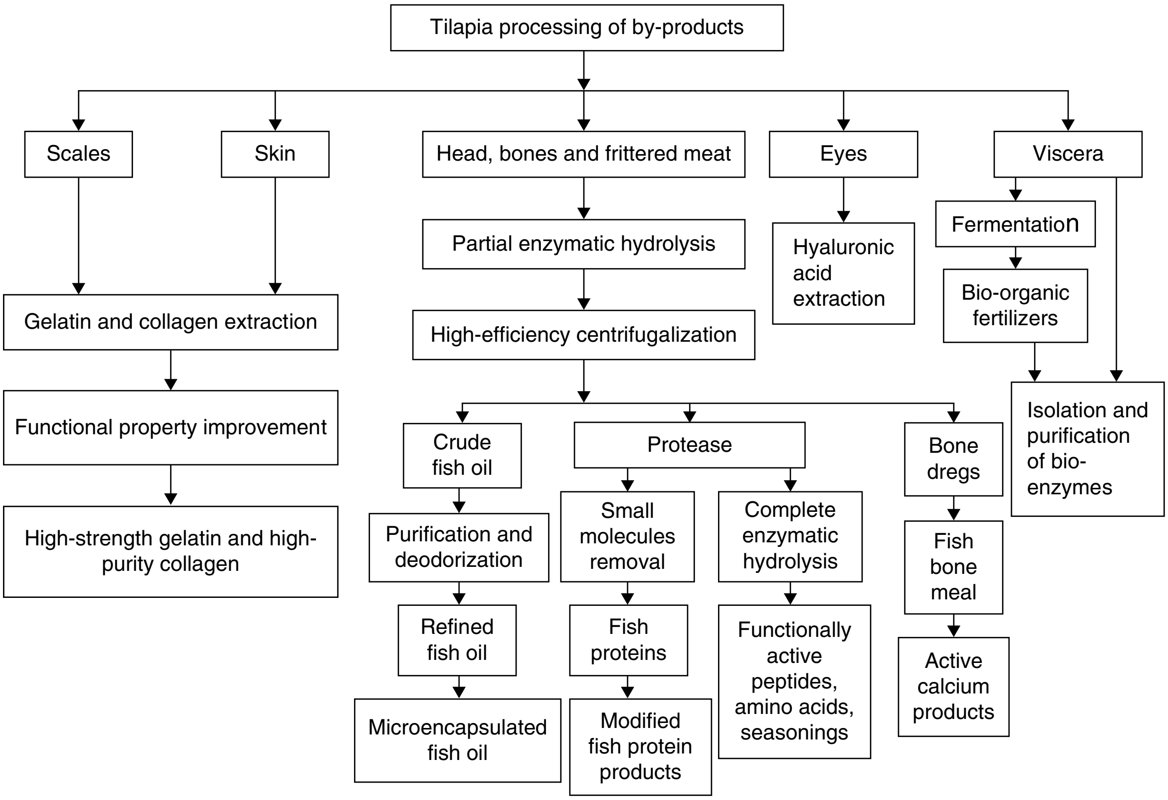

Figure 4.4.7 Flowchart of comprehensive development and utilization of tilapia processing by-products.

dissolved oxygen (DO) content. Most tilapia are omnivorous, feeding on water plants and debris. So for tilapia, there are vast suitable farming areas, and the yields from tilapia farming have improved significantly.

4.4.8.2 High Farming Yield

Tilapia itself has a lot of advantages, such as short growth period, high yield, and relatively easy adaptability to farming environments. It has low requirements for farming technology. Farmers have high expectations from tilapia farming practices. Attitudes influence behavior, so the enthusiasm of farmers is bound to increase the amount farmed, leading to the rapid development of tilapia farming.

4.4.8.3 Attractive Price and Low Production Costs

There are broad existing markets and potential markets to be developed for tilapia, resulting in attractive prices. And because tilapia are easy to farm, the production cost is low. Farmers are greatly enthused because of the low production costs and attractive market price in tilapia culture.

4.4.8.4 Extensive Domestic and International Market Demands

The international market for tilapia continues to expand. With the sharp drop in availability of cod and other demersal fish, and the price of whitefish products rising globally, some developed areas and countries like EU, the United States, Japan and South Korea have opted for tilapia as an alternative. Worldwide consumption of tilapia has increased year by year, and the international consumer market is taking shape. The domestic consumption market also has a great potential. With a price of 16–20 RMB/kg, it is a good deal for one meal for a family of three. Therefore, the price of tilapia is consistent with the consumer market.

4.4.8.5 Other Factors

From the perspective of government support, the central government and local governments in the main farming areas have introduced a number of tilapia farming subsidies, which have encouraged tilapia farming and promoted an increase in tilapia production. In addition, the scientific research output on the whole tilapia industry chain has also increased year by year, and reasonable development of key technologies for tilapia farming provides favorable guidance, facilitating tilapia production.

From the perspective of environmental benefits, the selection of broodstock, seed production, and rearing are in strict accordance with the requirements of healthy ecological farming. In addition to focusing on improved breeding technology, growth traits are also emphasized, as well as disease resistance, which can reduce disease outbreaks and decrease the impact of drugs on the farming environment. Energy saving and emissions reductions in the farming areas can also be promoted. The total production value and profits increase under fixed farming areas, indirectly promoting effective utilization of land resources. By improving feed conversion efficiency, feed resources can be saved. Through comprehensive utilization of tilapia processing wastes, the economic efficiency of enterprises are improved, and the environmental pollution caused by direct discharges of processing wastes reduced.

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4.5

Development of Largemouth Bass (*Micropterus salmoides*) Culture

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4.5.1 Introduction

Largemouth bass (*Micropterus salmoides*) is native to North America. It was introduced into Taiwan (China) in the mid 1970s, and following successful artificial propagation in 1983 was introduced into Guangdong in mainland China. This species is now distributed throughout the country and has become a major freshwater product in Chinese aquaculture (Bai *et al.* 2008). *M. salmoides* is well accepted by farmers due to its many advantages that include its suitability to a wide variety of culture environments, fast growth, ease of handling, and short culture cycle. It is also popular with consumers because of its favorable taste, the presence of few bones, and its appearance (Zhang and He 1994). After 30 years of development, there is a large-scale *M. salmoides* aquaculture industry in China with clear division according to the market requirements (Figure 4.5.1). Specifically, there are villages dedicated to production of seed stock, grow-out and large companies responsible for marketing. During the development of the industry, each link of the chain was gradually optimized. The market requirements, prices, and production have reached a delicate balance for commercial *M. salmoides* production. *M. salmoides* is well-suited for intensive industrial aquaculture, and is also suitable for cold storage and processing. Therefore, it is an ideal fish species for modern freshwater aquaculture in China.

4.5.2 Major Cultivation Regions and Artificial Propagation Models

M. salmoides is a eurythermic fish, capable of tolerating a temperature range of 1–36°C, and begins to feed when temperature reaches 10°C. Therefore, this species can be cultivated in most of the provinces in China. The successful overwintering of this species has been reported in cold northern areas, such as Dandong, Liaoning (Guo 2003), Kashi, Xinjiang (Yang and Pan 2007), and Jiamusi, Heilongjiang (Fang *et al.* 2000). However, the optimum growth temperature for *M. salmoides* is 20–30°C. The major cultivation regions for *M. salmoides* in China include Foshan in Guangdong Province, Suzhou and Nanjing in Jiangsu Province, and Huzhou in Zhejiang Province. In addition, large-scale *M. salmoides* aquaculture can also be found in the Jiangxi, Sichuan, and Fujian provinces. In 2013, the highest annual production of 230 000 tonnes of *M. salmoides* in China was in Guangdong province. The second largest producer was Jiangsu province with an annual production of 35 000 tonnes, followed by Jiangxi, Zhejiang, and Sichuan and Fujian provinces, which produced approximately 20 000, 18 000, and 10 000 tonnes, respectively (China Fishery Statistical Yearbook 2014). The yields of *M. salmoides* have increased rapidly over the last decade (2003–2013) (Figure 4.5.2). The total annual

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Figure 4.5.1 Largemouth bass, *Micropterus salmoides*.

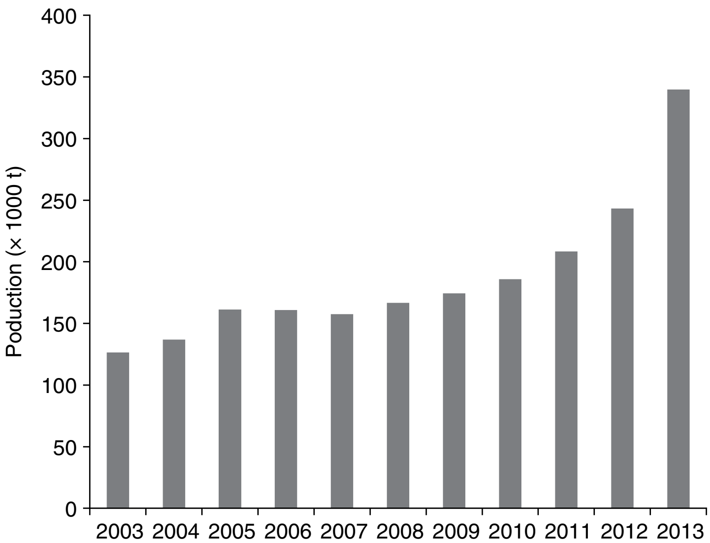

Figure 4.5.2 Annual production of *Micropterus salmoides* from 2003 to 2013 in China. *Source:* China Fishery Statistical Yearbook (2014).

output in 2013 was 340 000 tonnes, which represents an increase of 169.8 percent when compared to the annual output in 2003.

The leading aquaculture model for *M. salmoides* in China is pond culture. Culture ponds are typically between 0.3 ha and 1 ha in size and between 1.5–3.5 m deep. In the Pearl River Delta region, 45 tonnes of *M. salmoides* can usually be obtained from a 1 ha pond in a one-year culture cycle. In Jiangsu and Zhejiang, the yield from intensive culture ponds is 15–30 tonnes per ha. The second model for *M. salmoides* aquaculture is cage culture. Generally, the cages are constructed using woven polyethylene and their volumes range from 40–75 m^3 (Shi 2007). In some regions, the culture ponds contain a mixture of *M. salmoides*, *Tilapia* spp. *Pelteobagrus fulvidraco*, and other species (Li and Li 2000; Bai *et al.* 2009). Normally, a 1 ha pond can be stocked with 3000 to 4500 *M. salmoides* fingerlings of 5–10 cm. Fish of this size will be large enough for market at the end of year, without the provision of any additional feed.

4.5.3 *Micropterus salmoides* Culture Techniques

4.5.3.1 Large-Scale Production of Larvae

In *M. salmoides* seed production areas of South China, it usually takes about these fish one year to reach sexual maturity. Therefore, on many farms, the largest, strongest, and healthiest fish are selected at the

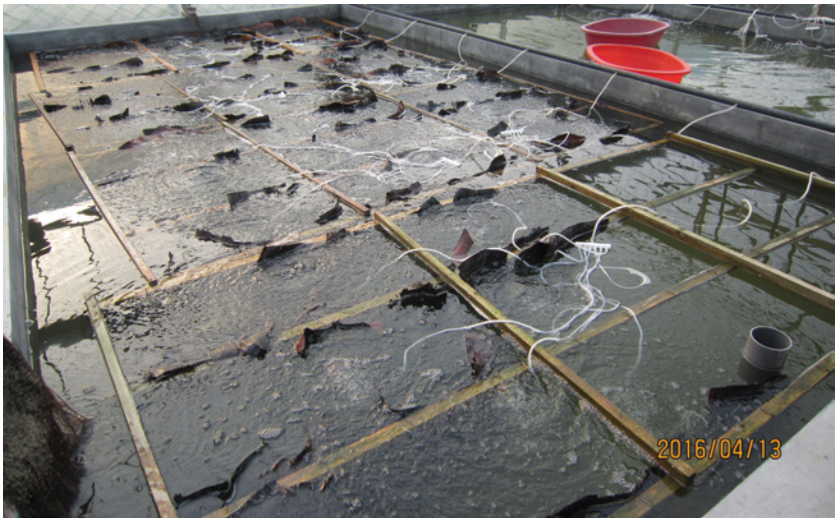

Figure 4.5.3 Largemouth bass spawning nest and incubation tank.

year-end harvest, and reserved in ponds as parental fish for breeding. For breeding in ponds, 250 to 300 pairs of parental fish are placed into every 667 m^2 pond. Nests are either laid directly on the substrate in shallow water or laid on bamboo at an approximate depth of 0.4 m. Normally, *M. salmoides* spawning is synchronized naturally (Figure 4.5.3). However, artificial induction can be used to ensure that spawning is synchronous among parental fish maintained in concrete ponds. Moreover, to avoid predation by adult fish, nests made from palm leaves are placed around the pond and the fertilized eggs (adhesive) are collected every day at regular intervals. Eggs collected are then introduced into concrete ponds for hatching (Figure 4.5.3). Good water quality, appropriate water depth (0.4–0.6 m), sufficient oxygen (naturally slow-flowing water or pump), and avoidance of direct sunlight greatly improve *M. salmoides* hatching rates. Egg hatching time is dependent upon water temperature, taking approximately 52 hr, 45 hr, or 31.5 hr at temperatures of 17–19°C, 18–21°C, and 22–22.5°C, respectively. The newly hatched larvae are translucent, about 0.7 cm length, and display schooling behavior. The larvae begin to ingest food on the third day post-hatch when the yolk-sac has been completely absorbed.

Zooplankton is a suitable first feed for *M. salmoides*. In general, feeding on zooplankton will last approximately 15 days. If zooplankton abundance is not sufficient, larvae will wander away from the nest. In this case, additional zooplankton from other ponds is needed. Once larval body length exceeds 1.5 cm, larvae can be weaned onto a diet of fish surimi concentrates. During the first two to three days of weaning, the larvae are fed zooplankton from a fixed location, to condition the larvae to feed in the area. Following this, larvae are fed a mixture of fish surimi and zooplankton, and the amount of zooplankton is gradually reduced over a ten-day period until they are fed only fish surimi. Attracting and conditioning the larvae to the feeding area by prodding the water for at least 6–8 hr per day is also necessary. As *M. salmoides* are carnivorous and will be cannibalistic when large size differences exist, especially during intensive breeding. This situation most frequently occurs with larvae below 6 cm. Therefore, larvae should be graded into different size classes, in a timely manner after a period of growth (usually after cultivation for 15–20 days), and cultivated separately to improve survival.

4.5.3.2 Intensive Pond Culture

In most regions of China, the leading aquaculture model for *M. salmoides* is pond culture. The optimal pond area is between 0.4 ha and 0.8 ha with a depth between 1.5 m and 3.2 m. Ponds should have loam on the bottom, with little sludge and a sufficient supply of non-polluted fresh water. Ponds should be equipped with controls to regulate inflow and outflow. During highly intensive breeding, aerators (15 kilowatts per ha), and water pumps are needed to ensure adequate water levels and dissolved oxygen (DO). In addition, nets should be placed at the inflow and outflow of the pond to avoid the introduction of garbage and to prevent the fish from escaping. Ideally, the pond should have a slow water flow.

Prior to stocking, ponds should be drained, the soil exposed to sunlight for 20–30 days, and the bottom of the pond sterilized with calcium oxide (CaO) in 6–8 cm of water. Following this, the pond can be filled to 60–80 cm of water, stocked with some fish, and observed closely for five to seven days to ensure the absence of toxic effects from residual disinfectants. Once the water is demonstrated to be non-toxic, *M. salmoides* fingerlings of 10 cm body length can be stocked. The stocking density used is different in different areas of China. In the Guangdong province, 6000–10 000 larvae can be stocked in a 0.066 ha pond, while in Jiangsu, Zhejiang, and Sichuan provinces only 1200–3000 larvae are cultivated in ponds of the same size. The stocking of large silver carp and bighead carp help to improve water quality by clearing residual feed and controlling the growth of plankton.

4.5.3.3 Intensive Cage Culture

Easily managed and pollution-free reservoirs, rivers, or lakes are appropriate for *M. salmoides* cage culture. The water areas for the cages should be open, leeward, exposed to the sun, and have gravel on the bottom (Figure 4.5.4). The minimum water depth should be not less than 4 m and the water transparency should be at least 40 cm. There should be a slow flow of water through cages. Generally, cages are constructed from woven polyethylene threads and their volume is always 40–75 m^3. The basic frame for cages is free-floating and constructed of moso bamboo or steel tubes. The cages are oriented based upon the direction of the water flow and are arranged in a triangular or quincunx pattern. Walking aisles are placed between rows of cages. Drop anchors and ropes are used to fix the cages to the river bank, and the cages can be conveniently moved when needed. The cages are placed into the water seven to ten days prior to stocking, to allow for the growth

Figure 4.5.4 Largemouth bass cage culture system in a reservoir.

of filamentous algae on the cages to avoid injury to the fish. The appropriate stocking density for fingerling of 4–5 cm length is 500 m^{-3}, while larger fish that exceed 12 cm should be stocked at 100–150 m^{-3}.

The feeding and management of *M. salmoides* in intensive cage culture is similar to that for cage culture of other fish species. Particular attention should be paid to the following four points. First, feeding should be frequent, and food should be offered several times per day during the first few days. As the fish grow, feeding frequency can be reduced to once or twice per day, feed quantity adjusted every day according to the particular conditions. However, the quantity of feed offered in cage culture should be slightly more than that used in pond culture. Second, the cages should be washed frequently. Algae can grow quickly on the cages, and may result in an oxygen deficiency by blocking the cage mesh and reducing water exchange. Therefore, the cage mesh should be washed every 10 days to ensure the smooth flow of water. Third, stocking densities should be reduced when necessary. After a period of growth, the individual sizes of the fish will be different and this makes it much more difficult for the smaller fish to compete for food. Large size differences between *M. salmoides* can result in cannibalism when food availability is low. Therefore, to avoid this situation, the stocking density should be reduced, and fish should be sorted into separate cages based on size. The fourth important point is to regularly check the condition of the cages as damage will result in the loss of fish. In addition, the cages should be transferred to areas sheltered from the wind, and the anchors and wires should be strengthened before the approach of a typhoon.

4.5.4 Consumer Demand for *Micropterus salmoides*

M. salmoides is also referred to as "California Bass". The appearance of this species is similar to other traditional fish in China and it is appealing to consumers in both restaurants and households because of its low price. Competitive prices make *M. salmoides* an alternative to other higher-priced fish such as *Siniperca chuatsi* and *Scophthalmus maximus*. The consumption patterns of *M. salmoides* differ by area. In Northern China, such as Beijing and Zhengzhou, *M. salmoides* are mainly consumed in restaurants and have a body weight that exceeds 0.5 kg. However, in other areas such as Shanghai, Zhejiang and Jiangsu, Xi'an, and others, the majority of *M. salmoides* between 400 and 500 g are consumed in households. Methods of cooking also vary by region. Cantonese prefer steamed *M. salmoides,* while sweet and sour fish or braised fish are more popular in Beijing and in the Jiangsu and Zhejiang provinces.

4.5.5 Key Factors Affecting the Development of the Industry

4.5.5.1 Improved Strain Development and Distribution

In China, most of the domestic *M. salmoides* have originated from wild stocks. Previous data suggested that the *M. salmoides* currently being cultivated originated from largemouth bass northern subspecies (Fan *et al.* 2009). Genetic diversity among the currently farmed *M. salmoides* in China is only about 70 percent of that observed among this species in the wild in the US (Bai *et al.* 2008). The major reason for this reduced genetic diversity may be that only a small founder population was introduced into China. In addition, little attention was paid to the operating instructions for the preservation of parental genetic diversity over the last 30 years. Some *M. salmoides* breeding farms use unsold and slow-growing fish as parents for future breeding for convenience of production. However, this has resulted in inbreeding, which has led to reduced growth rates, early maturation, and increased risk of disease.

More recently, aquaculture of *M. salmoides* has become concerned with ensuring the health, stability, and sustainable development of this industry in China. Since 2005, the Pearl River Fisheries Research Institute of the Chinese Academy of Fishery Sciences, and the agriculture and forestry service center in Jiujiang Town, Nanhai District of Foshan, Guangdong, have cooperated to improve the growth performance of *M. salmoides*. This research was funded by the National Science-Technology Support Plan Projects, and the improved

M. salmoides was named “Youlu No. 1”. In 2010, the fifth generation of “Youlu No. 1” was produced and it demonstrated an increased growth rate (about 20 percent), and a reduced aberration rate (from 5 percent to 1 percent) (Li *et al,* 2011; Bai and Li 2013a). This new variety was approved by the National Certification Committee for Aquatic Varieties in 2010. In recent years, the new variety of “Youlu No. 1” has become widely distributed and has yielded good results in areas such as Guangdong, Jiangsu, Zhejian, Tianjing, Hunan, Sichuan, and others. In 2013, the cultivation of “Youlu No. 1” exceeded 50 percent of the total *M. salmoides* volume cultured in China.

4.5.5.2 Improved Cultivation Techniques

The stocking density for *M. salmoides* can be up to 150 000 fish/ha by increasing the depth of the pond. Oxygenation of the water is the key for the cultivation of this species at high densities. Ponds should be equipped with aerators (15 000 W/ha) that should operate every night (Li *et al.* 2015). On sunny days, at least one aerator should be operated in a pond. The long-term operation of aerators not only increases the dissolved oxygen (DO), but also accelerates water circulation which improves the efficiency of the removal of fish waste. Water quality is important for successful cultivation of *M. salmoides*, especially in hot weather. Probiotics can be used regularly to improve water quality by helping to decompose organic residues, and lowering the concentrations of ammonia nitrogen and nitrites in the water.

4.5.5.3 Improved Long-Distance Live Transport Techniques

Traditionally, live *M. salmoides* were transported in oxygen-filled buckets or plastic bags by road or air. Currently, live fish can be transported long distances in refrigerated containers. Live fish transport involves three steps that include temporary fish holding, packaging, and transportation. Recently sold fish are placed in a special pool where the water temperature is decreased gradually to 10°C over a period of about 6 hr to 8 hr to aid defecation and reduce ammonia nitrogen production during transportation. Fish are then placed into plastic-foam boxes up to 40–50 kg/box. The ratio of fish to water weight is approximately 1:1. During transportation, the temperature in the container is maintained at 5–10°C. Every container is connected to an oxygen cylinder to ensure the supply of a sufficient level of dissolved oxygen (DO). Containers should be monitored for fish mortalities and turbid water during transport. Water should be changed as needed and typically at least once during transit. By employing these guidelines, more than 95 percent of the fish will be alive after 80 hr of transportation. Between five and ten tonnes of fish can be transported by each transport truck. The “Green channels” on Chinese expressways for the transport of fresh agricultural products are available for trucks transporting *M. salmoides*. Preferential road tolls and traffic priority of the “green channels” during long journeys greatly promote the long-distance transportation of fresh agricultural products. Therefore, *M. salmoides* is available in most areas of China that can be accessed by expressways. For instance, most of the *M. salmoides* (about 92–95 percent) from the Pearl River Delta Region is transported to the aquatic product markets in Beijing, Xi’an, Zhengzhou, and Shanghai. Only five to eight percent of the *M. salmoides* cultured in the Pearl River Delta Region supply local markets. In recent years, production of *M. salmoides* in the Jiangsu and Zhejiang provinces has increased. Most of the *M. salmoides* produced in these areas are consumed in the local aquatic product markets in Nanjing, Hangzhou, and Shanghai, with few of them being transported to areas such as Beijing, Xi’an, and others.

4.5.5.4 Disease Prevention and Control

For many years, farmers continually increased the stocking density of *M. salmoides* cultures in an attempt to obtain higher yields and greater economic benefits. The increased density combined with decreases in genetic diversity resulted in an increased frequency of disease outbreaks (Deng *et al.* 2011), which consequently led to the widespread abuse of pharmaceuticals to treat these diseases. Consumers began to question aquatic product safety, which adversely affected the sustainable development of the industry.

At present, there are several diseases that are common among *M. salmoides* that are caused by parasites, viruses, and bacteria. There are also multi-pathogenic diseases that affect *M. salmoides*. Research on the clinical symptoms of diseases, features of pathogens, and epidemiology have been performed, and efficient methods were developed for disease prevention and control (Deng *et al.* 2011). It has been reported that some of the viral diseases brought great economic losses to farmers (Deng *et al.* 2011; Ma *et al.* 2011 ,2013). Researchers have isolated several viruses that infect *M. salmoides* and cause mortality. These diseases can be rapidly diagnosed by PCR detection and controlled by appropriate methods at an early stage (Ma *et al.* 2010). With regards to management, a suitable stocking density and effective prevention through the use of probiotics are strongly recommended to culturists.

4.5.6 Trends in Industry Development

4.5.6.1 Development of Artificial Feeds

At present, feeds for *M. salmoides* consist mainly of small fresh-frozen miscellaneous fish. The direct feeding of whole fish may introduce bacteria that are pathogenic, increasing the chances of disease outbreaks. Meanwhile, feeding this type of feed is also labor intensive, and results in the deterioration of the environment and sanitary conditions. These feeding practices have seriously restricted the development of industrial *M. salmoides* aquaculture.

Since the 1990s, research institutions and feed production companies have made large investments to explore the development and use of compounded feeds for *M. salmoides* (Bai and Li 2013b). Commercial feeds are acceptable for juvenile *M. salmoides*, but they are unsatisfactory when feeding fish larger than 200 g, especially in hot weather (July and August). Consumption of commercial feed in *M. salmoides* was found to result in fish that were at a higher risk of developing fatty livers. Therefore, artificial feeds for *M. salmoides* require further improvements. The nutritional requirements of *M. salmoides* should be fully investigated, and this data used for the development of new artificial feeds for growing fish that meet the demands of the market. On the other hand, large differences in individual adaptability to artificial feeds have been observed, and these differences could be explored in the development of new strains of *M. salmoides* that are better suited for artificial diets. Combining these approaches for the development of improved feed formulations could allow for the establishment of a new aquaculture model for *M. salmoides* in the future.

4.5.6.2 Development of Industrial Management

The annual production of *M. salmoides* in China was 340 000 tonnes in 2013. Most of the farms are small scale – about 0.67 ha. In these small size farms the stock is often fed with fresh or frozen fish, and preparation of feed require large amounts of labor and is costly. It is estimated that 200 000–400 000 RMB/year is needed to maintain a 0.67 ha pond that would produce 25 tonnes of fish per year. The price of *M. salmoides* fluctuates every year due to a lack of commercial management, short industry supply chains, and low levels of industry development. For example, high prices cause farmers to breed an increased number of *M salmoides* for the following year, which results in an excess supply of market-ready fish, and a decrease in prices. In these situations, farmers will often then make the decision to culture other higher-priced species. For the reasons listed above, the sustainability of the *M. salmoides* industry will depend upon the development of industrial operational guidelines.

A market-oriented *M. salmoides* industry could be established based on the majority of farmers via a "company + farmer" model. This would allow for links within the industry between pre- and post-production to form an integrated industry supply chain, with cooperation between the distribution companies, processors, and large-scale aquaculture companies. Scientific and technological support would be important for the formation of such a linkage. In this industry model, the larvae would be provided by the company in a unified manner. The companies could also build refrigerated storage facilities and deliver freshly frozen fish or artificial feeds to the farmers. In addition, the companies could provide advanced technical training and market consultation. Meanwhile, the farmers would be requested to cultivate the fish according to the standard procedures, and the abuse of pharmaceuticals would not be permitted. At the end of the year, the companies would purchase all of the adult fish from the farmers, and sell them to the consumers. Some companies would sign an agreement to establish the lowest purchasing price and provide the farmers credit on certain selected inputs. This policy would not only help to form an integrated "production-supply-marketing" enterprise that includes fingerlings, cultivation, processing, transport, and sales, but would also strengthen the brand effect, and add value to the products.

4.5.6.3 Branding and the Promotion of Food Culture

Like most of other fish species that are cultured in China, *M. salmoides* has not yet become an iconic brand. The price of *M. salmoides* fluctuates greatly and has poor resistance to declines in price. To ensure the high quality and safety of *M. salmoides*, farming pratices should be standardized. Therefore, pollution-free safe and high-quality products can be marketed via various distribution channels, such as an *M.* sa*lmoides* counter in supermarkets. In this way, the branding of *M. salmoides* will gradually be established, and the profits for the farmers will be improved. A well-established brand will result in increased consumer confidence. In addition to fresh products, processing *M. salmoides* to develop frozen or salted products, or convenience foods such as fried fish, dried fish, or baked fish, would be suitable given the good meat quality, and would provide quality products of increased value. The development of such products with an extended shelf life would also reduce marketing difficulties during the harvest at the end of the year (Bai and Xiong 2010). The flesh of *M. salmoides* has a light color, is fragrant, and is ready to be developed into popular and delicious dishes. These fish are also easily temporarily preserved, and are suitable for long-distance transport, and live-fish marketing. It will also be important to explore new ways for eating and cooking this fish, and new ways to promote a *M. salmoides*-based food culture.

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Section 5

Developments in Feeds in Chinese Aquaculture

5.1

Feed Developments in Freshwater Aquaculture

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5.1.1 Introduction

China was one of the first countries to have freshwater aquaculture production (514 500 tonnes) exceed capture fisheries output (501 400 tonnes), in 1995. Freshwater aquaculture provides large amount of high quality animal protein for Chinese and it accounts for about 32 percent of the animal protein intake and 42 percent animal meat consumed in China (http://www.gdcct.net/politics/headline/201405/t20140513_816769.html). Freshwater aquaculture increased rapidly during the past 30 years from 901 500 tonnes in 1980 to 23 465 300 tonnes in 2010, and 29 358 000 tonnes in 2014 (China Fishery Statistical Yearbook 2011, 2015; also see Chapter 1.2). Freshwater aquaculture currently accounts for 61.8 percent of China's total aquaculture production and Chinese inland production is about 55.82 percent of total world inland aquaculture (FAO 2016).

The rapid development of aquaculture resulted in a correspondingly rapid aquafeed production when it increased from 75 000 tonnes in 1991 to 19 060 000 tonnes in 2014 (Figure 5.1.1), of which about 87.1 percent were used for freshwater aquaculture (Table 5.1.1). Freshwater aquaculture is based on species that feed low in the trophic chain, and has provided high-quality food at a lower cost of fish input (Han *et al.* 2016). Due to the low cost of grain-based feed, freshwater aquaculture has also been considered as one of the most important contributions of China to the world (Duan 2008).

The China aquafeed industry started around 1958, when a single or mixture of raw ingredients was used to feed cultured stocks. During 1976–1979, pellet feed use was recommended by the China Ministry of Agriculture. The China aquafeed industry developed from 1980s, with 1589 factories in 1989 to around 600 in 2001 (Mai *et al.* 2001; Mai 2011), and the proportion of aquaculture products based on formulated feeds showed several periods of increase (Figure 5.1.2).

During recent years, with the development of new technologies, a large proportion of aquafeed production (43.7 percent in 2012) is concentrated in the top ten aquafeed manufacturers (Zhang 2013). More than 80 percent is still pressed pellets, while the proportion of production of extruded pellets is still low (around 2 000 000 tonnes) (Yang 2012; Zhang 2013). There have been several developmental periods in the Chinese aquafeed sector associated with advances in nutritional research and feed technology. The period from 1958 up to the 1970s saw the use of artificial diets (mostly raw feed ingredient and/or mixtures), and the feed conversion ratio (FCR) was very high (4.0–10). In the 1980s, nutrient requirements of some species were investigated, pellet feeds began to be used, and FCRs improved to around 3.0–4.0. The 1990s was the period of rapid development of fish nutrition research and aquafeed development in China, and new feeds used resulted in further reduction of FCRs to around 2.0–3.0. In the 2000s, most research focused on quality safety,

Aquaculture in China: Success Stories and Modern Trends, First Edition.
Edited by Jian-Fang Gui, Qisheng Tang, Zhongjie Li, Jiashou Liu, and Sena S. De Silva.

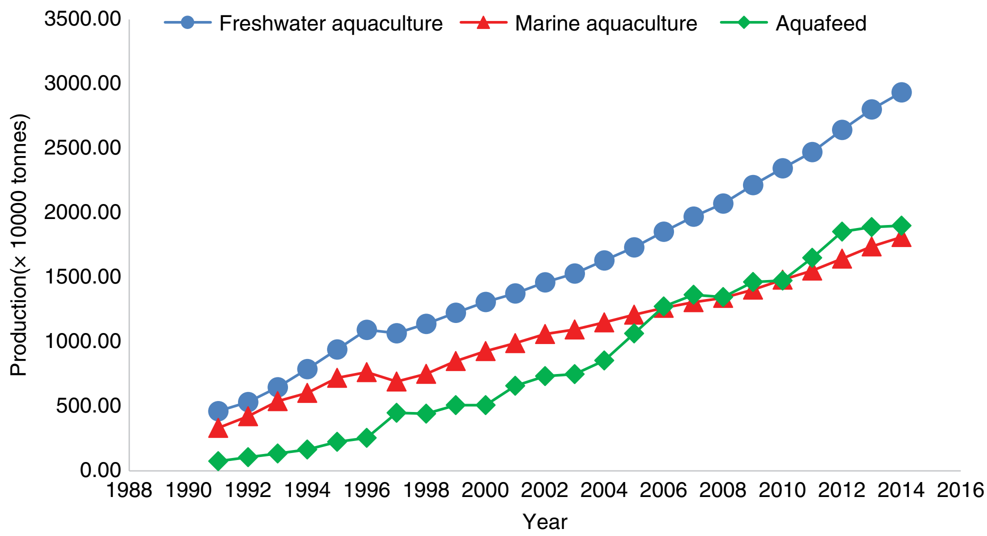

Figure 5.1.1 Relationship between aquaculture production and aquafeed production in China.

and large-scale production, and the FCR has been reduced to 0.9 or even lower (although it still as high as 1.8 in some species) (Mai 2010).

With the development of research on nutrition and feed of aquatic animals, aquafeeds have been developed in past years at a low cost, with low fishmeal content, low waste discharge, and also leading to improved quality of the fish (Han *et al.* 2016).

The development of freshwater aquafeed is based on nutrient requirements for different species, the technology for the utilization of alternative proteins and lipids and carbohydrates, use of additives for different purposes, and also feeding technologies. Some researchers have been focusing on the improvement of fish quality through nutritional manipulation.

5.1.2 Nutrient Requirements and Diet Formulation

Nutrient requirements are the basic data for diet formulation. In the past, some major aquaculture species such as grass carp (*Ctenopharyngodon idellus*), gibel carp (*Carassius auratus gibelio*), black carp

Table 5.1.1 Predicted aquafeed requirements in 2012 (x 10 000 tonnes).

Cultured group		Pellets	Extruded	Powder
Normal freshwater fishes	Grass carp, common carp etc.	1200	140	na
High-value freshwater fishes	Snakehead, largemouth bass etc.	5	45	na
Marine fishes	Sea bass, yellow croaker etc.	na	36	18
Crustaceans	Marine shrimps	160	na	na
	Crabs	12	3	na
Reptiles	Turtles	na	5	20
Amphibia	Frogs	na	13	na
Total		1377	242	38

na = not available. *Source:* From Zhang (2013).

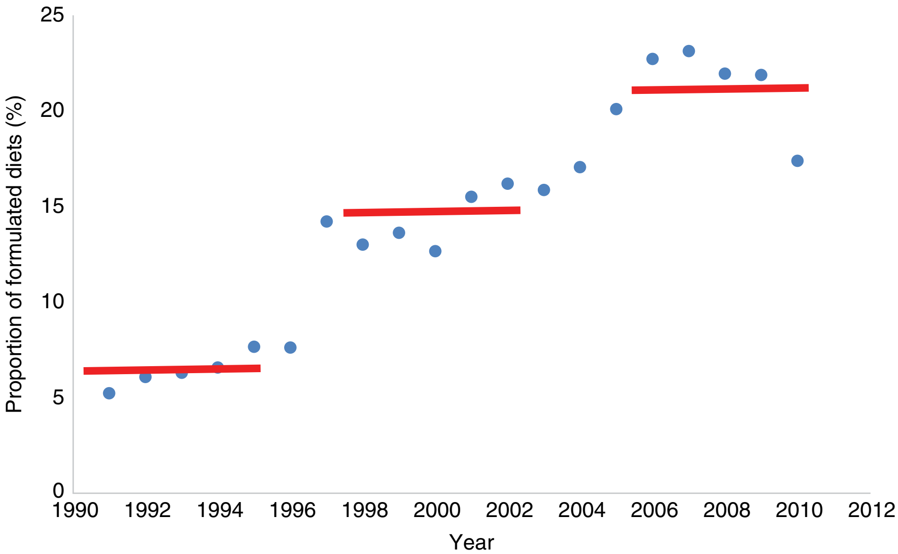

Figure 5.1.2 Proportion of formulated feeds used in aquaculture.

(*Mylopharyngodon piceus*), common carp (*Cyprinus carpio*), bluntsnout bream (*Megalobrama amblycephala*), tilapia (*Orechromis* spp.), largemouth bass (*Lateolabrax japonicus*), and mitten crab (*Eriocheir sinensis*) among others, were selected for investigation into their nutrient requirements. The requirements investigated included protein, lipid, amino acids, fatty acids, minerals and vitamins for different stages of growth. Using these data a nutrient-requirement database has been built which can be used as a reference for feed formulation, and made available nationally in China. Based on the nutrient requirements and utilization of feed ingredients, formulation for fish at different growth periods were recommended (see the examples of recommended nutrient requirements for diet formulation for gibel carp, Tables 5.1.2 and 5.1.3).

5.1.3 Alternative Proteins and Supplemental Amino Acids

Dietary protein generally accounts for more than 50 percent of the cost, and nitrogen discharged from protein metabolism impacts on water quality. At the early stage of development of the Chinese aquafeed industry, high dietary protein levels were used. Now, the national standard has been changed to an upper limit of dietary protein, in order to avoid high nitrogen discharge. On the other hand, fishmeal is considered as a good protein source for aquafeeds, but its usage is limited in freshwater species due to its high price and the low farm-gate price of the cultured fish (Table 5.1.4, Figure 5.1.3). Alternative proteins and supplemental amino acids are considered the most appropriate way to reduce dietary fishmeal content. The increasing inclusion of of alternative dietary proteins is based on research on digestibility, understanding the utilization by different animals at different stages of their lifecycle, a mixture of different proteins, supplemental amino acids and other technologies.

5.1.3.1 Development of a Digestibility Database for Most Major Cultured Species

Digestibility is the basis for accurate diet formulation. As examples, Tables 5.1.5, 5.1.6, 5.1.7, and 5.1.8 summarize the information on digestibility of commonly used ingredients in feeds for three commonly cultured fish species in China. Due to differences in digestibility, feeds should be supplemented with amino acids based on digestibility of amino acids, which can result in better growth and feed utilization than diets formulated on

Table 5.1.2 Nutrient requirements for gibel carp at different growth stages.

Nutrients	Unit	Juvenile (around 3g)	On-growing (around 70g)	Finishing (around 150g)
Protein	%	38.4, 36.0	33.7	37.4
Lipid	%	5.1, 14.0, 7.4	12.6	12.2
NFE	%	36, 15.6, 30.2	29.2	27.2
Energy/protein	kJ/g	18.81	ND	ND
Lysine	%	3.27	2.12	1.74
Methionine	%	0.69, 0.89	0.73, 0.98	ND
Arginine	%	1.55	1.65	1.28
Threonine	%	1.77	1.48	ND
Valine	%	1.21	0.95	ND
Tryptophan	%	0.26	0.17	ND
Histidine	%	0.82	0.64	ND
Phenylalanine	%	1.09	0.73	ND
Leucine	%	1.5	1.69	ND
Isoleucine	%	1.32	1.0	ND
Laurine	%	0.39	ND	ND
NFE/lipid	%	0.79–1.33	ND	ND
Linoleic acid	%	1.3	ND	ND
Linolenic acid	%	0.5	ND	ND
Vitamin A	IU/kg	2705	1969–2698	ND
Vitamin D	IU/kg	20 000	ND	ND
Vitamin E	mg/kg	42.59	50	ND
Vitamin K	mg/kg	3.73	ND	ND
Vitamin B1	mg/kg	1.45–1.62	ND	ND
Vitamin B1	mg/kg	>10.8	ND	ND
Vitamin B2	mg/kg	3.76	ND	ND
Vitamin B6	mg/kg	7.26	ND	ND
Vitamin B12	mg/kg	0.014	ND	ND
Niacin	m/kg	31.27	ND	ND
Pantothenic acid	mg/kg	34.1	30	ND
Inositol	mg/kg	477	ND	ND
Folic acid	mg/kg	0.92–0.97	ND	ND
Choline	mg/kg	1050	1212	ND
Vitamin C	mg/kg	300	193–223	ND
Ca	%	0.48	ND	ND
P	g/kg	6,15, 20	6.72–10.69	7.1–11.0
Mg	mg/kg	200, 745	ND	ND
Fe	mg/kg	202	1151	ND
Zn	mg/kg	50	38	ND
Cu	mg/kg	4–6, 3.1	ND	ND
Mn	mg/kg	13.77	ND	ND

Table 5.1.2 (Continued)

Nutrients	**Unit**	**Juvenile (around 3g)**	**On-growing (around 70g)**	**Finishing (around 150g)**
Se	mg/kg	1.18	0.73	ND
I	mg/kg	0.87	ND	ND

*ND: not determined
Source: Xie *et al.* (unpublished).

Table 5.1.3 Recommended ingredient inclusion levels in dietary formulation and feed conversion ratio for gibel carp at different growth stages.

	Larvae	**Juvenile (around 5g)**	**On-growing (around 70g)**	**Finishing (around 170g)**
Fishmeal	15	10	5	2
Soybean meal	19	18	18	18
Rapeseed meal	12	12	12	12
Cottonseed meal	10	10	10	10
DDGS	10	10	10	10
Rice bran	0	5	8	10
Wheat	18	18	22	24
Blood meal	8	8	6	4
Soybean oil	4.8	4.3	4	4
Ca (H_2PO_4)	2	2	2	2
Bentonite	0.45	1.95	2.25	3.25
Choline chloride	0.15	0.15	0.15	0.15
Vitamin premix	0.1	0.1	0.1	0.1
Mineral premix	0.5	0.5	0.5	0.5
Total	100	100	100	100
Dietary composition				
Crude protein	38.0	35.1	31.4	28.4
Crude lipid	7.8	7.8	7.9	8.0
Lysine	2.6	2.4	2.1	1.8
Methionine	0.4	0.4	0.4	0.3
Arginine	2.2	2.1	2.0	1.9
Threonine	1.2	1.2	1.2	1.1
Isoleucine	1.3	1.3	1.3	1.2
Leucine	2.3	2.5	2.7	2.5
Valine	1.6	1.5	1.6	1.4
Histidine	0.9	0.8	0.8	0.8
Phenylalanine	1.4	1.5	1.5	1.4
FCR	**1.2**	**1.2**	**1.5**	**1.5–1.8**

Source: Xie *et al.* (unpublished).

Table 5.1.4 Total production (mmt) and production based on feeds (mmt), average fishmeal in feed, and the weighted trophic level of major species in Chinese aquaculture in 2014.

Species	Total production (mmt)	Production with feeds (mmt)	Percent of freshwater or marine output (%)	Average fishmeal in feed (%)	Trophic level[1]
Freshwater culture					
Grass carp	5.38	4.57	18.33	1.5	2.03
Silver carp[2]	4.23	0.19	14.41	0.0	2.33
Bighead carp[2]	3.20	0.15	10.90	0.0	2.77
Common carp	3.17	2.70	10.80	6.0	2.12
Crucian carp	2.77	2.35	9.44	8.0	2.16
Tilapia	1.70	1.53	5.79	6.0	2.12
Other fishes[3]	5.58	3.82	19.01	25.0	2.50
Shrimp	1.76	1.10	6.00	27.0	2.54
Crab	0.80	0.56	2.73	40.0	2.80
Mollusks	0.25	0.00	0.85	—	2.25
Algae	0.01	0.00	0.03	—	1.00
Others[4]	0.51	0.51	1.74	45.0	2.90
Total	29.36	17.48	100.0		**2.36**[7]

1) **Trophic level** = the average fishmeal in feed × 3 × the percent of production with feeds + the content of the remain dietary ingredients × 1× the percent of production with feeds + the percent of production with low-valued fish × 3.59 +1, among which 3 is the trophic level of fishmeal, 1 is the trophic level of dietary plant ingredients and 3.59 is the average trophic level of low valued fish. In Chinese mariculture, the percent of production with feeds for sea bass, flatfish, large yellow croaker, grouper and other marine fish are 80, 50, 20, 10 and 60, respectively.
2) **Silver carp and bighead carp** are filter-feeding fish and the trophic levels of the two fish are 2.33 and 2.77 according to the food habit.
3) **Other freshwater fishes** include black carp, bream, catfish, eel, etc.
4) **Others** include turtle, frog etc.
5) **Other marine fishes** include cobia, sea bream, red drum, etc.
6) **Others** include jellyfish, sea cucumber, sea urchin, etc.
7) **Weighted average trophic level** (WTL) is estimated according to: WTL= $\Sigma(Dij \times Tj)$, where Dij is the proportion of the species j in total production, Tj is the mean trophic level of the species j.

Source: Computed from data from China Fishery Statistical Yearbook (2015); adopted from Han *et al.* (2016).

chemical composition (Figure 5.1.4) (Zhao 2014). It was also suggested that dietary protein requirements were similar for high quality diets (fishmeal protein) and poor quality diets (soybean meal protein) when calculated as digestible protein (Liu 2008). More and more databases for different aquaculture species in China have been developed by institutions/colleges and industries, and are widely utilized by feed manufacturers.

5.1.3.2 Evaluation of Utilization at Different Life Stages

Alternative proteins have been studied in many species with a view to reduce fishmeal content in feeds. Most researchers found decreased growth and feed utilization when fishmeal was substituted by soybean meal or other plant proteins in aquatic animals. It was found that the negative effect of plant proteins are related to some anti-nutritional factors such as soybean saponin, kaolin, etc. (Xie and Jokumsen 1997; Zhang 2010). Zhang (2010) found that 30 percent plant protein could cause significant loss in weight in gibel carp. Double-low (low erucic acid and glucosinolates) rapeseed meal can replace 75 percent of soybean meal without

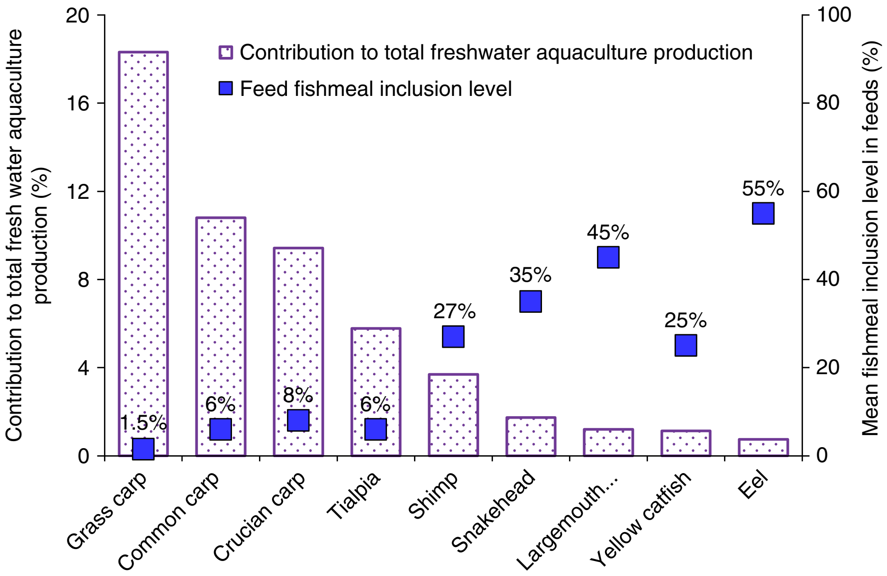

Figure 5.1.3 The percentage contribution of those species that are fed commercial feeds that include fishmeal to the total freshwater aquaculture production in China in 2014. For each species mean dietary fishmeal inclusion level is also given. Red swamp crayfish (*Procambarus clarkii* Girard) is not included in freshwater shrimp because most of the crayfish aquaculture do not use aquafeeds. Data are from *China Fishery Statistical Yearbook* (2015). Data of fishmeal inclusion level in feeds for each species are from the main aquafeed producers in China. (Adopted from Han *et al*. 2016.)

negative effects on the growth of gibel carp (Gao *et al.* 2004). When fishmeal was used as the control, 14 percent dietary soybean meal (Wang *et al.* 2009), or 40 percent potato protein concentrate both resulted in decreased growth (Zhou *et al.* 2002).

The utilization of alternative proteins is different in most species at different growth stages. Larval fish (not only carnivorous, but also omnivorous and herbivorous) show high dependence on fishmeal protein (Wang 2014; Wang *et al.* 2014). In gibel carp, larvae were also much more sensitive to dietary anti-nutritional factors, and show poor growth on soybean meal diets. Increased body size can increase the utilization of dietary plant

Table 5.1.5 *In vitro* digestibility of some feed ingredients by gibel carp (%).

Ingredients	Dry matter	Crude protein	Crude lipid	Gross energy
Rice bran	70.1	82.8	78.5	78.9
Malt root	55.9	82.7	69.7	62.3
Corn gluten	73.8	85.4	84.7	80.0
Peanut cake	89.6	98.9	92.3	94.5
Peanut meal	78.7	89.7	87.7	84.8
Soybean meal	57.9	84.8	95.2	68.9
Rapeseed meal	76.2	93.5	89.9	83.3
Cottonseed meal	82.8	93.3	96.7	86.3
Blood meal	84.4	95.4	93.6	88.5
Fishmeal	77.5	88.3	93.8	86.3

Source: Modified after Jiang *et al.* (2009).

Table 5.1.6 Apparent digestibility for gibel carp.

Ingredients	Dry matter	Crude protein	Ly	Me	Va	Arg	Le	Isol	His	Ph	Th
Domestic meat meal	63.90	76.54	78.09	75.40	79.78	81.97	76.95	71.27	79.22	76.95	65.27
Peru fishmeal	63.06	82.23	86.29	93.81	84.22	72.22	81.00	87.82	97.36	79.27	74.42
American seafood fish meal	68.91	82.17	88.16	94.93	86.61	85.71	86.65	89.40	/	84.50	80.13
Soybean meal	74.06	73.03	77.05	83.69	78.20	76.58	78.76	85.03	/	81.35	65.51
Russian white fishmeal	77.39	82.17	91.78	92.51	88.19	88.81	90.29	86.23	92.68	86.98	84.19
Tilapia fishmeal	44.85	67.18	82.86	88.25	77.99	74.93	82.12	78.01	83.08	78.77	69.12
Rice bran	51.85	41.19	73.01	88.66	75.81	83.20	77.80	73.51	81.97	77.03	68.02
Corn protein	81.94	79.52	75.84	90.69	81.99	80.98	89.36	79.13	85.26	85.11	74.44
Fermented soybean meal	69.01	91.40	92.18	94.28	90.93	96.27	92.15	92.10	87.52	93.25	90.93
Corn germ meal	43.98	79.79	68.17	90.40	77.16	83.16	79.34	68.80	68.43	71.01	71.77
Cannona meal	53.46	86.30	86.86	93.64	83.37	91.53	84.81	82.47	81.23	84.57	84.74
Cotton seed meal (Xinjiang)	49.37	81.73	65.64	83.15	77.23	91.31	76.33	73.27	79.76	84.59	74.46
Extruded soy	57.79	93.06	88.64	95.53	78.31	93.65	88.10	87.50	81.74	88.91	86.01
Feather meal	55.82	69.55	41.28	50.81	79.36	82.90	76.94	79.74	33.36	77.84	71.16
Domestic rapeseed meal	22.40	72.49	77.02	74.56	67.38	87.07	77.26	74.93	58.18	75.20	73.14
Distillers' grains	37.85	47.18	40.97	0.00	24.82	54.60	34.84	38.61	10.51	32.66	34.12
Wheat powder (Henan)	77.79	87.04	93.91	95.43	98.23	97.16	98.20	96.07	51.51	97.26	94.96
Cottonseed meal (Hunan)	62.00	79.94	73.74	98.10	85.33	92.03	82.97	84.40	79.95	88.79	79.28
Wheat bran	36.35	75.15	77.83	91.29	83.25	85.85	86.08	89.65	44.81	85.49	72.06
Corn DDGS	53.36	73.70	70.28	89.50	75.89	80.67	79.82	75.79	48.94	76.88	67.08
Peanut meal	89.45	72.30	75.57	115.32	74.15	110.32	80.70	57.33	91.99	97.62	96.55
Brown fishmeal (Peru)	37.91	36.27	55.65	18.94	33.61	88.41	19.71	14.61	26.34	35.78	18.74
Blood meal	52.23	/	24.13	45.36	/	57.13	2.00	6.94	0.47	20.99	27.55
Corn meal	55.18	55.24	40.43	73.55	48.05	102.70	60.32	38.37	70.34	72.61	79.14
Meat and bone meal	9.59	3.53	33.41	/	21.20	56.93	/	/	4.40	22.00	/
Wheat middling	67.36	15.25	52.61	96.19	62.52	98.77	65.66	42.44	77.81	77.74	75.76
Poultry by-product meal	53.66	44.78	74.24	54.21	60.66	76.31	45.51	45.49	63.62	56.11	65.00
Wheat bran	26.41	19.80	8.17	27.14	39.70	68.05	40.22	48.70	34.32	16.63	34.07

Ly = lysine; Me = Methionine; Va = Valine; Ar = Arginine; Le = Leuvcine; Isol = Isoleucine; His = Histidine; Ph = Phenylalanine; Th = Thronone. *Source:* Xie *et al*. (unpublished).

Table 5.1.7 Apparent digestibility of main feed ingredients by black carp (%).

	Domestic fishmeal	Worm meal	Corn gluten	Soybean meal	Peanut meal	Cotton seed meal	Rapeseed meal	Rice bran
Dry matter	75.73±0.51	73.28±0.52	86.47±1.09	80.62±1.38	70.53±0.66	62.17±0.79	64.63±1.32	62.41±0.71
Crude protein	90.24±0.31	83.34±0.43	93.90±0.28	95.84±0.48	91.77±0.55	85.14±0.59	87.76±0.42	86.96±0.95
Crude lipid	92.84±0.21	94.68±0.09	79.44±0.37	100.06±0.60	97.98±0.51	93.65±0.74	95.48±0.54	78.93±0.64
Total phosphorus	44.95±0.78	49.58±0.47	81.99±1.47	67. 19±0.64	72.18±0.83	43.84±1.08	61.23±0.50	37.33±0.64
Gross energy	86.23±0.59	77.19±0.69	89.86±0.49	87. 14±0.91	76.92±0.44	66.75±0.49	68.11±1.11	66.93±0.80
Thr	91.49±0.49	86.97±0.26	93.02±0.31	95.38±0.46	88.0±0.30	81.06±0.18	86.58±0.49	82.95±0.17
Val	91.63±0.34	87.66±0.28	94.68±0.37	95.62±0.59	92.78±0.39	84.11±0.29	89.8±0.37	85.91±0.27
Met+Cys	91.42±0.25	86.45±0.37	95.40±0.39	96.26±0.60	91.38±0.27	85.63±0.64	90.00±0.23	90.54±0.26
Ile	91.89±0.43	86.72±0.44	94.54±0.48	97.16±0.82	93.24±0.33	82.51±0.46	89.29±0.48	88.52±0.56
Leu	92.77±0.36	88.74±0.39	95.55±0.31	96.52±0.44	93.62±0.38	84.50±0.45	90.58±0.51	86.39±0.67
Phe	84.19±0.59	57.45±0.66	94.11±0.33	96.88±0.56	94.92±0.42	88.45±0.64	88.06±0.82	76.02±1.04
Lys	94.85±0.36	91.19±0.35	92.56±0.53	97.27±0.76	91.80±0.38	82.17±0.96	89.28±0.43	90.67±0.38
His	91.47±0.52	87.86±0.30	92.83±0.40	95.57±0.58	91.48±0.41	87.57±0.69	90.84±0.42	88.61±0.34
Arg	92.59±0.40	91.33±0.28|	94.52±0.54	97.63±0.57	97.11±0.25	92.47±0.75	92.47±0.46	90.00±0.26
EAA	91.91±0.46	83.23±0.67	94.71±0.29	96.73±0.56	94.00±0.29	86.48±0.60	89.87±0.43	87.01±0.43
NEAA	90.82±0.34	89.06±0.20	95.40±0.54	95.61±0.49	93.09±0.33	87.69±0.50	89.44±0.35	88.68±0.32
TAA	91.60±0.40	86.33±0.56	94.52±0.41	96.58±0.52	93.82±0.27	86.52±0.63	89.90±0.33	88.19±0.31

Source: After Ming *et al.* (2012).

Table 5.1.8 Apparent digestibility of main feed ingredients by blunthead bream (%).

	Extruded feather	Hydrolyzed feather	Blood meal	Silkworm meal	Corn gluten	Rice powder	Corn	Barley
Dry matter	68.07±0.88	71.11±1.20	73.00±0.13	79.33±0.98	92.69±l.00	91.79±0.92	92.65±0.73	74.87±0.05
Crude protein	81.54±1.08	84.48±0.34	84.93±0.74	89.07±0.42	92.75±0.66	88.00±0.14	87.90±0.63	88.29±0.80
Crude lipid	95.70±1.76	84.82±1.08	94.69±0.56	98.79±0.85	103.40±0.99	99.50±1.03	98.39±0.13	86.47±0.28
Total phosphorus	46.52±1.68	—	67.24±0.93	56.48±1.20	97.55±0.89	41.48±0.58	88.96±0.41	57.69±l.l0
Gross energy	68.91±0.24	77.27±0.67	76.36±1.03	86.01±1.09	97.81±0.39	90.5±0.84	93.60±1.01	79.40±0.49

Source: Modified after Jiang *et al.* (2011).

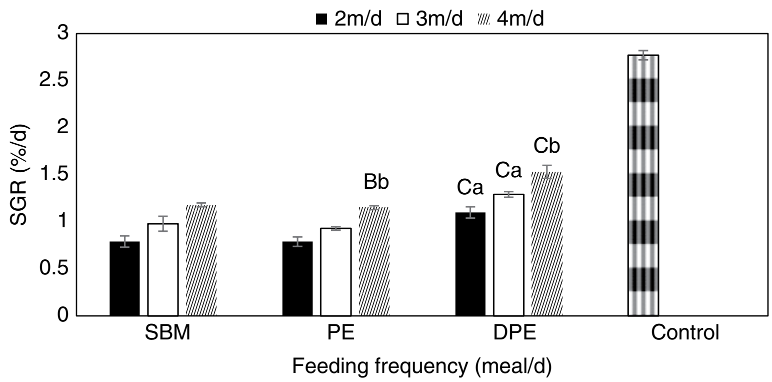

Figure 5.1.4 Specific growth rate (SGR) of gibel carp fed different diets at different feeding frequencies (■black bar: soybean meal diet; □hollow bar: soybean meal supplemented with amino acids based on the chemical composition of fish meal protein; ▨diagonal: soybean meal supplemented with amino acids based on the digestible composition of fishmeal protein) (Zhao 2014).

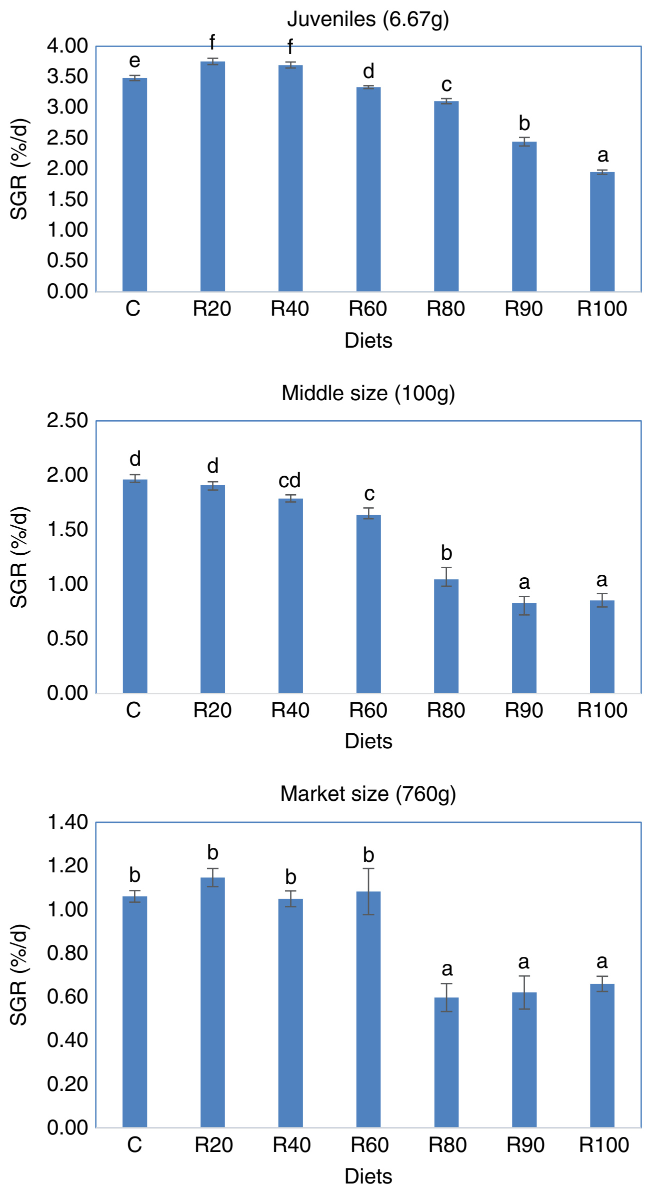

Figure 5.1.5 Effects of dietary substitution of fishmeal by cottonseed meal on the growth of grass carp at different life stages (juvenile, middle-sized and market size). *Source:* Modified after Yan (2012).

protein. One-year-old fish and broodstock show higher tolerance of dietary soybean meal (Liu 2014; Liu *et al.* 2016, 2017). Similar results have been reported in respect of the utilization of dietary cotton seed meal in grass carp (Figure 5.1.5) (Yan 2012; Liu *et al.* 2015).

The varying food habits of fish also affect the utilization of plant proteins. It was found that, when fed plant proteins, the growth of grass carp (*C. idellus*) (herbivorous) was significantly higher than that of the omnivorous gibel carp (*C. auratus gibelio*var, CAS III) or the carnivorous black carp (*M. piceus*). The utilization of soybean meal was similar at on-growing (juvenile size) and sub-adult stages (market size). In larval gibel carp and black carp, dietary soybean decreased the activities of proteinase and amylase, and these larvae showed histological intestinal damage. No histological damage was found in gibel carp and black carp when dietary soybean was used at on-growing and sub-adult stages. Dietary inclusion of soybean meal also changed the intestinal bioflora in black carp and gibel carp, while the effect on grass carp was not significant in grow-out. In the grass carp intestine, dominant genera of bacterial communities such as *Firmicutes*, *Fusobacteria,* and *Proteobacteria* were not directly associated with growth stages (Wang 2014). It has also been shown that the utilization of alternative proteins was also related to the taxonomic level of the cultured species. Shrimps showed higher tolerance on alternative proteins than fish, followed by soft-shelled turtle. It is suggested that animals at higher evolutionary levels showed poorer tolerance in utilization of alternative protein sources (Yang 2004).

5.1.3.3 Mixture of Different Protein Sources Could Help Elevate the Inclusion Levels

In view of the fact that the amino acid composition of different proteins is different, the utilization is improved when mixtures of proteins are used. For example, in gibel carp when mixed protein sources are used, the permissible individual level of ingredients in the total feed mix can be raised, such as in the case of cottonseed up to 56 percent of the total (Jiang *et al.* 2009) 12 percent for corn gluten (Chen *et al.* 2009), and 10.1 percent for blood protein powder (Ma *et al.* 2011).

5.1.3.4 Supplemental Amino Acids Improve Feed Quality

Amino acids have been shown not only to influence fish growth, but also to influence other nutrition-related behavior traits. Due to the presence of limited quantities of some essential amino acids in some plant proteins, supplemental amino acids has been proved to increase feed quality when plant meal was included, but the efficiency was affected by some other factors. Normally, the balance of dietary amino acids is more important than the levels of one or several amino acids. Supplemental lysine and methionine were reported to cause even lower growth performance in Chinese longsnout catfish with 30 percent fishmeal protein (Xie and Lei 1995). Liu and Zhou (2001) found dietary lysine and methionine could help to reduce dietary protein requirements by around 3 percent. Some specific amino acids can help to increase fish non-specific immunity (Deng 2014; Tu 2015). Dietary glutamine can reduce hydrogen peroxide-induced oxidative damage in intestinal epithelial cells of Jian carp (*Cyprinus carpio* var. Jian) (Chen *et al.* 2009).

5.1.4 Alternative Lipids

Some results show that freshwater fish could achieve normal, or even better, growth and feed utilization with fish oil-free diets. Soybean oil, rapeseed oil, coconut oil when mixed with fish oil showed higher growth than fish oil alone in gibel carp. Fish muscle fatty acids content was found to be related to dietary levels (Chen 2008). There was no difference in growth and feed conversion in loach (*Misgurnus anguillicaudatus*) fed different dietary lipid sources (Gao *et al.* 2016), but black carp fed fish oil and tallow showed better growth compared to soybean oil and corn oil (Wang *et al.* 1989). In Chinese yellow cheek carp (*Elopichthys bambusa*) inclusion of sunflower oil, fish oil, palm oil and soybean oil resulted in better growth than using pork lard and corn oil (Chen *et al* 2013). A combination of different oils could balance the composition of fatty acids, and showed better growth performance in grass carp and bluntsnout bream (*M. amblycephala*) (Wang *et al.* 2017).

5.1.5 Additives

Additives are often used to improve feed intake, growth, feed utilization and fish quality, etc.

5.1.5.1 Feed Attractants

Feed intake is important in aquaculture. The efficacy of potential feed-attractant additives, such as certain amino acids, betaine, nucleotide, AMP, and organic acids have been investigated (Wu 1993, 1996; Xie *et al.* 2003; Zhao 2007; Zhao *et al.* 2010a). It should be highlighted that the change from a strong attractant to a poor one could cause even poorer feed uptake (Zhao 2007).

5.1.5.2 Nutritional Additives

Nutritional additives that include amino acids, vitamins, and minerals are mostly used to meet the requirements of aquatic animals. Some specific nutritional additives, such as vitamins C and E, and zinc (Zn) etc., which show effects on fish immunity, are also used to improve the health of aquatic animals (Song *et al.* 2002; Zhang *et al.* 2004; Liu *et al.* 2008, 2009).

5.1.5.3 Immuno-Stimulants

Due to the introduction of stricter legislation on the use of medicines in aquaculture, many researches have been focusing on immuno-stimulants. It has been found that some chemicals can improve fish immunity including levamisole, β-glucan, chitosan, lysozyme, nucleotide, mannatide, Chinese herbs, *Bacillus*, etc., and showed dose-time relationship (Hua *et al.* 2001; Qiu *et al.* 2004; Wang *et al.* 2005; Chen 2012).

5.1.6 Feeding Technology

The feeding regime is very important in aquaculture. Optimal feeding regimes do not only provide suitable nutrients for the cultured stock, but they also improve stock health, and reduce feed cost and waste discharge. Feeding regimes normally include feeding rate, feeding rhythm, feeding frequency, and variations in the use of different diets. Accurate nutrient supply includes optimal feed formulation and feeding regime, so that the stock can obtain the required nutrients. Accurate nutrient supply should be based on the nutrient requirements for different life stages, and according to fish health, rearing conditions, and natural food supply, etc.

A feeding system based on bioenergetic models has been developed to predict feeding rate for gibel carp (Zhou *et al.* 2005) and Chinese longsnout catfish (Han *et al.* 2011b). The feeding regime could help reduce 0.86 tonnes feed input and reduce 31 kg nitrogen discharge at a production level of 1 tonne of gibel carp (Zhou 2003). Similarly, feed input can be reduced by 0.27 tonnes when producing 1 tonne of Chinese longsnout catfish with a corresponding reduction of 21.7 kg nitrogen and 7 kg phosphorous discharge (Han 2005). Based on research findings, certain standard feeding regimes have been recommended to farmers for gibel carp and grass carp (Xie *et al.* 2010a, b).

Increasing feeding frequency has been found to increase the utilization of crystallized amino acid utilization in gibel carp (Zhao 2014), and also increase the substitution of fishmeal by alternative proteins (Zhao *et al.* 2011a Zhao 2014) and reduce dietary protein level (Zhao *et al.* 2014).

5.1.7 Nutritional Manipulation for Improving Fish Quality

Fish appearance and taste are important for market value. Some additives have been shown to improve fish quality, including nutritional value, skin color, and taste. Nutrient composition was reported to be affected by different dietary factors.

It has been reported for gibel carp that substitution of dietary fishmeal by soybean meal modifies the muscle fiber characteristics and fat content of muscle, and an overall decrease in fillet nutritional quality, as evident from total amino acids and essential amino acids index (Zhou 2015). Dietary inclusion of soybean meal, rapeseed oil and pork lard oil mainly affect the fatty acid profile of cultured fish, especially in reducing fillet PUFA content, and n-3/n-6 ratio. Feeding with a fish oil diet before harvest is favorable to recover the fillet fatty acid profile. Dietary nutrient levels have a significant effect on myofibril histological characteristics, lipid content of fillet, overall texture, and organoleptic quality of gibel carp (Zhou 2015; Zhou *et al.* 2015) Dietary selenium can increase the chewiness, hardness, springiness and adhesiveness of the flesh (Han *et al.* 2011a). Dietary lipid affects fish skin color, meat physical quality, and the quality after freezing, and therefore is important for taste (Yuan *et al.* 2008; Liu *et al.* 2010; Zhuang *et al.* 2015). Supplemental vitamin E can help to reduce dressing loss and exudative loss after freezing, and vitamin C has been found to improve muscle composition and physical index in grass carp (Li *et al.* 2009, 2010). Due to specific hardness requirement of fish in Southern Chinese cuisine, broad/fava bean has been used in grass carp culture and has been found to increase fish fiber length and diameter, and collagen and myofibril length (Li *et al.* 2004; Lun *et al.* 2008; Mao *et al.* 2014).

Feeding technology has also been used to improve fish quality, including taste and in reducing off-flavor. Pre-harvest fasting of gibel carp can increase meat hardness, and three days' feeding with four days' fasting can obtain higher muscle hardness. Sensory tests showed that oily flavor in the flesh decreased with increased fasting days (Li 2013).

5.1.8 Future Prospects

5.1.8.1 Accurate Nutrient Supply (in Relation to Different Aquaculture Modes in China)

In order to reduce feed cost and waste discharge, accurate nutrient supply, including accurate diet formulation and feeding, are required. Research on dietary requirements at different life stages, and in different rearing conditions should be focused on the interaction between nutrients, the bioavailability of different feed ingredients, and the balance of nutrients should be investigated. Accurate feed formulation and feeding technology should be developed which takes into consideration animal physio-ecological characteristics, feeding behavior, metabolism and water quality. Due to different market requirements in different areas in China, diet formulation and/or feeding technology should also consider meeting the requirement of market, and control the rate of growth and product quality.

In addition, as China has different kinds of aquaculture modes including intensive monoculture, polyculture (including different species and/or macrophytes in ponds), and as the temperature varies from the north to the south of the country, diet formulation should take into consideration such differences for different aquaculture modes.

5.1.8.2 New Protein Sources

Due to the rapid increase in aquafeed production China's dependence on imported feed ingredients has increased significantly. About 1 000 000 tonnes of fishmeal, and 80 000 000 tonnes of soybean are imported into China every year. New feed ingredient resources should be developed, evaluated and processing improved, with a view to curtailing imports of ingredients for aquafeeds.

There also other potential feed ingredients, including worms or insects, which can be grown from by-product or agricultural waste. The recycling of nutrients not only helps to increase the availability feed ingredients, but also to reduce environmental degradation.

5.1.8.3 Product Quality and Food Safety

Legislation on aquafeed in relation to level of toxic substances should come in to prominence in order to comply to increasing market requirements on safety of products. Research should be focused on improving the quality of aquaculture animals, including nutrition, appearance, taste, and flavor. Standard methods for the evaluation of aquaculture products are also very important for the market. New technology should be developed to reduce or remove off-flavor, and toxins, and regulatory measures limiting inputs (e.g. medicine, toxic substances) into feeds should be strengthened.

5.1.8.4 Feed Processing Technology

The level of research into feed processing is still relatively poor in China. China needs to develop new technologies on pre-treatment of feed ingredients, grinding, and extrusion, so as to improve feed quality, reduce anti-nutritional factor activity, and reduce toxicity. Improved feed processing should also reduce nutrient damage, improve feed utilization, reduce waste production, and improve fish quality.

5.1.8.5 Animal Welfare

Animal welfare should be considered not only for a happy animal, but also for good quality aquaculture products. Welfare should include optimal stocking, feed formulation, feeding technology, and handling (capture, transportation, slaughter) so as to reduce stress on cultured animals.

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5.2

Feed Developments in Mariculture

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5.2.1 Introduction

Mariculture in China dates back to 2000 years. However, due to lack of feed development or other scientific support, mariculture fell into an extensive farming mode characterized by single species and low yields, until about the 1950s. The development of mariculture has experienced four waves: the algal culture wave in the 1950s, shrimp cultivation wave in the 1970s, the shellfish farming wave in the 1980s, and fish farming wave (Li *et al.* 2005). Knowledge on the nutrition of farmed marine species and consequent feed developments were fast and progressed mostly during the shrimp and fish farming waves.

The rapid growth of mariculture in China is inseparable from the development of the feeds used in mariculture. In order to meet the huge feed needs of aquaculture, and comply with the national economic development policies, many quantitative and qualitative changes occurred in the development of feeds for mariculture. Thus as a part of the success story of Chinese aquaculture, the story of mariculture feed development is a story about quantity and quality, in which production, product diversification, product efficiency, environmental friendliness, and product popularization rate, play key roles. The objective of this chapter is to review the successful development of mariculture feeds in China. It includes the following aspects:

- importance of mariculture feeds;
- history of mariculture feed development;
- current status of mariculture feeds;
- typical cases of mariculture feeds;
- factors contributing to the success of feed development.

5.2.2 Importance of Feeds for Mariculture

The demand for food proteins, including marine fish, increased with the global population explosion (FAO 2014). However, wild marine fishery resources declined gradually due to overfishing, and environmental and/or climatic problems (Pauly *et al.* 2013). In order to meet human demand for high-quality marine food, marine fish farming is considered the most important and plausible way (Cressey 2009). As the world's leading producer, consumer and processor of fish, China has a well-developed marine fish industry and it contributes to one-third of the global food fish supply (Shen and Heino 2014; China Fishery Statistical Yearbook 2016). Marine culture production in China reached 18 760 000 tonnes in 2015 (China Fishery Statistical Yearbook 2016).

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China's dramatic expansion in marine culture production is largely from highly intensive recirculation systems and sea cages. Highly intensive culture practices are dependent on high-quality feeds and efficient feed management (Mai 2011). In other words, highly intensive modern fish farms cannot constantly produce fish protein, and create any social value if high-quality feeds are not used (Lei 2005; Brudeseth *et al.* 2013). The development of the marine fish feed industry also triggered the development of related industries, such as industries for mechanical processing, resource and by-product machining, additive manufacture, as well as microbial fermentation, and vaccines (Mai 2011; Brudeseth *et al.* 2013; China Fishery Statistical Yearbook 2016). These developing industries create large numbers of employment opportunities, and contribute to social harmony and welfare. For example, the total output value of marine culture in 2015 was RMB 293.8 billion (6 RMB = 1 US$), and the added gross value was about RMB 171.8 billion, which was nearly twice that in 2009. Similarly, the average net income (per year) of farmers reached RMB 15.59 thousand in 2015 compared to RMB 6.24 thousand in 2009 (China Fishery Statistical Yearbook 2016).

High-quality formulated feeds increase marine fish growth, improve fish health, and alleviate environmental stresses (NRC 2011). For example, adequate dietary vitamin C (≥27.2 mg/kg) can significantly influence the growth performance and immune response of juvenile cobia (*Rachycentron canadum;* Zhou *et al.* 2012). Moderate dietary n-3 highly unsaturated fatty acids (0.6–0.98 percent) can increase growth and the innate immunity of large yellow croaker (*Larmichthys crocea*) to natural parasitic infestation of *Cryptocaryon irritans.* Similarly, 35 mg/Kg dietary Zn can significantly increase growth and improve anti-oxidative capacities in farmed pacific abalone (*Haliotis discus hannai)* (Tan and Mai 2001; Wu *et al.* 2011). In addition, different additives or immuno-stimulants incorporated into formulated feeds can enhance the innate immunity in marine fish and shrimp, such as iso-osmolality to oligosaccharides, probiotic *Bacillus OJ*, Arthrobacter XE-7, *Halomonas* sp. B12 and β-1,3 glucan (Li *et al.* 2008; Li *et al.* 2009; Zhang *et al.* 2009). For example, a high dose of *Halomonas* sp. B12 (7.18×10^{10}) in feed can significantly increase the resistance of shrimp to White Spot Syndrome virus (WSSV) (Zhang *et al.* 2009). Ai *et al.* (2007) found that dietary β-1,3 glucan influence macrophage, modulate the immunity, and then decrease the cumulative mortality of large yellow croaker after infection with *Vibrio harveyi*. These findings suggest that adding optimal immuno-stimulants can increase fish immunity and anti-infection capacity, which is important in decreasing the use and dosage of antibiotics or drugs in fish farming.

Many studies have found that the different level of nutrients can influence the body composition of marine fish. For example, dietary lysine can modulate crude protein and crude lipid contents in the whole body composition of sea bass (*Lateolabrax iaponicus*) and large yellow croaker (Mai *et al.* 2006; Zhang *et al.* 2008). Fatty acids (16:1, 18:1n-9 and 22:6n-3) were significantly affected by dietary vitamin E in abalone *H.d. hannai* cultured for 240 days (Fu *et al.* 2007), and dietary vitamin E can also increase the body vitamin E content in grouper (*Epinephelus malabaricus)* (Lin and Shiau 2005). In addition, high-quality fish protein can be consistently supplied to the market, since these marine fish products contain nutrients, such as ω-3 PUFA, and essential amino acids, which can help meet human nutritional requirements (Naylor *et al.* 2009). Taking these together, it is evident that formulated feeds could regulate the nutrient composition in mariculture animals, and then meet human demands for higher quality protein and fatty acids.

Although 25–40 percent of fish meal to date is included in formulated feeds for marine fish and shrimp, increased knowledge on the digestive processes and nutritional requirements of the main farmed species, together with improvements in processing raw materials have led to an impressive reduction in the levels of fish meal included in feeds for fish and shrimp in China. In addition, fish processing by-products have been effectively used in marine feeds (Lei 2005; Mai 2011). For example, it has been demonstrated that up to 60 percent of fish-meal protein can be replaced by meat and bone meal without negative effects on growth, survival, feed conversion ratio, protein efficiency ratio, or body composition of Pacific white shrimp (*Litopenaeus vannamei*) (Tan *et al.* 2005). Sun *et al.* (2015) found that up to 16 percent fermented cottonseed meal can be used to replace fish meal in diets for black sea bream (*Acanthopagrus schlegelii*). Chou *et al.* (2004) demonstrated that 40 percent of fish meal protein can be replaced by soybean meal protein, without causing reduction in growth and protein utilization in juvenile cobia. Zhou *et al.* (2011) found good-quality terrestrial poultry by-product meal can successfully replace fish meal in commercial diets for cobia, and the optimal level of fish meal replacement with poultry by-product meal was determined by quadratic regression analysis to be 30.75 percent on the basis of maximum protein efficiency ratio. As such, mariculture feeds have helped save significant amounts of fish meal being used in feeds, and thereby from the reduction processes of wild fish stocks, and hence indirectly contribute to conserving wild fish stocks.

In addition, marine fish and shrimp can efficiently intake and utilize digestible nutrients from high-quality formulated feeds due to advanced processing technology, such as extruding technology, and pretreatment processes (Zhou *et al*. 2004; China Feed Industry Yearbook 2010). With the increasing usage of high-quality extruded feeds, the use of low-valued fish as feed has been reduced markedly, which also helped decrease the probability of diseases (Naylor *et al*. 2009; China Feed Industry Yearbook 2010). Moreover, high-quality formulated feeds have balanced nutritional value with low fishmeal inclusion that could optimize metabolic efficiency in juvenile fishes (Li *et al*. 2009).

5.2.3 Present Status of Feeds Used in Mariculture

5.2.3.1 Output and Value

There has been a rapid development of aquaculture as well as mariculture in China in recent decades. Total mariculture production was only 1 500 000 tonnes in 1986, but after 28 years of rapid growth with an annual increment of ten percent, it reached 18 000 000 tonnes in 2015 (China Fishery Statistical Yearbook 2016). Development of aquaculture production relies on support from the aquatic feed industry. Since the 1990s, the aquatic feed processing industry has developed rapidly. Aquafeed production was 710 000 tonnes only in 1991, and over the next 20 years, an average annual growth of 17.2 percent was observed, and by 2015, total aquatic feed production reached 18 930 000 tonnes (China Feed Industry Yearbook 2016). China has now established a relatively complete aquatic feed industrial system, is the world's largest aquatic feed producing nation (Mai 2010a).

Long-term practices have shown that feed makes up more than 60–70 percent of the recurrent costs of intensive aquaculture. The rapid development of the aquaculture industry in China depends on the supply of high-quality compound feeds. Nutrition studies on mariculture species and feed research in China started in the early 1980s, and at that time stocks were mainly fed natural live foods. Use of compound feeds increased with the expansion of the scale of farming and intensity of farming practices, and the development of feed processing technology.

5.2.3.2 Usage Rates of Feeds in Mariculture

Although the output and value of mariculture feed are increasing, compared with the total aquaculture feed, including feeds for fresh water animals, its proportion is still small: in 2015, mariculture production (18 100 000 tonnes) accounted for 38 percent of the total aquaculture production, while, mariculture feed production was 1 500 000 tonnes, accounting for only around 7.9 percent of the aquafeed produced in China. This phenomenon could be attributed to the low popularization rate of most kinds of mariculture feeds. Percentage of stock that are artificially fed in total mariculture animal production by species in China from 1985 to 2014 is summarized in Table 5.2.1.

The usage rate of fish and crustacean feeds is relatively higher than that of mollusks and other mariculture animals, such as sea cucumber and jellyfish. By 2014, the usage rate of compound feed for sea bass, red drum (*Sciaenops ocellatus*) and pompano (*Trachinotus ovatus*) exceeded 90 percent. However, the usage of compound feeds for large yellow croaker, cobia, yellowtail (*Seriola quinqueradiata*), fugu (puffer fish) and grouper is less than 20 percent. Pacific white shrimp culture is based entirely on compounded feeds. However, most mollusk cultures, such as oyster, blood clam, mussel, pen shell, scallop, clam and razor clam are not based on compound feeds, but on natural food, primarily plankton. The utilization rate of feeds for other mariculture animals, such as sea cucumber, jellyfish and sea urchin is also quite low.

Table 5.2.1 Percentage production of cultured marine species that are fed formulated feeds in China from 1985 to 2014.

Species	1985	1990	1995	2000	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Fish [1]																
Sea bass	--	--	--	--	20+80*	30+70*	50+50*	50+50*	70+30*	70+30*	70+30*	70+30*	90+10*	90+10*	90+10*	90+10*
Flounder	--	--	--	--	20+80*	20+80*	40+60*	40+60*	40+60*	40+60*	40+60*	50+50*	50+50*	50+50*	60+40*	60+40*
Large yellow croaker		--	--	--	2+98*	2+98*	5+95*	5+95*	7+93*	7+93*	10+90*	10+90*	15+85*	15+85*	15+85*	20+80*
Cobia			--	--	2+98*	2+98*	5+95*	5+95*	5+95*	5+95*	5+95*	10+90*	10+90*	10+90*	10+90*	10+90*
Yellow tail			--	--	5+95*	10+90*	10+90*	10+90*	10+90*	20+80*	20+80*	30+70*	30+70*	45+55*	50+50*	50+50*
Bream	--	--	--	--	5+95*	10+90*	10+90*	10+90*	10+90*	20+80*	30+70*	30+70*	30+70*	30+70*	40+60*	40+60*
Red drum			--	--	20+80*	45+55*	50+50*	50+50*	55+45*	60+40*	70+30*	70+30*	80+20*	90+10*	95+5*	95+5*
Puffer	--	--	--	--	20+80*	30+70*	50+50*	50+50*	50+50*	60+40*	60+40*	70+30*	75+25*	75+25*	80+20*	80+20*
Grouper	--	--	--	--	2+98*	2+98*	5+95*	5+95*	5+95*	5+95*	7+93*	7+93*	7+93*	7+93*	10+90*	10+90*
Flatfish			--	--	5+95*	10+90*	20+80*	20+80*	25+75*	30+70*	30+70*	50+50*	50+50*	50+50*	60+40*	60+40*
Other	--	--	--	--	5+95*	5+95*	5+95*	10+90*	10+90*	30+70*	30+70*	30+70*	40+60*	40+60*	50+50*	50+50*
Crustacea [1]																
Pacific white shrimp			--	--	75+25*	85+15*	95+5*	100+0*	100+0*	100+0*	100+0*	100+0*	100+0*	100+0*	100+0*	100+0*
Tiger prawn	--	--	--	--	75+25*	80+20*	85+15*	85+15*	85+15*	90+10*	100+0*	100+0*	100+0*	100+0*	100+0*	100+0*
Chrinese shrimp	10+90*	30+70*	40+60*	50+50*	65+35*	80+20*	80+20*	80+20*	85+15*	85+15*	90+10*	100+0*	100+0*	100+0*	100+0*	100+0*
Kuruma prawn	--	--	--	--	70+30*	75+25*	80+20*	80+20*	85+15*	85+15*	90+10*	100+0*	100+0*	100+0*	100+0*	100+0*
Swimming crab	--	--	--	--	--	--	2+98*	2+98*	5+95*	5+95*	10+90*	10+90*	10+90*	15+85*	15+85*	15+85*
Green Crab	--	--	--	--	--	--	2+98*	2+98*	2+98*	5+95*	5+95*	5+95*	5+95*	5+95*	5+95*	5+95*
Shellfish																
Abalone [2]	--	0+70* --30	0+80* --20	0+85* --15	0+90* --10	0+95* --5	0+95* --5	1+96* --3	1+96* --3	2+95* --3	2+95* --3	2+95* --3	3+95* --2	3+95* --2	3+95* --2	3+95* --2
Conch [1]	--	--	--	--	--	--	0+100*	0+100*	1+99*	1+99*	1+99*	1+99*	1+99*	2+98*	2+98*	2+98*
Oyster [3]	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*

Blood clam [3]	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*
Mussel [3]	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*
Pen shell [3]	--	--	--	--	--	--	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*
Scallop [3]	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*
Clam [3]	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*
Razor clam [3]	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*
Other																
Sea cucumber [2]	--	--	0+70* --30	0+70* --30	0+75 --25	0+75* --25	1+74* --25	1+79* --20	2+83* --15	2+83* --15	2+88* --10	2+88* --10	2+88* --10	2+92* --6	3+91* --6	3+91* --6
Sea urchin [3]		--	--	--	--	--	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*	0+0*
Jellyfish [4]				--	--	--	0+97* --3	0+97* --3	0+97* --3	0+98* --2	0+98* --2	0+98* --2	0+98* --2	0+98* --2	0+99* --1	0+99* --1

Note: data expressed as C+O* represents percentage of farmed production with different diets.
1) C as percentage fed compound feed, O* as percentage fed trash fish. A negligible portion was non-fed and not presented;
2) data expressed as C+O*--n. C as percentage fed compound feed, O* as percentage fed algae, n as percentage of non-fed;
3) non-fed farmed mariculture animals;
4) data expressed as C+O*--n. C as percentage fed compound feed, O* as percentage fed rotifer and artemia, n as percentage of non-fed.
Blank means without specific farmed species in specific year; "--" means specific farmed species without data on production in specific year.

There are two main reasons for the low usage rate of marine fish feeds. The first is the wide range of species cultured and the lack of systematic nutrition research on many cultured species. Second, policy developments and related legal systems have lagged behind. Legislation banning raw materials such as low-valued fish has been practiced since the early 1970s in Norway, but in Chinese aquaculture significant amounts of low-valued fish are still being used. The growth of fish fed on low-valued fish may be a bit faster than when fed on compound feeds, but in the long run, the cost of low-valued fish is not any less than compound feeds. At the same time, low-valued fish is thought to pollute the environment; a notion, however, that has been refuted by some (Bunlipatanon *et al.* 2013). It is estimated that, at the end of the last decade, 4 000 000 tonnes of low-valued fish per year were directly used for aquaculture in China (Mai 2010a).

5.2.3.3 Diversity and Specialization of Mariculture Feed Development

The Chinese market is the driving force for the diversification of aquaculture species. Although market demand often results in stimulating nutritional research, research into most mariculture species has lagged behind in the past decades. The situation has now changed and accordingly systemic nutritional research on mariculture species, and related aspects on ingredients and processing of feed thereof ,have gained momentum in the recent years.

Maricultured fish species in China mainly include sea bass, large yellow croaker, cobia, yellowtail, sea bream, red drum, grouper and flatfish. Maricultured crustaceans include Pacific white shrimp, tiger prawn (*Penaeus monodon Fabricius*), Chinese shrimp (*Penaeus chinensis*) and kuruma prawn (*Penaeus japonicus*). Maricultured crab species include swimming crab (*Portunus trituberculatus*) and green crab (*Carcinus maenas*) (China Fishery Statistical Yearbook 2016). At present, the nutrient requirements of different growth stages, as well as utilization of main raw materials for the following mariculture species are known; shrimp, large yellow croaker, sea bass, cobia, turbot, flounder, tongue sole and abalone. Commercial feeds are now available for fish species such as sea bass, flatfish, large yellow croaker, cobia, red drum, sea bream, and grouper (Lin 2005).

5.2.3.4 Extruded Feeds

Due to the drawbacks of pellet feeds, such as poor water stability, fast sinking velocity, higher feed loss, and water pollution, extruded feeds prepared at high temperature under pressure are ideal for mariculture species. The advantages of extruded feeds mainly include effective digestion and utilization, enables the feeding to be managed,, good water stability, and decreased disease occurrences. Thus, application of extruded feeds has become popular in recent years. Due to differences in bulk density and expansion degree, the sinking rates of extruded feeds are also different. Extruded feeds, based on sinking rates, can be divided into three groups: extrusion-floating feeds, extrusion-slow-sinking feeds, and extrusion-sinking feeds. Generally speaking, shrimp and crab with "hold on" feeding habits, as well as benthic organisms prefer extrusion-sink feeds. Extrusion-slow-sink feeds are widely used for most marine animals which live in middle and lower depths of the water column. In recent years extruded aquatic feeds have become the leading product category of mariculture feeds.

5.2.3.5 Fish Meal and Fish Oil Replacement

Research is currently underway into feed stuffs, and into attempting to improve the quality of protein or lipid sources to replace dietary fish meal and fish oil. From 2004 to 2014, fish meal + fish oil used in mariculture compound feeds in China declined by around 1 percent annually. For example, fish meal + fish oil used in compound feed declined from 53 to 37 percent for sea bass, from 55 to 45 percent for large yellow croaker, from around 60 percent to around 45–50 percent for flounder, turbot, cobia, red drum and grouper, from around 40 to 35 percent or even lower than 30 percent for shrimp.

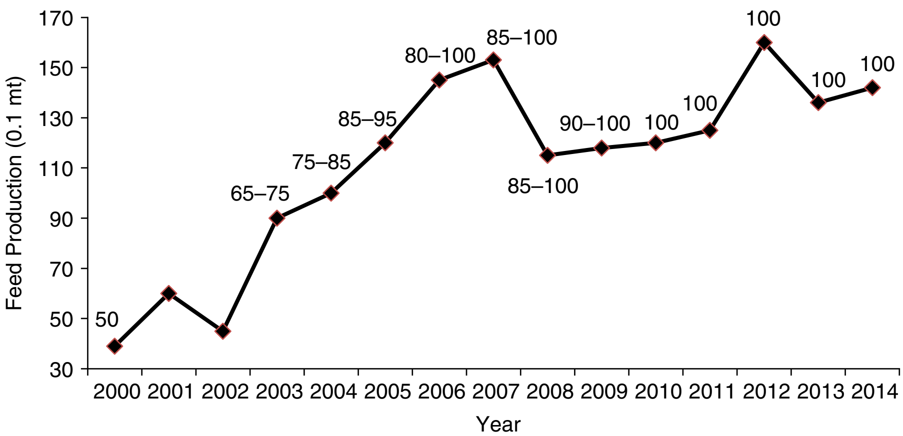

Figure 5.2.1 The production and popularization rate of shrimp feed in the period 2000 to 2014. The number on the point means the estimated usage rate of shrimp artificial feeds as a percentage of shrimp produced, based on feed in total shrimp production.

5.2.4 History of Mariculture Feed Development

The marine culture in China has a history of more than 2000 years, and its development has experienced four waves in last 60 years as indicated at the beginning of this Chapter. In these four waves, shrimp cultivation and fish farming stimulated the marine aquatic feed development in the 1980s. In these 30 years' development, the production of marine aquatic feeds has grown rapidly, and the specifications of feeds for specific fish species have become refined. Its usage rate also increased with time (Table 5.2.1).

In 2000, the production of shrimp feed was only 390 000 tonnes in total and only 50 percent of cultured shrimp was fed artificial feeds (China Feed Industry Yearbook 2016). Then, the production and usage rate of shrimp feeds grew rapidly. By 2007, shrimp production was nearly completely dependent on feeds and shrimp feed production reached 1 530 000 tonnes, 2.9 times higher than that in 2000. Then, due to disease, shrimp culture and consequently shrimp feed production fluctuated from 2008, but the use of live feeds or raw materials stopped completely (Figure 5.2.1). Such a situation was also seen in respect of marine fish feeds, especially for sea bass and flatfish feeds.

5.2.4.1 Typical Examples of Mariculture Feeds

Prior to the development of feeds, low-valued fish was the main feed for farmed marine fish and shrimp. Extensive use of low-valued fish not only causes disorderly offshore fishing, the waste of resources, and environmental pollution, but also increases disease occurrence, and degrades cultured fish quality. Therefore the usage rate of compound feeds in marine aquaculture should be improved, though this will be a gradual process. According to statistics, feed usage rates of large yellow croaker and sea bass were 2 percent and 20 percent in 2003, and increased by 9 times and 3.5 times to 20 and 90 percent, respectively, in 2014 (Table 5.2.1).

The increased usage rate owes to the strategic approach of the aquafeed industry in China, by selecting representative species, and then concentrating effort, unifying approach, and encouraging systematic research (Mai 2010b). The Chinese government invested funds to establish the database on nutrient requirements and feed stuff bioavailability for large yellow croaker and sea bass (Tables 5.2.2 and 5.2.3), and other important aquaculture species. In addition, a large amount of research on the nutritional regulation on reproduction, health, flesh quality in large yellow croaker and sea bass have been carried out in China. In

Table 5.2.2 Nutrients requirement of large yellow croaker of different sizes.

Nutrients	Initial Weight	Response Criteria	Dietary Requirement
Protein	1.76 mg	SGR	57.1%,
Fat	1.93 mg	SGR	17.20%
Protein energy ratio	0.57 g	WG	4.52 mg/kJ
n-3HUPA	1.93 mg	SGR	1.1–1.3%
Methionine	1.93 mg	SGR	0.58%
Nicotinic acid	0.56 g	WG, Hepatic Nicotinic acid	17.41–21.97 mg/kg
lnositol	0.56 g	WG, Hepatic lnositol	313.35–335.3 mg/kg
Protein	13 g	SGR	48.3%
Fat	10 g	WGR, Whole body Fat	10.42–11.07%
Carbohydrate	6.00 g	SGR	22%
n–3HUPA	10 g	SGR	0.98%
DHA/EPA	10 g	SGR	2.17–3.04%
Conjugated linoleic acid	8 g	SGR	0.42–1.70%
Methionine	1.23 g	SGR, FE	1.44%
Lysine	1.23 g	SGR, FER, PER, FE	2.43–2.48%
Arginine	6.16 g	SGR, FE	2.13–2.15%
Threonine	6.00 g	SGR, NRR	1.90–2.06%
Phenylalanine	6.00 g	SGR, NRR	1.56–1.62%
Leucine	6.0 g	SGR	2.92%
Isoleucine	6.00 g	SGE, FE, FER	1.59–1.78%
Valine	6.00 g	SGR	2.08%
Histidine	6.00 g	SGR	0.87%
Tryptophan	7.82 g	SGR	0.82%
Ascorbic acid	17.82 g	SGR, Hepatic ascorbic acid, Muscle ascorbic acid	28.2–71.08 mg/kg
Vitamin B12	11 g	SGR	very low
Vitamin K	11 g	Content of MK-4	10.42–10.55 mg/kg
Vitamin A	6.16 g	WG, Hepatic VA	1865.7–3433.0 IU/kg
Vitamin D	6.16 g	WG, Hepatic VD	426.5–2388.9 IU/kg
Vitamin E	6.16 g	WG, Hepatic VE	54.4–232.4 IU/kg
Biotin	6.16 g	WG	0.039 mg/kg
Riboflavin	6.35 g	SGR, Hepatic riboflavin	6.23–6.92 mg/kg
Pantothenic acid	6.20 g	SGR, Hepatic pantothenic acid	9.78–11.20 mg/kg
Pyridoxine	6.22 g	SGR,AST, ALT	2.40–4.61 mg/kg
Folic acid	6.34 g	SGR, Hepatic folic acid	0.85–0.93 mg/kg
Choline	1.22 g	WG, Hepatic cholin	1056–1124 mg/kg
Zinc	1.78 g	SGR, Bone zinc	59.6–84.6 mg/kg
Iron	1.78 g	SGR	101.2 mg/kg

Table 5.2.2 (Continued)

Nutrients	Initial Weight	Response Criteria	Dietary Requirement
Phosphorus	1.88 g	SGR, whole body phosphorus	0.70–0.91%
Phosphorus	17.82 g	SGR	0.68%
Fat	195 g	SGR	12.00%
Protein	137	SGR	44.8%
Protein	194	SGR	42.7%
Protein energy ratio	137	SGR	29.78 mg/kJ
Vitamin C	137 g	Contents of VC	46.14–80.91 mg/kg

SGR: specific growth rate, FE: feed efficiency, PER: protein efficiency ratio, NRR: nitrogen reservation rate, WG: weight gain, AST: aspartate transaminase, ALT: alanine transaminase.

Table 5.2.3 Nutrients requirement of sea bass at different sizes.

Nutrients	Initial Weight	Response Criteria	Dietary Requirement
Protein	34.0 g	SGR, FE, PER	45.73–45.89%
Fat	34.0 g	SGR	7.22%
Carbohydrate	34.0 g	SGR	17.75%
Protein energy ratio	34.0 g	SGR, FE	33.2 mg/kJ
Tryptophan	24.0 g	SGR, PER	0.40–0.39% Feed
Selenium	26.5 g	SGR	0.40 mg/kg
Mg	25.6 g	SGR, Content of Mg	Not needed
Arachidonic acid	9.4 g	SGR, Enzyme activities	0.22–0.56%
Protein	343.0 g	SGR	40.23 ‰
Fat	343.0 g	SGR	10.05%
Protein energy ratio	305.0 g	SGR, PER, PRR	29.10 mg/kJ
Tryptophan	160.0 g	SGR, PER	0.39–0.36% Feed
Lysine	215.0 g	SGR, PER	2.68–2.47% Feed
Leucine	168.0 g	SGR, PER	2.78–2.81% Feed
Isoleucine	159.0 g	WG	1.88–1.84% Feed
Methionine	180.0 g	SGR	0.79% Feed
Valine	183.0 g	SGR, FE	2.17–2.14% Feed
Phenylalanine	160.0 g	SGR	1.10% Feed
Histidine	174.0 g	SGR	0.57% Feed
Threonine	333.0 g	SGR, FE	1.84–1.87% Feed
Selenium	214.0 g	SGR	0.63 mg/kg
Magnesium	204.0 g	SGR, Content of Mg	Not needed
Arachidonic acid	208.0 g	SGR	0.30%

SGR: specific growth rate, FE: feed efficiency, PER: protein efficiency ratio, PRR: protein reservation rate, WG: weight gain.

order to increase the usage rate of feeds for large yellow croaker, researchers from Ocean University of China integrated existing nutrition-related research and feed production experiences on large yellow croaker to produce compound feeds for large-scale testing in 2012. The tests, that lasted for 18 months, covered juvenile fish (0.4 g) to marketable fish size (>300 g). Results showed that weight of fish fed with compound feeds and the control (fed low-valued fish) were similar. In addition, with compound feeds nitrogen and phosphorus emissions were reduced by 60 percent and 30 percent, respectively. These tests were supported by the government, and implemented by universities and research institutes, and gave confidence to entrepreneurs and farmers on the quality of feeds. The usage rate of feeds will be improved through such tests and related feed improvements.

5.2.4.2 Key Factors Contributing to Success of Feed Development

China faces environmental and food-safety issues. Consequently, the government and academia took the road of developing feeds which are environmentally friendly, high performance and safe. The Chinese government encourages and adheres to the concept that science and technology are a primary forces that drive production. As such the success of Chinese mariculture feed developments are inseparable from the scientific research of mariculture nutrition and feeds. China's aquatic animal nutrition researchers have made much progress in the pre-treatment of raw materials (e.g., fermentation strain screening, complex fermentation of plant protein sources, enzyme treatment, physical and chemical treatment), nutritionally balanced feed formulation (e.g., amino acid balance, energy balance), use of additives (nutritional additives, attractants, exogenous enzymes additives), all of which are aimed at improving the bioavailability of feeds at a low cost. Through exploration and technological transformation, and absorption of advanced technologies from outside China, rapid increases have been gained in technology and equipment in the aquafeed industry in China, particularly in development and popularization of pulverization and extruding equipment, which have improved the level of processing technology and feed quality. Now China's production of aquafeed processing equipment not only meets the basic needs of domestic aquaculture feed production, but also exports to the international market.

Commercial companies play an important role in the development of mariculture feeds. The scale of Chinese aquaculture and aquafeed processing enterprise is expanding. On the one hand, aquaculture and aquaculture feed-based enterprises constantly extend the industry chain and integrate seed production, aquatic feed production, culture, fish processing and trade. On the other hand, large-scale aquaculture and aquaculture feed-based enterprises are expanding across the country, which bring a collective advantage (China Feed Industry Yearbook 2016). Tongwei is a company mainly engaged in aquafeeds. It ranks top in aquafeed production in China. As the State's Key Leading Enterprise in Agricultural Industrialization, the company operates nationwide, as well as in South-east Asia, with over 110 branches/subsidiary companies. The company focuses on the use of new feed stuffs, nutrition technology optimization, and processing technology improvements. Haida, another leading aquafeed production enterprise in China, has a reputation for service marketing and providing full service support on all aspects on seed selection, breeding pattern designs, breeding technology guidance, environmental control, disease control, market information, and management techniques for farmers. All in all, the improved stature of feed manufacturing enterprises (the proportion of professionals, integrated scale, technology level, profitability, etc.) and the business pattern (development of raw materials, dynamic adjustment of formulae, performance tracking and service marketing) have all contributed to the success of mariculture feed development.

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Section 6

Genetic Breeding and Seed Industry

6.1

Applications of Genetic Breeding Biotechnologies in Chinese Aquaculture

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6.1.1 Genetic Breeding History and Genetic Improvement Contribution in Aquaculture

Genetic improvement is believed to be a significant contributor to aquaculture production (Gui and Zhu 2012). Similarly in 2012, Prof. Trygve Gjedrem, expressed the personal opinion in a review, "I am particularly impressed with the genetic gain obtained for growth rate, and also for disease resistance in several aquatic species, which is five to six times higher than what has been achieved in terrestrial farm animals" (Gjedrem 2012).

In comparison to terrestrial farm animals, the domestication and selective breeding history is relatively short in fish and aquatic animals, and most knowledge originates from livestock genetics (Gjedrem 2012). Looking back at the modern history of genetic breeding in aquaculture, the firstly documented experimental research on fish dates back to the early 1920s (Embody and Hyford 1925). The world's first professional laboratory dedicated to genetic improvement of commercial fish species was founded only in 1930s in the Soviet Union by the late Prof. Dr. Valentin S. Kirpichnikov, the first honorable life member of the International Association for Genetics in Aquaculture (IAGA) (Schröder *et al*. 1993), and the very successful research facilities for selective breeding programs of Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*) were established in the 1970s in Norway (Gjedrem 2012). Since then, along with rapid advances in fish biology and modern genetics, a series of biotechnologies and genetic approaches, such as intraspecific crossbreeding, interspecific hybridization, selective breeding, molecular marker-assisted breeding, polyploidy breeding, nuclear transplantation, cell cloning, artificial gynogenesis or androgenesis, gene transfer engineering, and sex control, have been established and widely applied to breeding programs of numerous commercial aquatic species (Dunham 2011; Gui 2015a).

In China, some traditional selective breeding in aquaculture can be traced back to more than 2000 years ago. In ancient times, the first fish culturists held fish in ponds, observed the rate of growth, and learned how to breed them. Farmers noticing red mutants for the first time were enthused and chose these as broodstock. As the red color was an attractive trait and was favored by the elite in Chinese society, the mutants were chosen and selective breeding was thereby "born" in China. The earliest observed inheritable trait was a color variation in aquaculture genetics. Archaeological records suggest that the earliest goldfish were recognized as golden or red mutants of *Carassius auratus* about 1750 years ago, and gradually selected as different varieties according to their color variations, body shape changes, fin alterations, and eye configurations (Chen 1928). Also, red strains of common carp (*Cyprinus carpio*) were originally noticed by red mutants from farmed populations at least 400 years ago. These mutants were selected as ornamental carp for aquaria and water gardens through long-term inbreeding (Gui 1986; Zhang 1994).

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Even though there is a long history of traditional selective breeding in ornamental fish, truly scientific and systematic studies on fish genetics and breeding began only from the 1970s. A significant landmark that preceded this was the breakthrough in the early 1960s of artificial propagation of grass carp (*Ctenopharyngodon idella*), black carp (*Mylopharyngodon piceus*), silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*) (Wu and Zhong 1964), which established the technological basis for fish genetics and breeding studies. In 1972, China's first professional Department of Fish Genetics and Breeding was founded in the Institute of Hydrobiology, Chinese Academy of Sciences (IHB, CAS). Since then, several corresponding departments have been set up in different Institutes of the Chinese Academy of Fishery Sciences, with their main focus on theoretical and applied research into the genetics and breeding specifically of fish of economic importance. Along with national reforms and rapid advances in science and technology, a series of genetic breeding biotechnologies have been developed since 1980s in Chinese aquaculture. Some remarkable achievements, such as the first somatic cell-cloned fish (Chen *et al.* 1986), the first transgenic fish (Zhu *et al.* 1985), and the first discovery of multiple modes of allogynogenesis and sexual reproduction in polyploid gibel carp (Jiang *et al.* 1983; Zhou *et al.* 2000; Gui and Zhou 2010; Zhang and Gui 2015), were achieved at the IHB, CAS, and most of them played a leading role in this field. More importantly, three successive new varieties, – allogynogenetic gibel carp (*Carassius gibelio*) (Jiang *et al.* 1983), high dorsal allogynogenetic gibel carp (Zhu and Jiang 1993), and allogynogenetic gibel carp "CAS III" (Wang *et al.* 2011) – were bred through heterologous sperm-induced gynogenesis and used for various reproduction modes during the past 30 years, and extended to aquaculture practices throughout China (Gui and Zhou 2010; Gui and Zhu 2012*).* Through artificial gynogenesis and chromosome set manipulation, triploid and all-female hybrid common carp were also produced (Wu *et al.* 1986). Moreover, some sex-specific or sex chromosome-specific genetic markers were identified from yellow catfish (*Pelteobagrus fulvidraco*) and other bagrid catfish (*Pseudobagrus ussuriensis*) (Wang *et al.* 2009; Dan *et al.* 2013; Pan *et al.* 2015), and all-males of yellow catfish have been mass propagated and used for commercial aquaculture (Liu *et al.* 2013; Gui 2015b). In addition, some valuable breeding biotechnologies, including intraspecific crossbreeding, interspecific hybridization, molecular marker-assisted breeding, polyploidy breeding, molecular module-based designer breeding, and genome-wide genotyping-based selective breeding, have been established and widely applied to breeding programs of numerous commercial aquatic species in China (Gui 2015b). Rapid developments in fish biology and biotechnology spilled over, resulting in rapid developments in aquaculture genetics and breeding (Gui 2015a).

To promote genetic breeding and variety improvement, a National Certification Committee for Aquatic Stocks and Varieties (NCCASV) was established by the Chinese Government in 1991. From this point onwards, a complete biotechnology and management system for improved varieties and aquaculture seed industries was established. Up to the present, a total of 25 aquaculture genetic breeding centers, 90 aquaculture stock breeding stations, 423 aquaculture variety hatcheries, and about 15 000 aquaculture seed hatcheries have been established throughout different parts of China. Moreover, a total of 156 new aquaculture varieties, including 87 fish, 14 shrimp, 5 crab, 21 shellfish, 21 algae, 2 amphibian, 3 reptile, and 3 echinoderm, have been identified and approved by the National Certification Committee (Secretariat of National Certification Committee 2015). According to the origin and breeding method, they are further classified into 68 selected varieties, 20 intraspecific hybrid varieties, 23 interspecific hybrid varieties, 8 monosex varieties, and 7 mutagenic algal varieties (Tables 6.1.1– 6.1.5), as well as 30 improved exotics.

From the turn of the twenty-first century, Chinese aquaculture has transformed from traditional farming into a modern industry that calls for a strengthening of fundamental research (Gui and Zhu 2012). Since 1999, nine projects (Table 6.1.6) have been supported by the National Key Basic Research Program of China (973 Program). These projects have not only promoted significant advances in molecular-based studies on several economically important traits, including reproduction (Gui and Zhou 2010), sex (Mei and Gui 2015), growth (Dai *et al.* 2015), immune response and disease resistance (Zhang and Gui 2012; Zhu *et al.* 2012; Zhang and Gui 2015;), and hypoxia tolerance (Xiao 2015), but also built technical platforms for genome manipulation (Ye *et al.* 2015), sex manipulation (Mei and Gui 2015), molecular design breeding (Gui 2015a; Tong and Sun 2015), genome-wide genotyping-based selective breeding (Wang *et al.* 2012; Jiao *et al.* 2014), and other

Table 6.1.1 Improved varieties produced through population selection and family selection in China.

Varieties	Approval year	Registration number	Breeding biotechnology	Parents	Superiorities compared to wild or cultured population	Major institutes for breeding
Fish varieties						
"Xingguo" red carp	1996	GS-01-001-1996	population selection	natural mutant with red body in wild population	To grow faster than wild population by average 12%	Jiangxi Xingguo Red Common Carp Seed Farm and Jiangxi University
purse red carp	1996	GS-01-002-1996	population selection	natural mutant with red body in wild population	Purse shape with a large abdomen	Institute of Purse Red Common Carp in Jiangxi, Wuyuan and Jiangxi University
"Pengze" gibel carp	1996	GS-01-003-1996	population selection	wild population	To grow faster than wild population by average 56%	Jiangxi Fisheries Research Institute
"Jian" common carp	1996	GS-01-004-1996	population selection, artificial gynogenesis and intraspecific crossbreeding	purse red carp and Yuanjiang common carp	To grow faster than parents by average 45%	Freshwater Fisheries research center, CAFS
cold-resistant purse red carp	1996	GS-01-006-1996	individual selection and intraspecific crossbreeding	Heilongjiang common carp and purse red carp	To increase the growth rate and cold resistance ability than parents 10% and 95%, respectively	Heilongjiang Fisheries Research Institute, CAFS
Germany mirror carp	1996	GS-01-007-1996	population and family selection	mirror carp introduced from Germany	To increase the growth rate, survival rate and cold resistance ability than parents by average 10.8%, 25.6% and 33.8%, respectively	Heilongjiang Fisheries Research Institute, CAFS
"Songpu" common carp	1997	GS-01-002-1997	population selection, intraspecific crossbreeding, and artificial gynogenesis	Heilongjiang carp, purse red carp, Germany mirror carp and scattered scale mirror carp	To increase survival rate of naturally overwintering than parents by 97%	Heilongjiang Fisheries Research Institute, CAFS and others
"Pujiang No.1" blunt snout bream	2000	GS-01-001-2000	population selection	wild population in Yuni lake	To grow faster than wild population by average 20%	Shanghai Ocean University
"Wanan" transparent red carp	2000	GS-01-002-2000	population selection	wild population	To grow faster than wild population by average 12%	Jiangxi Wan'an Grassy Red Carp Seed Farm
"Songhe" common carp	2003	GS-01-002-2003	population selection, intraspecific crossbreeding, and artificial gynogenesis	Heilongjiang carp, purse red carp, and scattered scale mirror carp	To grow faster than parents by average 91.2%. The survival rate of naturally overwintering is about 95%.	Heilongjiang Fisheries Research Institute, CAFS

(Continued)

Table 6.1.1 (Continued)

Varieties	Approval year	Registration number	Breeding biotechnology	Parents	Superiorities compared to wild or cultured population	Major institutes for breeding
RR-B strain of Swordtail fish	2003	GS-01-003-2003	family selection	wild population	It has red eyes and body. The average genetic similarity is above 98%	Pearl River Fisheries Research Institute, CAFS
"Molong" carp	2003	GS-01-004-2003	population selection	ornamental carp	The ratio of individual with black body in offspring is above 87%	Tianjin Huanxin Seed Farm
"Yu-selected" yellow river carp	2004	GS-01-001-2004	population selection	wild population in Yellow river	To grow faster than wild population by average 36%	Henan Academy of Fishery Sciences
new GIFT Nile tilapia	2005	GS-01-001-2005	population selection	GIFT Nile tilapia	To increase growth rate and meat yield than parents by average 30% and 5%, respectively.	Shanghai Ocean University and others
"Gansu" golden trout	2006	GS-01-001-2006	population selection	Natural mutant with golden body in wild population	To grow faster than wild population by average 30%	Gansu Fishery Technology Extension Station
"Xia'ao No. 1" blue tilapia	2006	GS-01-002-2006	mass and marker-assisted selection	blue tilapia introduced from Auburn University in 1983	To be used as female parent to produce hybrid of *O. is aureus* X *O. niloticus* which has 93% of males in offspring	Freshwater Fisheries Research Center, CAFS
"Jinxi" common carp	2006	GS-01-003-2006	population selection	"Jian" common carp	To grow faster, easy to harvest, and have higher cold resistance ability than parents	Tianjin Huanxin Seed Farm
"Songpu" mirror carp	2008	GS-01-001-2008	population selection	Germany mirror carp F4	To grow faster than wild population by average 30%	Heilongjiang Fisheries Research Institute, CAFS
"Changfeng" silver carp	2010	GS-01-001-2010	population selection and artificial gynogenesis	wild population	To grow faster than wild population by 13–20%	Yangtze River Fisheries Research Institute, CAFS
"Jin" silver carp	2010	GS-01-002-2010	population selection	wild population in Yangtze river	To increase growth rate, absolute and relative reproductive abilities than wild population by average 10%, 74% and 45.3%, respectively	Tianjin Huanxin Seed Farm
FFRC strain common carp	2010	GS-01-003-2010	population and BLUP selection	"Jian" common carp and wild population in Yellow river	To grow faster than parents by 13–20%	Freshwater Fisheries research center, CAFS
"Youlu No.1" Largemouth bass	2010	GS-01-004-2010	population selection	4 cultured populations in China	To grow faster than parents by 17.8–25.3%	Pearl River Fisheries Research Institute, CAFS and others
"Minyou No. 1" large yellow croaker	2010	GS-01-005-2010	population selection and artificial gynogenesis	wild population in Guanjinyang	To increase growth rate and survival rate than parents by average 23.9% and 13.7%, respectively.	Jimei University and Ningde Fishery Technology Promotion Station

"Songpu" red mirror carp	2011	GS-01-001-2011	population selection	cold-resistant strain of purse red carp and scattered scale mirror carp	To increase growth rate, survival rate and cold resistance ability than parents by 21.61–35.59%, 12% and 8.5%, respectively	Heilongjiang Fisheries Research Institute, CAFS
"Longshen No. 1" Oujiang color carp	2011	GS-01-002-2011	population selection	wild population	To grow faster than wild population by 13.68–24.6% and have five different color patterns of body. The homozygosity of color patterns reaches 91.55–100%.	Shanghai Ocean University and Zhejiang Longquan "Oujiang" Color Carp Seed Farm
"East China Sea No.1" large yellow croaker	2013	GS-01-001-2013	population selection	wild population	To grow faster than wild population by average 15.57% and have a higher cold resistance ability.	Ningbo University and Gangwan Aquatic Fingerlings Limited Company of Xiangshan
"Huakang No.1" mandarinfish	2014	GS-01-001-2014	population selection	wild population	To grow faster than wild population by average 18.6%	Huazhong Agricultural University and others
"Easily caught" common carp	2014	GS-01-002-2014	population selection and intraspecific crossbreeding	Barbless carp, Heilongjiang carp and scattered scale mirror carp	The average harvesting of two years old fish by twice netting is about 96.5%.	Heilongjiang Fisheries Research Institute, CAFS
"Zhongwei No. 1" GIFT Nile tilapia	2014	GS-01-003-2014	family selection and BLUP selection	60 families of GIFT Nile tilapia introduced from Worldfish center	To increase growth rate and survival rate than parents by average 15% and 14%, respectively	Freshwater Fisheries research center, CAFS and Tongwei Co .,Ltd .,
Shrimp varieties						
"Yellow Sea No. 1" Chinese shrimp	2003	GS-01-001-2003	population and family selection	wild population in Yellow Sea	To grow faster than wild population by average 26.9%	Yellow Sea Fisheries Research Institute, CAFS and Fisheries Research Institute of Rizhao in Shandong Province
"Yellow Sea No2" Chinese shrimp	2008	GS-01-002-2008	population, family and BLUP selection	wild population	To grow faster than wild population by average 30% and have significantly higher disease resistant ability	Yellow sea Fisheries Research Institute, CAFS
"South Tai lake No. 2" Oriental River prawn	2009	GS-01-001-2009	family, marker-assisted and BLUP selection	cultured populations introduced from Burma and Japan	To increase growth rate and survival rate than parents by average 36% and 7%, respectively	Zhejiang Institute of Freshwater Fisheries and Zhejiang South Tailake Freshwater Fish Breeding Co., Ltd
"Kehai No. 1" white shrimp	2010	GS-01-006-2010	population selection	cultured populations introduced from Hawaii, USA	To increase growth rate and survival rate than parents by 12.6–41.7% and 3.0–14.0%, respectively.	Institute of Oceanology, CAS and others

(Continued)

Table 6.1.1 (Continued)

Varieties	Approval year	Registration number	Breeding biotechnology	Parents	Superiorities compared to wild or cultured population	Major institutes for breeding
"CAS No. 1" white shrimp	2010	GS-01-007-2010	population and familyselection	5 cultured populations in China and 2 populations introduced from USA	To increase growth rate and survival rate than parents by average 21.8% and 31.2%, respectively.	South China Sea Institute of Oceanology, CAS and others
"Zhongxing No. 1" white shrimp	2010	GS-01-008-2010	family selection	cultured population introduced from Hawaii, USA	To increase survival rate than parents by average 20%	Sun Yat-Sen University and Guangdong Evergreen Feed Industry Co., Ltd.
"South China sea No. 1" tiger shrimp	2010	GS-01-009-2010	population selection	4 wild populations in Hainan province and Phuket, Thailand	To increase growth rate and survival rate than parents by 21.6–24.4% and 8.4%, respectively	South China Sea Institute of Oceanology, CAS
"Guihai No.1" white shrimp	2012	GS-01-001-2012	family selection	cultured population introduced from USA	To increase growth rate and survival rate than parents by average 15% and 11.32%, respectively	Guangxi Fishery Institute
"Yellow sea No.3" Chinese shrimp	2013	GS-01-002-2013	population selection	"Yellow Sea No.1" Chinese shrimp and wild population	To increase growth rate and survival rate than parents by 11.8% and 15.2–21.2%, respectively	Yellow Sea Fisheries research institute, CAFS and others
"Minhai No. 1" kuruma shrimp	2014	GS-01-004-2014	family selection and BLUP selection	wild population	To grow faster than wild population by average 25.3%	Xiamen University
Crab varieties						
"Yangtze river No. 1" ***Chinese*** mitten crab	2011	GS-01-003-2011	population selection	wild population	To grow faster than wild population by average 16.7%.	Freshwater Fisheries Research Institute of Jiangsu Province
"Guanghe No. 1" ***Chinese*** mitten crab	2011	GS-01-004-2011	population selection	wild population in estuary of Liaohe	To increase growth rate and survival rate than wild population by average 25.98% and 48.59%, respectively	Panjin Guanghe crab Co., Ltd
"Huangxuan No.1" swimming crab	2012	GS-01-002-2012	population selection	4 wild populations	To increase the growth rate and survival rate than wild populations by average 20.12% and 30%, respectively	Yellow Sea Fisheries Research Institute, CAFS and Changyi Haifeng Aquiculture Co. Ltd
"Keyong No. 1" swimming crab	2013	GS-01-003-2013	population selection	wild populations	To increase the growth rate and survival rate than wild populations by average 11.3% and 13.9%, respectively.	Institute of Oceanology, CAS and Ningbo University
"Yangtze river No. 2" Chinese mitten crab	2013	GS-01-004-2013	population selection	wild population in Rhine River	To grow faster than wild population by average 19.4%.	Freshwater Fisheries Research Institute of Jiangsu Province

Shellfish varieties						
"CAS red" bay scallop	2006	GS-01-004-2006	family and population selection	northern subspecies of bay scallop and subspecies with orange shell color introduced from USA	To increase growth rate, survival rate and output rate of adductor muscle than parents by average 10–15%, 15–20%, and 26% respectively	Institute of Oceanology, CAS
"Haida golden" yesso scallop	2009	GS-01-002-2009	family and BLUP selection	natural mutant with orange adductor muscle in wild population	To increase growth rate and survival rate than wild population by average 20–30% and 25%, respectively. Additionally, it possesses orange adductor muscle with rich carotenoid.	Ocean University of China and Daliang Zhang Zidao Island Fisheries Group
"CAS No. 2" bay scallop	2011	GS-01-005-2011	population and family selection	northern subspecies bay scallop introduced from Massachusetts and Virginia, USA	To increase shell length, shell height, total weight and adductor muscle's weight than parents by average 14.69%, 13.66%, 26.57% and 49.23%, respectively. The ratio of individuals with purple shell color in offspring is above 96%.	Institute of oceanology, CAS
"Haida No. 1"pacific oyster	2013	GS-01-005-2013	population selection	wild population	To increase growth rate and meat yield than wild population by average 24.6% and 18.7%, respectively.	Ocean University of China
"Penglaihong No. 2" scallop	2013	GS-01-006-2013	Genome-wide selection and BLUP	"Penglaihong" scallop	To increase growth rate and meat yield than parents by average 25.43% and 27.11%, respectively.	Ocean University of China and others
"Kezhe No. 1" clam	2013	GS-01-007-2013	population and family selection	wild population	To increase the total weight, shell length, shell height, and shell width than wild population by average 31.6%, 21.7%, 23.2% and 20.3%, respectively.	Institute of Oceanology, CAS and others
"Zebra" manila clam	2014	GS-01-005-2014	population selection	wild population	To increase survival rate than wild population by average 10%	Dalian Ocean University
"Yueqing Bay No. 1" bloody clam	2014	GS-01-006-2014	population and family selection	wild population	To increase total weight and shell length than wild population by average 31% and 11.4%, respectively	Zhejiang Mariculture Research Institute and Institute of Oceanology, CAS
"Wanlihong" clam	2014	GS-01-007-2014	population and family selection	individuals with jujube red shell color in wild population	To grow faster than wild population by average 24.1%. The average content of delicious amino acid and average content of DHA and EPA of variety are about 20% and 25%, respectively.	Zhejiang Wanli University

(Continued)

Table 6.1.1 (Continued)

Varieties	Approval year	Registration number	Breeding biotechnology	Parents	Superiorities compared to wild or cultured population	Major institutes for breeding
"Haixuan No. 1" pearl oyster	2014	GS-01-008-2014	population and family selection	wild population	To increase shell length, shell width, retention rate, thickness of pearl layer, and yield of pearl than wild population by average 20.8%, 21.2%, 22.3%, 22.2% and 24.7%, respectively.	Guangdong Ocean University and others
"Nan'ao golden" scallop	2014	GS-01-009-2014	population and family selection	individuals with gold color in culture population	To increase the average content of carotenoid pigment and cold resistance ability than wild population by 10.8 times and 2.9 times, respectively.	Shantou University
Echinoderm varieties						
"Kongtong island No. 1" sea cucumber	2014	GS-01-015-2014	population selection	wild population	To grow faster than wild population by average 190%	Shandong Marine Resource and Environment Research Institute and others
"Dajin" sea urchin	2014	GS-01-016-2014	population and family selection	3 culture populations	To grow faster than wild population by average 31.7%	Dalian Ocean University
Algal varieties						
"901" kelp	1997	GS-01-001-1997	population selection and interspecific hybridization	*Laminaria longissimi* and *L. japonica*	To grow faster than parents by average 60%	Yantai Municipal Aqua-Tech Spreading Center
"981" macroalga	2006	GS-01-005-2006	population selection	wild population	To grow faster than wild population by average 9–10%/day and have higher agar content and ability of higher temperature resistance.	Institute of Oceanology, CAS and Ocean University of China
"Ailian bay" kelp	2010	GS-01-010-2010	population selection	cultured populations	To grow faster than parents by average 25% and have higher align and huge sporangium content.	Shandong Xunshan Corporation and Ocean University of China
"Huanguan No. 1" kelp	2011	GS-01-006-2011	population selection	cultured population	To increase growth rate and vegetable rate than parents by average 27% and 20%, respectively	Yellow Sea Fisheries research institute, CAFS and others
"Sanhai"kelp	2012	GS-01-003-2012	population selection and intraspecific crossbreeding	cultured population in Fujian, China and "Rongfu" kelp	The variety grows faster than parents by average 11.1%.	Ocean University of China and others
"Haibao No. 1" *U. pinnatifida*	2013	GS-01-010-2013	directional selection and haploid clone	wild population	To grow faster than parents by average 48.1%	Institute of Oceanology, CAS and Dalian Haibao Fisheries Co., Ltd

"205" kelp	2014	GS-01-010-2014	population selection and intraspecific crossbreeding	wild population introduced from Korea and cultured population in Fujian, China	To grow faster than parents by average 15%	Institute of Oceanology, CAS and Shandong Li-Jiang Aquaculture Co. Ltd
"Dongfang No. 7" kelp	2014	GS-01-011-2014	population selection and intraspecific crossbreeding	wild population introduced from Korea and population with wide and thin thallus.	To increase growth rate and thallus width than wild populations by average 25% and 20%, respectively.	Shandong Oriental Ocean Sci-tech Co., Ltd.
"Haibao No. 2" *Undaria pinnatifida*	2014	GS-01-012-2014	population selection	cultured population	To grow faster than parents by average 30%	Dalian Haibao Fisheries Company Limited and Institute of Oceanology, CAS
"Zhedong No.1" *Porphyra haitanensis*	2014	GS-01-013-2014	population selection, somatic regeneration and unisexual reproduction	wild population	To increase growth rate and thallus width than wild populations by average 15% and 8.8%, respectively.	Ningbo University and Zhejiang Mariculture Research Institute
Reptile varieties						
"Qingxi" Chinese black soft-shelled turtle	2008	GS-01-003-2008	population selection	wild population	To have higher contents of amino acids in muscle than those in Japanese variety, Tai lake and Taiwan populations.	Zhejiang Qingxi Turtle Co., Ltd

Table 6.1.2 Crossbred hybrid varieties produced through intraspecific hybridization in China.

Varieties	Approval year	Registration number	Breeding biotechnology	Parents	Superiorities compared to wild or cultured population	Major institutes for breeding
Fish varieties						
"Ying" common carp	1996	GS-02-003-1996	intraspecific crossbreeding and nuclear transplantation	scattered scale mirror carp (♀) X nucleo-cytoplasmic hybrid of common carp nuclei in crucian carp egg cytoplasm (♂)	To grow faster than parents by 47–60%	Yangtze River Fisheries Research Institute, CAFS
"Feng" common carp	1996	GS-02-004-1996	intraspecific crossbreeding	purse red carp (♀) X scattered scale mirror carp (♂)	To grow faster than parents by over 130%	Institute of Hydrobiology, Chinese Academy of Sciences (CAS)
"Heyuan" common carp	1996	GS-02-005-1996	intraspecific crossbreeding	purse red carp (♀) X Yuanjiang common carp (♂)	To grow faster, easy to harvest, and have higher cold resistance ability	Yangtze River Fisheries Research Institute, CAFS
"Yue" common carp	1996	GS-02-006-1996	intraspecific crossbreeding	purse red carp (♀) X Xiangjiang common carp (♂)	To grow faster 50–100% than Xiangjiang common carp and 25–20% than purse red carp	Hunan Normal University and Yangtze River Yuelu Farm
"three crossbred" common carp	1996	GS-02-007-1996	intraspecific crossbreeding	"Yuanhe" common carp (♀) X scattered scale mirror carp (♂)	To grow faster than parents	Yangtze River Fisheries Research Institute, CAFS
"Furong" common carp	1996	GS-02-008-1996	intraspecific crossbreeding	scattered scale mirror carp (♀) X "Xingguo" red carp (♂)	To grow faster than parents by 40–60%	Hunan Fisheries Research Institute
Red white corporal and long tail crucian carp	2002	GS-02-001-2002	intraspecific crossbreeding	red crucian carp (♀) X Japanese crucian carp (♂)	red and white color patterns of body with long tail fin.	Tianjin Huanxin Seed Farm
Blue black, black spot and long tail crucian carp	2002	GS-02-002-2002	intraspecific crossbreeding	goldfish (♀) X color crucian carp (♂)	red head and long tail fin.	Tianjin Huanxin Seed Farm
"Denmark and French" turbot	2010	GS-02-001-2010	intraspecific crossbreeding	population introduced from Denmark (♀) X population introduced from French (♂)	To increase growth rate and survival rate than parents by average 24% and 18%, respectively	Yellow Sea Fisheries Research Institute, CAFS and Huanghai Aquaculture Ltd., Haiyang
"Pingyou No.1" flounder	2010	GS-02-002-2010	intraspecific crossbreeding	(population resistant to *Vibrio anguillarum* in China (♀) X populations introduced from Japanese (♂)) (♀) X populations introduced from Korea (♂)	To increase growth rate and survival rate than parents by average 30% and 20%, respectively	Yellow Sea Fisheries Research Institute, CAFS and Huanghai Aquaculture Ltd., Haiyang
"Jiangfeng No.1" channel catfish	2013	GS-02-003-2013	intraspecific crossbreeding and family selection	population introduced from Mississippi, USA in 2001 (♀) X population introduced from Arkansas, USA in 2003 (♂)	To grow faster than parents by average 25.3%	Jiangsu Institute of Freshwater Fisheries and others

"Duobao NO. 1" flounder	2014	GS-02-001-2014	intraspecific crossbreeding, population selection and family selection	Four populations introduced from England, France, Denmark and Norway, respectively.	To increase growth rate and survival rate than parents by average 36% and 25%, respectively	Yellow Sea Fisheries Research Institute, CAFS and Yantai Tianyuan Aquatic Limited Corporation
"Jinxin No. 2" common carp	2014	GS-02-006-2014	intraspecific crossbreeding and population selection	Ukraine scaly carp (♀) X "Jinxin" common carp (♂)	To grow faster than Ukraine scaly carp and "Jinxin" common carp by average 50% and 20%, respectively	Tianjin Huanxin Seed Farm
Shrimp varieties						
Renhai No. 1" white prawn	2014	GS-02-007-2014	intraspecific crossbreeding and population selection	Strains of Miami, USA (♀) X strains of Oahu, Hawa, USA (♂)	To increase growth rate and survival rate than parents by average 21% and 13%, respectively	Yellow Sea Fisheries Research Institute, CAFS and Qingdao Higene Aquabreeding Technology Co. Ltd.
Shellfish varieties						
"Dalian No.1" pacific abalone	2004	GS-02-003-2004	intraspecific crossbreeding	population in Daliang, China (♀) X population introduced from Iwate, Japanese (♂)	To increase the growth rate and survival rate than parents by 20% and 180–230%, respectively.	Institute of Oceanology, CAS
"Dongyou No.1" abalone	2009	GS-02-004-2009	intraspecific crossbreeding and population selection	population in Taiwan (♀) X population introduced from Japanese (♂)	To increase survival rate than parents by average 18%	Xiamen University
"Haiyou No. 1" pearl oyster	2011	GS-02-002-2011	intraspecific crossbreeding and MAS	population introduced from India (♀) X wild population in Sanya, China (♂)	To increase the average yield of pearl and the rate of pearl with good quality than parents by average 15% and 16%, respectively.	Hainan University
Echinoderm varieties						
"CAFS No.1" sea cucumber	2009	GS-02-005-2009	intraspecific crossbreeding and population selection	population in Daliang, China (♀) X Vladivostok, Russian (♂)	To increase growth rate and survival rate than parents by average 30% and 30%, respectively	Dalian Fisheries University and others
Algal varieties						
"Ronghu" kelp	2004	GS-02-002-2004	intraspecific hybridization and population selection	*L. japonica* (♀) X "Yuanza No. 10" kelp	To grow faster than parents by 25–27%	Ocean University of China
"Dongfang No. 6" hybrid kelp	2013	GS-02-004-2013	intraspecific crossbreeding	wild population introduced from Korea (♀) X cultured population in Fujian, China (♂)	To grow faster than parents by 36–46%	Shandong Oriental Ocean Sci-tech Co., Ltd.

Table 6.1.3 Crossbred hybrid varieties produced through interspecific hybridization in China.

Varieties	Approval year	Registration number	Breeding biotechnology	Parents	Superiorities compared to wild or cultured population	Major institutes for breeding
Fish varieties						
"Ao'ni" hybrid between Blue tilapia and Nile tilapia	1996	GS-02-001-1996	interspecific hybridization	Blue tilapia (♀) X Nile tilapia (♂)	To grow faster than Nile tilapia and Blue tilapia by 17–72%, respectively	Guangzhou Fisheries Research Institute and Freshwater Fisheries research center, CAFS
"Fushou" hybrid between Nile tilapia and Mozambique tilapia	1996	GS-02-002-1996	interspecific hybridization	Nile tilapia (♀) X Mozambique tilapia (♂)	To grow faster than Mozambique tilapia and Nile tilapia by 30–125% and 10–29%, respectively	Pearl River Fisheries Research Institute, CAFS
"Xiangyun" hybrid carp	2001	GS-02-001-2001	interspecific hybridization	common carp (♀) X tetraploid hybrid between red crucian carp and common carp (♂)	To grow faster than parents by 30–50%	Hunan Normal University and others
"Xiangyun" hybrid crucian carp	2001	GS-02-002-2001	interspecific hybridization	Japanese crucian carp (♀) X tetraploid hybrid between red crucian carp and common carp (♂)	To grow faster than diploid crucian carp by over 300%	Hunan Normal University and others
"Golden" hybrid between common carp and crucian carp	2007	GS-02-001-2007	interspecific hybridization	scattered scale mirror carp (♀) X red crucian carp (♂)	To grow faster than diploid crucian carp by average 200%	Tianjin Huanxin Seed Farm
"Xiangyun No.2" hybrid crucian carp	2008	GS-02-001-2008	interspecific hybridization	improved red crucian carp (♀) X tetraploid hybrid between red crucian carp and common carp (♂)	To grow faster than diploid crucian carp by over 300%	Hunan Normal University
"Furong" hybrid between common carp and crucian carp	2009	GS-02-001-2009	interspecific hybridization	(scattered scale mirror carp (♀) X "Xingguo" red carp (♂)) X red crucian carp	To grow faster than parents by average 56%	Hunan Fisheries Research Institute
"Jili" hybrid between new GIFT Nile tilapia and black-chip tilapia	2009	GS-02-002-2009	interspecific hybridization	new GIFT Nile tilapia (♀) X black-chip tilapia (♂)	To have higher salinity resistance ability	Shanghai Ocean University
"Hangli No. 1" hybrid between Taiwan snakehead and Northern snakehead	2009	GS-02-003-2009	interspecific hybridization	Taiwan snakehead (♀) X Northern snakehead (♂)	To grow faster than Taiwan snakehead and Northern snakehead by 20% and 50%, respectively. It can be fed by commercial feeds.	Institute of Biotechnology Hangzhou Academy of Agriculture Science

hybrid between bluntnose black bream and *Xenocypris davidi* Bleeker	2011	GS-02-001-2011	interspecific hybridization	bluntnose black bream (♀) X *X. davidi* Bleeker (♂)	To grow faster than Bluntnose black bream and *X. davidi* by 11.67% and 37.5%, respectively	Hunan Normal University
"Xianfeng No. 1" hybrid between topmouth culter and *Anoherythroculter nigrocauda*	2012	GS-02-001-2012	interspecific hybridization and MAS	topmouth culter (♀) X *A. nigrocauda* (♂),	To grow faster than *A. nigrocauda* and topmouth culter by 23–29% and 100–172%, respectively	Wuhan Fisheries Research Institute and Wuhan Xianfeng Aquaculture Technology Co. Ltd
"Lutai" hybrid between bluntnose black bream and topmouth culter	2012	GS-02-002-2012	interspecific hybridization and population selection	bluntnose black bream (♀) X topmouth culter (♂)	To grow faster than parents by 16.2–64.52 %	Tianjin Huanxin Seed Farm
"Jinxi black" hybrid crucian carp	2013	GS-02-002-2013	interspecific hybridization and population selection	red crucian carp (♀) X tetraploid hybrid between red crucian carp and "Molong"common carp (♂) (♂)	To grow faster than "pengze" gibel carp by average 10%	Tianjin Huanxin Seed Farm
"Wuban" hybrid between Northern snakehead and Taiwan snakehead	2014	GS-02-002-2014	interspecific hybridization and population selection	Northern snakehead (♀) X Taiwan snakehead (♂)	To grow faster than Northern snakehead and Taiwan snakehead by 37.6% and 123.7%, respectively	Pearl River Fisheries Research Institute, CAFS and others
"ji'ao" hybrid between new GIFT Nile tilapia and blue tilapia	2014	GS-02-003-2014	interspecific hybridization and population selection	new GIFT Nile tilapia (♀) X blue tilapia (♂)	To grow faster than blue tilapia by average 25%. The ratio of male individuals in offspring is above 92%.	Maoming Weiye Seed Farm and Shanghai Ocean University
hybrid between bluntnose black bream and topmouth culter	2014	GS-02-004-2014	interspecific hybridization and population selection	(bluntnose black bream (♀) X topmouth culter (♂)) (♀) X bluntnose black bream (♂)	To grow faster than parents by average 20%.	Hunan Normal University
"Qiufu"hybrid between spotted mandarin fish and mandarin fish	2014	GS-02-005-2014	interspecific hybridization and population selection	spotted mandarin fish (♀) X mandarin fish (♂)	To grow faster than spotted mandarin fish by average 160%.	Chizhou Qiupu Special Aquaculture Development Co. Ltd. and Shanghai Ocean University
Shrimp varieties						
"Taihu No.1" hybrid between river prawn and *Macrobrachium rosenbergii*)	2008	GS-02-002-2008	interspecific hybridization	river prawn and prawn (*M. rosenbergii*)	To grow faster than parents by average 30%	Freshwater Fisheries Research Center, CAFS

(Continued)

Table 6.1.3 (Continued)

Varieties	Approval year	Registration number	Breeding biotechnology	Parents	Superiorities compared to wild or cultured population	Major institutes for breeding
Shellfish varieties						
"Penglaihong" hybrid between *Chlamys .farreri* and *C. nobilis*	2005	GS-02-001-2005	interspecific hybridization population selection, and artificial gynogenesis	*C. farreri* introduced from Japanese (♀) X artificial gynogenetic population of *C. nobilis* (♂)	To grow faster than parents by 35-68%	Ocean University of China
"Kangle" hybrid between *Hyriopsis schlegel* and *H. cumingii*	2006	GS-02-001-2006	interspecific hybridization and population selection	*H. schlegel* (♀) X *H. cumingii* (♂)	To increase yield of pearl than *H.schlegel* and *H. cumingii* by average 15% and 32%, respectively.	Shanghai Ocean University
"XiPan" hybrid between *Haliotis sieboldii* and *H. discus discus*	2014	GS-02-008-2014	interspecific hybridization and population selection	*H. sieboldii* (♀) X *H. discus discus* (♂)	To grow faster than *H. discus* and *H. sieboldii* by average 6.3% and 8.9% and increase the survival rate than *H. discus* and *H. sieboldii* by average 33.4% and 35%, respectively	Xiamen University
Algal varieties						
"Dongfang No. 2" hybrid between *Laminaria japonica* and *L. logissima mijabe*	2004	GS-02-001-2004	interspecific hybridization	*L. japonica* (♀) X *L. logissima mijabe* (♂)	To grow faster than "901" kelp by average 28%	Shandong Oriental Ocean Sci-tech Co., Ltd.
"Dongfang No. 3" between *L. japonica* and *L. logissima mijabe*	2007	GS-02-002-2007	interspecific hybridization	Strain 7 of *L. japonica* (♀) X strain LZZ of *L. logissima mijabe* (♂)	To grow faster than parents by average 60%	Shandong Oriental Ocean Sci-tech Co., Ltd.

Table 6.1.4 Mono-sex varieties of fish species cultured in China.

Varieties	Approval year	Registration number	Breeding biotechnology	Parents	Superiorities compared to wild or cultured population	Major institutes for breeding
"Songpu" gibel carp	1996	GS-01-005-1996	natural gynogenesis, sex reversal	"Fangzheng" gibel carp	To grow faster than parents by average 10%.	Heilongjiang Fisheries Research Institute, CAFS
"High dorsal" allogynogenetic ***gibel carp***	1996	GS-02-009-1996	natural gynogenesis and marker-assisted selection	"Fangzheng" gibel carp	To grow faster than allogynogenetic ***gibel carp*** by average 10%.	Institute of Hydrobiology, CAS
"Pingxiang" red transparent gibel carp	2007	GS-01-001-2007	natural gynogenesis and population selection	natural mutant with red transparent body in wild population	To grow faster than wild populations	Jiangxi Pingxiang Fisheries Research Institute and others
"CAS ***III***" allogynogenetic ***gibel carp***	2007	GS-01-002-2007	natural gynogenesis, androgensis and marker-assisted selection	gynogenetic gibel carp clone D (♀) X A(♂)	To increase ***growth rate and*** meat yield than "high dorsal" allogynogenetic ***gibel carp by average*** 20% and 6%, respectively. Additionally, it has higher ability to a liver-parasitized myxosporean.	Institute of Hydrobiology, CAS
"all-male No. 1" yellow catfish	2010	GS-04-001-2010	sex reversal, artificial gynogenesis, sex-chromosome linked marker-assisted selection	wild population (♀) X yellow catfish YY (♂)	To grow faster than wild population by average 45.5%. The ratio of male individuals in offspring is above 95%.	The Institute of Hydro-ecology, Ministry of Water Resources and CAS, Institute of Hydrobiology, CAS and others
"North flounder No. 1" Japanese flounder	2011	GS-04-001-2011	artificial gynogenesis and sex reversal	wild population	To grow faster than wild population by 15.59–23.37%. The ratio of female individuals in offspring is above 90%.	Beidaihe Central Experiment Station, CAFS
"Luxiong No.1" Nile tilapia	2012	GS-04-001-2012	sex reversal, artificial gynogenesis, sex-chromosome linked marker-assisted selection	improved strain of Nile tilapia (♀) X Nile tilapia YY (♂)	The ratio of male individuals in offspring is above 99%.	Xiamen Luye Fisheries Co., Ltd. And others
"North flounder No.2" Japanese flounder	2013	GS-02-001-2013	sex reversal and artificial gynogenesis	wild population	To grow faster than wild population by average 50%. The ratio of female individuals in offspring is above 90%.	Beidaihe Central Experiment Station, CAFS and Center of Nature Resources and Environment Research, CAFS

Table 6.1.5 Algal varieties produced through mutagenesis in China.

Varieties-	Approval year	Registration number	Breeding biotechnology	Parents	Superiorities compared to wild or cultured population	Major institutes for breeding
"Shenfu-1" *P. haitanensis*	2009	GS-01-003-2009	inducing mutagenesis, somatic regeneration, and unisexual reproduction	wild population	To grow faster than wild population by average 25%. The total chlorophyll a, phycoerythrin and phycocyanin contents are higher by average 14%. The contents of protein and free amino acid increase about 10.8% and 24.8% respectively.	Shanghai Ocean University
"Minfeng No. 1" *P. haitanensis*	2012	GS-04-002-2012	inducing mutagenesis, intraspecific crossbreeding, somatic regeneration, unisexual reproduction	wild population	To grow faster than wild population by average 25% and have a higher hot resistance ability	Jimei University
"Sutong No. 1" *P. yezoensis* Ueda	2013	GS-01-008-2013	inducing mutagenesis and population selection	wild population	To increase grow rate and protein content than wild population by 18.6–37.8% and 15.4%	Zhejiang Mariculture Research Institute and Changshu Institute of Technology
"Shenfu No.2" *P. haitanensis*	2013	GS-01-009-2013	inducing mutagenesis, somatic regeneration, unisexual reproduction	wild population	To grow faster than wild population by 28–35%	Shanghai Ocean University and others
"2007" *Gracilaria lemaneiformis*	2013	GS-01-011-2013	inducing mutagenesis and directional selection	"985" *G. lemaneiformis*	To grow faster than "985" *G. lemaneiformis* by average 17.7%.	Ocean University of China and Shantou University
"Sutong No. 2" *P. yezoensis* Ueda	2014	GS-01-014-2014	inducing mutagenesis, unisexual reproduction and population selection	wild population	To grow faster than wild population by average 10%	Changshu Institute of Technology and Jiangsu Institute of marine fisheries
"Lulong" *G. lemaneiformis*	2014	GS-04-001-2014	inducing mutagenesis, population selection and intraspecific crossbreeding	wild population	To increase growth rate and protein content than wild population by average 15% and 12%, respectively.	Ocean University of China and others

Table 6.1.6 The basic aquaculture projects supported by National Key Basic Research Program of China.

Project	Start	End	Principal Institutions	Chief Scientist
Fundamental research on the disease occurrence and disease resistance of the commercially important organisms in mariculture	Aug, 1999	Jul, 2004	Institute of Oceanology, Chinese Academy of Sciences	Jian-Hai Xiang
Studies on genetic and developmental biological basis for improvement of important aquaculture fishes	Oct, 2004	Sept, 2009	Institute of Hydrobiology, Chinese Academy of Sciences	Jian-Fang Gui
Studies on the disease outbreak and immunological control of commercially important organisms in mariculture	Jan, 2006	Aug, 2011	Institute of Oceanology, Chinese Academy of Sciences	Jian-Hai Xiang
Investigation of crucial scientific issues in intensive aquaculture of freshwater ponds in China	Jan, 2009	Aug, 2013	Institute of Hydrobiology, Chinese Academy of Sciences	Pin Nie
Basic studies on functional genomics and molecular design breeding in important aquaculture fishes	Jan, 2010	Aug, 2014	Institute of Hydrobiology, Chinese Academy of Sciences	Jian-Fang Gui
The molecular basis for the important economic traits of the mollusks and the study on the molecular design breeding	Jan, 2010	Aug, 2014	Institute of Oceanology, Chinese Academy of Sciences	Guo-Fan Zhang
Basic studies on outbreak mechanism and immunological control of main virus diseases in marine aquaculture animals	Jan, 2012	Aug, 2016	Institute of Oceanology, Chinese Academy of Sciences	Lin-Sheng Song
Regulation mechanism of efficient utilization of aquaculture fish protein	Jan, 2014	Aug, 2019	Guangdong Ocean University	Kang-Sheng Mai
Studies on the key biological problems of Chinese sturgeon aquaculture in controlled water	Jan, 2015	Aug, 2020	Institute of Hydroecology, Ministry of Water Resources & Chinese Academy of Sciences	Jian-Bo Chang

biotechnologies (Xu *et al.* 2015). Significantly, most of these biotechnologies have been successfully applied to genetic breeding in aquaculture (Gui 2015b).

6.1.2 Genetic Breeding Biotechnologies and Bred Varieties

6.1.2.1 Selective Breeding and Selected Varieties

Selection is the basis of all breeding techniques. The purpose of selective breeding is to choose and breed individuals or populations with desirable traits, through four or more generations. As early as the 1920s, Embody and Hyford initiated a selective program to select surviving brook trout (*Salvelinus fontinalis*) from a population infected with furunculosis. After three generations of selection, the survival rate increased from 2 percent in the initial population, to 69 percent (Embody and Hyford 1925). Since the 1970s, mass or population selection has become a common strategy in aquatic animal breeding triggered by developments in aquaculture. Family selection has been successfully applied to aquaculture species from the 1980s. Moreover, Best Linear Unbiased Prediction (BLUP) methodology has been used to evaluate breeding values for each individual, family or population since the late 1990s (Gall and Bakar 2002; Ponzoni *et al.* 2005). These selective breeding techniques have resulted in significant improvement in growth rate, with 10–20 percent gain per generation in several of the main aquaculture species, including rainbow trout, Atlantic salmon, channel catfish (*Ictalurus punctatus*), coho salmon (*O. kisutch*), Nile tilapia (*Oreochromis niloticus*), common carp, freshwater prawn, and others (Hulata 2001; Nguyen 2015).

In China, the current selective breeding programs including population selection and family selection in aquaculture have been initiated from the 1970s (Hulata 2001). During the last 30 years, 68 improved varieties (Table 6.1.1) have been obtained for numerous aquaculture species. In common carp alone, more than 10 improved varieties have been bred by population or family selection, such as "Xingguo" red carp, purse red carp, "Wanan" transparent red carp, "Yu-selected" yellow river carp, "Jinxi" carp, "Songpu" mirror carp, "Songpu" red mirror carp, "Longshen No. 1", Oujiang color carp, Germany mirror carp, "Molong" carp, and FFRC strain common carp. Other improved varieties in fish, are detailed in Table 6.1.1. Since 2004, BLUP methodology has been used to analyze selection data on shrimps, prawns, crabs and fish (Table 6.1.1). Significantly, the application of these varieties has greatly promoted the development of the aquaculture industry. For example, selected and hybrid varieties of common carp are utilized 100 percent in the common carp industry, that produced 3 357 962 tonnes in 2015 (China Fishery Statistical Yearbook 2016).

6.1.2.2 Intraspecific Hybridization and Crossbred Hybrid Varieties

Intraspecific hybridization can crossbreed, resulting in excellent hybrids with better economic traits, through integrating the parental genomes. In the past, significant heterosis was observed in F1 hybrids between different strains of channel catfish, rainbow trout, common carp, and Pacific oyster (*Crassostrea gigas*) (Hulata 2001). In channel catfish, six of the nine hybrids were observed to exhibit heterosis (Dunham and Smitherman 1983). In common carp, numerous hybrids were crossbred among diverse strains in China, Israel, Vietnam and Hungary (Hulata 2001). In China alone, 20 hybrid varieties, including "Yin" common carp, "Feng" common carp, Heyuan" common carp, "Yue" common carp, "three crossbred" common carp, "Furong" common carp, "Jinxin No. 2" common carp, "Danmark-French" turbot (*Scophthalmus maximus*), "Duobao No. 1" and "Pingyou No.1" flounder (*Paralichthys dentatus*), "Renhai No. 1" white prawn, "Dalian No.1" abalone (*Haliotis discus hannai*), "Dongyou No. 1" abalone, "Haiyou No. 1", pearl oyster (*Pinctada margaritifera*), and "CAFS No. 1" sea cucumber (*Apostichopus japonicus*), have been crossbred by intraspecific hybridization (Table 6.1.2).

6.1.2.3 Interspecific Hybridization and Crossbred Hybrid Varieties

Interspecific hybridization is a powerful breeding strategy, and possibly results in genome level changes. For example, diploid, triploid, and tetraploid hybrids have been obtained through interspecific hybridization between common carp and crucian carp (*C. auratus*) (Liu 2010). Some hybrids exhibit heterosis in growth rate and disease resistance that result from the combination of the beneficial traits from both parents. More than 20 improved hybrid varieties (Table 6.1.3) have been obtained by interspecific hybridization since the 1950s (Liu 2010) and for example include "Xiangyun" and "Xiangyun No. 2" hybrid crucian carp, "Furong" hybrid between *Cyprinus carpio* (♀) and *Carassius carassius* red variety (♂), "Ao'ni" hybrid between *Oreochromis aureus* (♀) and *O. niloticus* (♂), "Fushou" hybrid between *O. niloticus* (♀) and *O. mossambicus* (♂) and so on (Table 6.1.3).

6.1.2.4 Polyploidy Breeding and Polyploid Varieties

Polyploids, containing three or more complete chromosome sets, are widespread in plants and animals. Polyploids are expected to have a better growth performance than their normal diploid siblings in theory (Dunham 2011). Among 1100 fish species whose chromosomes have been analyzed, at least 60 are polyploids. Polyploids have been bred in fish, shrimps, crabs and shellfish by retaining the first and/or second polar body (Dunham 2011). The methods used in polyploidy induction have been described (Piferrer *et al.* 2009; Dunham 2011), but it is difficult to guarantee a high proportion of triploids in offspring by direct induction with physical and chemical methods. Mating of tetraploids with diploids result in the large scale production of triploids. For example, triploid oysters were found to be preferred over diploids in the aquaculture industry owing to their faster growth and better flavor (Allen and Downing 1986), and the artificially induced tetraploid oysters reproduce abundant triploid oysters by mating with diploids, and this led to an overall expansion of triploid oysters in the shellfish aquaculture industry (Guo *et al.* 1996).

Interspecific hybridization is one of the most commonly utilized biological methods to obtain polyploids in fish. The most representative case is massive production of sterile triploid hybrids at Hunan Normal University. Fertile allotetraploid hybrid individuals were obtained by crossing red crucian carp and common carp. These allotetraploid hybrid males were crossed with diploid Japanese crucian carp when infertile triploid hybrids of novel variety “XiangYun” hybrid crucian carp were bred and extended to culture practices (Liu 2010; Xu *et al.* 2015). Through similar approaches, two further hybrid varieties (Table 6.1.3), “Xiangyun No. 2” hybrid crucian carp, and “Jinxin black” hybrid crucian carp, were also bred.

6.1.2.5 Gynogenesis and All-Female Varieties

In gynogensis, the egg is activated by a heterologous sperm and the resulting offspring carries genetic materials from the female parent only (Gui 1989; Gui and Zhou 2010; Avise 2015). Since the first gynogenetic fish, the Amazon Molly *Poecilia formosa*, was reported by Hubbs and Hubbs (1932), about 30 unisexual species have been reported to reproduce by gynogenesis. Among natural gynogenetic fish, natural polyploid gibel carp *Carassius gibelio* is an important aquaculture species, and is able to produce all-female offspring when its eggs are activated by heterologous sperm (termed allogynogenesis or kleptogenesis) (Gui and Zhou 2010). Owing to the discovery of dual modes of unisexual gynogenesis and sexual reproduction, three all-female monosex varieties, such as allogynogenetic gibel carp (Jiang *et al.* 1983), high dorsal allogynogenetic gibel carp (Zhu and Jiang 1993), and allogynogenetic gibel carp “CAS III” (Wang *et al.* 2011) have been bred, and their application has become a typical case of use of all-female varieties in aquaculture (Gui and Zhou 2010, 2012; Zhou and Gui 2016). In addition, other local stocks of gibel carp, such as “Songpu” gibel carp (Liu *et al.* 1994), “Pengze” gibel carp (Li *et al.* 2002), and “Pingxiang” red transparent crucian carp (Hong *et al.* 2005) (Table 6.1.4), were also reported to adopt allogynogenesis to produce all-female populations in aquaculture.

Artificial gynogenesis is a frequently used method to produce XX all-female populations in aquatic animals with XX/XY a sex-determining system. The haploid eggs are activated by genetically inactivated sperm, and then induced into diploid offspring by thermal shock or hydrostatic pressure. Artificial gynogenesis has been performed in many (>100) fish species, including common carp, grass carp, bluntsnout bream, large yellow croaker, tilapia, rainbow trout, flounder, turbot and so on (Komen and Thorgaard 2007; Mei and Gui 2015). Several all-female varieties, such as all-female common carp, “North flounder No. 1” and “North flounder No. 2”, were bred by using the combination of artificial gynogenesis and sex reversal. For example, individuals of gynogenetic common carp were fed with 17α-methyltestosterone (MT) to produce functionally physiological XX males. These physiological XX males were then crossed with pure red common carp to generate all-female common carp (Wu *et al.* 1986; Chen *et al.* 1990). In addition, artificial gynogenesis can rapidly purify genetic material of gametes to obtain pure inbred lines. Artificial gynogenesis has been used to produce several varieties, including “Jian” common carp, “Songpu” common carp, “Songhe” common carp, “Changfeng” silver carp, and “Minyou No. 1” large yellow croaker (Table 6.1.1), and it has been demonstrated that these have a shortened maturation.

6.1.2.6 Androgenesis

Unlike gynogenesis, androgenesis is accomplished by doubling the paternal genome in a genetically inactivated egg. Similar to gynogenesis, androgenesis has also been used to establish pure lines rapidly, to elucidate sex determination mechanisms, and to create monosex populations (Dunham 2011). Androgenesis also occurs occasionally in nature. For example, in hybrid offspring of common carp (♀) and grass carp (♂), diploid grass carp were found (Stanley 1976). An androgenetic nucleo-cytoplasmic hybrid clone, nominated as allogynogenetic gibel carp "CAS III" (Table 6.1.4), was created by using sexual reproduction mating between gibel carp clone D and clone A, and subsequent seven-generation multiplying of gynogenesis (Gui and Zhou 2010; Wang *et al.* 2011). In addition, artificial androgenesis has been attempted in rainbow trout, masou salmon, tilapia, common carp, grass carp, yellow catfish and so on (Komen and Thorgaard 2007). Because of the destruction of mitochondrial DNA (mtDNA), damaging of the egg cytoplasm and other negative impacts on the doubling of sperm nucleus genome, the survival rate of diploid induced by androgenesis is very low. To date, there are no varieties obtained through artificial androgenesis in aquatic animals.

6.1.2.7 Sex Manipulation and Mono-Sex Varieties

In long-term field surveys and aquaculture practices, researchers have observed significant sexual dimorphism in growth rate and body size in more than 20 fish species (Mei and Gui 2015). Culture practices that are based on the sex that has the most desirable traits, such as for example faster rate of growth, result in higher economic benefits.

During early gonadal differentiation, sex of aquatic animals is often influenced by external factors such as temperature, pH and hormones. The sex of a great number of fish species, including gibel carp, common carp, rainbow trout, Atlantic salmon, yellow catfish, orange-spotted grouper (*Epinephelus coioides*) and so on, can be altered by treating with androgen, 17β-estradiol or other sex hormones. XY physiological females or XX physiological males can be produced by 17α-ethinyloestradiol (EE2) treatment or 17α-methyltestosterone (MT), respectively (Li *et al.* 2016). For example, 98–100 percent male blue tilapia (*Oreochromis aureus*) were successfully sex reversed by oral administration of androgen ethinyltestosterone (Guerrero 1975). However, sex-reversed populations produced using hormones are prohibited because the metabolic rates of these sex hormones, and the derivatives thereof, are still unknown. In consideration of food security, other feasible procedures were established, such as, gynogenesis and androgenesis, which are effective ways to produce mono-sex populations.

In tilapia, mono-sex populations can be produced by interspecific hybridization. Predominately males can be generated by crossing two tilapia species with different sex-determining mechanisms (XX/XY or ZZ/ZW system). For example, an all-male tilapia population was obtained by crossing female Mozambique tilapia (*O. mossambicus*) (XX) with male Wami tilapia (*O. hornorum*) (ZZ) (Hickling 1960). Other tilapia crosses producing predominately male offspring are Nile tilapia with blue tilapia, with Wami tilapia or with the longfin tilapia (*O. macrochir*), respectively (Bartley *et al.* 2000). Furthermore, the offspring of several hybrid groups exhibit significant advantages in growth and survival (Wohlfarth *et al.* 1990). When Nile tilapia was hybridized with the variety "Xia'ao No. 1" selected from blue tilapia by population selection and marker-assisted selection, hybrid offspring had above 93 percent males, and these have been extended widely in China (Yang *et al.* 2005) (Table 6.1.1).

Recently, a great number of sex-specific or sex chromosome-specific genetic markers have been identified from yellow catfish, bagrid catfish (*Pseudobagrus ussuriensis*) (Wang *et al.* 2009; Dan *et al.* 2013; Pan *et al.* 2015; Ma *et al.* 2016), channel catfish, rainbow trout, Japanese pufferfish (*Takifugu rubripes*), Nile tilapia, turbot, Atlantic halibut (*Hippoglossus hippoglossus*), and others. These markers offer an efficient technological method for mass production of all-male or all-female populations (Mei and Gui 2015). For example, "all-male No. 1" yellow catfish and "Luxiong No.1" Nile tilapia have been bred by using the combination of artificial gynogenesis, sex reversal, and X- and Y-chromosome-specific molecular markers (Dan *et al.* 2013; Gui and Zhu 2012; Mei and Gui 2015; Wang *et al.* 2009) (Table 6.1.4), and have been mass produced for commercial aquaculture (Liu *et al.* 2013; Gui 2015b). Based on the successful breeding approach of "all-male No. 1" yellow catfish, the integration has been proposed of sex-manipulation biotechnologies for mass production of all-male populations (Gui and Zhu 2012) and all-female populations in fish with XX/XY sex determination system (Mei and Gui 2015; Zhou and Gui 2016).

6.1.2.8 Marker-Assisted Selection (MAS) and the Selected Varieties

Breeding programs based on population and family selection usually take a long time to yield results. The idea of marker-assisted selection proposed in the 1960s has been increasingly applied to many cultured aquatic animals. Along with advances in genomics and DNA sequencing techniques, numerous polymorphic DNA markers, such as Simple Sequence Repeats (SSR or microsatellite DNA markers), Inter-simple Sequence Repeat (ISSR), Variable Number of Tandem Repeats (VNTR or mini-satellite DNA markers), Random Amplified Polymorphic DNA (RAPD), Amplified Fragment Length Polymorphism (AFLP), Restriction Fragment Length polymorphism (RFLP), Sequence Characterized Amplified Region marker (SCAR), DNA Amplification Fingerprinting (DAF), Single Nucleotide Polymorphisms (SNP), Single-strand Conformation Polymorphism (SSCP), mitochondria DNA sequences and others, have been developed and used for genetic resource identification and marker-assisted selection breeding (Bai 2011; Liu 2011a, b; Tong and Sun 2015; Xu *et al.* 2015). For example, in polyploid gibel carp, several markers, including allozyme markers, serum transferrin phenotypes, transferrin allele polymorphism, RAPD, SCAR, SSR, AFLP, and mitochondria DNA sequences have been identified, and applied to variety evaluation (Gui and Zhou 2010; Wang *et al.* 2011). Furthermore, several improved varieties, such as "CAS III" allogynogenetic gibel carp (Wang *et al.* 2011), "Xia'ao No. 1" Blue tilapia, "Xianfeng No. 1" hybrid of *E. ilishaeformis* and *A. nigrocauda*, "all-male No. 1" yellow catfish, "Luxiong No.1" Nile tilapia, "Haiyou No. 1" pearl oyster (*P. martensii*) and others, had been selected and bred through the approach of MAS.

6.1.3 Potential Genetic Breeding Biotechnologies

6.1.3.1 Complete Genome Sequencing and Genome Technologies of Cultured Species

Since the beginning of the twenty-first century, the genomes of some important cultured aquatic animals, such as Atlantic cod (*Gadus morhua*) (Star *et al.* 2011), Nile tilapia (Brawand *et al.* 2014), channel catfish (Jiang *et al.* 2011, 2013), Atlantic salmon (Davidson *et al.* 2010), rainbow trout (Berthelot *et al.* 2014), gilthead seabream (*Sparus aurata*), European sea bass (*Dicentrarchus labrax*), and pearl oyster (*P. fucata*) (Takeuchi *et al.* 2012) have been sequenced or are being sequenced. In China, the genomes of five important cultured aquatic animals, including tongue sole *(Cynoglossus semilaevis*) (Chen *et al.* 2014), common carp (Xu *et al.* 2014), grass carp (Wang Y. *et al.* 2015), large yellow croaker (Wu *et al.* 2014; Ao *et al.* 2015) and pacific oyster (Zhang *et al.* 2012) have been determined. These significant genome resources are indicative of their evolution and adaptation mechanisms, and insights into ZW sex chromosome evolution and adaptation to a benthic lifestyle in tongue sole (Chen *et al.* 2014), whole-genome duplication and genetic diversity in common carp (Xu *et al.* 2014), vegetarian adaptation in grass carp (Wang *et al.* 2015), and well-developed innate immunity and stress adaptation in large yellow croaker (Wu *et al.* 2014; Ao *et al.* 2015). In addition, whole genome sequencing is also underway in many other cultured aquatic animals, such as gibel carp, crucian carp, orange-spotted grouper, Japanese flounder (*P. olivaceus*), silver carp (*H. molitrix*), bighead carp (*A. nobilis*), bluntnose black bream (*M. amblycephala*), yesso scallop, scallop, white prawn, and Chinese shrimp.

Next-generation sequencing (NGS) has revolutionized the identification technologies of genome-wide genetic markers (Davey *et al.* 2011). Especially, RAD-seq has rapidly become a cost-effective method of SNP genotyping in cultured aquatic animals, and has been applied in rainbow trout (Hohenlohe *et al.* 2011; Houston *et al.* 2012; Palti *et al.* 2014), westslope cutthroat trout (*O. clarkii lewisi*) (Hohenlohe *et al.* 2011), Chinook salmon (*O. tshawytscha*) (Brieuc *et al.* 2015), European eel (*A. anguilla*) (Pujolar *et al.* 2013), bighead carp, and silver carp (Lamer *et al.* 2014). Wang *et al.* (2012) have improved and developed a simpler protocol which was termed the 2b-RAD in view of its use of type IIB restriction endonucleases. Because this streamlined 2b-RAD approach is suitable for high-throughput genotyping in cultured aquatic animals lacking a complete genome sequence (Wang *et al.* 2012), the large number of markers speeds up the pace of selective breeding.

Linkage maps are valuable tools to identify quantitative trait loci (QTLs) associated with important economic traits which will assist the selection of desired traits. Linkage maps of various densities had been constructed in over 60 aquatic animals, since the first genetic linkage map was published for tilapia (*Oreochromis* spp.) in 1998 (Kocher *et al.* 1998). Microsatellites (Weber 1990), and SNP (Wang *et al.* 1998) have been the most extensively used in linkage mapping due to their wide genome distribution and high rate of polymorphisms. Recently, thousands of SNPs developed from RAD-seq have been used to construct linkage maps in rainbow trout (Campbell *et al.* 2014; Liu *et al.* 2015; Miller *et al.* 2012), farmed Atlantic salmon (Gonen *et al.* 2014; Houston *et al.* 2012), Chinook salmon (Brieuc *et al.* 2014), Nile tilapia (Palaiokostas *et al.* 2013a), Atlantic halibut (Palaiokostas *et al.* 2013b), and lake whitefish (*Coregonus clupeaformis*) (Gagnaire *et al.* 2013).

In China, RAD-seq has been applied to construct linkage maps in several important aquatic animals, such as turbot (Wang W. *et al.* 2015), pearl oyster (Li and He 2014), and scallop (Jiao *et al.* 2014). The important traits in QTL analyses of cultured aquatic animals include growth, meat quality, disease resistance, feed conversion rate (FCR), sex determination, salinity and temperature tolerance (Tong and Sun 2015; Yue 2014). To date, QTL analyses in more than 20 aquatic species have been performed (Yue 2014). Other genome mapping, including physical mapping, radiation hybrid mapping, and QTL mapping, were also applied in cultured aquatic animals. For example, physical mapping was constructed in Atlantic salmon (Ng *et al.* 2005), Nile tilapia (Katagiri *et al.* 2005), channel catfish (Quiniou *et al.* 2007), rainbow trout (Palti *et al.* 2009), Asian sea bass (*Lates calcarifer*) (Xia *et al.* 2010), common carp (Xu *et al.* 2011), half-smooth tongue sole (Zhang *et al.* 2014), and "Zhikong" scallop (Zhang *et al.* 2011). Altogether, these genomic biotechnologies, and the resulting mega genomic data, will not only pave the way for studies on molecular mechanisms on reproduction, growth, disease resistance, and other stress-resistance traits, but also provide significant knowledge for genetic improvement of these major cultured aquatic animals (Gui and Zhu 2012; Gui and Zhou 2015a, b).

6.1.3.2 Genome-Wide Genotyping-Based Selective Breeding

Genome-wide genotyping-based selective breeding is a marker-assisted selection on a genome-wide scale (Meuwissen 2007). It sounded like a crazy ideal when it was proposed firstly by Meuwissen and his colleagues in 2001 (Meuwissen *et al.* 2001). However, the development of complete genome sequencing and high-throughput SNP-genotyping technologies have made it possible, and its application has been promoted in aquaculture. GWAS (Genome-wide association study) has been used to identify economically important trait-related genes and alleles in several cultured aquatic animals, such as rainbow trout (Campbell *et al.* 2014; Liu *et al.* 2015a, b), channel catfish (Geng *et al.* 2015), yellowtail (*Seriola quinqueradiata*) (Ozaki *et al.* 2013), Atlantic salmon (Gutierrez *et al.* 2015), turbot (Rodriguez-Ramilo *et al.* 2013), and scallop (Jiao *et al.* 2014). Growth and sex are the most popular traits studied. Due to the huge economic losses caused by disease in the aquaculture industry, more and more research is being focused on the screening of QTLs for disease resistance. For example, Campbell *et al.* (2014) identified 12 SNPs and 19 SNPs in rainbow trout which were associated with resistance to bacterial cold-water disease (CWD) or infectious hematopoietic necrosis virus (IHNV), respectively. In rohu (*Labeo rohita*), 21 SNPs were found to show significant association with resistance to *Aeromonas hydrophila* (Robinson *et al.* 2014). In catfish, four QTLs associated with resistance to Columnaris disease were revealed by GWAS using the catfish 250 K SNP array (Geng *et al.* 2015). Through utilizing genome-wide genotyping-based selection and BLUP analysis, a novel variety, "Penglaihong No. 2", of scallop was bred for first time among cultured marine species in China (Table 6.1.1).

6.1.3.3 Molecular Design Breeding and Molecular Module-Based Designer Breeding

Molecular design breeding is a highly integrated system initially used for crops. It is based on molecular docking of three-dimensional biomacromolecular data, computational analysis, simulation, and optimization, to select the best breeding strategy procedure before field experiments (Peleman and van der Voort 2003). Based mainly on genetic studies on common carp, Chinese scientists proposed a multi-locus congruent molecular breeding technique in fish (Tong and Sun 2015). A strategic program, named molecular module-based designer breeding system, has been also initiated in 2013 by the Chinese Academy of Sciences, and has been performed in rice, wheat and carp (Xue *et al.* 2014).

6.1.3.4 Nuclear Transplantation, Stem Cell Transfer and Surrogate Technology

Nuclear transplantation, a method for whole-genome manipulation, has been used in China since the early 1960s (Sun *et al.* 2005). Tung *et al.* (1963) were the first Chinese researchers to perform nuclear transfer in goldfish and bitterling (*Rhodeus amarus*). In 1986, the first somatic-cell-nucleus cloned fish was produced in China (Chen *et al.* 1986). Since then, Chinese researchers successfully carried out a series of nuclear transplantations between different genera, subfamilies, families, and even higher taxa of fish (Yan 2000). Intraspecific nuclear transfer was successfully performed in zebrafish (*Danio rerio*) by using long-term cultured cells (Lee *et al.* 2002). As a lower vertebrate species, interspecific nuclear transfer in fish seems to be more successful when conducted between distantly related species. Several nucleo-cytoplasmic hybrids with desirable traits have been obtained through nuclear transfer. For example, crucian carp nucleoplasm hybrids have better traits with faster growth rate, higher protein content, and lower fat content (Yan 1990). Since nuclear transplantation leads to some problems, such as low success rate, low survival, physiological deficiency and immune deficiency, its application is currently limited to aquatic animal breeding.

Stem cell culture and transfer have been rapidly developed in fish. In addition to embryonic stem (ES) cells established in model fish, ES-like cells have also been established in several marine fish species, including the gilthead sea bream (*S. aurata*), red sea bream (*P. major*), sea perch (*Lateolabrax japonicus*), Asian sea bass (*L. calcarifer*), Atlantic cod, and turbot (*Scophtalmus maximus*) (Hong *et al.* 2011). Furthermore, Hong *et al.* (2004) successfully developed a normal medaka (*O. latipes*) spermatogonial stem cell line (SG3) from adult testes. By using semi-cloning technology, Yi *et al.* (2009) succeeded in the generation of medaka haploid ES cells and created a semi-cloned fertile female medaka.

Primordial germ cells (PGCs) are the first stem cells of the germline. Takeuchi *et al.* (2003) developed the first PGC transplantation system in rainbow trout in 2003. Since then, interspecific surrogates had been carried out in different salmonid species or pejerrey species (*Atherina* spp.), and resulted in more rapid production of donor-derived offspring (Takeuchi *et al.* 2004; Okutsu *et al.* 2006; Majhi *et al.* 2009). The transplantation of germ cells into a sterile triploid receptor also succeeded in salmonids. Two years after transplantation, triploid masu salmon (*O. masou*) recipients only produced donor-derived rainbow trout sperm and eggs (Okutsu *et al.* 2007). Although there remains a need for further theoretical studies and technical improvement, nuclear transplantation, stem cell transfer, and surrogate technology have opened up new possibilities for gene targeting, generation of genetically manipulated fish from *in-vitro* cultured cells, producing polyploid stocks, and restoring of endangered fish species.

6.1.3.5 Gene Transfer and Gene Editing

Transgenic breeding is an efficient and predictable technique for obtaining new strains with desirable and genetically inherited traits. The first transgenic fish was born by transferring the growth hormone (GH) gene, driven with a mouse metallothionein-1 (MT) gene promoter in China in 1985 (Zhu *et al.* 1985). Since then, many laboratories all over the world have carried out the transfer of the GH gene into loach (*Misgurnus anguillicaudatus*), common carp, channel catfish, Atlantic salmon, tilapia and other fish. Compared with their non-transgenic siblings, most GH-transgenic fish grow faster and have higher feed conversion efficiency (Ye *et al.* 2015). The GH-transgenic salmon (Mori *et al.* 2007) has been approved for market by the Food and Drug Administration (FDA) of the United States. In addition to the GH gene, several disease resistance-related genes have also been successfully incorporated into the fish genome. For example, lysozyme transgenic Atlantic salmon (Fletcher *et al.* 2011), cecropin B transgenic channel catfish (Dunham *et al.* 2002), and lactoferrin transgenic grass carp (Zhong *et al.* 2002; Mao *et al.* 2004) has been created, to enhance immunity and increase survival. In addition, the anti-freeze protein gene was transferred into goldfish (Wang *et al.* 1995) and Atlantic salmon (Hew *et al.* 1995) to increase resistance to low temperatures, and vitreoscilla hemoglobin gene was transferred into zebrafish to promote hypoxia-tolerance (Guan *et al.* 2011). Because polyunsaturated fatty acids (PUFA) are very important for the nutritional value of fish, both n-3 PUFA- and n-6 PUFA-rich transgenic zebrafish strains have been generated (Alimuddin *et al.* 2005, 2007, 2008; Pang *et al.* 2014). Furthermore, researchers also produced transgenic fish as a bioreactor to produce recombinant proteins, such as human coagulation factor VII (Hwang *et al.* 2004), luteinizing hormone (Morita *et al.* 2004) and insulin-like growth factors (Hu *et al.* 2011) in fish eggs or embryos.

In regard to bio-safety/security, researchers have focused on developing "all fish" transgenesis, and transgenic sterile triploid (Hu *et al.* 2007). For example, grass carp GH gene, driven by E-actin gene promoter of common carp, was first transferred into yellow river carp (Wang *et al.* 2001). Then, the "all-fish" GH transgenic yellow river carp was mated with improved allotetraploid crucian carp to produce transgenic sterile triploid carp (Yu *et* al. 2011).

Recently, a renaissance in genetic modification has begun with the development of gene (genome) editing technologies, such as ZFNs (zinc finger nucleases) (Urnov *et al.* 2010), TALEN (transcription activator-like effector nuclease) (Moscou and Bogdanove 2009; Bedell *et al.* 2012) and CRISPR (clustered regularly interspaced short palindromic repeats)/Cas9 (CRISPR-associated 9) (Cong *et al.* 2013; Mali *et al.* 2013). Among these tools, CRISPR/Cas9 has been rapidly developed and used as efficient gene "scissors" to modify multiple genes at precise sites (Wang *et al.* 2013), and in 2015. More importantly, when the CRISPR/Cas system is used together with single-stranded oligodeoxynucleotides for homology-directed repair, it introduces precise single nucleotide polymorphism (SNP) exchange (Yang *et al.* 2013) and does not bring any foreign DNA elements into the modified animals. Besides extensive application in gene functional studies and prospects in genetic disorder treatment (Hsu *et al.* 2014), and xenogeneic organ transplantation (Yang *et al.* 2015), CRISPR/Cas9 has also quickly been adopted for trait improvement in economically important crops (Schaeffer and Nakata 2015; Barabaschi *et al.* 2016) and livestock (Jenko *et al.* 2015; Laible *et al.* 2015). It is expected that CRISPR/Cas9 will be an enormously valuable tool for fish and cultured aquatic animal breeding (Ye *et al.* 2015) because it has been shown to work well in zebrafish (Hwang *et al.* 2013).

6.1.4 Conclusions

Over the past two decades, significant advances in genetic breeding biotechnologies have been made, and a high proportion of genetically improved varieties have been bred and widely applied to Chinese aquaculture. Future research issues should mainly focus on: (1) obtaining complete genome sequences, and the genetic information of major cultured aquatic animals; (2) to revealing gene regulation and control networks related to economical traits; (3) identifying the relative functional genes and molecular markers that are applicable to genetic improvement; (4) improving integrative selective breeding and sex-controlled breeding approaches; (5) to promote GWAS and genome-wide genotyping-based selective breeding; (6) establishing molecular design breeding, and molecular module-based designer breeding systems; and (7) developing gene or genome-editing breeding technology. Advances in all of the above will further strengthen the theoretical and technical foundations for breeding new varieties with better economic traits, and will contribute greatly to sustainable aquaculture and biotechnological innovation (Gui and Zhu 2012; Gui 2015b).

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6.2

Half-Smooth Tongue Sole (*Cynoglossus semilaevis*): Whole Genome Sequencing to Molecular Sex Control

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6.2.1 Introduction

Aquaculture is one of the most sustainable and increasingly important sources of food supply for human consumption. Many different finfish species are cultured worldwide. In aquaculture systems, the cultured organisms may have differential growth rates of the sexes, but an efficient production needs a synchronous and predictable maturation cycle. Therefore, it is imperative to understand and control the sex of cultured species, which allows effective artificial propagation and management.

Marine flatfishes comprise a group of teleost of high commercial interest because of their high price and nutrition-enriched white flesh (Cerdà and Manchado 2013). Half-smooth tongue sole (*Cynoglossus semilaevis*), belongs to Cynoglossidae of the Pleuronectiformes, and is a large flatfish species that is widely distributed in Chinese coastal waters. Due to its appealing taste, high nutritional value, fast growth, easy domestication, and the depletion of wild stocks, half-smooth tongue sole has become one of the most dominant, and economically important, cultured marine finfish species in China. Other cultured flatfish species are turbot (*Scophthalmus maximus*), olive flounder (*Paralichthys olivaceus*), spotted halibut (*Verasper variegatus*), and barfin flounder (*Verasper moseri*) (Liao *et al.* 2009) (also see Chapter 3.11). Through several years' effort, artificial propagation technology has been established and applied in sustainable farming of this fish. As the first Soleidae fish species to be artificially propagated, the farming practice of the half-smooth tongue sole has been successful in both industrial-scale hatcheries and pond culture practices. Currently, the annual farmed yield of half-smooth tongue sole has increased to nearly 10 000 tonnes, valued at about 2.0 billion RMB (6 RMB = 1 US$).

The half-smooth tongue sole exhibits sexual dimorphism; females grow much faster than males (Figure 6.2.1). Therefore, the sex-control technique is of great importance in artificial propagation to improve fish yield and economic benefits. In addition, tongue sole has a complex sex-determination mechanism, governed by both genetic and environmental factors.

In China, research on half-smooth tongue sole commenced in the 1980s. In the past decades, systematic studies have been carried out to elucidate various aspects of the biology of this species, including reproduction and development, chromosomal karyotyping, sex-determination mechanism, as well as population genetics. The whole genome sequence of the half-smooth tongue sole was reported in 2014 (Chen *et al.* 2014). It was the first flatfish genome sequenced worldwide, and also the first fish genome sequenced in China. Phylogenetic and comparative analysis provided insights into the evolution of sex chromosomes and sex-determination mechanisms (Chen *et al.* 2014). In addition, genes involved in important biological processes, such as adaptation to a benthic environment were also identified (Chen *et al.* 2014). The availability of the

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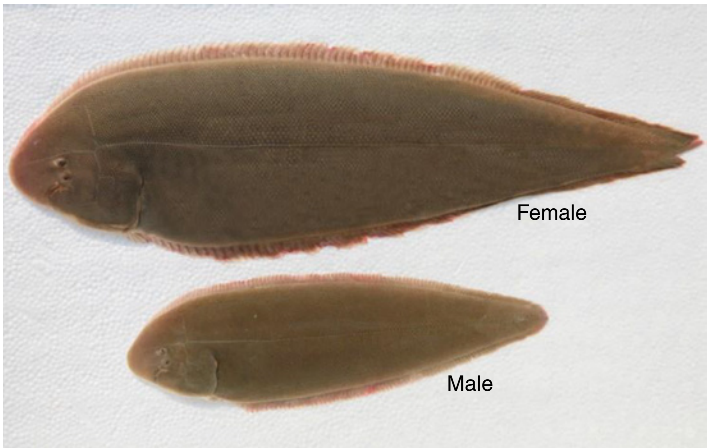

Figure 6.2.1 Two-year-old female and male half-smooth tongue sole (*Cynoglossus semilaevis*).

genome resource of the half-smooth tongue sole significantly promoted the interpretation on this species, and is crucial to reveal the molecular basis of physiological processes, to characterize the mechanism of sex determination, and to facilitate the genetic engineering of sex control and genome selection breeding.

6.2.2 Genetic Background

The half-smooth tongue sole exhibits sexual dimorphism. Females grow fast and the final body length and weight are two to four times those of males (Chen *et al*. 2009; Ji *et al.* 2011). Small body size lowers the market value of males. In farming males are usually discarded after their sex is determined. Therefore, reducing the ratio of males to females has significant economic implications in half-smooth tongue sole farming practices.

It is known that the half-smooth tongue sole has a complex and specific sex-determination mechanism, which is controlled by both genetic and environmental factors. The karyotype of half-smooth tongue sole was determined to be 2n=42t, NF=42 (Zhuang *et al*. 2006). G-banding pattern analysis confirmed that, in addition to having 20 euchromosome pairs, there was a pair of sex chromosomes (chromosome Z and W) and the chromosomal sex-determination mechanism in half-smooth tongue sole was verified to be female heterogametic with the ZW chromosomes, whereas males contain ZZ chromosomes (Chen *et al*. 2009; Shao *et al.* 2010a) (Figure 6.2.2). Moreover, despite the fact that sex is primarily determined by chromosome inheritance, environmental conditions can significantly influence the sexual fate. It has been observed that 14 percent of genetic females (with sexual chromosome type of ZW) are sex-reversed to phenotypic males (those so-called sex reversed “pseudo-males”) when reared under normal conditions (22°C) (Chen *et al*. 2014). Furthermore,

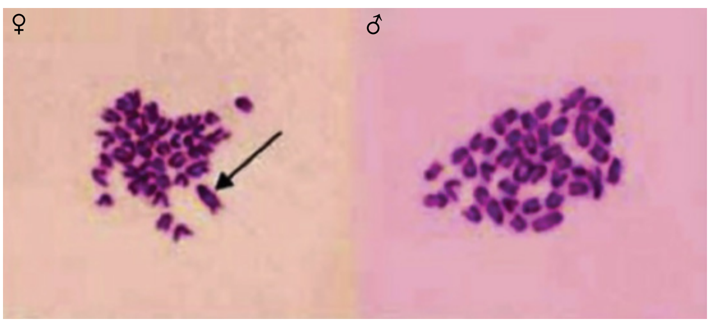

Figure 6.2.2 The chromosome spreads of female and male half-smooth tongue sole at gastrula stage. Arrowheads indicate the W chromosomes. *Source:* Adapted from Shao *et al.* (2010a).

the sex reversal rate of ZW genetic females to males increases to a high level of 73 percent, when the culture temperature is set at 28°C during a sensitive developmental period early in life (Chen *et al.* 2014). This phenomenon suggests that the sexual fate of half-smooth tongue sole can be overridden by environmental factors. Interestingly, the ability of sex reversal can be inherited. The pseudo-males are fertile and can mate with normal females to produce viable offspring, which also exhibit a high sex reversal rate (94 percent), even when reared under normal conditions (22°C) (Chen *et al.* 2014). All these special sexual features imply that the half-smooth tongue sole is an excellent model to understand the sex determination mechanisms in fish.

6.2.3 Genome Sequencing

The recent development of next-generation sequencing technology (NGS) provides a powerful tool permitting research and interpretation of the sequenced organism from a systematic point of view. However, using the short reads obtained from whole-genome shotgun sequencing platforms, it is difficult for the NGS technology to assemble some special sequences/genomic regions, such as repetitive sequences, high copy-number genes and extensive segmental duplications. High resolution physical maps, built by clustering bacterial artificial chromosome (BAC) or fosmid clones in a genomic library as a series of linear orderings using their overlapping, can help overcome these kinds of genome-assembly difficulties, and help to improve the precision of a sequence assembly (Warren *et al.* 2006; Lewin *et al.* 2009).

An initial attempt to getting the genome sequence of the *C. semilaevis* was the construction of a BAC-based physical map. Two BAC libraries of *C. semilaevis* were constructed with three female fish. Large and high-quality inserts were identified in the *BamH*I and *Hind*III enzymatic sites of the vector pECBAC1 with deep coverage (Shao *et al.* 2010b). As a result, a total of 55 296 BAC clones were obtained, which corresponded to 13.36 haploid genome equivalents. The combined libraries have a greater than 99 percent probability of containing any single-copy sequence (Shao *et al.* 2010b), suggesting that a high-quality library was established. Based on the BAC libraries, a physical map of half-smooth tongue sole with high reliability and accuracy was completed. Using the method of HICF (High-Information-Content Fingerprinting) and the Finger Printed Contig (FPC) program, a total of 29 709 clones were assembled into 1 485 contigs with an average length of 539 Kb and a N50 length of 664 Kb. The estimated physical length of the assembled contigs was 797 Mb, representing approximately 1.27 coverage of the half-smooth tongue sole genome (Zhang *et al.* 2014b). The BAC-based physical map is a useful and important foundation for integration of physical and genetic map, whole-genome assembly and fine-mappings of important genes and quantitative traits loci (QTLs), as well as comparative and evolutionary genomics studies.

In 2014, the whole genome sequence of the half-smooth tongue sole was obtained, with a final assembly size of 477 Mb and a scaffold N50 size of 867 Kb. Specifically, a female (which has sex chromosomes type of ZW) and a male (ZZ) were sequenced, respectively (Chen *et al.* 2014). High-quality data of 63.86 Gb and 46.67 Gb were produced by Illumina sequencing platform for the female and the male, respectively, with genome coverages of 212×. A variety of sequence information generated from physical maps and genetic linkage maps were integrated to facilitate the genome assembly. In addition to the formerly constructed BAC-library-based physical map (Zhang *et al.* 2014b) and microsatellite genetic maps (Liao *et al.* 2007; Liao *et al.* 2009; Sha *et al.* 2011; Song *et al.* 2012), a high-resolution genetic map with 12 142 SNPs by restriction site–associated DNA sequencing (RAD-seq) was constructed. These SNP and microsatellite genetic markers (Song *et al.* 2012) were assigned to 22 linkage groups corresponding to the 20 autosomes and 2 sex chromosomes. A significant proportion of 93.3 percent (445 Mb) of the sequences in the assembly and 92.0 percent (19 800) of the predicted genes were consistently anchored and localized on 20 autosomes and the 2 sex chromosomes (Z and W) (Chen *et al.* 2014). The sequences of Z and W chromosomes were identified through comparison of the female and male assemblies. The sequence of Z chromosome in *C. semilaevis* is the first reported full sequence of the Z chromosome outside of birds. The average GC content of the half-smooth tongue sole genome is consistent at around 40.8 percent, which is almost equal to that of medaka (*Oryzias latipes*) (40.5 per cent) and human (40.9 per cent) (Chen *et al.* 2014).

Several methods were used to obtain a comprehensive and reliable gene model of *C. semilaevis*, including *ab initio* predictions, homology detections and RNA-Seq matching to the genome assembly, and then these results were reconciled into a single gene set. The final reference gene set contained 21 516 genes, among which, 99 percent of the predicted genes were supported by homologs in other organisms, or in the tongue sole transcriptome. In particular, the highly conserved structure of homologous genes in other well-annotated teleost fish genomes confirmed the accuracy of the annotation. The predicted gene sets were annotated by searching several gene databases. More than 94 percent of the predicted genes were annotated in the Swiss-Prot database and 17 890 and 14 935 genes were functionally characterized by searching the InterPro and Gene Ontology databases, respectively (Chen *et al.* 2014).

Many important evolutionary events of the sex chromosomes can be identified by phylogenetic analysis. The dissection in genomic organization of W-linked and Z-linked scaffolds, and comparison of the half-smooth tongue sole sex chromosomes with those of mammals and birds, showed that massive gene loss occurred in the wake of sex-chromosome 'birth'. The sex chromosomes of this fish have evolved from a pair of ancestral vertebrate autosomes, which is similar to the avian W and Z chromosomes (Figure 6.2.3) (Chen *et al.* 2014). In *C. semilaevis*, sex determination operates through a Z-encoded mechanism that determines male development. A putative male sex-determining gene on the Z chromosome, *dmrt1* (double sex and mab-3 related transcription factor), which is specifically expressed in male germ cells and pre-somatic cells of the undifferentiated gonad at the sex-determination stage, and persists at high levels during testis development, may take over a master sex-determining role (Figure 6.2.4a,b) (Chen *et al.* 2014). *Dmrt1* has been validated as the male-determining gene in birds, and the *dmrt1* gene of the half-smooth tongue sole showed a convergent evolution that is compatible with a similar function to that in birds (Chen *et al.* 2014).

In addition, the half-smooth tongue sole undergoes a transition from living in the open sea to the seabed, during which time it metamorphoses as part of its adaptation to the new environment, shifting from a symmetric to an asymmetric body shape. Integrating genomic and transcriptomic analysis, a number of genes showing differential regulation between pre- and post-metamorphosis fish were identified, suggesting an involvement of these genes in adaptation to a benthic environment (Chen *et al.* 2014).

The whole genome sequence of *C. semilaevis* will play crucial roles in the investigation into deciphering important molecular mechanisms in flatfish, such as sex-determination, growth, reproduction and development, and immune reactions. It will also facilitate genetic engineering strategies of sex control and selective breeding, to further improve the production of female and high disease-resistant individuals in aquaculture of half-smooth tongue sole.

6.2.4 Epigenetic Regulation in Sex Reversal

In addition to genetic sex determination (GSD), environmental sex determination (ESD) also functions as an important sex-regulation mechanism that occurs in divergent, phylogenetically unrelated taxa. As described in Section 7 environmental factors, such as temperature, interacts with GSD mechanisms and controls the sex fate of *C. semilaevis* to a high degree. A genome-scale systemic analysis on epigenetic regulation of ESD and GSD revealed that DNA methylation plays a crucial role in transition from GSD to ESD (Shao *et al.* 2014).

The gonadal DNA methylome analysis of pseudo-male (ZW), female (ZW) and normal male (ZZ) fish reveals that the methylomic pattern of the pseudo-male fish, which sexually reversed from normal female fish, is similar to that of the normal males. The major target genes of essential methylation modification during the sexual-reversal process are significantly enriched in known sex-determination pathways. Moreover, comparative analysis in parental and F1 generations shows that the modification in the methylation of pseudo-males is globally inherited in their offspring, which can explain why an extremely high proportion (94 percent) of the female offspring of pseudo-males can naturally develop into pseudo-males even without high temperature induction (Shao *et al.* 2014). As a result, the percentage of phenotypic males in the offspring of pseudo-males can reach as high as 95.5 percent (Figure 6.2.5).

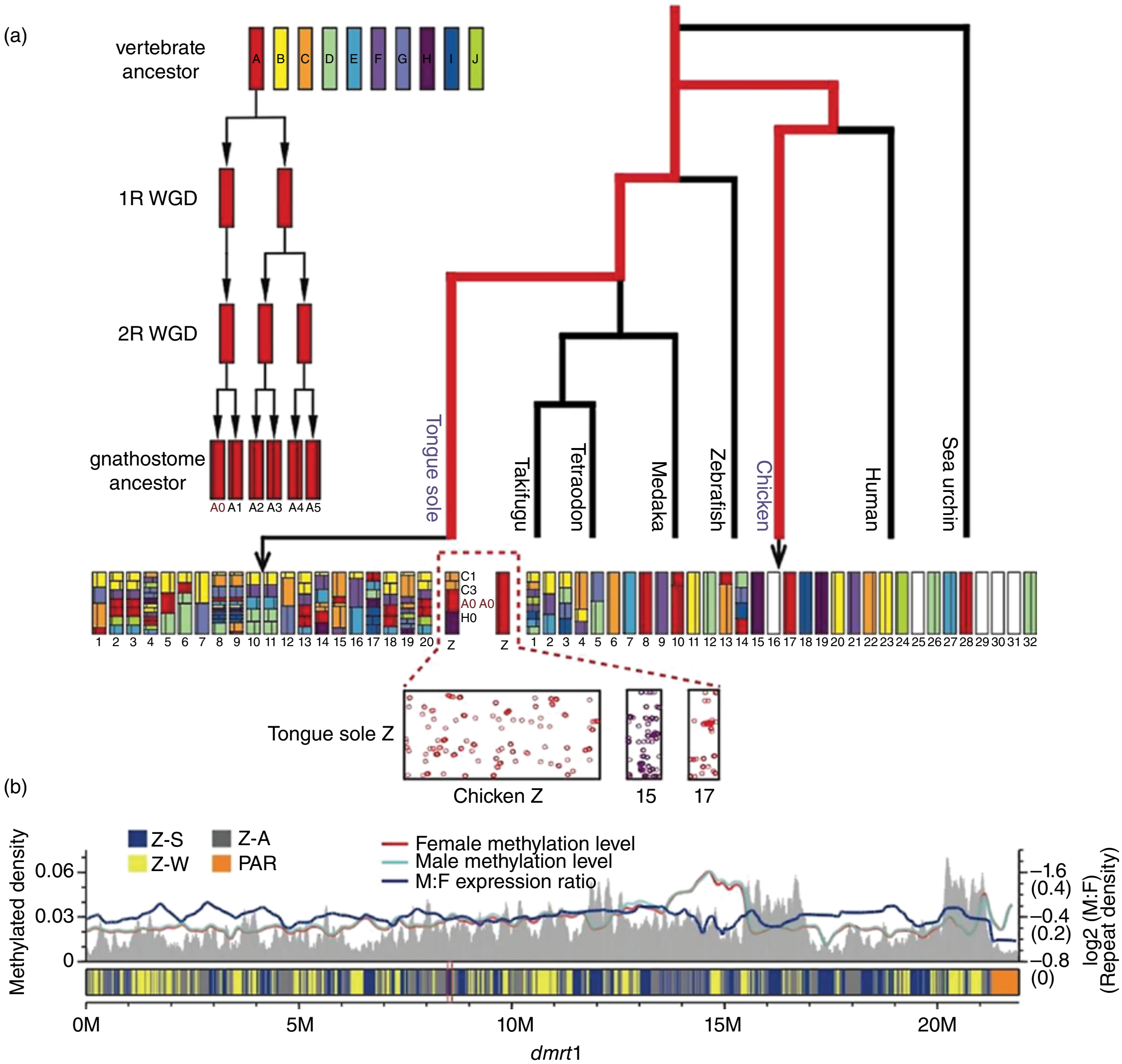

Figure 6.2.3 Evolution and structure of the Z chromosome. (a) Common origin of the tongue sole and chicken Z chromosomes. In the genomes of tongue sole and chicken, genomic regions are assigned colors, and vertical bars that represent the correspondence of individual regions to the ancestral chromosomes in the gnathostome ancestor, from which the respective regions originated. The tongue sole Z chromosome is orthologous to the chicken Z chromosome (red) and autosomes 15 (purple) and 17 (red). (b) The bar representing the Z chromosome is composed of differently sized fragments assigned by four colors (blue: Z–S, Z-specific genes; gray: Z–A, orthologous genes between Z and the autosome; yellow: Z–W, homologous genes between Z and W; orange: PAR, pseudoautosomal region). The red and cyan lines above the bar indicate the 5-methylcytosine density for the female and male, respectively, in 5-kb windows throughout Z. The blue line above the bar depicts the male-to-female (M:F) expression ratio by running an average of 20 genes throughout the Z chromosome. The gray background shows the distribution of TEs across the Z chromosome using a 100-kb sliding window with a 10-kb step. The y axis on the left denotes 5-methylcytosine density, and the y axis on the right denotes the log2 M:F ratio and the repeat density in parentheses. M, million. *Source:* Adopted from Chen *et al.* (2014).

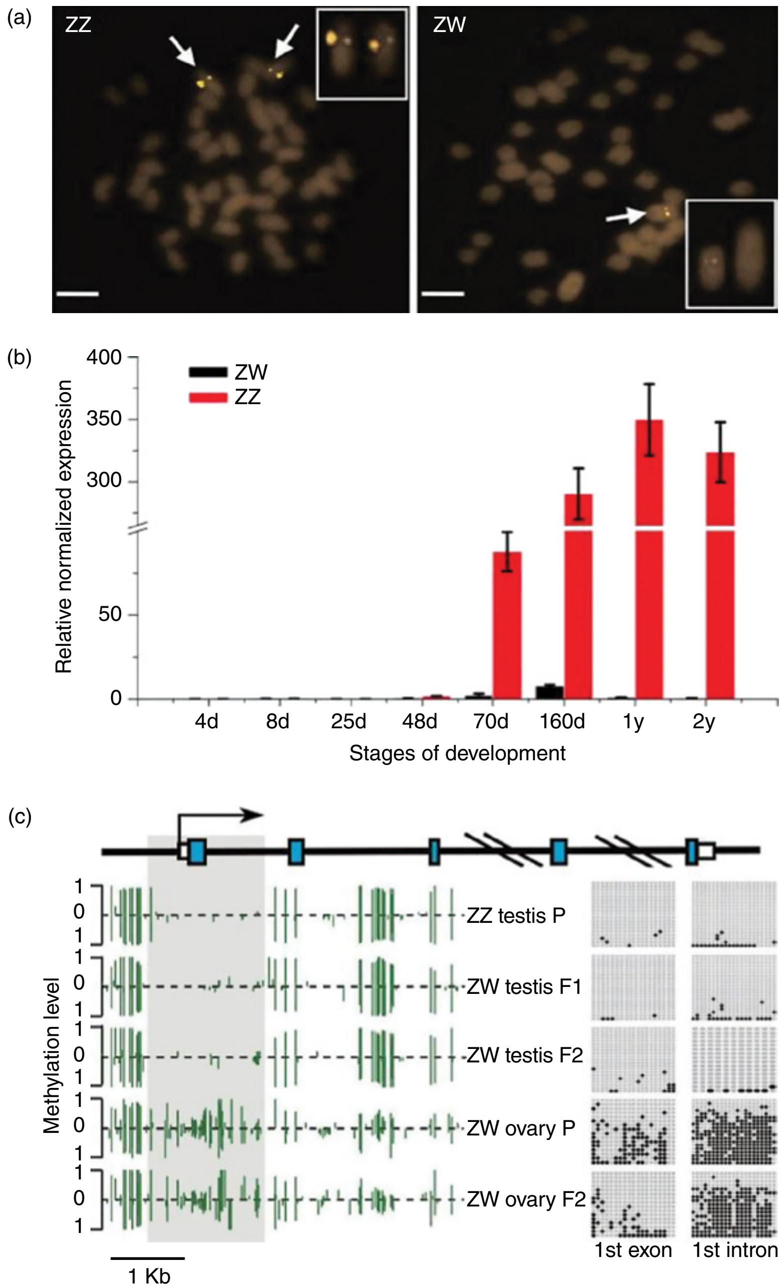

Figure 6.2.4 Characterization of *dmrt1* in half-smooth tongue sole. (a) *dmrt1* BAC FISH analysis of tongue sole chromosomes showing a double signal in males and a single signal in females. (b) RT-PCR analysis of *dmrt1* during developmental stages in female (black bar) and male (red bar) tongue sole. The data are shown as the mean ± s.e.m. (n = 3). (c) Methylation status across the differentially methylated region (DMR) of *dmrt1* in the gonads of an adult WZ female, a ZZ male and a WZ female compared to male sex-reversed fish. The schematic diagram at the top shows the genomic structure of *dmrt1* in tongue sole. Blue boxes: exons, white boxes: 3′ and 5′ UTR regions. Black arrow: the direction of the *dmrt1* gene from transcriptional start site. Green line: the methylation level of each cytosine, identified on both DNA strands throughout the *dmrt1* gene in female and male fish. Gray shadow: the DMR. *Source:* Adopted from Chen *et al*. (2014).

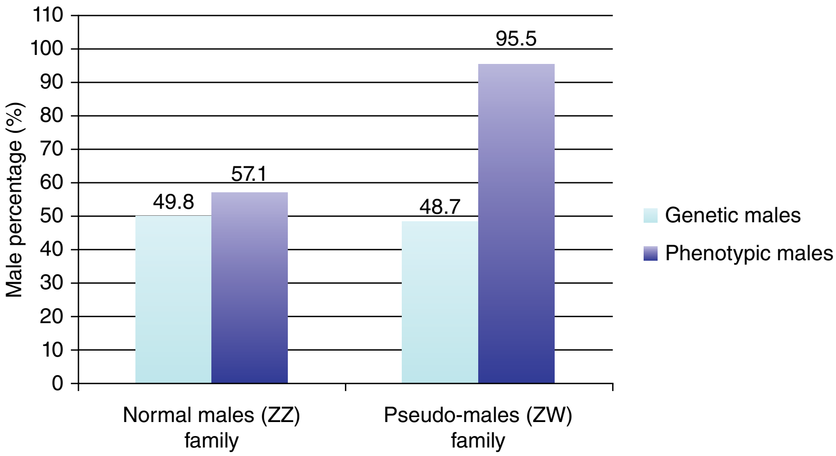

Figure 6.2.5 Sex-reversal rate in F1 generation of normal males and pseudo-males of the half-smooth tongue sole, *Cynoglossus semilaevis.*

Moreover, for animals with genetic sex-determining chromosomes, it is critical to overcome dosage imbalance of the sex chromosomes after phenotypic sex reversal. Compared to normal males (ZZ) of the half-smooth tongue sole, the pseudo-male (ZW) individuals have one less Z chromosome and one more female-specific W chromosome synchronously. Transcriptome analysis revealed that there is a specific dosage compensation mechanism on the Z chromosome to balance gene expression in pseudo-males. A unique dosage compensation region on the Z chromosome, which has equal gene expression level in normal male testes, was found in pseudo-male testes. Methylation variable positions and genes involved in spermatogenesis are enriched in this region (Figure 6.2.3b). Simultaneously, on the W chromosome, many genes maintain active expression in pseudo-males, which is proposed to function in the dosage compensation of the genes on Z chromosome. However, some female specific genes, such as *figla*, were suppressed by methylation regulation. Therefore, the DNA methylation plays multiple crucial roles in sexual-reversal process in half-smooth tongue sole (Shao *et al.* 2014).

6.2.5 Cloning and Characterization of Important Genes for Sex Determination and Differentiation

With the sex chromosomes, genetic sex determination in *C. semilaevis* involves a polygenic system. A number of gene families known to be associated with sex determination in other vertebrates have been identified to be similarly involved in the half-smooth tongue sole, suggesting conservation of sex-determination pathways. Gene expression analyses have been widely employed to study the sex-related genes in the half-smooth tongue sole, revealing their expression sites and profiling. Recently, it has been known that methylation regulation of some sex-related genes play an important role in the sex-shift process. Research on further functional validation is required to verify the specific contribution of these genes to the sex-determination mechanism.

The *dmrt* genes encode a large family of transcription factors whose function in sexual development is highly conservative in animals. Multiple *dmrt* gene homologues were discovered in *C. semilaevis*, among which, *dmrt1* displays typical features of sex-determining gene. The *dmrt1* gene in the half-smooth tongue sole is Z chromosome linked, showing testis-specific high expression during the critical stage of gonadal differentiation (Figure 6.2.4a,b.) (Chen *et al.* 2014). Epigenetic modification analysis exhibited that the *dmrt1* gene maintained low methylation levels throughout life in male gonads, whereas in female gonads it was up-methylated in its promoter region at the start of the critical sex-determination stage. Furthermore, the expression of *dmrt1* was repressed once the methylation had increased during this period (Figure 6.2.4c). This ingenious modification approach and resultant phenotypic effects raise the possibility that *dmrt1* is the critical gene that responds to environmental change and triggers the sex-reversal cascade in half-smooth tongue sole (Shao *et al.* 2014). In addition, as a transcription factor, the recombinant DMRT1 protein of *C. semilaevis* was able to regulate the expression of several other sex-related genes. It inhibited the expression of *cyp19a* and *foxl2,* but increased the expression level of *sox9aa* (Hu *et al.* 2013). Two other members of *dmrt* gene family, *dmrt3* and *dmrt4*, are expressed more significantly in males than females, but there was no evidence to indicate that these are critical for sex reversal (Dong *et al.* 2010; Dong and Chen 2013).

The DNA sequences of two other transcription factors, *sox9a* and *foxl2,* were cloned from half-smooth tongue sole. Real-time PCR (RT-PCR) revealed that the expression of *sox9a* gene in gonads of pseudo-males was higher than that of normal females. In addition, the expression of *sox9a* transcript was significantly regulated in the period of sex differentiation. Therefore, the *sox9a* gene was considered to have a close link with sex reversal, sex differentiation and cell differentiation of embryos and formation of spermatogenic cells (Dong *et al.* 2011). Although *foxl2* predominately expressed in females, it may not be necessary for sex determination and sex reversal (Dong *et al.* 2011).

Cytochrome P450 aromatase (P450arom) is an enzyme responsible for the conversion of androgen to estrogen. Two P450 aromatase, encoding by *cyp* genes, were found in half-smooth tongue sole: P450aromA belongs to the gonadal P450arom subfamily, which transcripts were highly abundant in ovary, less in testis, and absent in other tissues (Deng *et al.* 2009); P450aromB belongs to brain P450arom subfamily, which shares 45.1 percent sequence similarity with P450aromA of the half-smooth tongue sole. The RT-PCR analysis showed that the expression level of P450aromB mRNA was high in the brain and gills, but lower in gonads and skin. However, the P450aromB transcript was down-regulated in the brain of sex-reversed males after treatment of methyltestosterone or at high temperatures (Deng *et al.* 2008b). These results suggested that the P450aroms are involved in gonad development and sex determination in this species. Under high temperature incubation during the early development stage, the promoter region of the coding gene of P450arom, *cyp19a1a,* was up-methylated in ZW/ZZ testes compared with ovaries, suppressing its own expression as well as male development (Shao *et al.* 2014).

Anti-Müllerian hormone (AMH) is a glycoprotein belonging to the transforming growth factor β superfamily, which plays a major role during reproductive development in vertebrates. In *C. semilaevis*, the expression level of *amh* gene increased in the gonads of males and pseudo-male offspring, but did not change in females, indicating that the *amh* gene is required for sex reversal and plays a role during reproductive development (Liu *et al.* 2013).

The growth arrest and DNA-damage-inducible protein 45gamma (*gadd45g*) gene also plays a major role in embryonic development and sex determination. Three homologous genes of *gadd45g* were identified in the half-smooth tongue sole. Characterization and expression analysis suggested that *gadd45g1* may be necessary for sex differentiation in the early stage of gonad development, and then both *gadd45g1* and *gadd45g2* function in maintaining ovarian development and female characters of half-smooth tongue sole (Liu *et al.* 2014a). The *gadd45g3* gene expression suggested that it is a gender-related gene that is necessary for testes maturation and is involved in sex determination prior to gonadal differentiation (Liu *et al.* 2014b).

The Wilms' tumor suppressor gene (*wt*) is another sex-related gene. Cloning and expression analysis revealed that *wt1a* expressed in multiple tissue types and was higher in the gonad. Notably, its expression in the testes was significantly higher than that in the ovaries and gonads of sex-reversed female fish. Among them, the lowest expression was found in the gonads of sex-reversed females. However, there was no evidence to indicate that it is the key gene controlling gonad differentiation (Zhang *et al.* 2014a).

The sex-related gene of *ftz-f1* in the half-smooth tongue-sole was characterized to be highly abundant in the gonads, kidneys, brain and head-kidneys, but less so in other tissues. The expression level in females was higher than that in males. Moreover, the transcript of *ftz-f1* was distinctly expressed in embryos than in larvae, suggesting that the *ftz-f1* gene may be involved in organogenesis in the half-smooth tongue sole (Deng *et al.* 2008a).

The expression level of *ubc9* gene was significantly higher in the temperature-treated females than the normal females and males, indicating that it may also function in the sex-reversal process (Hu and Chen 2013).

6.2.6 Development of Genetic Linkage Maps

Construction of a genetic linkage map represents a powerful tool for research on genome evolution and brood stock enhancement projects using selective breeding. High-quality genetic linkage maps provide a promising platform for marker-assisted selection (MAS) breeding programs for economically important traits, and systematic genome searches to identify QTLs, such as disease resistance, growth and sex-related traits.

In recent years, many efforts have been made in genetic studies, and a variety of genetic linkage maps have been built in the half-smooth tongue sole. The earliest established genetic linkage map was based on amplified fragment length polymorphism (AFLP) technology, which has a total length of 934.6 cM and an average spacing of 8.4 cM, covering 64.4 percent of the estimated genome size. In total, 137 markers, including 103 AFLP markers, 33 microsatellite markers, and 1 female-specific DNA marker were mapped on twenty-six linkage groups (LGs) (Liao *et al.* 2009). This is the first genetic linkage map reported for the half-smooth tongue sole, which demonstrated a great application potential in development of MAS techniques.

Microsatellites are short segments of DNA that have a repeated sequence, occurring at thousands of locations in the genome. Due to high polymorphism, co-dominant Mendelian inheritance and abundant presence in a genome, microsatellite markers have been widely used in genetic linkage analysis and MAS to locate a gene or a mutation responsible for a given trait (Liu and Cordes 2004). To accelerate genetic studies and identification of biomarkers as well as QTLs, microsatellite genetic maps have been developed and persistently refined for *C. semilaevis.*

In 2012, a high-density map was constructed for *C. semilaevis* (Song *et al.* 2012). Female and male maps were composed of 828 and 794 markers with an average interval of 1.83 cM and 1.96 cM, respectively. By integrating these two maps, a high-quality consensus microsatellite genetic linkage map of half-smooth tongue sole was constructed with 1007 microsatellite markers, and two sequence-characterized amplified region (SCAR) markers in 21 linkage groups, covering a total of 1624 cM with an average interval of 1.67 cM (Figure 6.2.6) (Song *et al.* 2012). There were 812 and 785 unique positions in female and male fish, respectively. On the microsatellite genetic map, in addition to the sex-associated markers, four QTLs associated with growth traits were mapped. Among them, two QTLs that were identified for body weight that explained 26.39 percent and 10.60 percent of the phenotypic variation. Another two QTLs for body width explained 14.33 percent and 12.83 percent of the phenotypic variation, respectively (Song *et al.* 2012).

The completion of whole genome sequencing of the half-smooth tongue sole provides a foundation for large-scale comparative genomics research. By genomic re-sequencing and restriction-site-associated DNA (RAD) sequencing technique with the restriction enzyme, *PstI*, a high-density consensus genetic linkage map of a tongue sole family composed of 216 individuals was developed using single nucleotide polymorphisms (SNPs). In total, 12 142 SNPs were assigned to 22 linkage groups, one more than the number of chromosomes of half-smooth tongue sole (Figure 6.2.7). The average marker interval reached 0.326 cM and the total linkage distance were 1900.47 cM. The linkage groups averagely occupied by 552 SNPs, and all the SNPs together covered 91.8 percent of the total length of scaffolds, equaling a length of 438.8 Mb, indicating that the linkage map was genome-wide. On the SNP genetic map, the previously identified sex-specific simple sequence repeats (SSRs) were found to locate within scaffolds where two linkage groups were identified.

6.2.7 Isolation of Sex-Specific Molecular Markers and Identification of Genetic Sex

Characterization of suitable biomarkers associated with traits of commercial interest can be used in MAS breeding programs to identify and select individuals carrying desired traits. For the half-smooth tongue sole, the lower growth rate of males weakens the quality of the fish, and thus leads to an overall reduction in

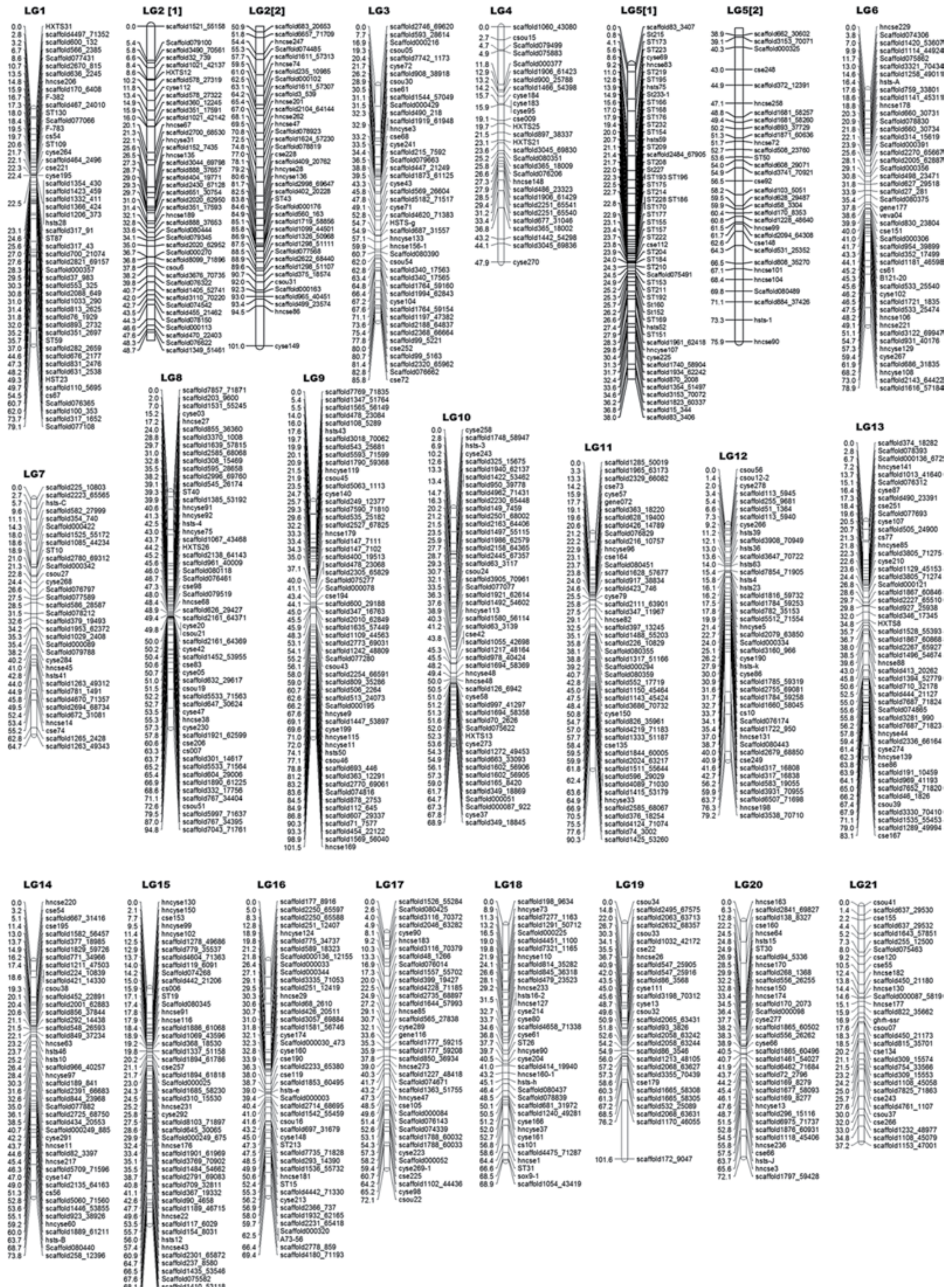

Figure 6.2.6 Microsatellite linkage map for the half-smooth tongue sole, *Cynoglossus semilaevis*. The consensus genetic map comprises of 1009 markers assigned to 21 linkage groups (LG1–LG21). Genetic distances in Kosambi centimorgans (cM) are listed on the left side of the linkage groups, and markers are listed on the right side of the linkage groups. *Source:* Adopted from Song *et al*. (2012).

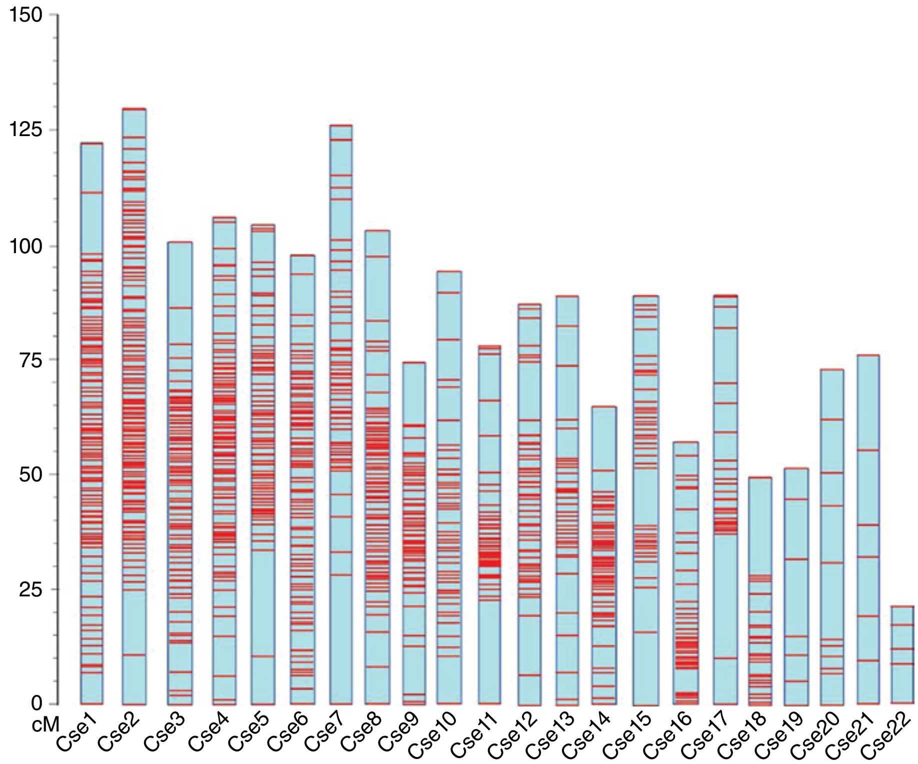

Figure 6.2.7 Schematic diagram of high-resolution SNP genetic bin map in half-smooth tongue sole. 12 142 SNPs were assembled into 1 350 bins having continuous 10 SNPs in each bin except for the insufficient SNPs on the distal of LGs. The intervals of bins were marked by red lines and the width of the bin stands for its genetic distance.

production and economic returns in aquaculture. Therefore, females are desired. However, one of the bottlenecks affecting artificial propagation has been the lack of sex identification and sex controlling approaches. After many years' of research, a large number of genetic biomarkers, especially sex-specific markers, have been identified. Based on some viable markers, convenient and effective sex-discrimination technology has been developed and applied in farming this fish. The sex-specific molecular markers are also useful genomic resources for studying sex-determination mechanisms and controlling the fish sex.

6.2.7.1 Isolation of Female-Specific AFLP Markers and Identification of Genetic Sex

By screening artificially propagated fish, seven AFLP molecular markers were identified that were specifically present in female, but absent in male half-smooth tongue sole (Chen *et al.* 2007). Five of the female-specific AFLP markers were converted into a single-locus polymerase-chain reaction (PCR) marker of a sequence-characterized amplified region (SCAR). Specific primers were designed and validated to amplify specific DNA fragments based on one of the markers, CseF382, and an easy-to-use PCR method was established for identification of genetic sex of half-smooth tongue sole (Figure 6.2.8) (Chen *et al.* 2007). This AFLP molecular sexing marker can successfully identify the genetic gender of half-smooth tongue sole, and differentiate females (ZW) and males (ZZ). It is the first genetic marker that can successfully distinguish the genetic sex of *C. semilaevis*.

However, since the AFLP genetic marker is a dominant-inheritance molecular marker, it cannot distinguish homozygote and heterozygote. Therefore, AFLP-based sexing technology can only differentiate genetic sex of male (ZZ) and female (ZW) individuals, but is not able to differentiate females (ZW) and super-females

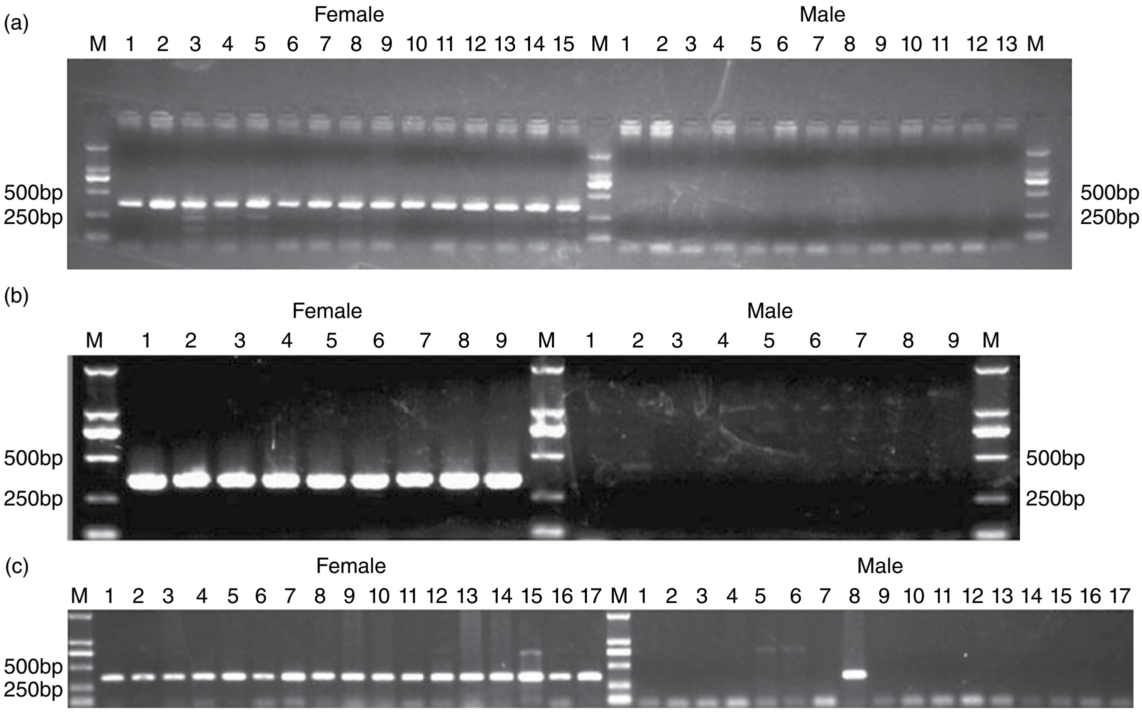

Figure 6.2.8 Agarose gel separation of SCAR CseF382 PCR amplification products with primers CseF382N1 and CseF382C1 in females and males. (A) DNA was from the 15 females and 13 males previously used for screening sex-specific AFLP markers. (B) DNA was taken from an additional nine female individuals and nine male individuals. (C) DNA was taken from an additional 17 female individuals and 17 male individuals. *Source:* Adopted from Chen *et al.* (2007).

(WW). In artificial propagation, an important target is to produce super-females, which are more valuable. Therefore, new and more accurate co-dominant molecular markers, which can distinguish ZW females and WW super-females, are required to promote the sex identification and artificial propagation technology.

6.2.7.2 Screening of Sex-Linked SSR Markers and Development of Molecular-Identification Technique for ZW Females and WW Super Females

A number of studies have been performed to isolate microsatellite markers, and many polymorphic microsatellite markers have been characterized from the genomic DNA of the half-smooth tongue sole (Liao *et al.* 2007; Wang *et al.* 2008; Liao *et al.* 2009; Sha *et al.* 2011). These markers can be used to evaluate the genetic diversity and brood stock management of *C. semilaevis*, but are still powerless in differentiating female and super-female fish. In 2012, a consensus high-density microsatellite genetic linkage map was built, based on female and male half-smooth tongue sole (Song *et al.* 2012). On this map, a total of 159 sex-linked simple sequence repeat (SSR) markers were identified and five sex-linked microsatellite markers were validated in their association with sex in a large number of individuals randomly selected from different families. In particular, one sex-linked SSR marker (CseF-SSR1) was successfully applied in the sex differentiation in half-smooth tongue sole (Chen *et al.* 2012). The amplification of genomic DNA using the sex-specific CseF-SSR1 marker produced one DNA band of 206 bp in ZZ males, two DNA bands of 206 and 218 bp in ZW females, and one DNA band of 218 bp in WW super-females (Chen *et al.* 2012) (Figure 6.2.9). Therefore, it can identify not only genetic females and males, but also females and super-females, and thus can be used to identify the genetic sex of ZW and WW of gynogenetic diploids of *C. semilaevis*. As a critical technical prerequisite, the finding of the sex-specific microsatellite genetic marker, and the development of sex

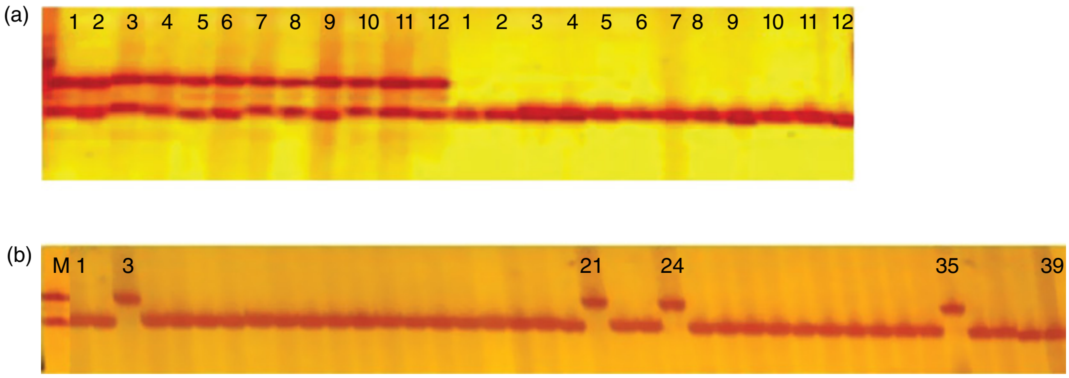

Figure 6.2.9 Genetic sex identification of half-smooth tongue sole using sex-specific microsatellite genetic marker (a) identification of females (ZW) and males (ZZ).1–12 on the left: females; 1–12 on the right: males; (b) identification of males (ZZ) and super-females (WW) in mitogynogenetic embryos. 3, 21, 24, 35: super-females; others: males. *Source:* Adopted from Chen *et al.* (2012).

identification technology have demonstrated wide application prospects in promoting the development of sex control and artificial gynogenesis technology, thus facilitating the improvement of the market value of cultured fish, and the quality of fish produced.

6.2.8 Development of Artificial Gynogenetic Induction Technique

Gynogenesis is considered to be a powerful approach of producing all-female stock, studying sex-determination mechanisms, and developing pure lineages in fish. Gynogenetic induction is very important in half-smooth tongue sole because females grow much bigger than males. If WW super-females can be obtained, it is possible to generate all-female populations. Therefore, in addition to conducting studies on screening of sex-linked molecular markers, sex identification and sex control, it is vitally important to develop artificial gynogenesis technology.

The female half-smooth tongue soles have Z and W chromosomes, and males have two Z chromosomes. Theoretically, two types of homozygous individuals, including normal males with ZZ chromosomes and super-females with WW chromosomes, could be induced through artificial gynogenesis. If super-females (WW) can be mated with males (ZZ), it is possible to produce all-female stock (ZW) progeny (Chen *et al.* 2009). However, due to genetic exchange and recombination, there are some heterozygous females (ZW) in gynogenetically obtained populations, which influences the efficiency of gynogenetic fish production. Therefore, both the induction of mitogynogenetic diploids and the identification of female (ZW) and super-female (WW) individuals are crucial for gynogenetic fry production in half-smooth tongue sole.

Currently, both meiogynogenesis and mitogynogenesis protocols have been successfully developed in half-smooth tongue sole (Chen *et al.* 2009; Chen *et al.* 2012). Inactivated heterogenous sperm were found to be capable of triggering gynogenesis in tongue sole. Both cold shock and hydrostatic pressure on mitogynogenetic embryos were validated to be effective and the optimal stimulation parameters, such as initiation time, temperature and treatment duration, were confirmed (Chen *et al.* 2009, 2012). Chromosome analyses of gynogenetic and normal fish were performed and verified the success of gynogenesis induction in half-smooth tongue sole. In normal half-smooth tongue sole, the chromosome number of diploid is 42 (Figure 6.2.10a). In gynogenetic haploid, it was observed that the chromosome number was 21 (Figure 6.2.10b), and that of gynogenetic diploid was 42 (Figure 6.2.10c), which was consistent with normal individuals. In addition, two huge WW chromosomes were observed in some of the gynogenetic embryos (Figure 6.2.10d). The discovery of WW "super-female" embryos also provides important evidence for a ZW sex determination mechanism in

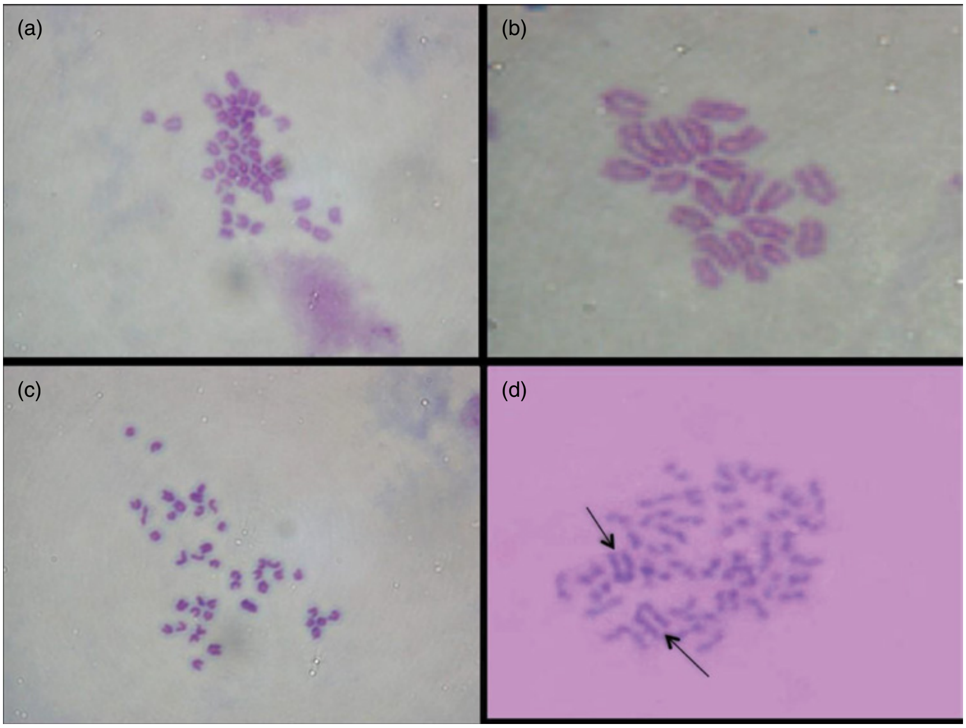

Figure 6.2.10 Chromosome analysis of normal embryos and gynogenetic embryos. (a) Normal male tongue sole; (b) gynogenetic haploids; (c) gynogenetic diploids, showing a ZZ individual; (d) gynogenetic diploid embryos, showing a WW individual, two huge WW chromosomes were observed (arrowhead). *Source:* Adopted from Chen *et al.* (2009).

the half-smooth tongue sole. In the obtained 39 mitogynogenetic embryos, four WW super-female embryos were identified using sex-specific SSR markers (Figure 6.2.9) (Chen *et al.* 2012).

The artificial gynogenesis technology provides an important tool for the elaboration of the sex-determination mechanism, artificial induction of WW super-female embryos, and development of clone line in the half-smooth tongue sole. More efforts are needed to further optimize the induction parameters, and improve the efficiency of large-scale gynogenetic production.

6.2.9 Technology Development of High Production of Female Offspring

Phenotypic females, which exhibit advanced growth traits, are desired in half-smooth tongue sole aquaculture. However, only 10–30 percent (average of 20 percent) of the naturally breeding progeny are phenotypic females. Sex-ratio analysis in the F1 generation showed that the proportion of phenotypic females in the offspring of normal males is remarkably higher than that of pseudo-males. In addition, a high percentage (94 percent) of the genetic female offspring with parental pseudo-males naturally sex-reversed to pseudo-males, which grow much slower than females. The high ratio of male individuals significantly decreased the overall production and increased the farming costs, thus severely influencing the promotion and marketing prospects of the half-smooth tongue sole culture industry. Therefore, in the artificial propagation of the tongue sole, it is necessary to remove the pseudo-males from the male parental population, and to retain the normal ZZ males in breeding, which can raise the ratio of the phenotypic females in offspring and improve the overall production.

The availability of the sex-specific genetic markers significantly pushed the technology development of high production of female offspring. Through this approach, the male parents are sex-screened, and genetic males

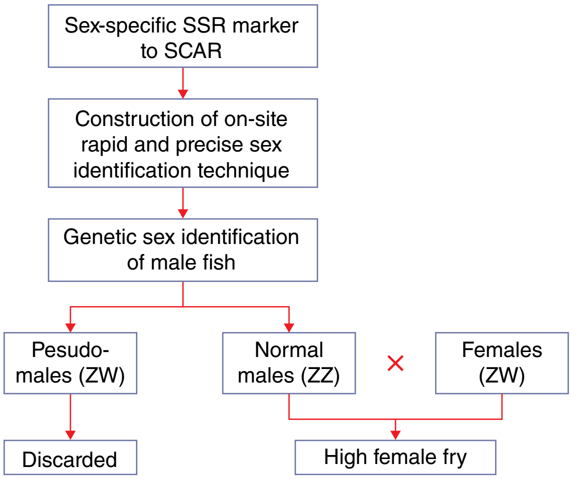

Figure 6.2.11 Roadmap of the high-female breeding technology. SSR: simple sequence repeat; SCAR: sequence-characterized amplified region.

(ZZ) can be distinguished from pseudo-males (ZW). The pseudo-males are discarded and the genetic males are used to mate with female fish (Figure 6.2.11). It is demonstrated that when this technology is used, the ratio of the phenotypic females offspring could be improved to about 42 percent, representing an increase of 20 percent compared to that obtained from un-selected male parents. Development and widespread application of this technology have promoted the industrialized production of half-smooth tongue sole, and achieved considerable economic benefits.

6.2.10 Summary

The half-smooth tongue sole has important traits for mono-sex breeding, as well as utility as a model for the study of sex-determination mechanisms. Recent accomplishments on whole genome sequencing provide a crucial basis to study the inheritance of phenotypic traits and action of genes in *C. semilaevis*. Epigenetic regulation is essential to sex determination in the half-smooth tongue sole, and the sex reversal brought about by external factors can be traced back to evolutionary adaptations of conserved molecular pathways that are under inherent flexible methylation regulation. The high-efficient sex-specific SSR marker, which was obtained based on whole-genome sequence, laid the foundation for sex control and the high production of female offspring. Artificial gynogenetic techniques have been developed and used to continually explore possible WW gynogens, studying sex-determination mechanisms, and developing pure lines in half-smooth tongue sole.

These studies and aquaculture of the half-smooth tongue sole, fueled by systematic biological and genomic research is timely for accelerated development of aquaculture of the species. Although many issues need to be studied further and resolved, more research and technology innovations will permit a healthy, sustainable. and rapid development of the culture industry of half-smooth tongue sole. It is believed that the culture industry of *C. semilaevis* has entered into the genome era, and thus it will develop to a much larger-scale, sustainable and profitable aquaculture sector in China.

Acknowledgments

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6.3

Stock Enhancement and Genetic Preservation of Chinese Mitten Crab (*Eriocheir sinensis*) in the Yangtze River Estuary

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6.3.1 Introduction

The Chinese mitten crab *Eriocheir sinensis*, also commonly known as Shanghai hairy crab or Chinese river crab, has become a dominant aquaculture species in China (also see Chapter 3.2). Annual aquaculture production of the species exceeds 700 000 tonnes, with a production value of more than 50 billion RMB (6 RMB = 1 US$). The species is distinguished by extensive setae around the edges of the chelipeds, which are used mainly for feeding, and fighting other crab species. In China, the mitten crab is naturally distributed in the Yalu River of Liaoning Province to the north, the Jiulong River of Fujian Province to the south, and the Three Gorges area near Yichang, Hubei Province, to the west. The central distribution of Chinese mitten crab is located within the region of the Yangtze and Huai rivers, and especially in the middle and downstream portions of the Yangtze River (Xu *et al.* 2011). The Yangtze River population is known for its enormous yield and optimum quality, and it is widely grown in freshwater lakes and rivers of the Yangtze River basin. Its biology and ecology in China, particular its breeding migration, were first studied as long as 1000 years ago. The artificial breeding of this crab, including considerable attention to methods for its enhancement and successful release, has contributed to its current popularity in aquaculture across China. Mitten crab was also introduced to Germany at the beginning of the twentieth century, and is currently found in most European waters, where it is considered an invasive species (Rudnick *et al.* 2003; Paunovic *et al.* 2004).

Chinese mitten crab have excellent characteristics as an aquaculture product, such as fast growth, individual hypertrophy, tender meat, good flavor, and high economic value. In 100 g of edible parts, there is approximately 14 percent protein, 5.9 percent fat, and 7 percent carbohydrate. Moreover, the meat has a high level of vitamin A, riboflavin and niacin; in addition, its calorific value is generally higher than the nutrition level of common edible fish. As a result, the crab is exceedingly popular with producers and consumers alike.

Once their gonads develop to stage IV, *E. sinensis* undertake a breeding migration into estuarine waters. The Yangtze estuary has a great variety of habitats, making the region a prime environment and a key spawning ground for the species. Before the 1980s, the production of *E. sinensis* in the Yangtze estuary was already nearly one hundred tonnes. The production of juvenile crab was as high as 67.9 tonnes, and *E. sinensis* in the Yangtze River system once provided the seed stock, commonly referred to as coin-sized crabs, for at least 45 counties or cities in 14 provinces (Figure 6.3.1). The maintenance and promotion of excellent germplasm resources for the *E. sinensis* aquaculture industry in China have benefited from the natural populations in the Yangtze estuary; even so, artificially propagated juvenile crabs have gradually become the main source of seed stock for many aquaculture operations. Nevertheless, both parent and juvenile crabs produced in spawning grounds of the Yangtze estuary continue to play an exceptional role in the Chinese mitten crab industry because of the excellent germplasm resources they harbor (Gu and Zhao 2001).

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Figure 6.3.1 Chinese mitten crab caught in the Yangtze river estuary.

This chapter introduces key ideas and technical issues on research on *E. sinensis* recovery, and germplasm preservation technology in the Yangtze estuary region. Also presented are some results of research using parent crabs, particularly concerning enhancement and release, evaluation of stock enhancement, spawning-ground investigation, and germplasm preservation. It is expected that findings from these studies will lay the foundation for development of the Chinese mitten crab industry in China through the recovery of *E. sinensis* resources in the Yangtze estuary, as well as germplasm preservation.

6.3.2 Chinese Mitten Crab Resources

Chinese mitten crab inhabit freshwater lakes and rivers, but generally reproduce in estuaries. The crabs are demersal, live in burrows, and are nocturnal. As an omnivorous animal, mature crabs or larval stages will feed on fish, shrimp, snails, clams, earthworms, and insects and their larvae, and they may also feed on aquatic plants.

In recent years, major hydraulic engineering structures have been constructed in the Yangtze River basin: the rapid development of industry and agriculture, accompanied by increasing water pollution, have greatly impacted the estuarine habitats. Continued degradation of the estuary's ecosystems is causing declines in macrobenthos diversity and biomass, and changes in plankton community structures (including their distribution in space and time).

At present, the protection of *E. sinensis* resources in the Yangtze estuary is facing severe challenges. Construction along the river has not only adversely effected its migration patterns, but has also significantly worsened the water quality. In addition, the long-term excessive exploitation of *E. sinensis* resource (i.e., fishing of parents, young and juvenile crabs) has caused a sharp decline in the natural populations (Liu *et al* 2007), and hence the production of juvenile crabs has declined sharply. As a result, scientific methods are needed to improve this resource by ensuring sustainable *E. sinensis* germplasm production and greater stability of the Yangtze estuary ecosystem.

During the 1970–80s, the yield of parent crabs and crab seed in the estuary reached 114 tonnes and 20 tonnes, respectively. However, due to overfishing, environmental degradation, and new hydraulic structures, yield has dropped off since the 1990s. To restore Chinese mitten crab resources in the Yangtze River, the Chinese government and scientific research institutes have carried out a stock enhancement, and large-scale release of juveniles since 2004.

The enhancement and release of aquatic organisms not only help to increase the income of fishery workers, but also aids sustainable development of aquatic animal resources and contributes to the stability of the environment. 'Releasing' refers to the process of a cultured animal adapting from an artificial rearing environment to life in the natural environment. Ultimately, the animal's adaptability will directly determine the outcome of the enhancement and releasing endeavors.

6.3.3 Key Scientific Issues

The Yangtze estuary holds an important ecological status in the Yangtze River basin. Its special effect of "three arms, one channel" makes it one of the regions with the highest biodiversity and fishery potential in the world. The region's fish resources have extremely important strategic value. Enhancement and releasing are important ways to conserve and restore biological resources, thus are commonly used in the field of domestic and international aquatic biological resource conservation and ecological restoration (Bartley and Bell 2008; Lorenzen 2008). When developing methods for the enhancement and release of fisheries resources, it is useful to consider key scientific and technical issues, such as: what to stock, how much to stock, and where, when and how to stock.

In view of the fact that the Yangtze estuary is a key habitat and spawning ground for *E. sinensis*, important means of restoring natural resources are through supplementing reproductive populations and protecting spawning grounds. With relevant national support, the project team of the East China Sea Fisheries Research Institute undertook three progressive initiatives: monitoring and evaluation; multiplication and repair; and sustainable use. This has entailed systematic development of resource recovery efforts of *E. sinensis* in the Yangtze estuary. As a result of systematic research in recent years, the East China Sea Fisheries Research Institute has mastered certain enhancement and releasing specifications for *E. sinensis* (e.g., quantity, time and place of release), has set up a tagging technology and an effective evaluation system, and has led the technology on survival of frozen crustacean tissues and embryos.

6.3.4 Ecological Conditions of the Yangtze River Estuary

The Yangtze River estuary is the largest river mouth on the western Pacific coast, and is located at the center of China's south-east coastal zone. The estuary has a special configuration: the river mouth channels are as narrow as 5.8 km, while the greater delta is as wide as 90 km. This river mouth has the richest aquatic biodiversity in China, and consequently a huge potential for cultured products (Qin *et al.* 2015), and it is also the main habitat for migratory birds along the western Pacific coast (Figure 6.3.2).

The Yangtze estuary is located in a subtropical monsoon climate zone of eastern Eurasia, and has the following climate characteristics: high humidity, adequate rainfall and illumination, and four distinct seasons, with hot summers and cold winters. Furthermore, the estuary is located at middle latitude, and is susceptible to the influence of the alternation of warm and cold air, the climate is changeable, and prone to adverse weather conditions. The annual average air temperature is 15.5–15.8°C; the highest annual temperatures are approximately 27.3–28.3°C, and the lowest are usually between 2.7–3.6°C. However, the water temperature of the whole water area of the estuary is relatively uniform.

Mean annual precipitation of the region is 1083 mm; approximately 70 percent of the rainfall occurs mainly from April to September, when the summer monsoon prevails. The monthly average precipitation from April to September is >100 mm, and the average total rainfall during these six months is generally about 750 mm. Mean annual sunshine duration is 1800–2000 hr. Annual median humidity is approximately 80 percent, and annual average evaporation capacity is 1300–1500 mm. To the east of the estuary, more than 50 fog days occur year round (commonly in February to May). The wind direction in the region displays distinct seasonal

Figure 6.3.2 Habitats of the Yangtze river estuary.

variation: a southeasterly prevails in summer and a northwesterly in winter. Annual mean wind speed is 3.7 m/s, and the wind directions with the highest frequency of occurrence are NW–N and ESE–SSE, with a frequency of 24 percent and 23 percent, respectively. The annual average number of days with strong wind is 20.7 d; the wind speeds in winter and spring are relatively high, yet the greatest wind speed occurs in the summer typhoon period.

The water yield of the Yangtze River is relatively stable and its runoff is mainly composed of rainfall. The average annual precipitation in the drainage basin is about 1,067 mm, and the runoff basically shows a positive correlation with rainfall. Inter-annual variation in the runoff is relatively stable. The dry season along the Yangtze River is from December to March; median levels of precipitation occur in April, May, October and November. The flood period is from June to September, and run-off during the four months of the flood period accounts for about 60 percent of the total yearly run-off. The average run-off of the Yangtze estuary is 31 060 m^3/s, ranking third in the world, after that of the Amazon and Congo rivers. The tide in the estuary originates from the tidal bulge of the East China Sea, and its average cycle is 12.2 hours. The estuary holds a huge tidal prism, and the tide is relatively powerful.

The sea area of the Yangtze estuary is influenced by several water bodies, including freshwater from the Yangtze River, the Taiwan Warm Current, and the Yellow Sea Cold Water Mass; the estuary's water area thus forms an intersection zone wherein many frontal zones form near the river mouth and the open sea. The wave action in the estuary is mainly comprised of stormy waves, with swells taking second place, but the frequency of swells increases in the eastern area. The seasonal variation in stormy wave direction in the Yangtze estuary is quite obvious: northerly waves prevail in winter, and southerly waves prevail in summer. However, the swells are mainly easterly. The Yangtze estuary itself is the area where seawater mixes with freshwater, and the horizontal distribution of salinity varies greatly. Salinity in the southern waterway is usually $<1‰$, while salinity in the northern waterway is slightly higher. As a seasonal effect of changes in run-off into the Yangtze River, the seasonal change in salinity in the Yangtze estuary is also considerable, with salinities higher in winter than in summer. The composition of suspended sediment grain composition is within the scope of 0.0012–0.05 mm. The concentration of suspended sediment in the estuary is relatively high in western areas and relatively low in eastern areas, as the sea sediments are mainly diffused to the southeast.

6.3.5 Biology of Chinese Mitten Crab in the Yangtze River Estuary

Chinese mitten crab in the Yangtze River generally have a two-year life span. In roughly the last ten days of September, when exuviation is complete, there is rapid growth of the gonads. Within a 30–40-day period, the gonad index of female crabs can reach 10–15 percent, up from 0.36 percent before exuviation.

By middle-to-late October, when gonad development enters stage IV, Chinese mitten crab in the river will begin to migrate towards the estuary, and thus begin their breeding migration. A change in water temperature marks the beginning of migration, but a greater factor influencing the downward migration is salinity.

In the first ten days of November, *E. sinensis* adults congregate in the Yangtze estuary and commence spawning. The usual spawning grounds are located at the Hengsha and JiuduanSha sections of the estuary. The salinity of the spawning grounds is typically 18–26‰, and the water temperature about 5–10°C. While mating, the male crab tightly grasps the cheliped of a female crab by its own cheliped, and then positions its copulatory organ to inject semen into the seminal receptacle. The entire mating event may last several minutes to an hour. The spawning of female crabs starts within 7–16 hours after mating. The fertilized eggs attach to the bristles of the female pleopods. The cleavage pattern of the fertilized egg is a typical superficial cleavage. The egg attaches to the foot of its parent body, where it lives on yolk as its main nutrition and goes through the following stages: fertilization, cleavage, blastula stage, gastrula stage, nauplius stage, protozoea larva, preliminary hatching, and larval hatching. It takes 30–60 days for a fertilized egg to hatch to a protozoea larva at water temperatures of 10–17°C. The zoea will develop into a megalopa after five molts, and more than 35 days in the estuary. Six to ten days later, when the megalopa metamorphoses into a crablet after molting, it assumes a benthic life. At this time, the first crab stage returns to the freshwater of the river. This process is essentially a feeding migration and usually occurs in March–May of the year following the breeding migration (Figure 6.3.3).

Chinese mitten crab inhabit both freshwater and marine habitats depending on the life stage (Wang *et al.* 2012); hence, it is adaptable to different salinities as it changes from protozoea larva to megalopa, and from megalopa to crablet. Therefore, the crab is able to migrate back to a river to obtain food. In conditions of sufficient food, the weight of a crablet is ~50–70 g (maximum ~150 g). The two migration events of *E. sinensis* span their entire lifetime.

The lifespan of female crabs is two years, as calculated from the zoeal stage. Male crabs die soon after mating, and so their life span is approximately two months shorter than that of females. Chinese mitten crabs that mature within a year have only a one-year life span, and most of these are male crabs; however, individuals with relatively slow gonad growth may live three to four years.

Figure 6.3.3 Chinese mitten crab.

6.3.6 Stock Enhancement Technology

6.3.6.1 Tagging and Releasing of Chinese Mitten Crab

Prior to release, parent crabs can be tagged using fluorescent labeling or physical methods (OEMs, T-bars, and lantern rings), and their tag-retention rate, survival, and behavior can be monitored for comparative purposes. Tagging also enables us to study the activity routines and migratory habits of released parent crabs, and to evaluate the stock enhancement and the related manner of releasing parent crabs. Studies have shown that lantern rings and labeling are most effective and conducive to identify and recapture labeled crabs. The double-tag technology of 'labeling + lantern ring' for parent crabs was conceived based on this; the technique has since laid a foundation for tagging and effectively evaluating *E. sinensis* populations. Each labeled crab carries two sets of a five-figure code. In order to improve the survival rate of released crabs, and to normalize their behavior after release, equipment for the continuous automatic release of parent crabs was also invented. Importantly, this innovation has reduced damage to tagged crabs and permits automatic release (Figure 6.3.4).

For determining the best release time and place, the following need to be considered: (1) the migratory habits of natural populations, including the migration time of parent crabs to the Yangtze estuary area, the migration path, and the habitat locations; (2) the environmental conditions of the Yangtze estuary area; (3) the adaptability of parent crabs to salinities in the Yangtze estuary; (4) the time of winter fishing operations on *E. sinensis* in the Yangtze estuary, in order to avoid excessive loss of the released parent crabs. In general, Chinese mitten crab make their way to the Yangtze estuary from November to December, and mostly enter spawning grounds along the south branch of the estuary. Additional studies on the migratory behavior of *E. sinensis*, and surveys of the main fishing operations in the Yangtze estuary, have concluded that the best release time for the crab in the estuary is mid- to-late December, and is best conducted in the south branch (Figure 6.3.5).

6.3.6.2 Quality Control of Chinese Mitten Crabs

The Yangtze estuary is not the only key habitat and spawning ground for *E. sinensis*. In theory, releasing parent or juvenile crabs will partly supplement and aid recovery of the natural resource. Artificially propagated crabs

Figure 6.3.4 Double tag on Chinese mitten crab.

Figure 6.3.5 Stock enhancement of Chinese mitten crab: automatic releasing equipment used (a), as well as the traditional (past) mode of release (b).

were first released in the region in April 2004. However, the results of monitoring found a relatively high mortality rate and a weak impact on the natural crab resource. Based on additional studies of the reproductive migratory behavior, researchers deemed it better to release parent crabs that had freshly molted, and with stage IV gonads. Parent crabs at that stage showed strong adaptability to the environment, and were generally non-feeding after mating and oogenesis. Appropriate weights for the released parent crabs are set at: female crabs >100 g, and male crabs >150 g.

The number of parent crabs released each year is determined based on the ecological conditions of the Yangtze estuary. Also taken into consideration is the correlation between resources historically available to the parent crabs and changes in ecological/environment factors.

Since 2004, 17 monitoring sites have been set up in the estuary. Surveys of the relevant physical and chemical factors, primary productivity, benthos, plankton composition, and other physicochemical and biological factors of the water area are monitored four times a year. At least 60 000–100 000 parent crabs (with a male to female ratio of 3:1) are released into the Yangtze estuary area, under the assumption that the releases will play an effective role in increasing the natural populations. The released parent crabs are developed from the seed stock of filial generations of wild Yangtze parent crabs. Breeding of these is conducted in accordance with technical specifications for the production of large-sized *E. sinensis*, and the quality specifications for parent *E. sinensis* in the Yangtze estuary. Before each release of parent crabs, institutions qualified in fishery sciences, aquatic germplasm detection, and quarantine issues must inspect for quality to fully guarantee the quality of the parent crabs to be released.

6.3.6.3 Behavioral and Physical Responses of Crabs

Behavioral responses among mature female *E. sinensis* were monitored by video recordings after gradually acclimatizing the crabs to salinities between 18‰ and 30‰, or between 18‰ and 0‰. The findings suggested that increased salinity induced locomotor activity, and other related behaviors in mature crabs. Abdomen extension under hypo-osmotic stress can bring the hindgut into direct contact with water, functioning as an additional means of ion uptake under low salinity conditions. A closure reaction under hyper-osmotic stress could assist with reduced water absorption and salt loss in high salinity environments. Females and males exhibit different salinity preferences and behaviors that are possibly related to the asynchronism in gonadal development, and the importance of salinity on gonadal development. The results also indicates that other physical factors, such as water depth and substrate type, could also be vital for controlling their distribution in the estuary. Mature *E. sinensis*, are a strong hyper-osmoregulator but a weak hypo-osmoregulator. No differences between mature males and females appears to exist in terms of osmotic and ionic regulation when exposed to different salinities.

To understand the metabolic, immune system, and digestive adjustments of mature *E. sinensis* during their reproductive migration from freshwater to seawater, the concentrations of seven hemolymph metabolic variants and the activities of three immune enzymes and five digestive enzymes were determined after gradual acclimatization of females and males moved from freshwater (0‰) to various salinities (7, 14, 21, 28, 35‰). The results showed that 21‰ salinity was the turning point of several biochemical parameters in mature crabs. Immune and digestive-enzyme activities of mature *E. sinensis* were affected when the salinity was near or above 28‰, which might exert a negative effect on reproduction. Metabolic and immune parameters in the hemolymph of females were slightly higher than those of males at some salinities (Table 6.3.1). The initial salinity induced a decrease in enzyme activity in males, with values that were lower than were less than in females. These observations suggest that females were more tolerant of elevated salinities than males were in relation to their digestive, metabolic and immune-level activities, which, in the natural environment, could be reflected in their distribution in estuarine habitats after mating. The results of these investigations advance our understanding of some aspects of the metabolic, digestive, and immune adjustments functioning in euryhaline crabs with respect to osmoregulation (Wang *et al.* 2013).

6.3.7 Effects of Stock Enhancement

6.3.7.1 Resource Evaluation

Taging and releasing work on *E. sinensis* in the Yangtze estuary was first carried out in 2010. In recent years, the number of released parent crabs of *E. sinensis* has exceeded 400 000; of these, 45 000 parent crabs are tagged using the double marking technology of 'label + lantern ring.' After investigations and monitoring, 2017 tagged parent crabs were recaptured, with an average tagging recapture rate of 5.76 percent. The recapture rate of tagged *E. sinensis* is generally much higher than recaptures of other aquatic animals tagged in China and abroad. There are two main reasons for this. The first relates to the migration habits of *E. sinensis*:

Table 6.3.1 Mean digestive enzyme activities in hepatopancreas of mature females and males of *E. sinensis* in response to increasing salinities (Mean ± S.E.M, *n*=7–9); Unit: μ/mg protein.

Salinity	Pepsin	Trypsin	Amylase	Cellulose	Lipase
	Females				
0	4.36 ± 0.34^{ab}	0.54 ± 0.09^{a}	64.69 ± 5.88^{a}	3.26 ± 0.42^{a}	$2.62\times10^{-2} \pm 0.02^{a}$
7	4.93 ± 0.53^{a}	1.14 ± 0.09^{b}	65.39 ± 6.61^{a}	2.94 ± 0.34^{ab}	$2.48\times10^{-2} \pm 0.02^{a}$
14	5.20 ± 0.41^{a}	0.92 ± 0.08^{ab}	61.56 ± 5.65^{ab}	2.55 ± 0.16^{ab}	$4.63\times10^{-2} \pm 0.01^{a}$
21	4.75 ± 0.49^{a}	1.21 ± 0.10^{b}	67.88 ± 7.03^{a}	2.85 ± 0.27^{ab}	$3.51\times10^{-2} \pm 0.02^{a}$
28	2.71 ± 0.51^{bc}	0.23 ± 0.07^{ac}	40.36 ± 1.65^{bc}	1.86 ± 0.27^{ab}	$3.14\times10^{-2} \pm 0.01^{a}$
35	1.00 ± 0.26^{c}	0.54 ± 0.12^{ac}	30.56 ± 3.02^{c}	1.76 ± 0.32^{b}	$0.60\times10^{-2} \pm 0.00^{a}$
	Males				
0	$7.29 \pm 0.46^{A*}$	$1.39 \pm 0.09^{A*}$	$151.35 \pm 4.96^{A*}$	$6.27 \pm 0.46^{A*}$	$3.51\times10^{-2} \pm 0.02^{A}$
7	$7.51 \pm 0.47^{A*}$	1.26 ± 0.06^{AC}	$138.53 \pm 5.42^{A*}$	$4.60 \pm 0.36^{B*}$	$5.76\times10^{-2} \pm 0.02^{A}$
14	$11.19 \pm 0.42^{B*}$	$2.10 \pm 0.08^{B*}$	$182.10 \pm 8.24^{B*}$	$8.51 \pm 0.51^{C*}$	$4.91\times10^{-2} \pm 0.02^{A}$
21	5.12 ± 0.47^{C}	1.06 ± 0.06^{C}	77.90 ± 4.54^{C}	3.44 ± 0.22^{BD}	$5.51\times10^{-2} \pm 0.01^{A}$
28	$5.92 \pm 0.34^{AC*}$	$1.27 \pm 0.06^{AC*}$	$89.38 \pm 1.90^{C*}$	$3.62 \pm 0.28^{BD*}$	$2.45\times10^{-2} \pm 0.01^{A}$
35	$2.21 \pm 0.39^{D*}$	1.39 ± 0.10^{D}	$70.93 \pm 5.50^{C*}$	$2.93 \pm 0.43^{D*}$	$2.40\times10^{-2} \pm 0.01^{A}$

Note: Different lowercase superscripts indicate statistically significant differences between salinity levels in females. Different capital letters denote significant differences between salinity levels in males ($P<0.05$). The asterisks at the upper right of the capital letters indicate significant sexual differences at given salinity.

the migration distance of released parent crabs is relatively short, and a large number of released parent crabs gather near the spawning grounds in the estuary. The second reason relates to the emphasis placed on tagging recapture efforts in the region. Tagging recapture plans are actively publicized and fishery workers are encouraged to actively participate in every release event. After releasing parent crabs, tracking and monitoring and recapture of the tagged parent crabs are carried out in a planned manner; in addition, posters of prized recaptures are handed out and displayed at the main fishing ports, such as the Chongming, Changxin, and Hengsha wharves.

Since 2010, continuous survey monitoring and statistics have been maintained on the catch of *E. sinensis* parent crabs in the Yangtze estuary area. Combining tag-and-release and recapture data, and using the Lincoln index method, the resource of *E. sinensis* parent crabs in the Yangtze estuary was estimated as fluctuating between 150 and 260 tonnes, and indicated an increasing yearly trend. During the periods 1997 to 1999, and 2000 to 2004, the *E. sinensis* resource in the Yangtze estuary averaged 3.5 tonnes and 30 tonnes, respectively. Moreover, the *E. sinensis* resource in the estuary has significantly increased in recent years — amounting to 40 and 5 times the averages for the above periods, respectively. Estimates of the occurrence of juvenile crabs in the estuary show a positive relationship with the parent crab resources. In 1981, the maximum production of *E. sinensis* juveniles was as high as 20 tonnes, but thereafter the production plummeted. By 2000, the juvenile crab resource in the estuary appeared to be almost depleted; the annual output was calculated at less than 500 kg. Nonetheless, surveys and monitoring determined that the production of juvenile crabs in the estuary from 2011 to 2015 reached 10–30 tonnes. The current resource is estimated at 30–50 tonnes. A comparison of the numbers of *E. sinensis* parent crabs released and the rise in the numbers of juvenile crabs in the environment in recent years goes to show that recovery has occurred — to the degree that production matches the historically best-recorded levels. This proves a positive relationship between *E. sinensis* enhancement methods and parent-crab releases in the Yangtze estuary area since 2004.

6.3.7.2 Migration Speed and Adaptability of the Crabs

Tagged parent crabs at capture are monitored using GPS data. The mean migration rate of *E. sinensis* parent crabs in the estuary has been calculated at 3–7 km/d, which is lower than the species' migration rate (8–10 km/d) in the middle and lower reaches of the Yangtze River (Du 2004). Two explanations for this are possible: one is the fast water current in the middle and lower reaches of the river, as compared with the estuary current which slows their downward migration; the other is that after entering the estuary, parent crabs need time to physiologically adapt to new environmental parameters, especially salinity. The monitored distribution of tagged-and-recaptured parent crabs showed that their main migration routine is along the south water course of the south estuary branch, and the ratio of crab quantity along the south and north water courses was 7:3.

Parent crabs show good adaptability to habitat after release. The continuous comparative study of hemolymph biochemical indices among released groups and wild-caught groups detected no significant differences in most of the indices. Parent crabs displayed some reactions within six days after release, such as a decline in their immunity response, and an enhanced metabolism. Yet all indicators among the parent crabs were gradually restored by 22 days after release, and within 70 days the values either approached or reached the levels prior to release. During the same period of gonadal development, released populations and natural populations showed no significant difference in gonad index, hepatopancreas index, and total lipid content in the gonads; however, the total protein level in the gonads and hepatopancreas were significantly lower in the released groups than in the natural populations (Feng *et al.* 2015). From these observations, it can be inferred that the energy metabolism of released populations may be higher than that of natural populations, and this may have a certain effect on the second oogenesis in released populations. Released populations can complete mating and spawning by adapting to the environment. Their fertility appears not to differ significantly from that of natural populations. Likewise, recent research results indicate no significant differences between released and natural populations in hemolymph biochemical indices, fertility, etc., although released populations appear slightly weaker than natural populations in energy storage and metabolism (Cao *et al.* 2013).

6.3.7.3 Spawning Grounds

Spawning grounds are vital for the proliferation and maintenance of natural populations. The Yangtze estuary is a place where massive amounts of *E. sinensis* parent crabs mate, spawn, and carry and hatch-out eggs. Therefore, protecting the spawning grounds for *E. sinensis* is vital to restoring the species as a prominent natural resource. Surveys in the 1970s and 1980s showed that the *E. sinensis* spawning grounds were located in the shallow saltwater of the estuary and the Huangguasha, located to the west of Sheshan Island and to the east of Chongming Island and Hengsha Island. Over the past 20 years, owing to rapid development and associated construction along the Yangtze River, dramatic changes have occurred in the hydrological conditions of the estuary, often causing environmental pollution and other adverse effects; as a result, the spatial and temporal distribution of the spawning grounds of *E. sinensis* in the Yangtze estuary appears to have changed.

Since 2010, continuous monitoring has been conducted on the spatial distribution and habitat characteristics of egg-carrying *E. sinensis*, zoea larva, and megalopa larva, within a scope of nearly 100 000 km^2 of the estuary. The surveys found that from March to May, *E. sinensis* parent crabs without eggs mainly inhabit the central waters to the north of the shoal at Tongsha and to the north-east of the Jiuduansha wetlands, with a distribution range of 122°11 'E, 31°25' N to 122°11 'E, 31°11' N. Egg-carrying crabs were mainly distributed in the central waters to the north-east of the Jiuduansha wetlands, with a distribution range of 122°11 'E, 31°00' N to 122°11 'E, 31°25' N. Based on assessments of habitat suitability for egg-carrying *E. sinensis*, it is believed that ovigerous crabs mainly inhabit water with a salinity of 15–22‰, flow rate of 1.3–1.5 m s^{-1}, depth of 3–6 m, and transparency of 10–23 cm. It is speculated that the main, suitable distribution for egg-carrying crabs is the water area 20 nautical miles to the east of Hengsha, and five nautical miles downstream, at the Jiuduansha wetlands. The range of the spawning grounds is estimated to be 121°58' – 122°12' E, 31°05' – 31°22' N (Jiang *et al.* 2014). Compared with historical data, the water area of the breeding grounds has reduced slightly; furthermore, the position has shifted somewhat, withdrawing about 5.14 nautical miles upstream in the Yangtze estuary. By delimiting the scope of *E. sinensis* spawning grounds in the Yangtze estuary, and by studying the demands of changing environmental factors, researchers have laid the foundation for subsequent studies and the establishment of nature reserves.

6.3.7.4 Genetic Preservation

Currently, both the natural resource and idioplasm of *E. sinensis*, especially in the Yangtze estuary, but possibly elsewhere in China, have largely declined owing to numerous direct and indirect anthropogenic influences. Cryopreservation of fish gametes and embryos is an important method of preserving germplasm, which has tremendous potential application. Vitrification was first introduced into cryopreservation of crustacean embryos related to the stock enhancement study. We selected the embryos of *E. sinensis* as the material to systematically investigate crustacean embryo vitrification, and the mechanisms of cryodamage (Figure 6.3.6). The choice of cryoprotectants and vitrifying solutions, establishment of vitrification frozen methods, effects of cryopreservation on biochemical composition of the embryos, effects of cryopreservation on the exterior shape and interior structure, and effects of cryopreservation on mitochondrial DNA, have been studied (Huang *et al.* 2011).

Tolerance to code-A vitrifying solution, and vitrification cryopreservation methods for five stages of embryonic development were investigated. The survival rate of different embryo stages declined, with an increase in equilibration time in code-A vitrifying solution; the egg-nauplius stage and original zoeal-stage embryos in vitrifying solution displayed a longer adaptation time (40–50 min). The adaptation ability to vitrifying solution differed for different embryo stages during embryonic development; the adaptation ability for cleavage-stage embryos was the lowest (20–30 min), and the original zoeal stage embryos had the best adaptation ability. The survival rate among egg-nauplius stage embryos did not significantly differ when embryos were equilibrated for 40 min in code-A vitrifying solution and eluted for either 5, 10, 15, or 20 min with 0.25 mol/l sucrose, although the survival rate was highest after elution for 10 min. Once the egg-nauplius stage embryos were equilibrated for 40 min in code-A vitrifying solution, and frozen for 40 min at −196°C, the frozen embryos were quickly thawed, and then eluted for 10 min with sucrose: eight embryos survived, and the overall survival rate was 9.3±2.5 percent, but all embryos died by the fourth day (Figure 6.3.7). When the original zoeal-stage embryos were equilibrated for 40 min in code-A vitrifying solution and then frozen

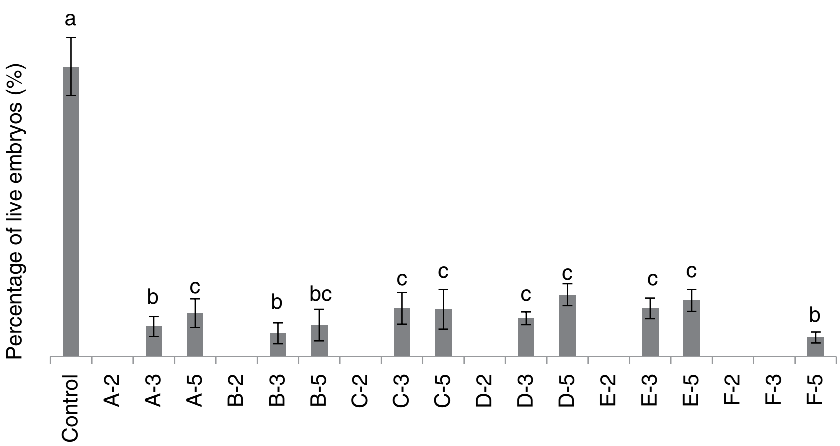

Figure 6.3.6 Survival (mean±S.E.M) rate of *E. sinensis* cleavage embryos (seven days after spawning) exposed to six vitrifying solutions. A (30%PG+20%DMF), B (30%MeOH+20%DMF), C (30%PG+20%MeOH), D (30%PG+10%MeOH+10%DMF), E (30%DMSO+20%PG), F (20%DMSO+30%MeOH), whereas 2-5 represent two-step, three-step, and five-step method. Same letters above the error bar indicate that values are not significantly different (P>0.05).

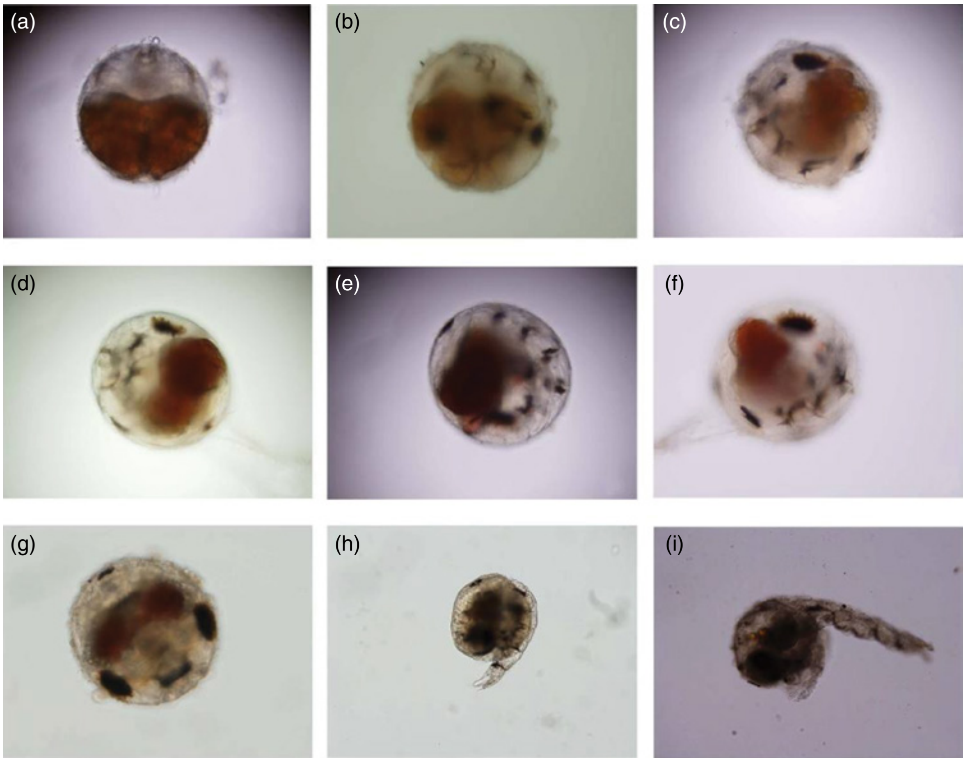

Figure 6.3.7 Embryonic development of *E. sinensis* after cryopreservation. (a) the second day of pre-nauplius stage embryo after elution. It was equilibrated for 40 min in code "A" vitrifying solution and frozen for 40 min in liquid nitrogen; (b) the third day of frozen pre-nauplius stage embryo; (c) the fourth day of frozen egg-nauplius stage embryo; (d) the second day of original zoea-stage embryo after elution. It was equilibrated for 40 min in "A" vitrifying solution and frozen for 2 hr in liquid nitrogen; (e) the third day of frozen original zoea-stage embryo; (f) the fourth day of frozen original zoea-stage embryo; (g) the fifth day of frozen original zoea-stage embryo; (h) the sixth day of frozen original zoea-stage embryo, the tail curved; (i) the seventh day of frozen original zoea-stage embryo, the embryo hatched.

for 1 h at −196°C, seven embryos survived and the survival rate was 11.3±3.6 percent; only one frozen-thawed embryo hatched on the sixth day (Huang *et al*. 2013).

6.3.8 Conclusions and Areas for Future Study

In recent years, stock enhancement with adult Chinese mitten crabs released in selected areas of the Yangtze River estuary, a prime spawning and breeding area for the species, has shown positive results. The numbers of juveniles collected in the estuary nearly four years after initiation of the stock enhancement program matched historically high levels. This stock enhancement work has attracted the attention of the government and society. It may now be surmised that: (1) a simple and reliable double-tagging technology and continuous automatic releasing equipment has aided the *E. sinensis* stock-enhancement program. This solved the bottleneck in evaluating the tags employed in the enhancement program, and significantly improved the survival rate of the released crabs. Consequently, much important scientific information has been obtained through ongoing assessments in the context of the tagging efforts; (2) for the first time, advanced ultrasonic techniques for tracking tagged Chinese mitten crabs, and a model to assess their adaptability to natural habitats after release, were used to reveal the crabs' main migration routes, migration speed, and range of the spawning grounds in the Yangtze estuary. These aspects of mitten crab biology and ecology had previously been difficult to quantify, whereas the acquisition of new data now help with conducting scientific releases as well as protecting the germplasm resource; (3) the natural function of *E. sinensis* spawning grounds in the Yangtze estuary restored more effectively through integrated measures, namely habitat rehabilitation of the spawning grounds and artificial enhancement of the spawning populations. In recent years, the juvenile crab resource has been restored from near depletion to the best levels ever recorded, with an annual output of 30–50 tonnes; (4) cryopreservation methods were invented using *E. sinensis* embryos, primarily to solve the problem of incubating crustacean embryos subsequent to freezing, thereby achieving ex-situ genetic conservation of a invaluable aquatic resource.

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6.4

Enhancing Aquaculture Through Artificial Propagation: Freshwater Fish Fry and Fingerling Production

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6.4.1 Historical Changes of Species Cultured

As early as in the periods of Spring and Autumn and Warring States (473 BCE), Fan Li summarized the experiences of rearing common carp in his book *The Treatise on Pisciculture*, the earliest historical record on pisciculture. During the Han Dynasty (206–220 CE), common carp aquaculture was even more popular, and gradually developed to large-scale aquaculture. In the Tang Dynasty (618–907 CE), catching, selling and eating of common carp were forbidden because the pronunciation of common carp in Chinese was the same as the surname of the emperor. Although the development of common carp culture was stagnant during this period, cultivation of "four major Chinese carps" (black carp, grass carp, silver carp and bighead carp) began in this era. Aquaculture species developed from a single carp to a range of species (Wang 2000). The time from the Tang Dynasty to the Yuan Dynasty (618–1368 CE) was a period of self-sufficiency in pisciculture, and fry collection in the Yangtze River and Pearl River occurred during this time. In the Ming Dynasty (1368–1644 CE), there were detailed records of the whole process of aquaculture from fry to adult, and commercial pisciculture was beginning. In the Qing Dynasty (1644–1911 CE), commercial fish culture became economically important (Wang 2000). After the founding of the People's Republic of China, the development of artificial propagation of cultivated fishes and good government strategies promoted rapid development of commercial pisciculture. Aquaculture has rapidly developed in China since the end of the 1970s, and has gradually become the mainstay of world aquaculture (Subasinghe 2005).

Artificial propagation of four major Chinese carps reared in ponds have been conducted successively by Chinese scientists since 1958. Since then, the same method have been successfully applied in artificial propagation of mud carp, Wuchang bream, white amur bream, Hong Kong catfish, snakehead, Chinese longsnout catfish, mandarin fish, Chinese sturgeon, among others. The breakthrough in artificial propagation technology has greatly promoted the increase in the number of aquatic species cultured, and also have led to the development of polyculture and intensification of aquaculture. Of the relatively large number of aquatic species in China, about 170 are cultured of which about 40 are the mainstay of the industry (Zhang 2005).

Introduced species also have played an important role in aquaculture in China (Liu and Li 2010). For example, Mozambique tilapia was introduced to China in the 1950s, and widely cultivated in the south of China. In the 1970s, Nile tilapia gradually substituted Mozambique tilapia and was popularized across the country (Yao 1999; see Chapter 4.3). China's freshwater aquaculture has developed rapidly, with a large increase in the number of species cultured in the 1970s. In addition to the traditional aquaculture species, such as the four major Chinese carps, common carp, crucian carp, mud carp, and white amur bream, there were new cultivated species, such as Wuchang bream, Nile tilapia, Hong Kong catfish and Prussian carp. Moreover, farming of some valued aquatic species, such as eels, started during this period. Since 1973, net-cage culture has been

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conducted in large water bodies such as lakes and reservoirs. The primary goal of this first stage of cage culture was to raise broodstocks of silver crap and bighead carp. After 1975, the number of species used in cage culture increased and included species such as Nile tilapia, white amur bream, trout and salmon.

Since the 1990s, culture of new high-valued species, among which were Chinese sturgeon, amur sturgeon, hybrid sturgeon (*Huso huso* ♀× *A. ruthenus* ♂), Danube sturgeon, rainbow trout, ice fish, eels, allogynogenetic crucian carp (gibel carp), Chinese sucker, rohu, Chinese large-mouth catfish, North African catfish (*Clarias gariepinus*), Chinese longsnout catfish (*Leiocassis* longirostris) channel catfish, Asian swamp eel, mandarin fish, Japanese seabass, largemouth black bass, striped bass, Nile tilapia, blue tilapia, hybrid tilapia (*Oreochromis mossambicus* × *O. niloticus*), pufferfish, Chinese ocellated sleeper (*Perccottus glenii*), became profitable and expanded nationwide (Yao 1999; Wang 2000).

With the rapid development of the aquaculture industry, and the concurrent intensification of practices, diseases began to occur. Aquatic species had degenerated because of overexploitation of natural stocks, large-scale stocking, extensive artificial propagation, and poor management of broodfish in the 1980s–1990s (Li 2001). Therefore, developing new varieties for aquaculture was urgently needed. The National Certification Committee for Aquatic Varieties was established in 1991 under the Ministry of Agriculture. These initiatives led to the commencement of artificial breeding programs on some new aquatic varieties, such as Xingguo red carp (*Cyprinus carpio* var. *singuonensis*), purse red carp (*Cyprinus carpio* var. *wuyuanensis*), Pengze crucian carp (*Carassius auratus* var. *pengze*), etc. By 2015, there were 156 varieties, including 126 independently cultivated new varieties, and 30 introduced species (Xiong *et al.* 2015; Zhan 2015; http://www.shuichan.cc/news_view-259977.html). Trends in the development in the number of aquatic varieties in aquaculture are shown in Figure 6.4.1, including artificially propagated species, ceno-species and others (Zhang 2015). Moreover, large-scale cultivation of ornamental fish, shellfish and algae was started after 2003.

6.4.2 Historical Developments of Fry Production

There were three sources of aquatic fingerlings in China. The first was natural fry from rivers. From the Tang Dynasty to the founding of the People's Republic of China, fry of cultivated "four major Chinese carps" had been collected from the Yangtze River and Pearl River, which was exceedingly laborious and time-consuming. Aquaculture production was completely dependent on the catches of natural fry during this period. The second was artificial propagation of wild matured broodstock, which were collected from natural waters. Third, fingerlings for aquaculture practices originated exclusively from the offspring of parents that resulted from artificial breeding (Tang 2014). Since 1958, the breakthrough in artificial propagation technology has

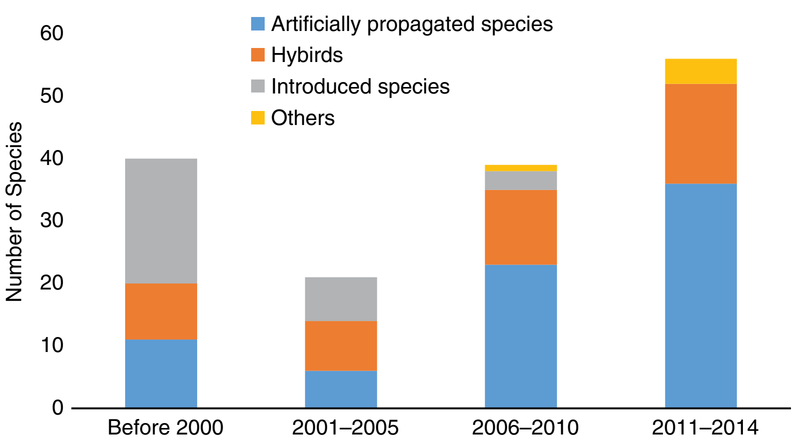

Figure 6.4.1 Trends in the changes of the mean number of new varieties used in aquaculture in China, in different periods. *Source:* Adopted from Zhang 2015; http://www.shuichan.cc/news_view-259977.html.

greatly enhanced the development of aquaculture in China. More and more cultured species are artificially propagated successfully. Furthermore, some species, for example the common carp, can be artificially propagated all the year around.

Nursing of fry and fingerlings is an important part of aquaculture. As the Chinese proverb goes, "good fry is half of the yield, and good fingerling is half of the revenue", point to the importance of fry and fingerlings. The industrialization of fry production can be divided into three stages: natural fry collection, technology breakthrough stage, and rapid development. Before the founding of the People's Republic of China, the production of fish mainly depended on natural catches, and aquaculture relied on fry availability in the wild. In 1950s, as techniques advanced, artificial propagation of the "four major Chinese carps" was successfully conducted, and reduced dependence on wild fry. In the initial stages, there were 665 farms that artificially propagated fry (Hu 2005). From the 1960s to 1970s, aquatic fry production entered into the next developmental stage, and 1582 aquatic fingerling farms were established during this period. The breakthrough in fry propagation technology promoted the development of freshwater aquaculture. After the 1980s, aquatic fry production entered in to a phase of rapid development, and the number of species cultured increased during this period (Table 6.4.1). At the end of 2010, there were 15 306 farms involved in artificially propagated fry production (Lü 2012) (Table 6.4.1).

When the traditional "four major Chinese carps" were cultured in ponds, the gonads matured but the fish did not spawn naturally. Before the 1950s, wild fry were collected from rivers (Figure 6.4.2), and the availability was highly unstable and unpredictable. Before the breakthrough in artificial propagation, the production of freshwater aquaculture was significantly and positively correlated with wild fry availability ($y = 2.695x-3.140$, $R^2 = 0.808$, $P < 0.05$, Figure 6.4.3). The production of fry plays an important role in the production of freshwater aquaculture (Shanghai Fisheries College 1961; Anonymous 1949–1978). At the end of the 1950s, with the success of artificial propagation, aquaculture removed its dependence on natural/wild-caught fry, and an increase in aquaculture production followed. In Guangdong Province (southern China), the leading province for freshwater aquaculture production (Wang *et al.* 2015), the production of artificially propagated fry and aquaculture gradually increased ($y = 1.013x + 30.183$, $R^2 = 0.903$, $P < 0.05$), and the dependence on natural fry gradually declined ($y = -3.331x + 86.179$, $R^2 = 0.012$, $P > 0.05$) (Figure 6.4.4). The production of freshwater aquaculture was significantly positively correlated to the production of artificial fry, and gradually reduced the industry's dependence on natural fry (Yao 1999; Anonymous 1949–1988).

Table 6.4.1 Changes in the number of farms involved in production of fry through artificial propagation of cultured species.

Year	Number of farms	Main artificially propagated species
1950s	665	"Four major Chinese carps", common carp
1960s–1970s	2247	"Four major Chinese carps", common carp, crucian carp, mud carp, white amur bream
1980s	5581	Traditional species: four major Chinese carps, white amur bream, crucian carp, mud carp, Wuchang bream, tilapia, Hong Kong catfish, predatory carp
1990s	11622	In addition to traditional species, further species are cultured, such as mandarin fish, largemouth black bass, Chinese large-mouth catfish, yellow catfish
2002	16435	In addition to the above species, Chinese mitten crab, blotched snakehead, pond loach, Asian swamp eel, salmon, trout, pirapitinga, yellowcheek carp, small-scale yellowfin, barbel chub, Chinese longsnout catfish, etc.
2010	15306	In addition to the above, many high-valued species are added, including Chinese sturgeon, rock carp, Russian sturgeon, Siberian Sturgeon, *Huso huso*, Mississippi paddlefish, Sterlet sturgeon, hybrid sturgeon, etc.

Figure 6.4.2 Traditional method of collecting wild fry in rivers (the trap net).

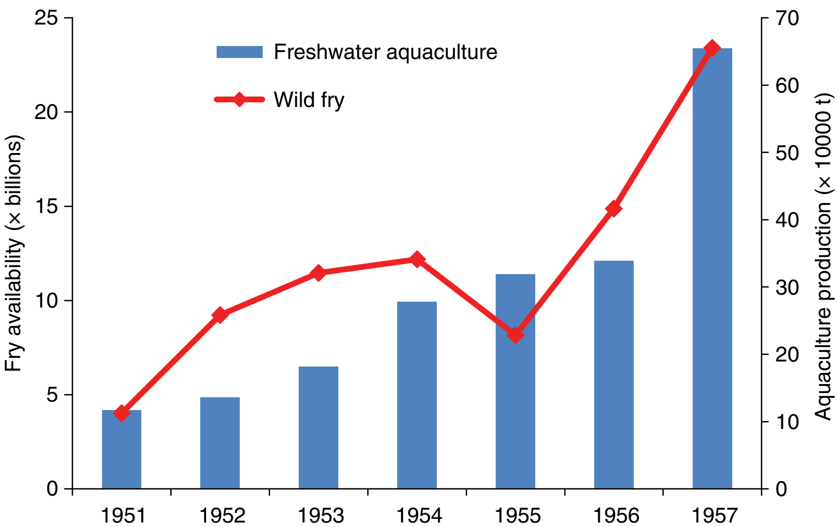

Figure 6.4.3 The relationship between freshwater aquaculture production and wild fry availability in China, prior to the development of artificial propagation techniques.

6.4.3 Key Technologies of the Aquatic Seed Industry

6.4.3.1 The Aquatic Seed Industry

Three key technologies of the aquatic seed industry are germplasm preservation, artificial propagation, and breeding for genetic improvement. Aquatic germplasm preservation includes DNA preservation, cell preservation and in *vivo* preservation, etc. The first fish frozen semen library was established in the 1990s, and

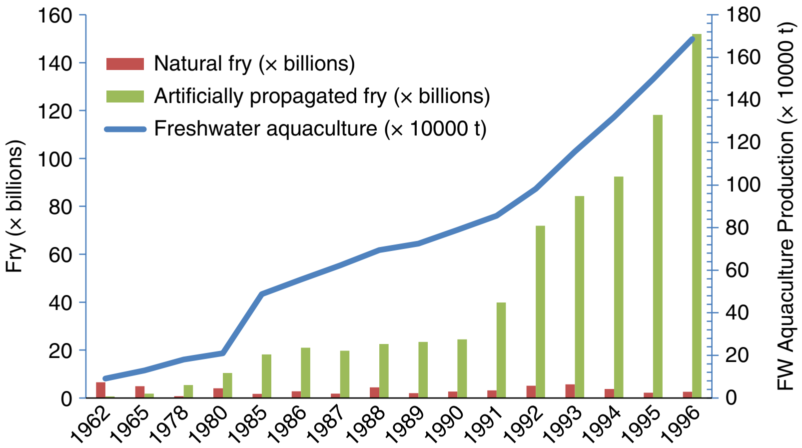

Figure 6.4.4 Changes in the production of wild fry, artificially propagated fry, and aquaculture production in Guangdong province.

currently holds preserved sperm of 131 species of marine and freshwater fish, or geographical populations, such as "four Chinese major carps", as well as Wuchang bream, common carp, and crucian carp (Tang 2014). Using in *vivo* individual preservation sperms of about 731 aquatic organisms are currently preserved in China (Tang 2014).

Techniques of breeding for genetic improvement mainly include selective breeding, hybridization, cell engineering, and molecular-marker-assisted selection (MMAS; also see Chapter 6.1). China carried out selective breeding early compared to other countries in the world and applied it to many species, such as Xingguo red carp, Wuyuan red purse carp, tilapia, channel catfish, among others. Hybridization among cyprinids was started in the 1950s in China, and so far has produced 45 hybrids (Zhang 2015). Some of these hybrid populations usually showed a degree of heterosis, which were valuable characteristics for aquaculture. Cell engineering was a technique of genetic manipulation at the level of cells and chromosomes, and allogynogenetic crucian carp (see Chapter 2.4) with a dominant faster growth, was one of the key results of this technique (Li 2001).

There are currently three sources of broodstock for artificial propagation in China; wild parents, domesticated or artificially cultivated natural fingerlings, and new varieties produced by artificial breeding (Tang 2014). By 2015, a total of 79 national farms for wild and domesticated aquatic organisms have been certified by the National Certification Committee for Aquatic Varieties, of which 62 were freshwater species (Table 6.4.2). Further research on controlling sexual maturity should be carried out to meet the demand for aquaculture fry and fingerlings at any time of the year.

6.4.3.2 Artificial Propagation Practices

Wild mature individuals collected from rivers were induce-spawned by injection of human chorionic gonadotrophin (hCG) during the preliminary stages of artificial propagation. There are many disadvantages associated when eggs and sperm are squeezed out by applying pressure on the belly. This method of artificially induced spawning results in increased mortality, decreased fecundity and fertilization, and asynchronous development of oocytes (Institute of Experimental Biology, Chinese Academy of Sciences 1962). These unfavorable results led to the next stage of development, when gonads were induced to mature through hormone injection, and broodstock were provided with conducive ecological conditions when the fish ovulated naturally, resulting in increased fertilization rates and embryo survival. The application of physio-ecological methods resulted in successful artificial propagation of silver carp and bighead carp in 1958 (Institute of Experimental Biology, Chinese Academy of Sciences 1962). Circular concrete ponds were used for ovulation and spermiation, with two water inlets in the same direction at the bottom of

Table 6.4.2 Information on 79 National farms with responsibilities for fry and fingerling production of wild and domesticated aquatic organisms.

No.	Farm	Species	Authorized date	No.	Farm	Species	Authorized date
1	Qingduo Tilapia Farm	Tilapia	1996	41	Dongting Fish Seed Farm	Crucian carp	2006
2	Hunan Origin Fish Farm	Four major Chinese carps	1996	42	Chongzhou Chinese Longsnout Catfish Farm	Longsnout catfish	2006
3	Qinghai Origin Fish Farm	Qinghaihu naked carp	1997	43	Chongzhou Channel Catfish Farm	Channel catfish	2006
4	Guangdong Tilapia Farm	Tilapia	1998	44	Huzhou Giant Freshwater Prawn Farm	Giant freshwater prawn	2007
5	Ruichang Yangtze River Origin Chinese Carps Farm	Four major Chinese carps	1998	45	Weihai Origin Sea Cucumber Farm	Sea cucumber	2007
6	Hanjiang Yangtze River Origin Chinese Carps Farm	Four major Chinese carps	1998	46	Tongliao Chinese Carps Farm	Four major Chinese carps	2007
7	Heilongjiang Fangzheng Crucian Carp Farm	Fangzheng crucian carp	1998	47	Weihai Origin Japanese Seabass Farm	Japanese sea bass	2008
8	Jiaxing Fish Farm	Four major Chinese carps	1998	48	Linxia Salmon And Trout Farm	Golden trout	2008
9	Guangdong Lvka Soft-shelled Turtle Farm	Soft-shelled turtle	1999	49	Hangzhou Soft-shelled Turtle Farm	Soft-shelled turtle	2009
10	Yantai Kelp (Laminaria)Farm	Kelp	2000	50	Hunan Origin Mandarin Fish Farm	Mandarin fish	2009
11	Nantong Zicai *Porphyra* Farm	Zicai	2000	51	Beijing Origin Amur Sturgeon Farm	Amur sturgeon	2009
12	Hunan Soft-shelled Turtle Farm	Soft-shelled turtle	2000	52	Yantai Origin black snapper Farm	Black snapper	2010
13	Anhui Yongyan Origin River Crab Farm	Chinese mitten crab	2000	53	Wujiang Origin Chinese Carps Farm	Four major Chinese carps	2010
14	Penglai Turbot Farm	Turbot	2000	54	Dalian Sea Urchin Farm	Sea urchin	2011
15	Jianli Origin Chinese Carps Farm	Four major Chinese carps	2000	55	Helong Origin Lenok Farm	Lenok	2011
16	Laohe Yangtze River Origin Chinese Carps Farm	Four major Chinese carps	2000	56	Xinmin Shanxi Origin Chinese Carps Farm	Four major Chinese carps	2011
17	Jinan Tilapia Farm	Tilapia	2001	57	Nanning Tilapia Farm	Tilapia	2011
18	Jiangxi Xingguo Red Carp Farm	Xingguo Red Carp	2002	58	Tongzhou Colorcarp Farm	Colorcarp	2012

Table 6.4.2 (Continued)

No.	Farm	Species	Authorized date	No.	Farm	Species	Authorized date
19	Huanxin Tianjin Aquatic Seed Farm	Common carp, crucian carp	2002	59	Jingshan Origin Turtle Farm	Turtle	2012
20	Shaoxing Soft-shelled Turtle Farm	Soft-shelled turtle	2002	60	Wuhan Origin Black Carp Farm	Black carp	2012
21	Jiujiang Pangze Crucian Carp Farm	Pangze crucian carp	2002	61	Panjin Chinese Mitten Crab Farm	Chinese mitten crab	2012
22	Beijing Fish Farm	Sturgeon	2003	62	Guanjingyang Origin Large Yellow Croaker Farm	Large yellow croaker	2012
23	Wuyuan Purse Red Carp Farm	Purse red carp	2003	63	Penglai Origin Sea Cucumber Farm	Sea cucumber	2013
24	Shishou Chinese longsnout catfish Farm	Longsnout catfish	2003	64	Penglai Origin Marbled Sole Farm	Marbled sole	2013
25	Renqiu Chinese Carps Farm	Four major Chinese carps	2003	65	Xiantao Paddlefish Farm	Paddlefish	2013
26	Hangzhou Qiantang River Origin Black Amur Bream Farm	Black amur bream	2003	66	Taibaihu Hubei Origin Topmouth Culter Farm	Topmouth culter	2013
27	Songjiang Changhai Aquatic Seed farm	Wuchang bream	2003	67	Huanghua White Shrimp Farm	White shrimp	2013
28	Gaochun Yangtze River Origin Chinese Mitten Crab Farm	Chinese mitten crab	2003	68	Rongcheng Origin Sea Cucumber Farm	Sea cucumber	2013
29	Gehu Lake Wuchang Bream Farm	Wuchang bream	2004	69	Chaohu Channel Catfish Farm	Channel catfish	2014
30	Ezhou Origin Wuchang Bream Farm	Wuchang bream	2004	70	Jiayu Channel Catfish Farm	Channel catfish	2014
31	Hainan Tropical Sea Aquatic Seed Farm	White shrimp	2004	71	Zhejiang Sturgeon Farm	Sturgeon	2014
32	Zhongjie Hebei Tilapia Farm	Tilapia	2005	72	Haian Origin Pufferfish Farm	Pufferfish	2014
33	Chongqing Origin Chinese Large-mouth Catfish Farm	Chinese large-mouth catfish	2005	73	Maoming Weiye Tilapia Farm	Tilapia	2014
34	Tianjin Origin Mullet Farm	Mullet	2005	74	Zhanjiang Haimao White Shrimp Farm	White shrimp	2014
35	Hongzehu Aquatic Seed Farm	Fangzheng crucian carp, xingguo red carp, allogynogenetic crucian carp	2006	75	Zhanjiang Hengxing White Shrimp Farm	White shrimp	2014

(Continued)

Table 6.4.2 (Continued)

No.	Farm	Species	Authorized date	No.	Farm	Species	Authorized date
36	Yaowan Hubei Yellow Catfish Farm	Yellow catfish	2006	76	Dongying Yellow River Estuary Origin Soft-shelled Turtle	Soft-shelled turtle	2014
37	Nanning Giant Freshwater Prawn Farm	Giant freshwater prawn	2006	77	Zhangzi Island Yesso Scallop Farm	Yesso scallop, Haida golden scallop, Penglaihong scallop	2014
38	Taiyuan Aquatic Seed Farm	Jian carp, pengze crucian carp, blunt snout bream	2006	78	Penglai Yesso Scallop Farm	Yesso scallop	2015
39	Dalian Origin Sea Cucumber Farm	Sea cucumber	2006	79	Huanghua Origin Swimming Crab Farm	Swimming crab	2015
40	Laizhou Origin Half-smooth Tongue Sole Farm	Flatfish	2006				

(http://nccav.moa.gov.cn/news-show.asp?anclassid=130&nclassid=17&xclassid=0&id=2168)

the pond. The pond inlet made the water circulate continuously, simulating the ecological conditions of natural spawning (Figures 6.4.5 and 6.4.6) (Pearl River Fisheries Research Institute 1980). The outlet installed at the center of the pond is used to collect fertilized eggs. The production of artificial fry is rapidly increased by physio-ecological inducing spawning and spread throughout China, and across south Asia.

Figure 6.4.5 Circular spawning ponds commonly used for carp species.

Figure 6.4.6 Circular incubating ponds (spawning pond of removable polythene nets and concrete stairs).

6.4.3.2.1 Species with Demersal Eggs

Fish eggs that sink are of two types: sticky eggs that adhere to a substrate, such as plants, and those that sink to the bottom. Common carp, for example, produce sticky eggs, and artificial propagation is carried out in the following manner. First, mature common carp are collected in the spawning season, and males and females are kept separately in ponds. Submerged plants, boiled willow branches, or boiled leather palm made into bundles, are placed in the spawning ponds as substrates for the eggs to attach to. Oulation and spermiation are induced in broodstock, with injections of pituitary extracts or human chorionic gonadotrophin (hCG), or luteinizing hormone, releasing hormone analogues, used independently or in any combination. Eggs are fertilized naturally or artificially. Thereafter, the fertilized eggs are treated with a suspension of e.g. talcum powder, river silt or urea solution, to inhibit clumping and suffocation of the eggs. Non-adhesive eggs are transferred to circular incubating ponds or incubators. Another alternative method of incubation is when the substrates with attached fertilized eggs are placed in an incubator, and incubated with a gentle water flow, and provided with aeration (Zhou 1986; Cao 2008).

6.4.3.2.2 Species with Pelagic Eggs

Mandarin fish produce floating eggs. After injection of gonadotropins, floating ova or sperm are collected separately in dry bowls by manual stripping, and sperm and eggs are mixed and rinsed with water. Finally, the fertilized eggs are placed in circular incubating ponds, or incubators, for incubation (Cao 2008).

6.4.3.2.3 Species with Pelagic Eggs

The "four major Chinese carps" are species which produce pelagic eggs. After hormone injection, carp can be made to spawn naturally in spawning ponds provided with flowing water, simulating natural conditions. Ovulation and spermiation are induced in circular spawning ponds, and the fertilized eggs drift with flowing water into circular incubating ponds. This method results in a low broodstock mortality rate and high hatching success rate (Zhou 1986; Cao 2008).

6.4.4 Contribution of Improvements in Fry Availability to Freshwater Aquaculture

6.4.4.1 Fry for Commercial Aquaculture

6.4.4.1.1 Development of Artificially Propagated Species

Since the 1960s, most cultured species such as, yellow catfish, Chinese large-mouth catfish, snakehead, Mozambique tilapia, allogynogenetic crucian carp, Wuchang bream, Asian swamp eel, small-scaled yellowfin, and mandarin fish, have been artificially propagated. In 1976, wild broodstock of Chinese sturgeon and Yangtze sturgeon were used to successfully conduct artificial propagation, and large-scale rearing techniques for Chinese sturgeon fry and fingerling were carried out in 1997. Artificial propagation of cultured Chinese sturgeon, using pond-reared broodstock, was successfully conducted in 2012, and has helped to reduce dependence on wild broodstock (Wei *et al.* 2013). In the late 1990s and early 2000s, artificial propagation of high-valued culture species was conducted, and include the catfish *(Hemibagrus macropterus*), yellowcheek (*Elopicthys bambusa*), Siberian sturgeon, a type of minnow (*Spinibarbus hollandi*), rock carp, Japanese grenadier (*Nezumia* spp.), anchovy (*Engraulis* spp.), and beluga (*Huso huso*).

6.4.4.1.2 The Relationship Between Production of Fry and Aquaculture

Fry and fingerlings play an important role in aquaculture, the quantity and quality of which are closely associated to production and monetary value of aquaculture. Production of natural fry collected from Yangtze River and Pearl River was 20 billion in 1957. After 1958, the yearly production of fry was over 40 billion, of which fry from artificial propagation accounted for 95 percent (Pearl River Fisheries Research Institute 1980). The relationship between artificially propagated fry production and freshwater aquaculture is shown in Figure 6.4.7 ($y = 1.022x + 1116.7$, $R^2 = 0.601$, $P < 0.05$). Freshwater aquaculture production has been increasing, and is associated with the production of artificially propagated fry from 1996 to 2013. Aquaculture production was 28.02 million tonnes in 2013, and the corresponding production of artificially propagated fry was 1 914.3 billion. The example of tilapia aquaculture in China also demonstrates that the overall production of tilapia was related to fry production ($y = 0.657x + 102.68$, $R^2 = 0.397$, $P < 0.05$) (Figure 6.4.8).

6.4.4.2 Fry Production of Prey Fish as Feed for Predatory Fish

6.4.4.2.1 Biological Characteristics of Mandarin Fish

Mandarin fish (*Siniperca chuatsi*) belongs to the order Perciformes and family Serranidae, and is widely distributed around China, especially in the Yangtze River basin. Mandarin fish is a carnivorous species, preferring lentic habitats (see Chapter 3.7). The minimum age of sexual maturity of the Mandarin fish is 2+ years,

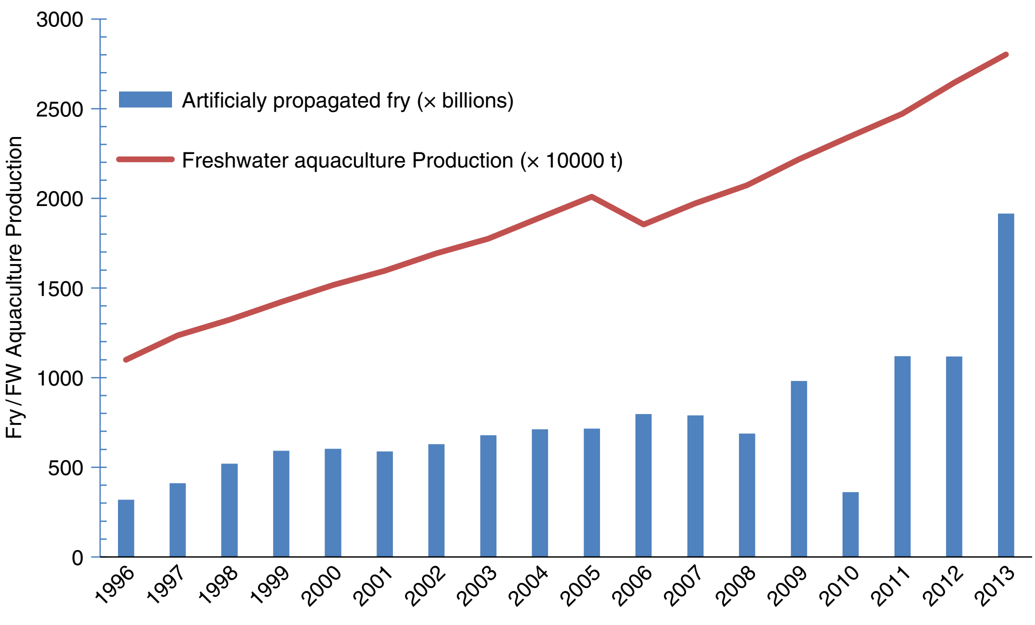

Figure 6.4.7 Trends in production of artificially propagated fry and freshwater aquaculture in China, from 1996 to 2013. *Source:* Compiled from China Fishery Statistical Yearbook.

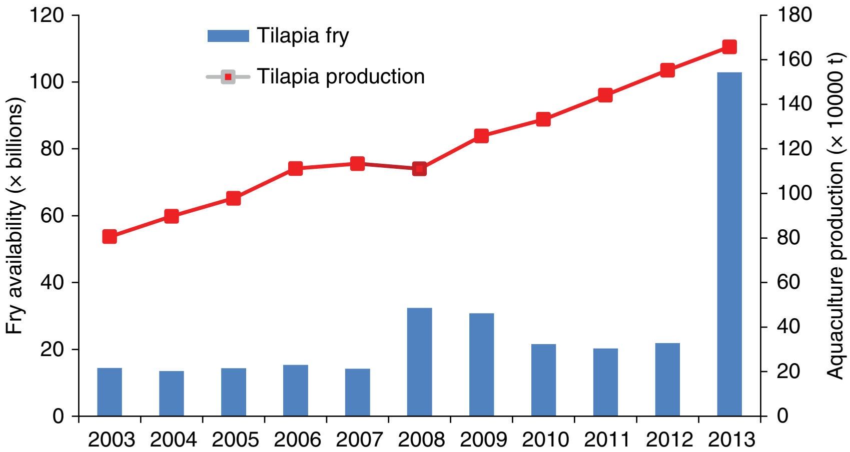

Figure 6.4.8 The production of cultured tilapia and fry in China from 2003 to 2013. *Source:* Compiled from China Fishery Statistical Yearbook.

and it spawns in lentic environments from May to July. The range of fecundity is 30 000 – 200 000 eggs ind.$^{-1}$ (Cheng and Zheng 1987; Li 2000).

6.4.4.2.2 Biological Characteristics of Mud Carp

Mud carp (*Cirrhinus molitorella*) belongs to the order Cypriniformes family Cyprinidae, and is distributed in southern China (e.g. Pearl River, Hainan Island, Taiwan, Minjiang River, and Yuanjiang River), and is a semi-migratory species. Mud carp prefer warm water, above 7°C. The minimum age of sexual maturity is three years, and the range of fecundity is 25 520–314 492 eggs ind. $^{-1}$. Spawning occurs from the end of April to early July. In the Pearl River basin, spawning grounds are distributed in the Xunjiang, Qianjiang, and Yujiang rivers (Wuming district). In the spawning season, mature individuals group in the spawning grounds and produce pelagic eggs. Mud carp mainly feed on periphytic algae, and also on some zooplankton and plant debris.

6.4.4.2.3 The Relationship Between the Production of Mud Carp Fry and Mandarin Fish

Mud carp, is the favorite prey fish of mandarin fish. The production of mandarin fish has increased in relation to the growth of mud carp culture. The production of mud carp per growth cycle is about 7500 kg/ha, while mandarin fish was about 6000–7500 kg/ha, and feed coefficient was about 1:3–4. When the feed coefficient is 3.5, the production of mandarin fish was 284 780 tonnes in 2013, and required a prey fish production of mud carp of about 996 730 tonnes. Almost all prey for mandarin fish is provided through artificial propagation. The production of mandarin fish has increased over the years, and is significantly positively correlated with fry availability (Figure 6.4.9) (Pearson correlation = 0.70, $P < 0.01$) (China Fishery Statistical Yearbook 1996–2014). As a high-quality food for mandarin fish, the variation in production of mud carp is directly related to the aquaculture scale of mandarin fish, as shown from the example in Guangdong Province (Figure 6.4.10). Here again, there is a significant linear correlation between the production of mandarin fish and mud carp ($y = 0.348x - 48057$, $R^2 = 0.765$, $P < 0.05$) (Yao 1999).

6.4.5 Government Policies

China is the largest producer and consumer of aquatic products in the world, and the government attaches great importance to fisheries research and development. Thirty two "Genetic Breeding Centers" and six "Quality Supervision and Inspection Centers" have been certified by the Ministry of Agriculture (MOA) (http://nccav.moa.gov.cn/news-show.asp?anclassid=130&nclassid=16&xclassid=0&id=2167). There were set

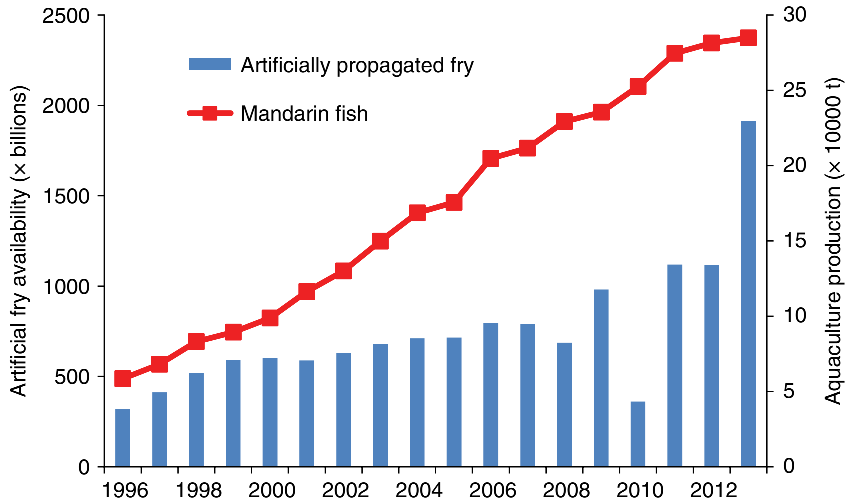

Figure 6.4.9 The relationship between the production of mandarin fish and freshwater artificially propagated fry production in China from 1996 to 2013.

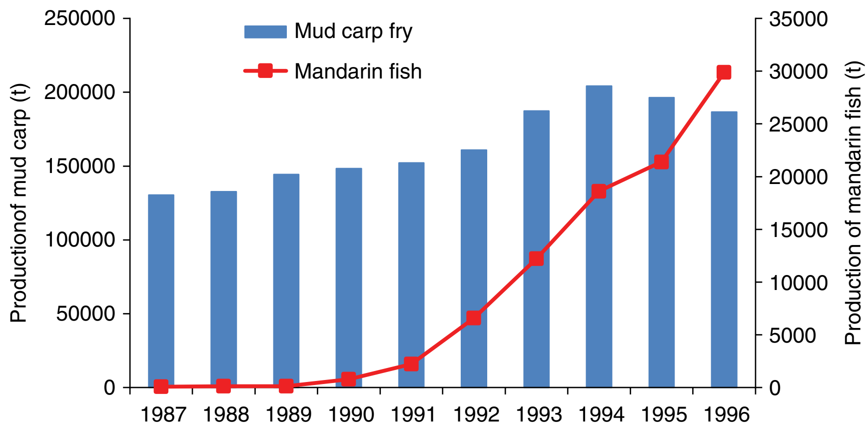

Figure 6.4.10 The relationship between the production of mud carp and mandarin fish in Guangdong province from 1987 to 1996.

up to conduct genetic breeding research, and protect the genetic resource of specific fish species. By 2015, 79 national farms for wild and domesticated aquatic organisms were established by the National Committee of Aquatic Varieties Certification under the MOA (http://nccav.moa.gov.cn/news-show.asp?anclassid=130&nclassid=17&xclassid=0&id=2168), and 282 national aquatic germplasm resource conservation areas had been established (Tang 2014) to ensure supplies of better brooders for hatcheries. In addition, many regulations have been enacted by the government in order to standardize the quality of aquatic fry and fingerlings, and industry standards established. These standards involved the processes for the protection of germplasm resources, farm administration, broodstock selection, larval and fingerling rearing, and import and export management.

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Section 7

Environmental-Related Issues in Chinese Aquaculture

7.1

Multi-Trophic Mariculture Practices in Coastal Waters

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7.1.1 Introduction

With the rapid development of intensive mariculture, the impacts of the mariculture industry on the ecosystem have become a serious concern, especially because of the environmental degradation resulting in higher mortality of cultured organisms, and the quality and quantity of products. For example, finfish monoculture discharges large amounts of solid effluents (feed waste and feces) and dissolved nutrients (excretory products). Fish wastes can contribute to eutrophication of the water column (Wang *et al.* 2012) and then affect the benthic environment of cage area (Wildish and Pohle 2005). The mariculture industry worldwide is searching for sustainable methods, and integrated aquaculture has been proposed as a potential tool in assisting such sustainable development. Integrated aquaculture is defined as an aquaculture production system where the output (waste) of one sub-system is utilized by another, with the sequentially linked sub-systems bringing about a greater efficiency of the overall system. Integrated aquaculture has many benefits, including increment of carrying capacity, bioremediation, enabling a diversification of products, and prevention of disease (Edwards *et al.* 1988; Edwards 1998; Troell *et al.* 2003; Neori *et al.* 2004; Soto 2009). Integrated aquaculture has the potential to contribute to the sustainability of aquaculture by reducing its ecological footprint, increasing economic diversification, and increasing social acceptability of culture systems.

Integrated multi-trophic aquaculture (IMTA) is a form of an integrated aquaculture approach which focuses on the explicit incorporation of species from different trophic levels or nutritional levels in the same system (Chopin and Robinson 2004; Mariah *et al.* 2009). In brief, IMTA is a practice in which organic and inorganic wastes from fed aquaculture species are assimilated by organic extractive species (e.g. bivalves, sea cucumbers, sea urchins) and inorganic extractive species (seaweed, seagrass) (Neori *et al.* 2004; MacDonald *et al.* 2011; Nelson *et al.* 2012).

In the past two decades, integration of seaweeds with marine fish culture has been examined and studied in Canada, Japan, Chile, New Zealand, and USA (Chopin *et al.* 1999, 2001, Chopin 2008; Troell *et al.* 2003; Neori *et al.* 2007; Buschmann *et a*l. 2008; Abreu *et al.* 2009). In effect, IMTA have been commercially successful at industrial scale in China for many years. In the past, this was named polyculture or eco-culture. Though the concept and contents were to some extent different, the main purposes were similar: to mitigate aquaculture waste release, reduce ecological footprint, increase economic diversification, and improve social acceptability of culture systems.

In this Chapter, we provide two case studies of integrated mariculture practices in Sungo Bay, China. One was IMTA for sea ranching in subtidal zone, and the other was IMTA practiced for suspendied/floating mariculture in open waters.

Aquaculture in China: Success Stories and Modern Trends, First Edition.
Edited by Jian-Fang Gui, Qisheng Tang, Zhongjie Li, Jiashou Liu, and Sena S. De Silva.

7.1.2 Sungo Bay

Sungo bay, 144 km^2 is located (37°01′–37°09′ N, 122°24′–122°35′ E) in Shandong Province, and has been a center for aquaculture for more than 30 years (Figure 7.1.1). The main cultivation method is longline culture, and cultivated species include seaweed (*Saccharina japaonica*), oyster (*Crassostrea gigas*), and scallop

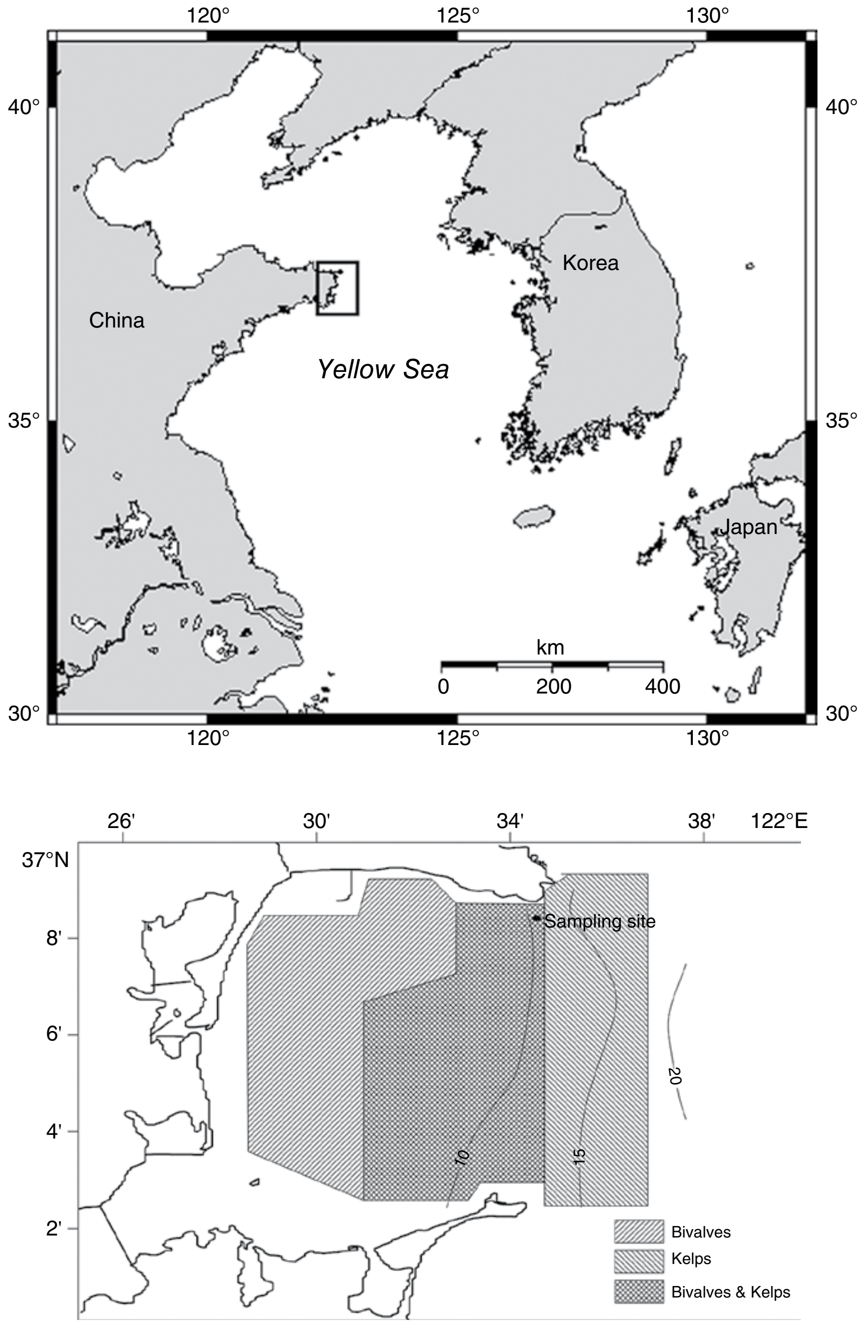


Figure 7.1.1 The location and distribution of mariculture practices of Sungo Bay, China.

(*Chlamys farreri*). In the northern and southern area of Sungo Bay, there are several finfish cages. A small-scale seagrass bed in the southern area of the Bay.

7.1.2.1 Open Water Culture of Abalone, Seaweed and Sea Cucumber

7.1.2.1.1 Principle of the IMTA System

The system of kelp, abalone and sea cucumber includes organisms from three trophic levels – a primary producer (kelp), a herbivore (abalone) and a detritivore (sea cucumber) – forming the food web/chain (Figure 7.1.2). The abalone feed on kelp and produce organic waste in the form of feces and uneaten feed, which can be extracted and utilized by sea cucumber. The excretory and waste products (NH_4, CO_2) generated by abalone and sea cucumber can be assimilated by kelp, which can increase its productivity, and thereby recycling the nutrients present in the effluent. Kelp plants can in turn be used as a source of nutrition for herbivores, e.g. abalone. The IMTA system can form a simple and effective 'recycling' system. Theoretically, the system is only reliant on the input of inorganic nutrients for kelp growth, as well as sunlight and carbon dioxide, and the input of kelp, abalone and sea cucumber juveniles. In addition to the recycling of nutrients within the system, there is an exchange of dissolved inorganic nutrients and particulate organic matter (POM) with the external environment. The input of inorganic nutrients is necessary for kelp growth, while POM from natural sources in the external environment, may be an additional food source for sea cucumbers.

In this study, sea cucumber were added directly to abalone cages without any modification of the culture facility, in order to allow simple, low-cost production. The cages were suspended from kelp longlines.

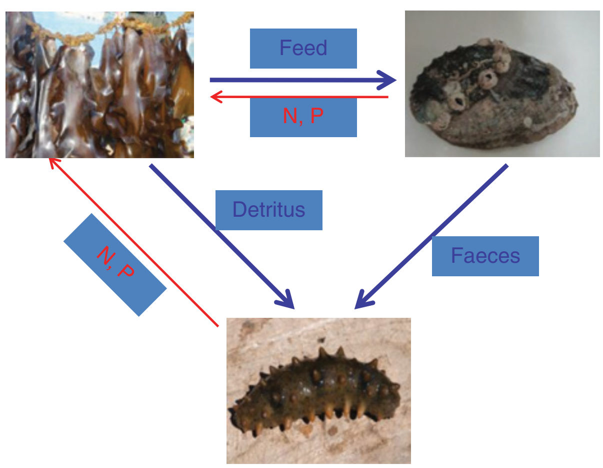
7.1.2.1.2 Methods

Abalone and kelp are co-cultured on a large scale from suspended longlines in the coastal waters of North China. A demonstration area (1600m^2) for polyculture of abalone and kelp was developed at Xunshan Fishery Company, located on the north coast of Sungo Bay. Each cultivation unit consisted of four rafts with longlines, containing in total 12 000 kelp *Saccharina japonica* and 33 600 abalone (Figure 7.1.3). Kelp was cultivated from November to June. When the plants reached 1-m length they were removed from the culture ropes, and placed into the net cage for feeding the abalone. When feeding the abalone once a week in this way, market size (8–10cm) can be reached within two years.

7.1.2.1.3 Main Results

This study indicates that 1kg cage^{-1} can be produced after seven months' cultivation, when the majority of sea cucumbers will have reached marketable size (Fang 2009). The high overall observed growth rate of sea

Figure 7.1.2 Schematic representation of the principle of the IMTA system of kelp, abalone, and sea cucumber, as practiced in Sungo Bay.



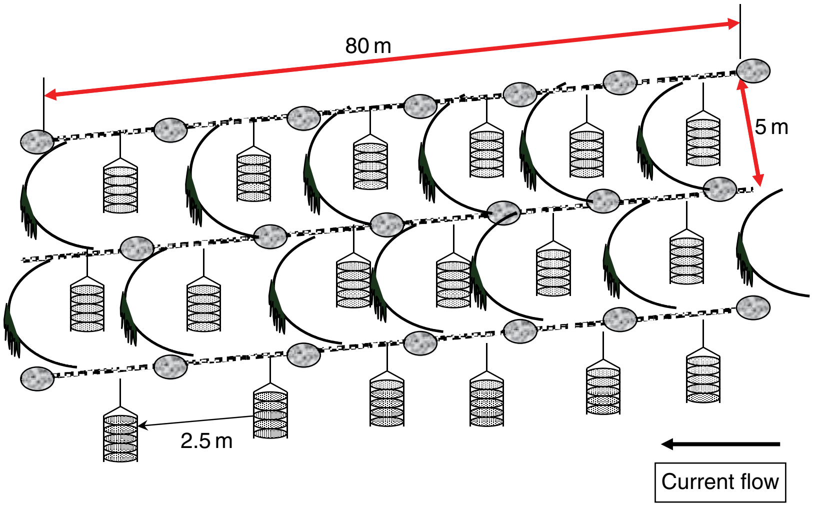


Figure 7.1.3 Schematic diagram and practice of IMTA system of abalone, seaweeds, and sea cucumber, in Sungo Bay.

Table 7.1.1 Comparison of growth of sea cucumber at different densities (treatments).

Treatment	Initial BW (g)	Final BW (g)	SGR (% day^{-1})	Total growth (%)
1SC	98.7 ± 5.3[a]	186.7 ± 11.5[1]	0.32 ± 0.07	89.2
1SC	60.6 ± 3.6[b]	137.8 ± 5.7[2]	0.40 ± 0.04	129.2
2SC	63.4 ± 5.3[b]	120.3 ± 4.1[2]	0.32 ± 0.02	90.4
4SC	66.2 ± 2.8[b]	132.4 ± 9.6[2]	0.34 ± 0.05	100.0
6SC	63.4 ± 5.7[b]	118.5 ± 13.1[2]	0.30 ± 0.01	78.3

In any column the values with the same superscripts are significantly different from each other ($P < 0.05$).

cucumber 0.33 percent/day^{-1} (Table 7.1.1) showed that adding sea cucumbers directly to abalone cages may be a feasible production option. Compared to production in land-based facilities, tidal ponds, or extensive bottom culture, this method is simple and requires minimum extra labor or additional investment.

Aquaculture, especially integrated aquaculture, provides not only goods (such as food products), but also many other direct and indirect service functions to the ecosystem (such as e.g. waste assimilation). Based on the 17 major evaluation criteria and methods presented by Costanza *et al.* (1997), the core services of mariculture ecosystem in Sungo Bay were estimated and results shown in Table 7.1.2.

7.1.2.2 Open Water Culture of Finfish, Bivalves and Kelp

7.1.2.2.1 Principle of the Imta System

Marine fish cage farming releases organic and inorganic wastes into the environment, in the form of uneaten food, feces, and excretory products. In order to reduce the environmental impact of cage culture, 'extractive species' (e.g. bivalves, and seaweed) are cultured in conjunction with 'fed species' (fish). In such systems bivalves function as a filter to remove suspended particulate organic materials, which originate from fish feces, small-size residual feed, and phytoplankton.

Seaweeds are used to remove and transform dissolved inorganic nutrients from effluents of both finfish and bivalves, and in return provide dissolved oxygen (DO) to finfish and bivalves (Figure 7.1.4). Dissolved inorganic nitrogen (DIN) was selected as the parameter to balance the seaweed absorption and fish production.

Table 7.1.2 The service values afforded to people by the core services of mariculture systems in four different mariculture modes in Sungo Bay, based on ecosystem-valuing approaches.

Mariculture mode	Food provision services	Waste treatment services	Climate regulating services	Air quality regulating services	TN (RMB ha^{-1} yr^{-1})
Monoculture/ kelp	49 219	428.24	4859.32	6750	61 257
Monoculture/ scallop	31 406	73.54	973 028	–7.8832	32 445
IMTA kelp and abalone	325 553	2274.58	13 591.28	7488.6972	348 809
Kelp, abalone, and sea cucumber	483 918	2293.75	13 832.61	7489.0565	507 532

All values are presented in RMB ha^{-1} yr^{-1} (6 RMB = 1US$)
Source: Tang *et al.* (2013).

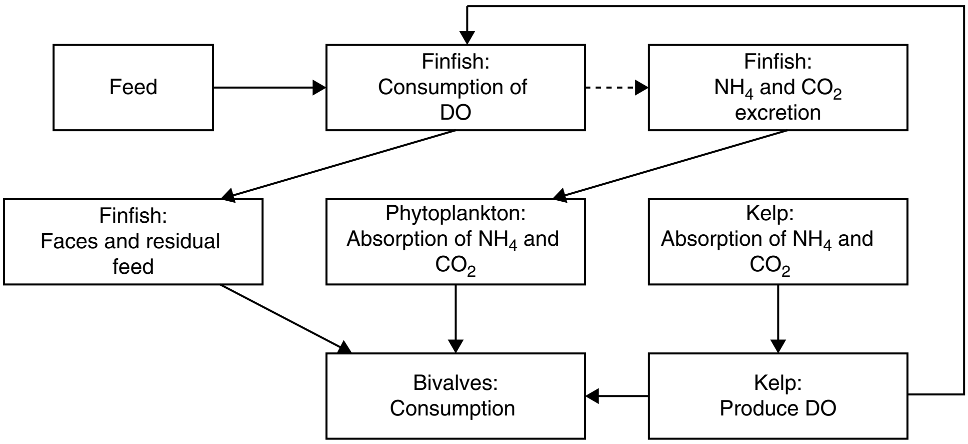


Figure 7.1.4 Diagrammatic IMTA of longline culture of finfish, bivalves, and kelp, practiced in Sungo Bay.

7.1.2.2.2 Optimum Co-Culture Densities of Fish, Seaweeds and Bivalves

(1) Total Nutrients Released from Fish Culture

To evaluate the optimal densities for simultaneous culture of finfish and seaweeds, a field study was conducted at a farming site in Ailian Bay, Yellow sea (Ge *et al.* 2007). Sea bass (*Lateolabrax japonicus;* 72 percent) and black rock fish (*Sebastodes fuscescens*; 28 percent) cultures were fed frozen, low-valued fish.

The Specific Growth Rate (SGR), was calculated using the formula:

$$SGR = 100 \times \frac{(\ln W_{t_2} - \ln W_{t_1})}{t_2 - t_1}$$

Where W_{t2} and W_{t1} are the body weight at time t_2 and t_1, respectively.

The production period lasted from April to January of the following year with an annual production of 3250 kg for this site (5.6 km^{-2})

The specific growth rates of *L. japonicus* and *S. fuscescens* are given Table 7.1.3. It can be seen that the SGR in May was negative, which can be explained by the adaptation process of the larval fish after stocking in April. During the culture period, the growth trend was different for *L. japonicus* and *S. fuscescens*. From June to December, the SGR of *L. japonicus* ranged from 0.0571 to 0.5214, and reached a peak in August,

Table 7.1.3 Seasonal changes in mean weight, and specific growth rates of cultured fish species.

		L. japonicus		*S. fuscescens*	
Month	**Temp. (°C)**	**Weight (g)**	**SGR**	**Weight (g)**	**SGR**
May	10.4	205.0	–0.6400	438.0	–0.0710
June	15.2	235.0	0.4406	280.0	0.2391
July	19.0	295.0	0.7335	285.0	0.0571
August	21.0	335.0	0.4102	335.0	0.5214
September	21.6	460.0	1.0229	365.0	0.2767
October	18.0	525.0	0.4264	375.0	0.0872
November	12.0	630.0	0.5881	390.0	0.1265
December	7.5	664.0	0.1709	425.0	0.2780

while the SGR of *S. fuscescens* ranged from 0.1709 to 1.0229 and peaked in September. SGR and temperature were positively correlated for *L. japonicus* and *S. fuscescens*, the correlation coefficient being 0.38 (n=8, α=0.05) and 0.65 (n=8, α=0.05), respectively. SGR and weight were positively correlated for *L. japonicus* (r=0.344, n=8, α=0.05), but negatively correlated for *S. fuscescens* (r=–0.268, n=8, α=0.05) SGR of *L. japonicus* was higher than that for *S. fuscescens*.

Ingestion Rates:

For *S. fuscescens*:

$$\ln\ (R+1) = (S+0.307+0.018\ T)/0.778$$

$$F = RW/100$$

Where *F, R, T, W* are food consumption rate $(\text{g.ind}^{-1}\cdot \text{d}^{-1})$, ratio of ingestion (%), temperature $(°\text{C})$ and wet weight (g).

For *L. japonicus*:

$$\text{In}\, C = -13.3031 + 1.3380\ T - 0.0237\ T^2 + 2.2570\ \ln W - 0.2203\ T\ \ln W + 0.0042\ T^2 \ln W$$

$$F = CW/100$$

Where, *F, C, T, W* are food consumption rate $(\text{g.ind}^{-1}\cdot \text{d}^{-1})$, average ratio of ingestion (%), temperature $(°\text{C})$ and wet weight (g).

Ingestion rate was calculated using food consumption rates and standing stock (Table 7.1.4). Results showed that the ingestion rate for *L. japonicus* ranged from 1.36 percent to 4.38 percent and in *S. fuscescens* from 0.06 percent to 3.50 percent. The maximum ingestion rate occurred in August and July, respectively for *L. japonicus and S. fuscescens* suggesting higher ingestion activity in summer.

Ammoniacal Nitrogen Excretion:

For *S. fuscescens*:

$$N = 1.774 + 9.551C_f + 0.012T^2 - 1.300C_f \ln W + 0.134C_f T \ln W - 0.003C_f T^2 \ln W$$

Table 7.1.4 Trends in changes in standing stock and food consumption rates of cultured fish species.

	L. japonicus			*S. fuscescens*		
Month	**Quantity ($\times10^5$ ind.)**	**Standing stock (t)**	**Food consumption (t)**	**Quantity ($\times10^5$ ind.)**	**Standing stock (t)**	**Food consumption (t)**
April	1.2	48.37	29.50	0.99	44.31	7.73
May	1.02	21.99	9.25	1.12	48.97	23.78
June	1.02	27.38	19.82	1.01	39.77	15.15
July	2.19	43.24	51.48	1.10	42.16	45.76
August	2.19	46.93	63.70	1.06	42.88	32.46
September	2.19	65.22	7.39	1.10	44.94	23.40
October	2.19	81.16	68.68	0.68	25.34	12.94
November	2.19	96.54	59.33	0.75	28.87	15.59
December	1.33	57.56	30.49	1.22	39.56	18.68

For *L. japonicus*:

$$\ln N = 1.97784 + 0.01316\ T^2 - 3.63959 \ln W + 0.2979\ T \ln W - 0.00837\ T^2 \ln W$$

Where, N is ammoniacal nitrogen excretion rate $(\mathrm{mg \cdot ind^{-1} \cdot d^{-1}})$.

About 3.13 tonnes nitrogen was released into Ailian bay as a result of cage culture, 1.66 tonnes and 1.47 tonnes for *S. fuscescens and L. japonicas,* respectively (Table 7.1.5). The nitrogen excreted by *S. fuscescens* from July to September accounted for 75 percent of the whole year. And also, the nitrogen excreted by *L. japonicas* from July to August accounted for 71 percent for the whole year.

Table 7.1.5 Trends in seasonal changes in standing stock and ammoniacal nitrogen excretion of main cultured fish species.

	L. japonicus		*S. fuscescens*	
Month	**Weight (t)**	**Excretion (t)**	**Weight(t)**	**Excretion (t)**
April	48.37	4.0×10^{-6}	44.31	0.031
May	21.99	2.1×10^{-4}	48.97	0.107
June	27.38	8.64×10^{-3}	39.77	0.088
July	43.24	0.135	42.16	0.262
August	46.93	0.269	42.88	0.197
September	65.22	0.294	44.94	0.760
October	81.16	0.089	25.34	0.079
November	96.54	1.57×10^{-3}	28.87	0.076
December	57.56	7.65×10^{-9}	39.56	0.058

Fecal Production:

For *S. fuscescens*:

$$Lnf = -3.341 + 1.450 \ln F - 0.866 \ln W - 0.198 \ln W \ln F + 0.094\ T \ln W - 0.003\ T^2 \ln W$$

For *L. japonicus*:

$$\ln\ f = -3.150 + 0.433 \ln W - 0.043\ T \ln W + 0.002\ T^2 \ln W$$

Where *f* is the dry weight of faeces $(g \cdot ind^{-1} \cdot d^{-1})$

The feces production of main cultured fish in different seasons is given in Table 7.1.6. Results show that about 12.37 tonnes (dry weight) of particulate matter were dispersed to the water column. *L. japonicas* accounted for 98.11 percent of the total feces production, and the monthly average feces excretion was 1.34 tonnes, the maximum fecal excretion occurred in August and September, which was 2.427 and 3.145 tonnes, respectively.
According to above results, we could calculate that the quantity of nitrogen released by the combined fish culture of sea bass and rock fish represented 510 kg N and 5874 kg N in winter/spring and summer/autumn respectively.

(2) Nutrient Absorption by Seaweed
Based on biological characteristics, *Laminaria* and *Gracilaria* were selected as extractive species. These two seaweed species were cultured sequentially throughout the year: kelp from December to May (winter/spring) and *Gracilaria* from June to November (summer/autumn). The yield (by wet weight) of seaweed was 5.6 kg m^{-2} and 3 kg m^{-2} for *Laminaria* and *Gracilaria,* respectively. Nitrogen content of *Laminaria* and *Gracilaria* was 1.34 percent (dry weight) and 2.70 percent (dry weight), respectively.

(3) Ratio of Mariculture Fish and Seaweed
Assuming the nitrogen in feed residue and fish feces is converted to dissolved inorganic nitrogen completely (100 percent) (including direct conversion and microbial degradation), then the nitrogen balance equation can be represented as follows:

$$N_{\text{seaweed}} = N_{\text{fish excretion}} + N_{\text{feedresidue}} + N_{\text{fishfaeces}}.$$

Where feed residue and feces are 1.5 and 0.1 times the nitrogen excretion (Jiang *et al.* 2010).

Table 7.1.6 Trends in seasonal changes in fecal production (t) of main cultured fish.

Month	*L. japonicus*	*S. fuscescens*
April	0.610	0.014
May	0.402	0.052
June	0.506	0.048
July	1.625	0.058
August	2.427	0.036
September	3.145	0.030
October	1.715	0.032
November	0.947	0.030
December	0.681	0.016

To balance the nitrogen release, the estimated optimum co-culture proportion is 10.44 for *Laminaria* in winter/spring, and 11.12 for *Gracilaria* in summer/autumn. Where fish is expressed in kg wet weight and seaweeds in kg dry weight.

(4) Role of Bivalves

Static methods were used to study the behavior of oyster (*Crassostrea gigas*) and scallop (*Chlamys farreri*), feeding on flounder (*Paralichthys olivaceus*) feces, residual feed, and deposition. Results showed that the two species of bivalve could assimilate fish feces and residual feed. Ingestion rates of oyster was higher than scallop (ANOVA, $p < 0.01$). Absorption efficiency (AE) of residual feed was not significantly different, but these were significantly different between the two species. AE was positively correlated to organic content, and there was a significantly linear relationship between absorption rate (AR) and particle organic material (POM). Total particle material (TPM) threshold for pseudo-feces production of oyster and scallop was 26.24, 21.64 mg l^{-1}, respectively (Zhang *et al.* 2013).

Growth and origin of food sources of the Pacific oyster (*C. gigas*) integrated with sea bass (*L. japonicas*), and Chinese scallop *(C. farreri)* integrated with (*P. olivaceus*) culture were studied in Northern Sungo Bay, during a field study from April to October (Jiang *et al.* 2013), and May to August (Chen 2015). Both shell and tissue growth of the oysters and scallops were higher (30–40 percent) and (10–32 percent), respectively, at the fish farming site, compared to a control site where there was no fish farming. Furthermore, stable isotope signatures in oyster and scallop tissue showed enriched values at the farming site, indicating that the difference in growth performance between the cage and the control area was due to the utilization of organic matter derived from fish culture operations. This finding is in accordance with several other studies which reported that mussels and oysters can effectively remove fish wastes, and increase their growth when cultured in proximity to finfish (Chopin 2008; Handå *et al.* 2012).

7.1.2.2.3 IMTA in Sea Grass Grounds in Sungo Bay

The IMTA experiments on the sea-ranching of abalone and sea cucumber were carried out in the area of Chudao Island Company, located on the south cape of Sungo Bay. In this case, seaweed is used as food for abalone and sea urchin, while sea grass in the system is regarded as having the function of providing shelter for pelagic and benthic organisms, and for nutrient cycling. In this system, the feces of clam and abalone, and natural organic sediment are utilized as food by sea cucumber. The ammoniacal nitrogen excreted by feeding animals is absorbed by phytoplankton and seaweed. Phytoplankton is utilized as feed by clam. Meanwhile, seaweed and phytoplankton provide oxygen (DO) for the animals. The enhancement of abalone (*Haliotis discus hannai*), sea cucumber (*Apostichopus japonius*), sea urchin (*Strongylocentrotus nudus*), ark shell (*Scapharca Broughtonii*,) clam (*Ruditapes philippinarum)*, and seaweeds (*L. japonica*) were studied in a demonstration area of 665 ha located in south cape of Sungo Bay (5–15m depth). In the study area, natural sea grass (cover area of approx. 400 ha), and seaweed are abundant. Each spring nearly 300 000 sea cucumber and 150 000 abalone juveniles were released into the area. In 2009, total production in the demonstration area (665 ha) was 1.5 tonnes abalone, 20 tonnes sea cucumber, 200 tonnes manila clam, 80 tonnes ark shell, and 2.5 tonnes sea urchin with a total value of more than 10,450 RMB ha^{-1} (6 RMB = 1US$) (Figure 7.1.5).

7.1.3 IMTA Developments in China

The IMTA developed in China gets very high evaluation from scientists, such as, Ken Shellman from NOAA (National Oceanic and Atmospheric Administration) who said:

> "In the penultimate chapter on the Yellow Sea LME [Large Marine Ecosysytem; YSLME], Professor Qisheng Tang and Dr. Jianguang Fang reviewed the variable states of productivity and biomass yields under the influence of climate change and anthropogenic forcing. […] (Sherman and McGovern 2012). The IMTA technology includes the production of algae (kelp), mollusks (abalone), bivalves

IMTA in Sea Grass (eel grass) bed, Sungo Bay

Annual production and value (Area:500 ha)

Species	Annual production (kg)	Unit price (RMB/kg)	Sub total (RMB million)
Sea cucumber (partially released)	20000	160	3.20
Abalone (partially released)	1500	600	0.90
Sea urchin	2500	56	0.14
Manila Clam	200000	7	1.40
Conch	20000	10	0.20
Seaweeds	80000	6	0.48
oyster	300000	0.5	0.15
clam	80000	6	0.48
Total			6.95 million RMB

Figure 7.1.5 Production of main species of enhancement in Sungo Bay.

(bay scallop), and echinoderms (sea cucumber), to help close the food fish protein gap, while capture fisheries recover to sustainable levels. Preliminary results suggest that the IMTA pilot should be expanded throughout the YSLME, and into other Asian LMEs, where applications could provide job opportunities, and alleviate food security. The pilot IMTA project proved to be highly energy efficient, and optimized the carrying capacity of coastal embayment while improving water quality, increasing protein yields, and, through carbon capture, contributing to mitigation of the effects of climate change." (Tang and Fang 2012).

IMTA is the BAP (Best Aquaculture Practice) for recycling food and energy for increased sustainability and profitability of the aquaculture industry. However, there have some challenges that need to be studied in the future include:

- environmental pollution from land-based industry and agriculture is the biggest threat to mariculture, which not only causes frequent disease outbreaks, but affects mariculture yields, and seafood quality;
- man-made and or -induced ecological disasters occur frequently in recent years and impact on the development of mariculture;
- traditional mariculture areas of China are threatened by the development of industry, especially real estate.

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7.2

Ecological Engineering Technologies for Optimizing Freshwater Pond Aquaculture

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7.2.1 Introduction

The main form of aquaculture in China is freshwater pond aquaculture. It was estimated that the freshwater pond acreage in 2015 in the country was 2.7012x10^6 ha that yielded 21.9569x10^6 tonnes of aquatic products and accounted for 71.7 percent of the total freshwater aquaculture output of Chinese fisheries (China Fisheries Statistical Yearbook 2016). Pond aquaculture was first practiced in China of which past models included, "mulberry fish pond" and "sugarcane fish pond", for example. Intensive aquaculture technologies were based on eight facets: water (water body), species (fish species), feed (fish feeds), density (appropriate density), type of culture (mono-/polyculture), cycles (harvesting and stocking cycles), prevention (prevention of fish diseases), and management (careful management), developed in China, and these have greatly contributed to the aquaculture industry worldwide (Liu and He 1992).

Most freshwater aquaculture ponds in China were built in the 1960s and 1970s. After being used for over 40 years, these ponds are currently encountering problems, amongst which are environmental deterioration, damaged and obsolete facilities, collapsed banks and silted pond bottoms, water-quality deterioration, and waste of water resources. These problems have resulted in poor ecological and economic benefits, restricting sustainable development and technological advancement of pond aquaculture in China. Currently, in freshwater pond aquaculture 3–13.4m^3 of water are consumed to produce 1 kg fish in China (Zhang and Zhang 1997). Accordingly, to produce 19.887 million tonnes from nationwide pond aquaculture in 2014, the annual demand for water was about 6–26.7x10^{10} m^3/year, accounting for more than 40 percent of the agricultural water supply (3585.7x10^8 m^3/year) (Xu *et al.* 2008). Frequent disease outbreaks in seawater pond aquaculture since the mid 1990s led to investigations on environmental recovery, water conservation, and effluent reduction. For example, Wang *et al.* (2006) studied closed-system pond shrimp aquaculture, and this lead to the development of integrated shrimp polyculture with *Cyclina sinensis* and *Gracilaria tenuistipitata,* when the shrimp yield increased by 25.7 percent, and the utilization of nitrogen by 85.3 percent. To solve problems such as disease and water quality deterioration in shrimp aquaculture, Huang *et al.* (2001) a multi-pond recirculating aquaculture system for *Fenneropenaeus chinensis*, in which each pond is a composite aquaculture unit and a water treatment unit, and water quality of the shrimp pond is maintained stable via the adjustment and control between ponds. Feng *et al.* (2006) used micro-ecological preparation (MP), *Ruditapes philippinarum* together with *G. tenuistipitata* to recover water quality and provide a healthy aquaculture system. Shen (2003) studied the ecological characteristics and biomanipulation technologies of shrimp aquaculture in land-based ponds, Yang (2004) the ecological characteristics of "rice-fish polyculture", Guo (2004) the clean-up effects of higher terrestrial plants on aquaculture effluent, and Pan and Jiang (2004) built a "zero-discharge recirculating aquaculture machinery-germ-grass comprehensive water treatment" laboratory system. Liu (2011) and

Aquaculture in China: Success Stories and Modern Trends, First Edition.
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Liu *et al.* (2014) studied and designed an integrated wetland-ecological pond aquaculture system. The above studies undertaken in China in the last two decades have laid the foundation for developing ecologically conducive pond-aquaculture systems in the country (Liu *et al.* 2014).

Since 2003, in order to combat environmental deterioration of freshwater pond aquaculture, a number of institutions, for example, the Fishery Machinery and Instrument Research Institute, Freshwater Fisheries Research Center (Wuxi), Yangtze River Fisheries Research Institute, Pearl River Fisheries Research Institute, Heilongjiang River Fisheries Research Institute, and Fishery Engineering Research Institute of the Chinese Academy of Fishery Sciences, have been engaged in a National Key Technology R&D Program. This program has addressed a multitude of problems encountered in freshwater pond aquaculture in China, with the resultant development of suitable technologies and dissemination thereof to over eight million mu (0.533×10^6 h m^2). This Chapter focuses on the control technology for ecological engineering of freshwater pond aquaculture. However, before doing so, an attempt is made to review our knowledge on sources of nutrient discharge, and the quantities thereof, in freshwater aquaculture ponds, in order to portray the magnitude of the problems encountered. For this purpose examples are drawn from a wide range of material published in a number of provinces across China.

7.2.2 Sources of Effluent of Pond Aquaculture

Pond aquaculture in China requires the water to be fertilized, circulating, fresh, and clean. Fertilized equates to a phytoplankton concentration of 20–100 ml/l, COD_{Mn} of 10–20 mg/l, and transparency of about 30 cm; Circulating, equates to a dominance of *Cryptomonas*; Fresh, to a few and low levels of suspended material, transparency of 25–40 cm, and a dissolved oxygen concentration (DO) higher than 3 mg/l; and clean, to a bloom of mainly *Cryptomonas*. China covers a large territory, with great climatic differences across different regions. As a result, pond aquaculture features numerous variations, simple approaches, and wide ranges in water quality.

7.2.2.1 Water Replenishment in Pond Aquaculture

Investigations conducted on a range of freshwater aquaculture pond farms have revealed that water renewal of conventional freshwater fish ponds is carried out according to demand, and that water renewal peak occurs in August and September, with the daily renewal ratio up to 10–30 percent. In November and December, all ponds are emptied, and each pond needs 400 percent of replenishment each year, the number of water renewal activities is three to five, and the water demand of unit aquatic product is about 4.0–6.7 m^3/kg (Liu 2011). The annual water drainage for *Penaeus vannamei* broodstock ponds is about 200 percent, and the annual water discharge of unit production is 3.0–4.5 m^3/kg. Water renewal is minimal for crab broodstock ponds, needed to make up for losses due to evaporation and leakage. Generally, the annual water demand of unit production is 1–2 m^3/kg.

7.2.2.2 Pond Aquaculture Effluents

The average growth period is three to four years for grass carp raised in ponds (Jiangsu and Zhejiang provinces), and the culture cycle is about two years for silver carp, spotted silver carp, crucian carp, bream, and common carp, and one year and two years, respectively for shrimp and mitten crab. For pond aquaculture of conventional freshwater fish, the stocking density of fry is 2.3–6 t/ha, which yields 3.8–12 t/h m^2, a net yield of about 750–7500 kg/h m^2. Feed and fertilizer (mainly urea) input per annum, generally, amount to 10–31 t/h $m^2$and 0.23–1.5 t/h m^2, respectively. In addition, organic fertilizer (including night soil and livestock excreta) amounting to per annum 7.5–75 t/h m^2, prophylactics (including pesticide) of 30–390 kg/h m^2, lime input is 150–3900 kg/h m^2 are used. Table 7.2.1 shows the effluents of conventional freshwater fish pond aquaculture.

Table 7.2.1 Range, average and net emission levels of main effluents from conventional freshwater fish pond aquaculture.

Parameter	SS	CODcr	COD_M	BOD	NH_3-N	NO_3-N	TN	TP
Range (mg/l)	5 ~ 169	32 ~ 91.8	8 ~ 20.3	4 ~ 16.7	0 ~ 5.35	0 ~ 4.08	2 ~ 9.72	0.1 ~ 0.4
Average (mg/l)	116	63.3	15.6	10.8	1.54	1.45	5.5	0.28
Net emission ($kg/hm^2 \cdot a$)	2280	999	199	145	13.5	12.7	101	4.95

SS – suspended solids; COD –Chemical oxygen demand (Cr3+ and Mn+2, respectively; BOD_5 – five hr biological oxygen demand; NH_3 -N- ammoniacal nitrogen; NH_3 -N- nitrate nitrogen; TN – total nitrogen; TP – total phosphorous.

For broodstock ponds of conventional adult freshwater fish, the annual nitrogen and phosphorus input is about 1550 kg/h m^2 and 580 kg/h m^2, respectively of which the direct effluent production is about 2280 kg/h m^2, 199 kg/h m^2, 101 kg/h m^2, and 5.0 kg/h m^2, respectively for TSS – total suspend, TN – total nitrogen, TP – total phosphoroused solids, COD_{Mn} – chemical oxygen demand, and the direct proportion is about 6.5 percent and 1 percent, respectively for nitrogen and phosphorus.

7.2.2.3 Water Quality in Pond Aquaculture

Analysis of water quality of conventional freshwater fish broodstock ponds in Qingpu District, Shanghai revealed that in August and September, the average concentrations of total nitrogen, ammonia nitrogen, nitrate nitrogen, and total suspended substances are 2.44 mg/l, 0.56 mg/l, 7.38 mg/l, 0.01 mg/l, and 165 mg/l, respectively (see Table 7.2.2); the concentration of TN in the pond water body is 1.22 times higher than that in class-V water specified in the relevant national standards, showing serious eutrophication in the water body.

The monitoring data concerning conventional freshwater fish aquaculture ponds in Changzhou, Jiangsu in consecutive years (2009–2010) revealed that all year round ammoniacal nitrogen concentration ranged 0.06–1.10 mg/l, with an average of 0.173±0.015 mg/l; hydrogen sulfide ranged 0–0.235 mg/l, with an average of 0.054±0.003 mg/l; nitrite, was 0.015–1.114 mg/l, and averaged 0.255±0.015 mg/l; total nitrogen concentration ranged 0.510–2.652 mg/l, 0.491±0.035 mg/l; total phosphorus concentration ranged 0.030–0.242 mg/l, and averaged 0.097±0.004 mg/l; COD concentration ranged 6.15–27.12 mg/l, and averaged 14.40±0.29 mg/l.

7.2.2.4 Pond Bottom Sediments

Sediments are a major cause of eutrophication in a water body. Sediments mainly result from the sedimentation of particulate matter, the dissolution of animal and plant residues, the exchange and adsorption of

Table 7.2.2 Mean concentration of selected parameters of fish pond water (in mg/l) quality in August and September.

Sampling location		Parameter				
Pond	Location	Total nitrogen	Ammoniacal nitrogen	Nitrate nitrogen	Nitrite nitrogen	TSS
T1	31N04.306;121°E00.611	2.57	0.43	2.2	0.01	182
T2	31°N04.301;121°E00.491	2.70	0.55	2.08	0.01	214
T3	31°N04.347;121°E00.415	2.15	0.52	1.52	0.01	154
T4	31°N04.331;121°E00.344	2.32	0.75	1.56	0.02	110
Average		2.44	0.56	7.38	0.01	165

nutritive salts, the weathering and disintegration of sediment matrices, and the precipitation of particulate matters in a water body. According to Yao (2010), concentration of organic matter, available nitrogen, total nitrogen, total phosphorus and total potassium in aquaculture pond sludge (air-dried samples) is generally 3 percent. 0.01–0.1 percent, 0.2 percent, 0.2 percent, and 0.7–1 percent, respectively. The proportion of nitrogen: phosphorus: potassium is 1:1:3.5.

The amount of total nitrogen, total phosphorus and organic matter in the pond-bottom soil of aquaculture ponds in Qingpu, Shanghai were 6.9 times, 1.5 times and 3.9 times that in natural soil. The nitrogen, phosphorus, and organic matter differ at different soil layers of the pond-bottom material. In ponds beyond a depth of 15 cm, total phosphorous shows an increasing trend with depth, whilst the total nitrogen content shows the reverse, and the organic matter is mainly concentrated in the top 5–10 cm of the sediment. In aquaculture pond bottom material, the nitrogen sediment > organic matter sediment > phosphorus sediment, which means that nitrogenous organic compounds are the leading pollutants of aquaculture.

7.2.2.5 Nitrogen and Phosphorus Budgets

Aquaculture is not only affected by the quality of the external water source, but it also impacts the external environment. Based on mass balance computations, the ammoniacal nitrogen and COD emissions of aquaculture drainage of broodstock ponds of conventional freshwater fish in Jiangsu and Zhejiang provinces were 2.63 kg/m^3 and 52.4 kg/m^3. Nitrogen input of conventional freshwater fish aquaculture in Jiangsu and Zhejiang provinces was about 90.24 g/kg fish, and the inputs of feed, fertilizer and allogenic water were 72 g/kg fish, 10 g/kg fish, 8.24 g/kg fish, respectively, amounting to proportions of 80 percent, 11 percent and 9 percent. Output of nitrogen through feed input is 57.6 g/kg fish. As nitrogen transformation of a unit aquatic product accounts for 20 percent of the nitrogen input through feed and nitrogen, discharge to the water body is 13.76 g/kg fish, accounting for 15.2 percent of the total nitrogen input; nitrogen deposition of bottom mud accounts for 80.6 percent of the total nitrogen discharged due to aquaculture or 63.2 percent of the total nitrogen input. Phosphorus input of fish yield per kilogram in Jiangsu and Zhejiang provinces was 21 g/kg fish, where phosphorus in the feed accounted for 82 percent, and fertilizer phosphorus for 9.5 percent, phosphorus brought in by the water source for 8 percent, and from rainfall for 0.2 percent. Phosphorus assimilation of aquatic products accounted for 45.2 percent of the total phosphorus input; phosphorus discharge of pond aquaculture accounted for 5.3 percent of the total phosphorus input, and 9.7 percent of aquaculture phosphorus discharge; bottom mud sediment accounted for 49.4 percent of the total phosphorus input, and 90.3 percent of the aquaculture phosphorus discharge (Liu 2011).

7.2.3 Treatment Facilities for Ecological Engineering of Water Quality of Ponds

7.2.3.1 Eco-Slope Purification System

Eco-slope is an ecological engineering measure for slope bank belts, such as river ways and water fronts. Its functions are to prevent water and soil scouring, for beautification and conservation, being widely used for ecological restoration of river ways and lakeshores in recent years (Liu *et al*. 2014). Generally, "living branch cuttings", "living branch fascines", "bush wood cushion", and soil bioengineering technologies are adopted. Ecological slope protection can significantly improve the bank slope soil-shear force, degree of compaction, and soil moisture content, and can decelerate run-off, and remove suspended matter. These factors help improve water quality through significant reductions in the total nitrogen and total phosphorus. Eco-slopes also help improve biodiversity.

7.2.3.1.1 Design

The regulation and control system of eco-slope pond water is generally composed of the pond-bottom automatic-control water intake equipment, water distribution pipeline, three-dimensional vegetation net, and

Figure 7.2.1 A representative example of an eco-slope.

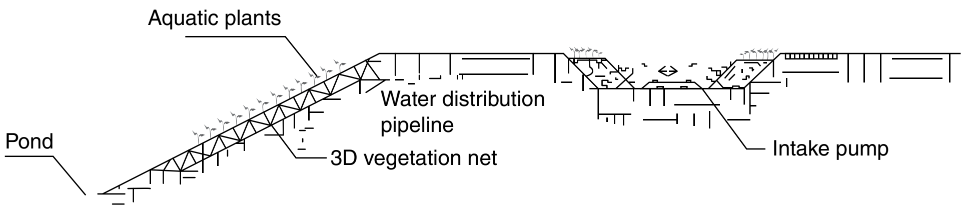


Figure 7.2.2 Schematic representation of an eco-slope.

aquatic plants (see Figures 7.2.1 and 7.2.2). The pond-bottom automatic-control water intake system consists of a water pump and UPVC water supply pipe. Bottom water in the central part of the pond is pumped by a submersible pump to the eco-slope water distribution pipeline. The power and head of the submersible pumps are based on the eco-slope hydraulic load. The pumps should have a daily carrying capacity not lower than 10 percent of the capacity of the pond water body. Since the eco-slope is relatively long, the water distribution pipeline system is often composed of three kinds of water supply pipes of different diameters. The main water supply pipe is an Ø 150UPVC pipe which is connected to two Ø 75UPVC pipes via a tee on the slope, and then each Ø 75UPVC pipe is connected to two Ø 50UPVC water distribution pipes via a tee. The bore diameter sectional area of the water distribution pipe is generally 1.2–1.4 times that of the water inlet pipe to facilitate uniform water distribution (Figure 7.2.2).

Greening bricks and three-dimensional vegetation net cover the pond ridge, and the pond ridge slope ratio is 1:2.5. The vegetation net is covered with a soil layer of of about 10 cm. Under these conditions and water depth of 1.8 m, the width of the flooded part is 0.3–0.5 m.

Aquatic plants, such as *Oenanthe benghalensis, Ipomoea aquatica, var. ramose* Hort., and *Cyperus alternifolius* are planted on the eco-slope to intercept and absorb nutrients of the aquaculture water body. The pond water, after being purified via the eco-slope, seeps into the pond. Design parameters for eco-slope purification facilities are given in Table 7.2.3.

7.2.3.1.2 Application Effects

The eco-slope purification, adjustment and control system of the pond three-dimensional vegetation net features both subsurface wetland and surface flow wetland. The percentage of void is four to nine percent, the constructed gradient shall be lower than 1:2.5, and the water velocity shall be higher than 0.13 ms^{-1}. If the daily circulation rate is 10 percent for the pond water body, the three-dimensional vegetation net eco-slope

Table 7.2.3 Design parameters for eco-slope purification facilities.

Parameter	Method	Unit	Scope
Pond area	W×L	m^2	4200
Eco-slope area	As = QCo/ALR	m^2	120 (L80 m, W1.5 m)
ALR	(BOD)	$g/(m^2{\cdot}d)$	6
Water treatment capacity	Q = t×S	m^3	30
Slope ratio	H:L		1:2.5
Plant biomass	W	Kg/m^2	12-30

can reduce the concentration of ammoniacal nitrogen, nitrite nitrogen, nitrate nitrogen, total nitrogen, and total phosphorus by 46 percent, 65 percent, 49.2 percent, 64.4 percent, and 39 percent, respectively, and reduce the concentration of chlorophyll *a* in the water body by 8.8 percent (Liu *et al.* 2012). The purification efficiency for total nitrogen, total phosphorus, and COD in the water body of the eco-slope is 0.27, 0.015, and 0.94 g/h m^2, respectively. Compared with control ponds, the green algal varieties increased by 10.7 percent in the pond with the three-dimensional vegetation net eco-slope, and reduced the blue green algae by 2.5 percent, and the algal Shannon Wiener diversity index (H') increased by 38 percent (Liu *et al.* 2012). Meanwhile, the density of algae in the test pond water body dropped by 23 percent, of which, that of blue algae was by 48.4 percent. The density of *Cryptomonas* and Euglenophyceae increased by 24 percent and 34 percent, and the structural composition of dominant algal population was more beneficial for aquaculture. In summary, the three-dimensional vegetation net eco-slope system can protect pond ridge and purify, regulate, and control water quality, functioning as an "economical, ecological, and emission-reducing" slope protection technique.

7.2.3.2 Biochemical Ditch

Biochemical sewage treatment technology is efficient and widely used in industrial and domestic sewage treatment (Table 7.2.4). It is also widely used in the water treatment of industrialized recirculating aquaculture (Wang 2001). In addition, it is used in pond water body purification, and pond recirculating aquaculture system construction (Chen and Wang 2008). Generally, three-dimensional, elastic packing, ceramic-biochemical, and efficient filter beds are used to purify, regulate and control the pond water body.

Table 7.2.4 System design parameters for biochemical ditch purification facilities.

Parameter	Unit	Qty.
System area	m^2	16 800
Channel area	m^2	200
Three-dimensional elastic packing bed	m^2	
Elastic packing specific surface area	m^2/m^3	200
Pond area	m^2	12 600
Water exchange volume	m^3/h	100–120
Ceramicite rotating and purification facilities	m^2	75
Ceramicite grain size/specific gravity	$mm/kg/m^3$	2–4/0.98

7.2.3.2.1 Design Principle

- Determine the hydraulic load (Q): The daily water treatment capacity of filter per unit area is generally 1–4 $m^3/(m^2{\cdot}d)$;
- Relationship between biological filter purification efficiency and load (purification efficiency η):
- $\eta = \frac{So - Se}{So} \times 100\%$; where, So is the BOD_5 concentration of crude sewage, and Se is the BOD_5 concentration of effluent.
- Volume load of biochemical filter $N = \frac{Q}{V}$ So; filter material volume $V = \frac{So}{Nv} Q \times 10^3$

7.2.3.2.2 Design

The biochemical treatment-based composite pond aquaculture system consists of piscine. The three-dimensional elastic packing of the biochemical bed is placed in the pond drainage channel to function as a biological purification channel. Water in the biological purification channel, after being purified, is pumped into the ceramic filter bed, and then returned to the intake channel and fish pond after being treated (Figure 7.2.3).

7.2.3.2.3 System Design

According to the theory and principle of design, the system design parameters are given in Table 7.2.4.

7.2.3.2.4 Construction Technology

The schematic layout of a composite water quality regulation and control pond aquaculture system is shown in Figure 7.2.3. The piscina and biological purification channel have the same elevation of water. The efficient ceramic filter bed is above the intake channel, the piscina connects to the biological purification channel via the tubing device, the biological purification channel connects to the efficient ceramicite filter bed via water pump, and the ceramicite filter bed connects to the piscina via the intake channel.

The three-dimensional elastic packing purification bed is composed of angle iron pieces and packing, and its structure is consistent with the drainage channel (Figure 7.2.4). The biopak is put in the drainage channel, which is of the cement slope protection structure, inverted trapezoid, with an upper base of 3.0 m, a lower base of 2.0 m and a height of 2.2 m.

Three-dimensional elastic packing purification beds (Figure 7.2.4) are placed in the biological purification channel at intervals of 3–5 m. The three-dimensional elastic packing purification bed, of 3–5 m length, is consistent with the channel section. The specific surface area of three-dimensional elastic packing is 200 m^2/m^3, and the upper surface height of the three-dimensional elastic packing purification bed is

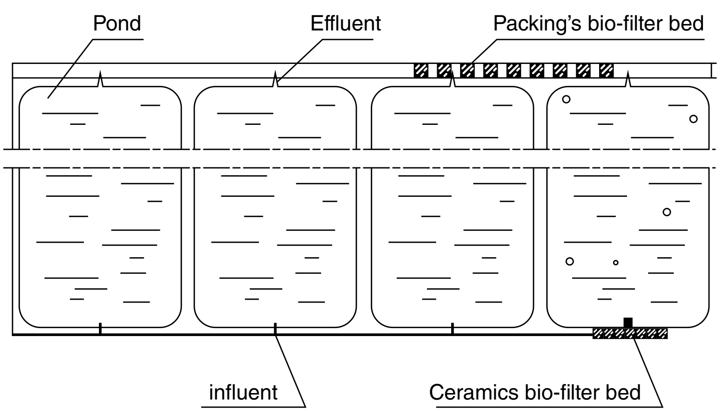


Figure 7.2.3 The layout of a composite water-quality regulation, and control-pond aquaculture system.

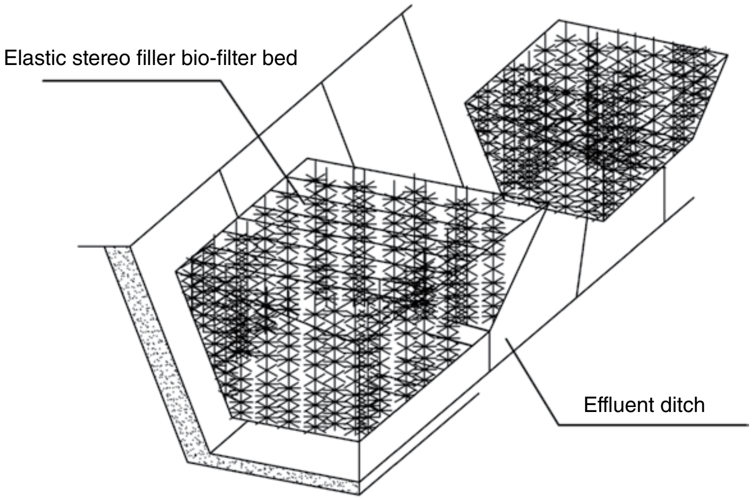


Figure 7.2.4 Purification channel with three-dimensional elastic packing.

5–10 cm lower than the channel water-crossing surface. The biochemical bed is 1.5 m high and its sectional area is 3.75 m^2.

The principle of the ceramicite biochemical filter bed is consistent with that of the three-dimensional elastic packing purification bed, where biochemical reactions purify such nutrients such as nitrogen and phosphorus in the water body. Ceramicite has a larger specific surface area, and relatively smaller specific gravity. This design is mainly for pond aquaculture water purification devices, designed and manufactured based on the principle of the fluidized bed. Its water purification efficiency is relatively high. In addition to nutrient concentration of discharged water, the factors relating to the purification efficiency include duration of stay, ceramicite volume weight, percentage of void, dissolved oxygen (DO), and the like.

The ceramic biochemical filter bed is of a rotary structure and composed of the PE barrel, high-strength clay ceramicite, a water diversion and backflow plate, water intake and drainage system (Figure 7.2.5). The PE barrel has a diameter of 3 m and a height of 1.5 m; the high-strength clay ceramicite is 10–20 mm in diameter, 0.95 kg/l in specific gravity, and 50 cm in thickness; the water diversion plate is made of PE or PVC, with a plate interval of 1 m; the Ø10 mm holes are uniformly distributed at the bottom water-crossing part with a length and width range of 20–30 cm; the combined area of all the openings is larger than 1.5 times the inlet pipe orifice area; the intake and discharge system is composed of the inlet pipe and drainage pipe. The intake pipe is a perforated PVC pipe, inserted into the bottom of clay ceramicite, while the discharge pipe is a side-hole PVC pipe, and its diameter is 1.5 times larger that of the intake pipe. The hydraulic retention time of the purification device for rotary aquaculture water body is more than 15 minutes.

7.2.3.2.5 Application Effect

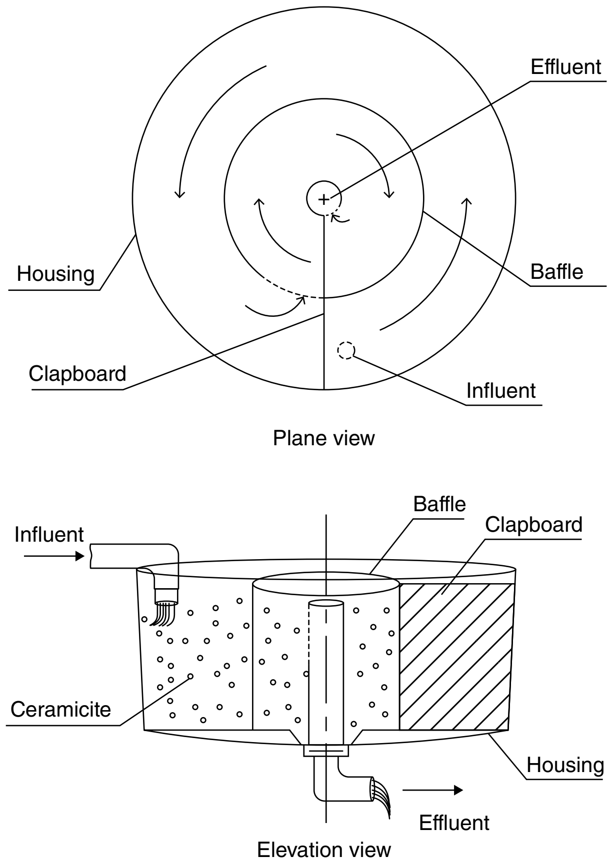
The purification efficiency of ammonia nitrogen and nitrite nitrogen by biopak of in water body is 0.61 g/h m^{-3} and 0.133 g/h · m^{-3}, respectively. The removal efficiency of ceramicite biochemical bed against chlorophyll a, total phosphorus, and total nitrogen is 2.7 g/h · m^{-3}, 0.07 g/h · m^{-3}, and 1.65 g/h · m^{-3}, respectively.

7.2.3.3 Eco-Ponds

7.2.3.3.1 System Structure

In an eco-pond aquatic macrophytes are grown, and snails are introduced in order to maintain water quality at a desirable range. Commonly used aquatic plants are eel grass, *Elodea nuttallii*, *Tribonema*, *Hydrilla verticillata*, *Ceratophyllum submersum*, and the like. The total coverage is over 75 percent. The density of snails is 3000 kg/hm^2. An eco-pond is essentially a mature sewage purification facility. In terms of pond aquaculture,

Figure 7.2.5 Ceramicite biochemical filter bed.



it can be used to purify the water, and improve the material utilization of the pond aquaculture system, with economic benefits.

7.2.3.3.2 Relation Between Aquaculture Pond and Eco-Pond

With TN as an index, the method of pollutant discharge and treatment balance is used to calculate the configuration proportion relation between aquaculture pond and eco-pond:

$$M = V \times \Delta n;\ S = M / QKv$$

where, M is the total TN of aquaculture effluent; v is the absorption efficiency of aquatic plants against TN ($g/m^2 \cdot d$); K is the absorption coefficient of water plants against TN, generally 30 $g/m^2 \cdot d$; Q is the density of aquatic plants (kg/m^2); V is the aquaculture water discharge volume; Δn is the TN removing concentration in the discharge water (mg/l).

With a daily water renewal ratio of 10 percent, Q of 50 percent, V of 1200 m^3 and Δn of 1.5–5.0 mg/l, the relation between eco-pond and aquaculture pond is $Se / s = QKv / V \times \Delta n$.

From the above, it is deduced that the ratio of eco-pond to traditional aquaculture pond is about 1:3–7.

7.2.3.4 Bio-Floating Beds

A floating bed, dry and or wet (Ren and Deng 2007), is also called an artificial floating island or an ecological floating bed (ecological floating island). In recent years, use of artificial floating bed technology has developed

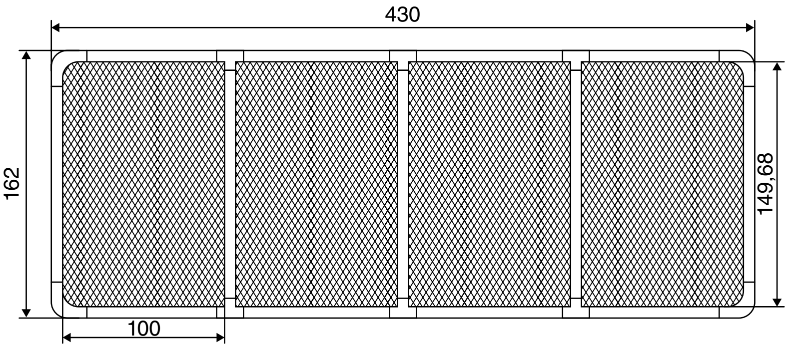


Figure 7.2.6 Plan of a bio-floating bed framework (unit: cm).

rapidly, and spread through China. It is used particularly in sewage treatment, ecological restoration, river regulation, and landscaping. A diverse array of artificial floating beds is available, and these are primarily used for wave dissipating, water quality, and habitat improvement. The shape of a floating bed is generally square, triangular, or rectangular, or round. A bio-floating bed is generally composed of the floating island framework, a plant floating bed, an anchoring device, and aquatic vegetation. The framework can be made of natural materials, such as bamboo and batten. The floating body is generally made of light molecular material, and hydrophytes. Floating beds applied to pond aquaculture mainly involve common bio-floating beds, bio-net cages and composite bio-floating beds.

7.2.3.4.1 Common Bio-Floating Beds

A common bio-floating bed is generally fabricated with Ø50–150 mm UPVC pipe, and 1 cm polyethylene meshes (Figure 7.2.6). In order to maintain structure and stability, a floating bed with large UPVC pipes (>100mm) as its framework, with fewer fixed intersections, is generally preferred. The number of intersections is related to the material used and thickness of UPVC pipe. The floating bed enclosure is generally made of polyethylene meshes, and the size of screen depends on the diameter of aquatic plants used. An excessively large screen will be unfavorable to anchor the plants, and an excessively small screen will increase the weight of the floating bed.

7.2.3.4.2 Bio-Net Cage Floating Beds

A bio-net cage floating bed is the integration of a floating bed and a net cage. Its upper part is a floating bed composed of Ø50–100 mm UPVC pipes and 1 cm polyethylene meshes, and its lower part is a net cage composed of polyethylene meshes (Figure 7.2.7). Water plants such as water spinach, Bengal water dropwort herb, *Phellandrium* spp. and iris, are planted on the top of the floating bed. In the lower net cage are raised clams, snails, and omnivorous fish. Net cage buoyancy is mainly created by the UPVC pipes. The maximum biomass of aquatic plants should be maintained around 20–50 kg/m^2, and those of fish and shellfish at 1–3 kg/m^3.

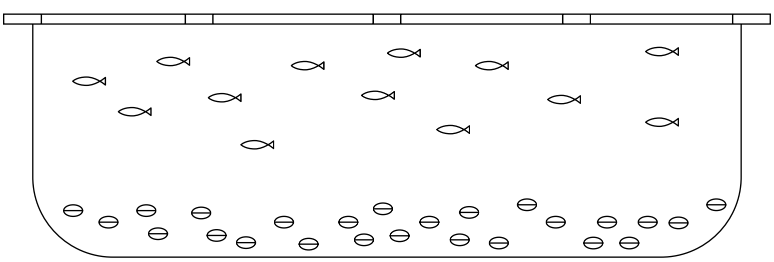


Figure 7.2.7 Schematic diagram of a bio-net cage floating bed.

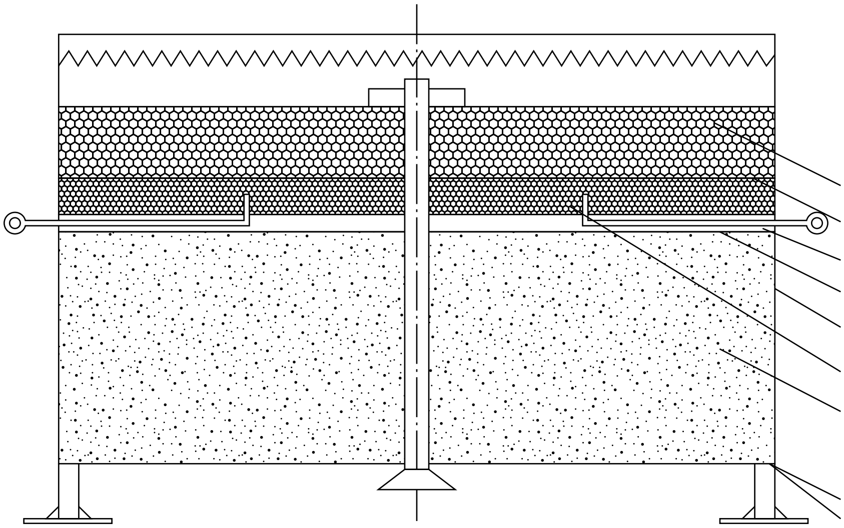


Figure 7.2.8 Schematic diagram of a composite bio-floating bed.

7.2.3.4.3 Composite Bio-Floating Beds

A composite bio-floating bed is of cylindrical structure, and it has a biopak, and water circulation functions, in addition to the functions of a common bio-floating bed. It is generally composed of supports, a water-elevating device, and water distribution parts (Figure 7.2.8). The supports are made of splicing, L-shaped, stainless steel pieces; the water-elevating device uses a vortex air pump as the power source, and elevates water via the water-elevating pipe; the water distribution parts, composed of eight water distribution pipes that uniformly distribute water by the elevating pipes to all parts of the composite bio-floating bed. The water outlet of water distribution pipes is a weir-shaped groove, and can distribute the water uniformly. There are three layers of bio-packing in the composite bio-floating bed: the upper layer is the settleable packing layer, the middle layer is the foamed particle layer, and the lower layer is the PE bio-packing layer. The settleable layer of packing with a diameter of 10–20 mm is the base material for growing plants. The foam particle layer of packing, with a diameter of 5 mm, provides buoyancy for the composite bio-floating bed. The lower layer of PE bio-packing with a diameter of 8–1- mm provides a substrate for biochemical reaction of microorganisms (Table 7.2.5).

Table 7.2.5 Design parameters for a composite bio-floating bed.

Parameter	Method	Unit	Range
Floating bed diameter/height	Ø/H	cm	200/100
Hydraulic retention time	HRT	min	10–20
Filter material	Ø	mm	5–10
Immersed depth of water-elevating pipe	h	cm	120
Water elevating volume	Q	l/min	200
Diameter of water-elevating pipe	Ø	mm	6.0
Plant biomass	W	kg/m^2	12–30

Figure 7.2.9 Examples of operational eco-channels: (a) compartmentalized on left; (b) non-compartmentalized on right.

7.2.3.4.4 Arrangement

Two methods are available for arranging common bio-floating beds in an eco-channel. One is to place a bio-floating bed at intervals of 5–8 m, and use ropes to fix the four corners of the bed to the shore. The other one is to directly line up all floating beds. In the middle of an aquaculture pond, floating beds are placed side by side or in groups in the water, and the floating beds occupy about 5–20 percent of the water surface area (Figure 7.2.9).

Bio-net cages are generally placed in the eco-channel or eco-pond, and fixed in the same way as that of fixing common bio-floating beds.

Composite bio-floating beds are generally arranged in the diagonal section of the pond, and are fixed to the specified places with pull ropes.

7.2.3.4.5 Planting Macrophytes

Two methods are available for laying out plants on floating beds. For floating beds with floating plants such as water lettuce (*Pistia* spp.) and water hyacinth (*Eichhornia crassipes*), plants can be uniformly arranged on the floating bed, and will uniformly grow on the beds. For plants that are rooted to the bed such as Bengal waterdropwort herb, iris, and *Thalia dealbata*, plants are inserted into the areoles of meshes. The size of screen depends on the size of the root system of plants, and the planting density is generally 8–12 plants/m^2.

Water spinach has the features of high purification efficiency, vigorous growth, and good economic benefits. If water spinach is chosen as the floating bed plant, water spinach seeds are scattered on soil, and when seedlings are 5 cm or taller they are transplanted to the floating beds.

Research shows that the maximum biomass of water spinach floating beds can reach 23.2 kg/m^2. The TN and TP concentration of floating bed proportions of 5 percent, 10 percent, and 20 percent ranged from 1.65–5.42 mg/l, 1.62–3.13 mg/l, and 1.63–2.62 mg/l, and 0.18–0.28 mg/l, 0.17–0.26 mg/l, and 0.18–0.21 mg/l, respectively (Liu 2011). Floating beds in different proportions greatly relate to the primary productivity of the water body, and the proportion of floating beds should not exceed 20 percent of the water body.

7.2.3.5 Eco-Channels

An eco-channel is an ecological purification system constructed in a pond aquaculture drainage channel (Figure 7.2.9). It is composed of a number of animals and plants, and functions ecologically, purifying the water flowing through it, and also contributing to aesthetic landscaping. Currently, there are a number of methods for constructing an eco-channel. The main methods involve sectioning, facility layout, and bottom shaping. Sectioning means that the eco-channel is divided (Figure 7.2.9a) into several sections, and different aquatic plants are planted, or omnivorous fish and shellfish are raised in each section; facility layout is a bio-floating bed, a biochemical framework and wet land; the bottom is sloped in the large drainage channel to facilitate growth of different plants, and to facilitate water flow. An eco-channel can be divided into different functional areas, such as composite ecological area, periphytic algal area, and floating plant area.

7.2.3.5.1 Composite Ecological Area

Emergent plants are mainly planted on both sides of the channel, and this is known as the, "composite ecological area". To provide aquatic plants with adequate light, the channel slope gradient should not be lower than 1:1.5, in general. The hydraulic retention time of an eco-channel is generally 2.0–3.0 h, and the organic load COD_{Mn} of the water is 50–100 g/h.

7.2.3.5.2 Periphytic Algal Area

It is designed in two forms:

- the periphytic filamentous algae framework fixation purification area, with a channel depth of 1.5 m (natural depth). Reticular, pile-type periphytic algae experimental inoculation and cultivation periphytic base is arranged to treat the water body via periphytic algae, and;
- cobble stone periphytic algae fixation experimental area with a design depth of 50–70 cm (underwater).

7.2.3.5.3 Floating Plant Area

Bio-net cages are placed in the water, inside which filter feeders such as shellfish are stocked. Multiple floating plants are planted at the top of the net cage to comprehensively treat the water body.

Main plants used in eco-channels include *Elodea nuttallii*, *Hydrilla*, *Potamogeton malaianus*, *Vallisneria natans*, *Potamogeton crispus*, *Myriophyllum verticillatum*, *Nuphar pumilum*, *Nymphaea*, *Euryale ferox*, *Hydrocharis dubia*, *Phragmites australias*, *Sagittaria sagittifolia*, *Iris tectorum*, *Canna indica*, *Typha orientalis* and *Vetiveria zizanioides*. The purification effect/reduction of the concentration of COD, TN, and TP, in the aquaculture water body is closely related to temperature and plant density. However, for reasons of plant succession, the purification effect of TN and DTP in the aquaculture water body in winter is higher than that in spring (Liu 2011). In addition, the purification and absorption efficiency of different nutrients of an eco-channel vary seasonally.

7.2.3.6 Constructed Wetland

7.2.3.6.1 Principle

Constructed wetland can effectively remove pollutants, from domestic sewage and industrial wastewater, for example textile and petroleum industries. As research on wetland pollutant removal mechanisms moves on, and together with recent development in water body ecological restoration, use of constructed wetlands has demonstrated tremendous potential in reducing eutrophication. Currently, based on wetland vegetation, constructed wetlands can be divided into floating plant, floating-leaved plant, emergent plant, and submerged plant wetlands. Based on conditions of water flow, constructed wetlands can be divided into surface flow wetlands (Figure 7.2.10) and subsurface flow wetlands, which can be further divided into horizontal subsurface flow, and vertical subsurface flow wetlands (upward flow, downward flow, and integrated vertical flow).

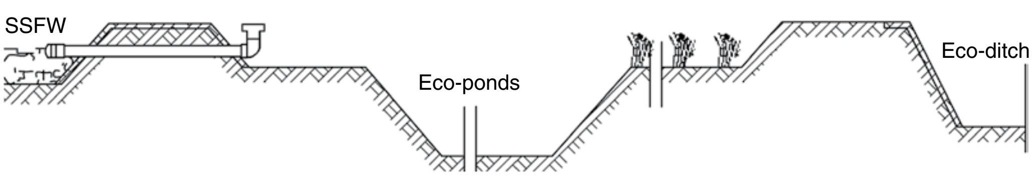


Figure 7.2.10 Examples of representative wetlands with rooted vegetation.

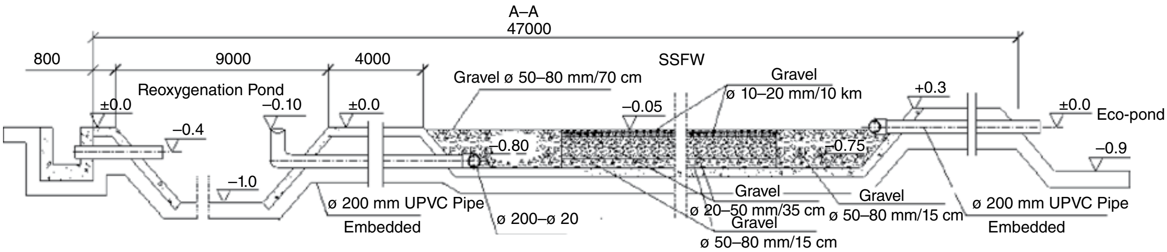


Figure 7.2.11 Vertical structure of the subsurface-flow wetland.

Overall, surface flow wetlands have strong re-aeration capacity, the bed is not easily clogged, and this was widely used at the early stage of development of wetland processes. However, such weaknesses as a low pollutant removal rate, poor sanitary conditions, and its acting as breeding grounds for mosquitoes and flies, restricts its large-scale popularization and application. Compared with the surface-flow wetlands, the packing, and pollutants inside the subsurface wetland have immediate impact on dissolved oxygen (DO); the pollutant removal efficiency is high, the flow of sewage inside the packing can prevent breeding of mosquitoes and flies, and the sanitary condition is relatively good. As a result, subsurface wetland currently have become a focus for the study and application of the artificial wetland processes. Artificial wetland technology applied to pond aquaculture water treatment is an emerging technology, and features good ecology, as well as simple operation and management.

7.2.3.6.2 Subsurface Flow Wetland (SFW)

Subsurface flow wetland volume: $V = Q a v t / \varepsilon$, where, Q a v is the average flow rate (m^3/d), t is the hydraulic retention time (d), V is the wetland volume (m^3) and ε is the wetland percentage of void (dimensionless). According to aquaculture discharge water conditions, generally, t is 0.4d; ε is 0.50 (average Ø50 gravel).

SFW substrate is generally class-3 graded broken stone, the substrate thickness is 70 cm, the 0.5 mm HDPE plastic cloth is laid at the bottom for seepage control. The water inlet and outlet area is 2.5 m-thick Ø50–80 mm of broken stone filtering area, the water treatment area is 25 m long, and the substrate is divided into three layers: the bottom layer is for the 30-cm-thick Ø50–80 cm broken stone, the middle layer is for the 30 cm-thick Ø20–50 mm broken stone, and the upper layer is for the 10-cm-thick Ø10–20 mm broken stone (Figure 7.2.11). Generally, perennial aquatic plants with developed roots, and large biomass as canna, iris, and calamus are chosen for wetlands (Table 7.2.6).

7.2.3.6.3 Purification Effects

The total nitrogen, total phosphorus, and COD in the inlet and outlet water of subsurface wetland differ greatly ($P < 0.05$), indicating that the subsurface wetland can effectively remove nitrogen and phosphorus nutrients in the aquaculture water body. Analysis reveals that the total nitrogen, total phosphorus and COD in an aquaculture water body is removed to the extent of 52–59 percent, 39–69 percent, and 17–35 percent , respectively in subsurface wetlands.

7.2.4 Eco-Engineered Recirculating Aquaculture Systems

7.2.4.1 System Layout

The eco-engineered pond recirculating aquaculture system is composed of facilities such as the eco-channel, eco-pond, subsurface flow wetland, and an aquaculture pond. Aquaculture ponds are connected in series to water-flowing facilities. The water is discharged from the pond and overflow to the eco-channel via water-level control pipes, and it is initially purified in the eco-channel, and then raised by water pump

Table 7.2.6 Design parameters for subsurface wetland applied to aquaculture water treatment.

Parameter	Content	Scope	Remarks
Hydraulic retention time	t = V ε / Q a v	0.5–4 d	t- hydraulic retention time (d), V is wetland volume (m^3), ε is wetland percentage of void (dimensionless), Q a v is average flow rate (m^3·d–1)
Hydraulic slope	S = dh/dl	0.5–2 %	s -hydraulic slope (dimensionless), h is average depth of wetland (m), and l is average length of wetland
Percentage of void	ε	0.30–1.0	
Surface loading rate	AS = (Q)(C0)/ ALR	BOD 80 ~ 120 kg/ (hm-2·d-1)	As is wetland treatment area, Q is wetland inflow rate, C0 is inlet pollutant concentration
System depth	h	40–80 m	
Length	L = (AS)/(W)	20–40m	
Length-width ratio	L/W	1-3:1	

to the eco-pond, where it undergoes further sedimentation and purification, and then flows onto the subsurface flow wetland. The water from the subsurface flow wetland passes through the re-aeration pond, and then flows to the aquaculture pond at the head end, constituting a recirculating aquaculture system (Figure 7.2.12).

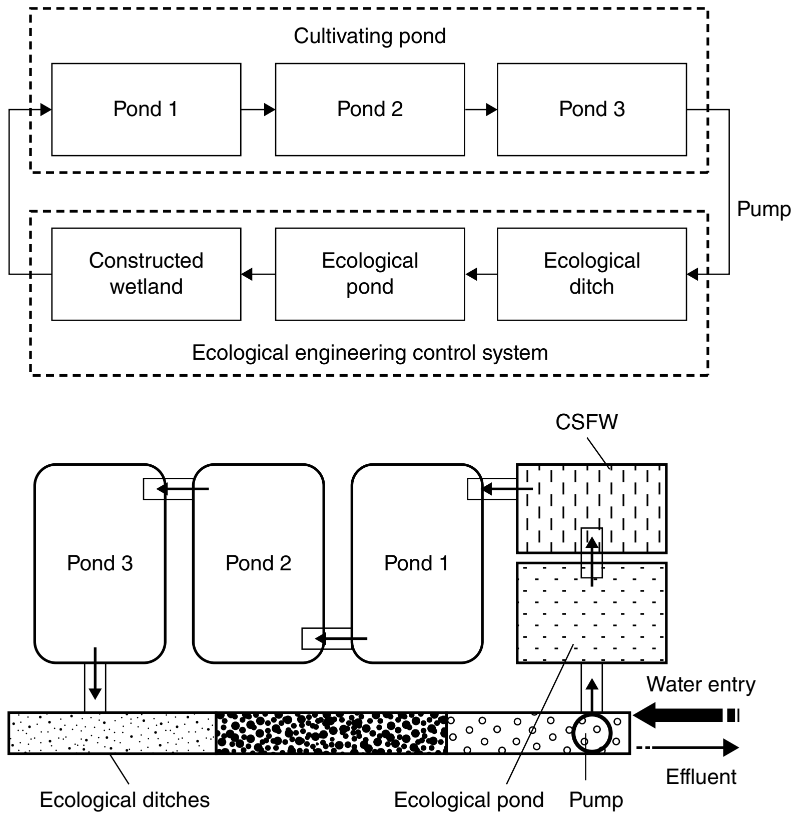


Figure 7.2.12 Flow chart of a pond recirculating aquaculture system.

Figure 7.2.13 An operational pond recirculating aquaculture system.

7.2.4.2 System Structure

The eco-engineered pond recirculating aquaculture system is composed of the aquaculture pond, subsurface flow wetland, eco-pond, and eco-channel. Ponds are laid out in series, inlet and discharge channels are on both sides of the ponds, the eco-pond and subsurface area are on one side of the ponds, and the inlet end of the eco-channel is connected to the water from an external source (e.g. river) to replenish water losses. In addition, water from the external source is treated before entering the pond (Figure 7.2.13; Table 7.2.7).

Table 7.2.7 Design parameters for an eco-engineered pond recirculating aquaculture system.

Content		Parameter
Ecological engineering system		Eco-channel, eco-pond, subsurface wetland, aquaculture pond
Subsurface wetland area		1500 m^2
Eco-pond area		2500 m^2
Eco-channel area		500 m^2
Pond area		15 000 m^2
Water exchange volume		1500 m^3/d
Pond water exchange rate		10 %
Pond fish density		0.20–0.82 kg/m
Make-up water volume		>10 %
Length-width ratio	L/W	1–3:1

Table 7.2.8 Comparison between water consumption and discharge in different aquaculture modes (TN, TP and COD discharge amounts).

Item	Water replenishment (m^3/kg)		TN g/kg	TP g/m^3	COD g/m^3
	Evaporation makeup	Discharge volume			
Traditional pond aquaculture	0.18	4.0–6.7	16.8–28.1	6.4–10.8	49.2–82.4
Ecological engineering aquaculture	0.18	1.3–2.6	1.7–3.5	0.4–0.7	7.9–15.9
Average reduction rate (%)		63.6	88.4	93.6	81.9

Note: TN discharge (TN discharge amount per unit output) = TN content in discharge water body × water discharge of unit product; the method of calculating the TP and COD discharge is the same as that for calculating the TN discharge.

Pond aquaculture in these systems mainly use *Ctenopharyngodon idellus*, *Megalobrama amblycephala*, and also *Hypophthalmichthys molitrix*, *Aristichthys nobilis* and *Carassius auratus*. The fish loading capacity per cycle is 0.20–0.82 kg/m^3; wetland plants are mainly *Pistia stratiotes*, *Ipomoea aquatica*, *Alternanthera philoxeroide*s, *Zizania latifolia*, *Iris tectorum*, *Canna indica*, *thalia dealbata*, and *Phragmites australias*.

7.2.4.3 Water Conservation and Emission Reduction Analyses

The provinces of Guangdong, Jiangsu, Hubei, and Zhejiang dominate freshwater aquaculture in China (Wang *et al.* 2015). In general, the number of water renewal steps is three to five times every year for traditional pond aquaculture, and is at most twice for ecological engineering recirculating aquaculture systems, and the discharge water is purified in the eco-pond (Xu *et al.* 2008).

Pond aquaculture water is mainly used for water renewal, to replenish evaporation losses and for water discharge during harvesting. Average annual precipitation in Jiangsu and Zhejiang provinces is 1078.l mm, and the average annual evaporation is 1346.3 mm, based on which, it is estimated that the amount of water replenishment for evaporation in pond aquaculture in these two provinces is about 268.2 mm/yr, which is about 13.4 percent of the total water volume (Table 7.2.8).

Water consumption in eco-engineered pond recirculating aquaculture systems (Table 7.2.9) mainly lies in making up for evaporation and discharge at harvesting, with the replenishing water volume being the

Table 7.2.9 Features of an ecological engineering system.

Content	Parameter
Ecological engineering system	Eco-channel, eco-pond, subsurface wetland, aquaculture pond
Subsurface wetland	$V = Q\,a\,v\,t/\varepsilon$ (t is 0.4-0.7d; ε is 0.50 (average Ø50 gravel); subsurface wetland depth is 0.6-0.8m)
Eco-slope	ALR = [Inlet velocity (m^3/d) x pollutant concentration (mg/l)]/Substrate void volume m^3 (Water velocity of about 25 cm/h)
Eco-pond	A = QSOt/NA(SO is 40 mg/l, NA is 40 g/(m2 ·d), t is 1.5 d)
Biochemical bed	Purification efficiency $\eta = So - Se/So$; filter material volume $V = (So/Nv)Q * 10^3$
Pond water exchange rate	10–20%
Pond fish density	0.20–0.82 kg/m
Pond: subsurface wetland: eco-pond: eco-slope $\mathbf{(100:5\sim10:10\sim15:7\sim12)}$	

same as that of a traditional pond. The discharge mainly lies in pond cleaning discharge, with a frequency of once a year generally. Table 7.2.6 compares the water consumption and discharge in ecological engineering circulating aquaculture mode and traditional aquaculture mode.

7.2.4.4 Conclusions

Eco-engineered pond recirculating aquaculture systems feature "ecological, safe and efficient" provisions, and can effectively change the traditional aquaculture mode, and improve aquaculture productivity. The composition ratio of eco-channel, eco-pond, subsurface wetland, and aquaculture pond, depends on the features and requirements, such as the species cultured and density. The area of ecological engineering facilities should not exceed 20 percent of the pond area generally. The cascade structure of pond water flow helps to exchange water at the upper and lower layers of different ponds, reduces power consumption, and provides flow through in ponds.

Experimental results show that in the aquaculture water surface of 14 000 m^2 supported by artificial wetland of 4200 m^2, circulation of two to three hours per day can ensure that the total nitrogen, total phosphorus, and COD in the pond water body do not exceed 1.5 mg/l, 0.5 mg/l, and 10 mg/l, respectively (Liu *et al.* 2010). Analyses reveal that the nitrogen and phosphorus are removed to the extent of 64.4 percent and 39 percent, and 63.5 percent and 81 percent by eco-channel, and subsurface wetland, respectively (Table 7.2.9). Artificial wetland significantly reduces the proportion of harmful algae in the aquaculture system, whereas eco-channels increase the proportion of diatoms, which is good for aquaculture. This indicates that artificial wetland and eco-channels are conducive to optimizing the population structure of algae in aquaculture water bodies, and improving water quality.

7.2.5 Establishment of Ecological Aquaculture Zones

Batches of typical pond aquaculture modes are planned and constructed in accordance with the characteristics of aquaculture in different regions of China.

7.2.5.1 Ecological Pond Engineering Water Conservation and Emission Reduction

Based on the requirements for water conservation and effluent reduction, the ecological pond engineering water conservation and effluent reduction mode has been studied and established in such provinces and regions as Shanghai, Ningxia, Xinjiang, Zhejiang, and Jiangsu. This mode integrates ponds with ecological engineering facilities, and cyclically utilizes the pond aquaculture water body, via primary power, to conserve water and reduce discharge. Application shows that within the system adopting the ecological pond engineering water conservation and effluent reduction mode, ammoniacal nitrogen, nitrite, nitrate, total nitrogen, total phosphorus, and permanganate, are maintained at a lower level, and in a stable state. The pond algal structure is also optimized, the algal species meet aquaculture requirements, over 60 percent of water can be conserved, and over 80 percent of effluent can be reduced (Figure 7.2.14).

7.2.5.2 Ecological Pond Crab and Fish Culture Mode

Ecological crab and fish culturing mode covering adult crab aquaculture ponds, crab seedling culture ponds, fishponds, and tailwater treatment areas, have been established in Jiangsu and Zhejiang provinces, and other places (Figure 7.2.15). After the tail water is treated in the ecological crab culturing pond and tailwater system, over 50 percent of nitrogen and phosphorus in the fish-farming tailwater can be removed, and the crab yield increased (Xu and Liu 2015).

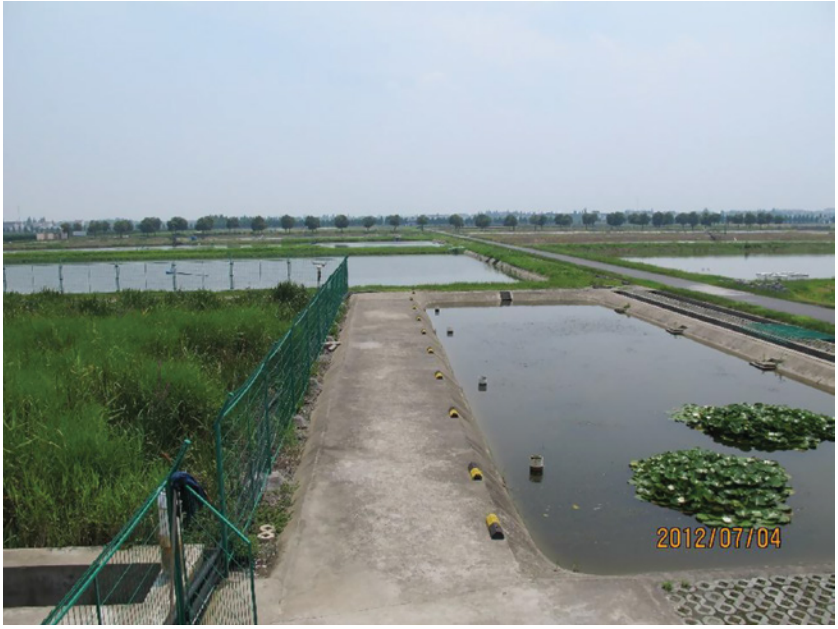


Figure 7.2.14 Ecological pond engineering water conservation and emission reduction mode.

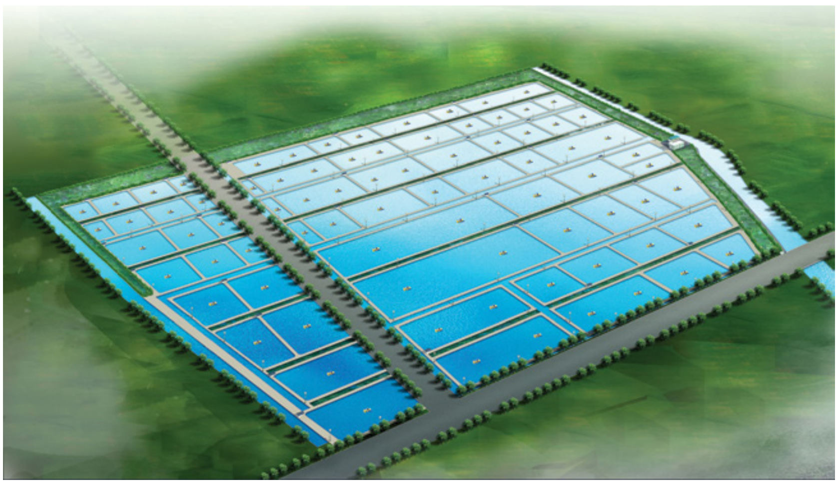


Figure 7.2.15 Ecological pond crab-fish culture mode.

7.2.5.3 Pond Rice-Fish Polyculture Mode

In Shanghai, Ningxia and Xinjiang, rice-fish polyculture mode has been established based on local aquaculture features (Figure 7.2.16). The water discharged from an aquaculture pond in the system enters into an organic rice field and passes through the water distribution channels and catchment area in rice fields to purify the rice field, and reuse the catchment water. The practice shows that, in this mode, the system improves the comprehensive benefit by 20 percent, reduces the aquaculture water discharge by over 60 percent, and the discharge of pollutants by over 50 percent (Xu and Liu 2015).

Figure 7.2.16 Pond rice-fish polyculture mode.

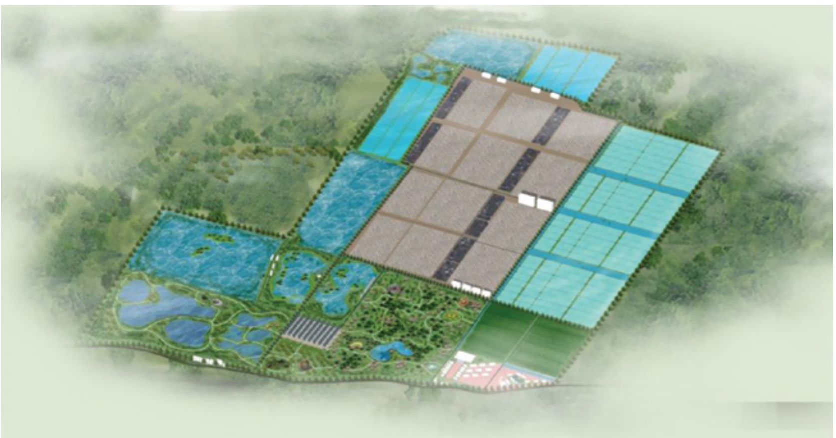


Figure 7.2.17 Coastal ecological pond aquaculture mode.

7.2.5.4 Coastal Ecological Pond Aquaculture Mode

The coastal pond aquaculture mode has been established in Dafeng and Guandong of Yancheng, Lianyungang, and other places in Jiangsu Province (Figure 7.2.17). This mode involves seawater aquaculture areas, freshwater aquaculture areas, and rice field areas. Up to now, ponds of over 20000 ha have been planned and constructed with pond aquaculture yield exceeding 30000kg/hm^2, resulting in good economic benefits, and driving the development of coastal pond aquaculture.

7.2.5.5 Yellow River Coastal Area Ecological Pond Fishery Mode

According to the characteristics of aquaculture in Yellow River coastal area, a complex planting and breeding mode has been established (Figure 7.2.18). This mode is dominated by pond aquaculture. The aquaculture

Figure 7.2.18 Yellow River coastal area ecological pond fishery mode.

discharge water, after being treated in the eco-channel, lotus root ponds, and organic rice fields, meets the standard for discharge, or is recycled. To date, this mode has been adopted in over 2000 mha, achieving an annual output of 300 million RMB, and yielding high economic, ecological, and social benefits.

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7.3

Disease Prevention and Control

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7.3.1 Introduction

Aquaculture plays an increasingly important role in food security and global economies (Naylor *et al.* 2000), but its economic value can often be diminished by infectious diseases. Viruses, bacteria, fungi, and undesirable parasites, are widely distributed throughout aquatic environments. Cultured organisms are constantly exposed to a wide range of pathogens (microbes or microorganisms), such as viruses (Zhang and Gui 2008, 2012), bacteria, fungi and parasites. Species with weak resistance to disease, undesirable environmental conditions, including poor water quality, overcrowding, and/or stresses caused by incompatible species, create conditions that can lead to destructive disease outbreaks. Infectious diseases are a major constraint on aquaculture efficiency (Austin 2012). Therefore, disease prevention and control are essential for the sustainability of the aquaculture industry.

Aquatic diseases have caused severe economic losses in China and led to losses of over 10 billion RMB per year (6 RMB = 1 US$) in the last decade. For example, in 2014, aquatic animal disease alone caused direct economic loss of about 14 billion RMB (China Fishery Statistical Yearbook 2014). Among different disease-causing pathogens, viruses are the most common and destructive, and there are still no cures or specific treatments for viral diseases. In this Chapter on Chinese aquaculture, advances in viral disease diagnostics, the interaction between viruses and their aquatic hosts animals are dealt with, followed by bacterial and fungal diseases, and parasitic diseases.

7.3.2 Viral Diseases of Cultured Animals

Viral pathogens in aquatic animals are spread through injury (e.g. bites, scrapes), through water, and/or direct or indirect contact with feces of infected individuals. Although the survival rate for most viral pathogens is limited in aquatic environments, viral diseases are one of the major challenges that threaten sustainable growth of global aquaculture.

7.3.2.1 Viral Pathogens in Cultured Animals

More than 100 genomes of cultured animal viruses have been described. The important pathogenic viruses, such as iridoviruses, reoviruses, rhabdoviruses, herpesviruses and baculovirus in animals were reviewed (Zhang and Gui 2015) and some of them are listed in Table 7.3.1.

Aquaculture in China: Success Stories and Modern Trends, First Edition.
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Table 7.3.1 Some pathogenic viruses isolated from organisms in Chines aquaculture.

Virus	Host	Symptom/ Disease	Genome	Authority
Iridovirus				
Rana grylio virus (RGV)	Frog	Systemic hemorrhagic disease	dsDNA	(Zhang *et al.* 1999b, Zhang *et al.* 2001, Lei *et al.* 2012b)
TFV (Tiger frog virus)	Frog	Edema, hemorrhage	dsDNA	(He *et a*l. 2002)
*Andrias avidianus ranaviru*s (ADRV)	Chinese giant salamander	Systemic hemorrhagic disease, edema	dsDNA	(Chen *et al.* 2013)
Infectious spleen and kidney necrosis virus (ISKNV)	Mandarin fish	Spleen and kidney necrosis	dsDNA	(He *et al.* 2001)
Large yellow croaker iridovirus (LYCIV)	Large yellow croaker	Swollen congested tissues	dsDNA	(Ao and Chen 2006)
Lymphocystis disease virus-China (LCDV-C)	Flounder	Lymphocystis disease	dsDNA	(Zhang *et al.* 2006)
Rhabdovirus				
Siniperca chuatsi rhabdovirus (SCRV)	Mandarin fish	Systemic hemorrhagic disease and high mortality rates	(-)ssRNA	(Zhang and Li 1999, Tao *et al.* 2008)
Scophthalmus	Turbot	Hemorrhagic disease	(-)ssRNA	(Zhang *et al.* 2007)
Maximus rhabdovirus (SMRV)				
Paralichthys olivaceus				
rhabdovirus (PORV)	Flounder		(-)ssRNA	(Zhu and Zhang 2014)
Spring viraemia of carp virus (SVCV)	Carp	Lethargy, edema, exophthalmia hemorrhaging	(-)ssRNA	(Teng *et al.* 2007)
Reovirus				
Grass carp reovirus strain 109 (GCReV-109)	Grass carp	Widespread hemorrhaging in the muscles	dsRNA	(Pei *et al.* 2014) (Liu *et al.* in press)
Scophthalmus maximus reovirus (SMReV)	Turbot	Systemic hemorrhagic disease	dsRNA	(Ke *et al.* 2011)
Micropterus salmoides reovirus (MsReV)	largemouth bass	deep-muscle bleeding	dsRNA	(Chen *et al.* 2015)
Herpesvirus				
Crucian carp herpesvirus (CaHV)	crucian carp	bleeding gills	dsDNA	(Wang *et al.* pers. comm.)
Baculovirus				
White spot syndrome virus (WSSV)	Shrimp, crab and crayfish	White spot syndrome	dsDNA	(Wang *et al.* 1998, Wu *et a*l. 2005)

7.3.2.2 Diagnosis of Viral Diseases

Routine inspection of stock should be an essential management activity in aquaculture. Inspection of the health of cultured organisms may include observing behavioral activities such as swimming, feeding, breathing, and inspection of body surface. The first distinct signs of an infection are reduction in feed intake or abnormal swimming patterns (AFCD 2014).

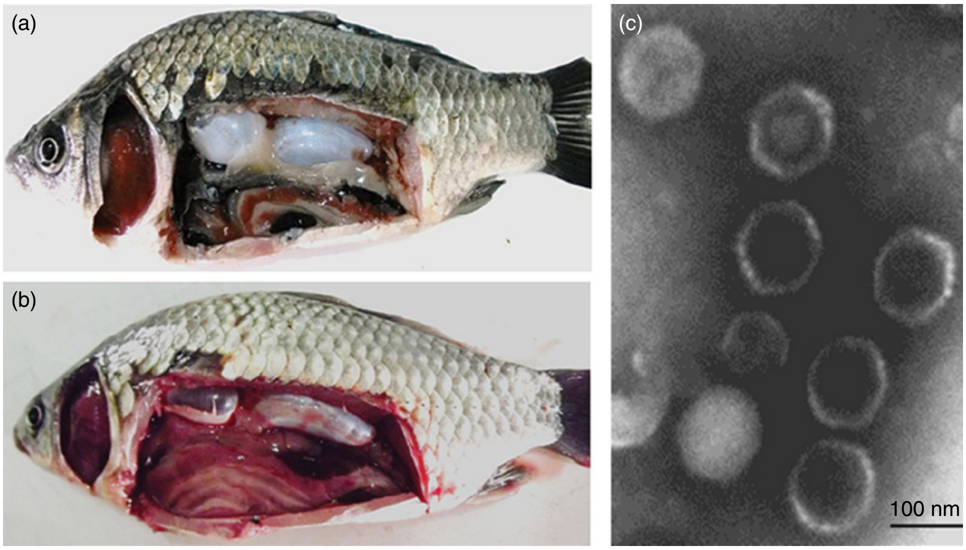

Figure 7.3.1 Normal (a) and diseased gibel carp (*Carassius auratus*) (b), the viral pathogen (c), which can cause acute severe gill hemorrhage associated with systemic hemorrhage in the fish occur within one week.

a) Erratic swimming of cultured fish includes swimming in circles, lying flat, rubbing against the net cage edges, or jumping out of water, and fish may also display upside down movements. Common symptoms of viral diseases are: dark body tone, hemorrhage (gill and internal hemorrhage of crucian carp *Carassius auratus* (Figure 7.3.1), tumors, smallpox, protruding eyes, edema, and whitened gills.
b) Diagnosis refers to a veterinary condition, or a disease identified by its signs. There are several common virus-testing methods to identify infections in cultured animals: bioassay of suspect animal populations with a sensitive indicator species, virus cell culture, electron microscopic observations, immunofluorescence and antibody staining, polymerase chain reaction (PCR) methods, and molecular biology tools, and rapid other diagnostic tests (Zhang and Gui 2008, 2012).

7.3.2.2.1 Bioassays

White spot syndrome virus (WSSV), an important viral pathogen of shrimp, and crabs are used for performing bioassays. Grass carp (*Ctenopharyngodon idellus*) reovirus (CGRV), or grass carp hemorrhagic virus (GCHV) cause hemorrhage and widespread economic loss.

Bioassays have also been used to detect grass carp asymptomatic carriers of GCRV (grass carp reo virus), and GCHV (Grass carp hemorrhagic virus), using rare minnow (*Gobiocypris rarus*) in China (Zhang *et al.* 2003b; Su *et al.* 2009).

Histological and *in situ* hybridization data also confirmed that WSSV tissue tropism in *Scylla serrata* crab larvae is similar to that found in shrimp (Chen *et al.* 2000).

7.3.2.2.2 Virus Cell Culture

A red-spotted grouper (RSG) *Epinephelus akaara* skin cell line was established and characterized. RGS cells had a normal diploid chromosome number, the morphology of which was fibroblastic-like. Susceptibilities of RGS and grass carp ovary (GCO) cells to two viruses were tested, and the results showed that the titer of an iridovirus, *Rana grylio* virus (RGV), in RGS cells was $10^{3.5}$ $TCID_{50}$ ml^{-1}, which was much higher than a rhabdovirus, spring viremia of carp virus (SVCV), in the cells ($10^{0.5}$ $TCID_{50}$ ml^{-1}). The titers of RGV and SVCV in GCO were $10^{6.0}$ $TCID_{50}$ ml^{-1} and $10^{8.0}$ TCID50 ml^{-1}, respectively, which were higher than those in RGS cells. Observations with electron and immunofluorescence microscopy have shown that virus particles scattered in the cytoplasm and virus protein appeared in both the cytoplasm and nucleus. The results suggested that RGS cells could be used as a potential *in vitro* model to study the cutaneous barrier function against virus infection (Lei *et al.* 2012a).

Known as lethal pathogens, ranaviruses have been identified in diseased fish, amphibians (e.g. Chinese giant salamander *Andrias davidianus*) and reptiles, causing organ necrosis and systemic hemorrhage (Figure 7.3.2). Chinese giant salamander cell lines of the thymus (GSTC), spleen (GSSC) and kidney (GSKC) have been established, and their sensitivities to ranaviruses, wild-type.

Andrias davidianus ranavirus (ADRV), and recombinant *Rana grylio* virus (RGV), carrying enhanced green fluorescent protein (EGFP) gene (rRGV-EGFP), were tested. Temporal transcription pattern of ranavirus major capsid protein (MCP), combined with fluorescence and electron microscopy observations showed that all three cell lines can be used for the detection of ranaviruses (Yuan *et al.* 2015).

7.3.2.2.3 Electron Microscopic Observations

A pathogenic virus RGV, that is lethal, was isolated from diseased pig frog *Rana grylio* and was observed by electron microscopy. Different stages of virus amplification, maturation, and assembly were observed in the nucleus, cytoplasm and cellular membranes. The matured virus particles were diffused in the nucleus, cytoplasm, and cellular surface, and also aggregated as pseudo-crystalline arrays in the cytoplasm. Virions were released by budding from the plasma membranes, or following cell lysis. Various types of cell damage, such as small vacuoles, spherical inclusions, and swollen and empty mitochondria, were also observed. Some typical characteristics of RGV include symmetrical shape of the virions, replication process involving both nuclear and cytoplasmic phases, budding release from cellular membrane and intracellular membrane, and viromatrix and para-crystalline aggregation in cytoplasm (Zhang *et al.* 1999b).

The causative agent of lymphocystis disease that frequently occurs in cultured flounder *Paralichthys olivaceus* in China is lymphocystis virus. Thirteen fish cell lines were tested for their susceptibility to the virus. The propagated virus particles were observed by electron microscopy. Ultrastructure analysis revealed several distinct cellular changes, such as chromatin compaction and margination, vesicle formation, cell-surface convolution, nuclear fragmentation, and the occurrence of characteristic 'blebs' and cell fusion. The observation provides a detailed report of fish lymphocystis virus infection and propagation in a freshwater fish cell line, and presents direct electron microscopic evidence for propagation of the virus in infected cells (Zhang *et al.* 2003a).

7.3.2.2.4 Immunofluorescence and Antibody Staining

Five monoclonal antibodies (mAbs) against spring viraemia of carp ($SVCV_{0504}$, isolated from common carp in China) were produced from mice immunized with purified virus preparations. The virion of SVCV contains five structural proteins, representing the nucleoprotein (N), phosphoprotein (P), matrix protein (M), glycoprotein (G), and RNA-dependent RNA polymerase (L). Western blotting analysis revealed that three mAbs (1H5, 1E10, and 1H7) recognized specifically to a single protein of 47 kDa (N), the mAb 3G4 reacted with two $SVCV_{0504}$ proteins of 69 kDa (G) and 47 kDa (N), while the mAb 1A9 reacted with three$SVCV_{0504}$ proteins of 69 kDa (G), 50 kDa (P), and 47 kDa (N). By indirect enzyme-linked immunosorbent assay (ELISA), two mAbs (1H5 and 1H7) showed cross reactivity with pike fry rhabdovirus (PFRV). Indirect immunofluorescence showed intense fluorescence in the cytoplasm of the $SVCV_{0504}$-infected *epithelioma papulosum cyprini* (EPC) cells in areas corresponding to the location of granular structures. The sucrose gradient-purified $SVCV_{0504}$ particles could be detected successfully by these mAbs using immuno dot blotting. mAb 1A9 could completely neutralize 100 $TCID_{50}$ (50 percent tissue culture infective dose) of $SVCV_{0504}$ at a dilution of 1:8. This is the first report of development of the neutralizing mAbs against SVCV. The mAb 1A9 was analyzed further, and could be used successfully to detect viral antigens in the infected-EPC cell cultures, or in cryosections from experimentally infected crucian carp *C.auratus* by immunohistochemistry (IHC) assay. Furthermore, a flow cytometry procedure for the detection and quantification of cytoplasmic $SVCV_{0504}$ in cell cultures was developed with mAb1A9. At 28 hr after inoculation with the virus, about ten percent of infected cells could be distinguished from the uninfected cells. These

Figure 7.3.2 Normal (a, b), and diseased (c, d, e), Chinese giant salamanders. The viral pathogen (f) which can cause severe systemic hemorrhage in the amphibians.

mAbs will be useful in diagnostic test development and pathogenesis studies for fish rhabdovirus (Chen *et al.* 2008).

7.3.2.2.5 Polymerase Chain Reaction (PCR), and Other Molecular Biological Methods

Grass carp reovirus (GCRV) can be divided into three genotypes based on genome sequence. A one-step duplex real-time reverse transcriptase polymerase chain reaction (rRT-PCR) assay was developed for simultaneous detection of GCRV. The PCR assay is suitable for early diagnosis of grass carp hemorrhagic disease, and for epidemiological surveillance. One hundred and twelve samples from grass carp suspected of hemorrhagic disease were collected from South and Central China. Eleven samples were positive for GCRV by RT-PCR alone, and fourteen samples were positive by single-target and duplex rRT-PCR (Zeng *et al.* 2014).

A rapid and sensitive loop-mediated isothermal amplification (LAMP) assay for cyprinid herpesvirus 2 (CyHV-2) detection in gibel carp was developed. Following cloning and sequencing of the putative DNA helicase gene of CyHV-2 isolate from China, a set of four specific primers was designed based on the sequence. The $MgCl_2$ concentration and the reaction temperature were optimized to 6 mM, 64°C, respectively. LAMP products were detected by visual inspection of a color change due to addition of SYBR Green I stain. The specificity and sensitivity of the LAMP assay were determined. No cross-reactions were observed with other fish DNA viruses, including eel herpesvirus, koi herpesvirus, and Chinese giant salamander iridovirus. The LAMP assay was found to be equally sensitive as a nested PCR. A comparative evaluation of ten fish samples using LAMP and nested PCR assays showed an overall correlation in positive and negative results for CyHV-2. These results indicate that the LAMP assay is simple, sensitive, and specific, and has a great potential use for CyHV-2 detection in the laboratory and the field (Zhang *et al.* 2014).

Goldfish hematopoietic necrosis caused by cyprinid herpesvirus 2 (CyHV-2) is a major fish disease which has a high level of mortality. This is the first study on detection of this disease by loop-mediated isothermal amplification (LAMP). A set of six primers targeting terminase gene was determined after a series of tests. Detection limit was about 10^{-4} μg/μl, which was superior to conventional PCR and real-time PCR. No cross reaction with 28 other viruses or bacteria commonly found in fish was observed. The use of commercial kits and instruments for the LAMP assay is suitable for detection of infections under field conditions (He *et al.* 2013a).

7.3.2.3 Antiviral Immunity and Virus-Host Interactions in Cultured Animals

Viral diseases are one of the major challenges threatening sustainable growth of global aquaculture. Recent years have witnessed significant progress in understanding of animal interferon (IFN) antiviral response of aquaculture species. IFNs are the hallmark of fish and other vertebrate antiviral systems (Zou and Secombes 2011). A number of IFN genes have been identified in different aquaculture species but they do not show a one-to-one orthologous relationship with mammalian IFN homologs. Interferon (IFN) response is the first line of host defense against virus infection. These genes are divided into two groups with different abilities to induce downstream gene expression through binding to different receptor complexes. It has been consistently shown that some fish IFN-stimulated genes, such as Mx (interferon-inducible Mx protein is responsible for a specific antiviral state against virus infection) and PKR (protein kinase-R), have been confirmed for their antiviral effects (Lei *et al.* 2012a). Interferon-inducible transmembrane protein (IFITM1) a family of small interferon-stimulated proteins (~15 kD) that mediate the activities of interferons from flounder *Paralichthys olivaceus*, has been characterized. The expression and promoter activity of PoIFITM1 are markedly induced by aquatic animal viruses: *Rana grylio* virus (RGV) and *Scophthalmus maximus* rhabdovirus (SMRV). The data provide the first evidence that IFITM1 functions as a key effector of the innate immune to restrict virus replication in lower vertebrates, through the action of impeding viral entry (Zhu *et al.* 2013).

It is expected that well thought-out combinations of vaccination and immuno-stimulants could provide protection against viral diseases of farmed fish (Kibenge *et al.* 2012). Active immunization involves administration of vaccines containing antigenic molecules (or genes for these molecules) derived from infectious agents. As a result, vaccinated animals mount acquired immune responses and develop prolonged, strong immunity to those agents. When properly used, vaccines are highly effective in controlling infectious diseases. Plasmid DNAs containing *Siniperca chuatsi* rhabdovirus (SCRV) glycoprotein gene (pcDNA-G) and nucleoprotein gene (pcDNA-N) were constructed and used to determine the antiviral immune response elicited by DNA vaccination in mandarin fish. *In vitro* and *in vivo* expression of the plasmid constructs were confirmed in transfected cells and muscle tissues of vaccinated fish by Western blot, indirect immunofluorescence or RT-PCR analysis. Fish injected with pcDNA-G exhibited protective effect against SCRV challenge with a relative percent survival (RPS) of 77.5 percent, but no significant protection (RPS of 2.5 percent) was observed in fish vaccinated with pcDNA-N. Immunohistochemical analysis showed that vaccination with pcDNA-G decreased histological lesions, and suppressed the virus replication in fish target organs, e.g. kidney, liver, spleen, gill and heart. Transcriptional analysis further revealed that the expression levels of type I IFN system genes including interferon regulation factor-7 (IRF-7) gene, Mx gene, and virus inhibitory protein (Viperin) gene were strongly up-regulated after injection with pcDNA-G, whereas the level of transcription of immunoglobulin M (IgM) gene did not show a statistically significant change. The results reveal that type I IFN antiviral immune response is rapidly triggered by the plasmid DNA containing rhabdovirus glycoprotein gene in fish, which offers an explanation of molecular mechanisms for DNA vaccination inducing mandarin fish to resist to SCRV disease (Tao *et al.* 2008; Chen *et al.* 2012).

The effects of β-glucan, an immune stimulatory agent, on the superoxide dismutase (SOD) and catalase (CAT) activities of erythrocytes and Mx gene expression were studied in grass carp that were challenged with grass carp hemorrhage virus (GCHV). The SOD and CAT activities in erythrocytes and Mx gene expression in spleen from the fish were detected by spectrophotometry and RT-PCR, respectively. Negative control fish were injected with PBS (phosphate-buffered saline); positive control groups were injected with either ß-glucan or GCHV only; and the experimental groups were pre-injected with β-glucan 15 days prior to injection with GCHV. The results showed that the SOD and CAT activities were higher in fish injected with β-glucan for 15 days than the negative control group injected with PBS. The SOD and CAT activities significantly decreased when the fish were challenged with GCHV, but it was higher in the group pre-treated with β-glucan than in un-pre-treated infected fish, 15 days after GCHV infection. Mx gene expression levels increased during the early stages (at 12 hr and 36 hr) of GCHV infection, and it remained at higher levels from the sixth till the tenth day in the β-glucan pre-treated group, but it fell from the sixth day in the β-glucan untreated group. The GCHV-infected group pre-treated with β-glucan had a higher survival rate (60 percent) than the group not pre-treated with β-glucan (20 percent), suggesting that β-glucan possesses or enhances anti-viral responses (Kim *et al.* 2009).

Ranaviruses (belong to family *Iridoviridae*) are increasingly prevalent pathogens infecting fish, amphibians and reptiles, and are promiscuous pathogens of cold-blooded vertebrates worldwide (Chinchar and Waltzek 2014). *Rana grylio* virus (RGV), was isolated from the diseased *Rana grylio* in aquaculture, RGV thymidine kinase (TK) gene, and viral envelope protein 53R gene, were chosen as targets for foreign gene insertion. The enhanced green fluorescent protein (EGFP) gene which fused to the virus major capsid protein promoter p50 was inserted into TK and 53R gene loci of RGV, respectively. The recombinant RGVs expressing EGFP, were constructed (He *et al.* 2013b). The recombinant fish iridovirus, infectious spleen and kidney necrosis virus (ISKNV), were also constructed, and the humoral immunity and cellar immunity of mandarin fish were induced by the recombinant iridovirus, infectious spleen and kidney necrosis virus (ISKNV) (Fu *et al.* 2012). Recently, a ranavirus-induced thymus cDNA library have been constructed from Chinese giant salamander, the largest extant amphibian species, and used to identify genes involved in immune response. Among the 137 putative immune-related genes derived from this library, these molecules received particular focus: immunoglobulin heavy chains (IgM, IgD, and IgY), IFN-inducible protein 6 (IFI6), and T-cell receptor beta chain (TCRb) (Zhu *et al.* 2014). Tetraspanins and their role in the innate immune system of invertebrate (such as shrimp) are also widely found and discussed, and could inhibit the infection of WSSV, and the antibody can significantly reduce the mortality of shrimp challenged by WSSV (Gui *et al.* 2008, 2012).

Research showed the complex interaction between viruses and aquaculture animal hosts, such as adaptive immune (neutralizing antibody), and innate immune responses to virus infections. Immunity in teleost fish have led to major new insights about mammals in innate and adaptive immunity (Workenhe *et al*. 2010; Sunyer, 2013). The teleost adaptive immune system also has other features, which are similar to and in some cases differ from those of the mammalian immune system (Table 7.3.2).

Table 7.3.2 Comparison of essential features of immune systems in teleost fish and mammals.

	Teleost Fish	**Mammal**
Biotic constrictions		
Temperature range	−2 to 35°C	36.5–37.5°C
Primary environment	Water	Air
Metabolism	Poikilothermia Endothermia (e.g. bluefin tuna and some pelagic fishes)	Homeothermia
External interfaces	Mucous skin, gills	Respiratory tree
Lymphoid organs		
Haematopoietic tissue	Head kidney (Teleostei) Epigonal and Leydig organs, meningeal tissue,	Bone marrow
Thymus	Orbital / sub-cranial hematopoietic tissue (Chondrichthyes) Involution species-dependent, influenced by seasonal	Involution with age
Lymphoid nodes	changes and hormonal cycles Absent	Present
Gut-associated lymphoid tissues	Not organized, lymphoid aggregates Leydig organ and spiral valve (Chondrichthyes)	Organized, Peyer patches
Germinal centers	Absent (melanomacrophage centers?), dendritic cells probably present	Present
Antibodies/Cytokines		
Immunoglobulin	IgM, IgD and IgT (or IgZ)	IgM, IgG, IgA, IgD and IgE
AID (activation-induced cytidine deaminase)	Yes	Yes
Class-switch recombination	No	Yes
Somatic hypermutation	High	High
Affinity maturation	Weak	High
Memory responses	Weak	High
TCR, CD4, CD8	Yes	Yes
MHC class I and II	Yes	Yes
CD28, CD40, CD80, CD86, ICOS	Yes	Yes
TH1, TH2 and TH17 cytokines	Yes	Yes
Spleen, thymus and bone marrow	Spleen and thymus but no true bone marrow	Yes
Mucosa-associated lymphoid tissue	Yes	Yes
Germinal centers and lymph nodes	No	Yes
Cellular adaptive immune response		
NK cell	have NK-like cells and non-specific cytotoxic cells	specific and nonspecific responses
Macrophages	Similar response as in mammals	Specific response on antibody coated cells

Table 7.3.2 (Continued)

	Teleost Fish	Mammal
The gut-associated lymphoid tissue (GALT)		
Main GALT immunoglobulin	Polymeric IgT	Polymeric IgA
Main GALT B cell subset	IgT+ B cells	IgA-producing B-1 and B-2 cells
GALT ultrastructure	LP, IELs, No PP and MLNs	LP, IELs, PP, MLNs
Main immunoglobulin that coats gut commensals	IgT	IgA
pIgR used to transport sIg to gut lumen	Yes	Yes
Generation of specific IgT or IgA responses to gut parasites	Yes	Yes
Overall performance		
Antibody affinity	Low	High
Antibody response	Slow	Fast
Memory response	Weak	Strong

7.3.2.4 Prevention and Control of Viral Diseases in Aquaculture

To ensure high rates of survival and growth during a culture cycle, it is especially important to prevent infection and have control measures for viral diseases. Research into causes, prevention and control of viral disease in aquaculture is ongoing.

7.3.2.4.1 Immune Responses in Cultured Animals

The immune system is made up of special cells, proteins, tissues and organs, and the collection of biological processes within an organism that defend against diseases by identifying, interference and suppression. Recent studies show that in cultured animals that virus infection induces antibodies, IgM, IgD, and IgT response (Zhu *et al.* 2014).

7.3.2.4.2 DNA Vaccination Against Fish Viruses

Vaccination of farmed fish plays an important role in commercial fish farming to mitigate viral diseases (Dhar *et al*. 2014). Application of molecular genetic techniques on fish viruses offer the possibility of recovering a series of live recombinant viruses in which the viral genome has been irreversibly modified to generate cost-effective live, safe vaccines (Bremont 2005).

DNA vaccines (glycoprotein gene, pcDNA-G) against *S.chuatsi* rhabdovirus (SCRV) was constructed in China, and used to determine against rhabdovirus SCRV, and assessment of immune protection, in mandarin fish (Chen *et al.* 2012). Furthermore, in 2011, a live vaccine for GCRV-892 strain, developed by the Pearl River Fishery Research Institute, Chinese Academy of Fishery Sciences, obtained the "State Medicine Manufacturing Approval Number" awarded by the pharmaceutical supervisory and administrative department of the State Council of People's Republic of China, which is the first State Medicine Manufacturing Approval Number for a vaccine for aquatic animals in China (Rao and Su 2015).

a) ***Recombinant virus vaccine and immune defense against cultured animal viral diseases*****:** Ranaviruses (belong to the family *Iridoviridae*) are increasingly prevalent pathogens that infect fish, amphibians and reptiles, and are promiscuous pathogens of cold-blooded vertebrates worldwide (Chinchar and Waltzek 2014). Frog *Rana grylio* virus (RGV) (family *Iridoviridae*, genus *Ranavirus*), was isolated from infected cultured *R. grylio* (Zhang *et al*. 1996), and RGV thymidine kinase (TK) gene and viral envelope protein 53R genes were chosen as targets for foreign gene insertion (Zhao *et al.* 2008a, b). The enhanced green fluorescent protein (EGFP) gene which fused to the virus major capsid protein promoter p50 was inserted into TK and 53R gene loci of RGV, respectively. The recombinant RGVs expressing EGFP, were constructed (He *et al*. 2013b). The recombinant fish iridovirus was also constructed (Huang *et al*. 2011). The humoral immunity and cellar immunity of mandarin fish were induced by the recombinant iridovirus, infectious spleen and kidney necrosis virus (ISKNV) (Fu *et al.* 2012).

b) **Immuno-potentiators can enhance immune responses:** Experiments have shown that the survival rate of grass carp injected with GCHV after β-glucan (an immuno-potentiator) treatment was higher than that of β-glucan untreated group. This suggests that β-glucan possesses anti-viral properties that may stem from its ability to activate antioxidant enzymes and anti-viral response genes (Kim *et al.* 2009).

7.3.3 Bacterial and Fungal Diseases in Aquaculture

Bacteria can survive well in aquatic environments independently of their hosts, making bacterial diseases an important impediment to aquaculture.

7.3.3.1 Pathogenic Bacteria and Fungi in Aquaculture Ponds

Thus far, bacterial species belonging to at least 13 genera have been reported to be pathogenic to aquatic animals, including: Gram-negative bacteria such as *Aeromonas, Edwardsiella, Flavobacterium, Francisella, Photobacterium, Piscirickettsia, Pseudomonas, Tenacibaculum*, *Vibrio* and *Yersinia*; and Gram-positive bacteria such as *Lactococcus, Renibacterium* and *Streptococcus*. Major pathogenic bacteria are listed in Table 7.3.3 (Pridgeon and Klesius 2012).

Some of the common pathogenic bacteria in aquaculture have also been reported in China (Table 7.3.4). These for example include, *F. columnare*, the causative agent of Columnaris disease that infects a wide range of freshwater fish in China, with major symptoms being gill-rot and caudal rot (Wang *et al.* 2010).

A. salmonicida induce typical furunculosis and cause severe septicemia, with resultant mortality, especially in coldwater fish, all species of salmon, trout, char, and grayling, are susceptible to such infections. Recent studies show that swimming performance of Atlantic salmon might be a useful indicator of the disease, and it has been feasible to warn of outbreaks of acute disease based on changes in fish behavior (Yi *et al*. 2015).

Vibrio infections usually occur in fish from marine and estuarine environments, occasionally it is reported in freshwater fish, and both have been reported in China. The disease can cause significant mortality (more than 50 percent) once an outbreak is in progress. Common names for *Vibrio* infections offish include "red pest" of eels, "salt-water furunculosis", "red boil", and "pike pest". Vibrio infections can spread rapidly at high stocking densities, and can also bring about host immune responses (Reed and Francis-Floyd 1996; Chen *et al*. 2004; Shi *et al*. 2007; Li *et al*. 2008a; Mei *et al*. 2010). In a very serious tail rot disease outbreak in cage-cultured *Epinephelus coioides*, the isolates were identified as *Vibrio harveyi* by biochemical tests, and 16S rDNA sequence analysis (Wu and Pan 2003).

S. agalactiae and *Streptococcus iniae* are bacterial pathogens that cause streptococcosis in many fish species (Agnew and Barnes 2007; Qiang *et al*. 2012). Some pathogenic species, i.e., *Fusarium falciforme* and *F. keratoplasticum,* are globally distributed in major turtle nesting areas (Sarmiento-Ramirez *et al.* 2014). Fungus consists of fine white threads known as hyphae that pass through organic material. These hyphae form distinctive patches on fish that resemble cotton wool. The diseases caused by fungal pathogens are chronic with no clear external symptoms (Hatai 2012) (Table 7.3.5).

Table 7.3.3 List of known pathogenic bacteria and aquaculture hosts around the world (Pridgeon and Klesius 2012).

Bacteria (G^{-} *bacteria*)	Reported hosts	Symptom / Disease
Aeromonas hydrophila	Catfish, carp, trout, eel, sturgeon, tilapia, bass	Motile aeromonads septicaemia
Aeromonas salmonicida	Salmon, trout, flounder, turbot, carp, tilapia , sole	Furunculosis
Chryseobacterium sp.	Salmon and trout	Chryseobacteriosis
Edwardsiella ictaluri	Catfish	Enteric septicaemia of catfish
Edwardsiella tarda	Turbot, flounder, carp, catfish, eel and tilapia	Edwardsiellosis or putrefactive disease
Flavobacterium columnare	Carp, trout, perch, tilapia, catfish and salmon	Columnaris
Flavobacterium johnsonae	Barramundi	False columnaris
Flavobacterium psychrophilum	Trout	Flavobacteriosis or rainbow trout fry syndrome
Flavobacterium branchiophilum	Trout	Bacterial gill disease
Francisella spp.	Tilapia and hybrid striped bass	Francisellosis
Moritella viscosa	Salmon	Winter ulcer disease
Photobacterium spp. (*formerly Pasteurella* spp.)	Sturgeon, hybrid striped bass, sea bream, yellowtail, sea bass, snakehead	Pasteurellosis
Piscirickettsia salmonis and Piscirickettsia-like organism	Salmon, trout, tilapia	Piscirickettsiosis or rickettsial septicaemia
Pseudomonas spp.	Sea bream, trout, eel, rabbitfish, catfish, eel, shrimp, salmon	Pseudomonads septicaemia or redspot disease
Tenacibaculum maritimum	Sole and turbot	Tenacibaculosis
Vibrio spp.	Croaker fish, puffer fish, grouper, cod, shrimp, big-scale sand smelt, flounder, abalone, sea bream, turbot, sole, red drum, cobia, eel, salmon, sweetfish, sheatfish	Vibrosis
Yersinia ruckeri	Trout, tilapia , salmon	Yersiniosis or enteric redmouth disease
Gram-positive bacteria		
Lactococcus garvieae (*formerly Enterococcus seriolicida*)	Yellowtail, trout, rockfish and mullet	Lactococcosis
Nocardia sp.	Tigerfish, snakehead, croaker, mullet, sea bass, largemouth bass, gourami and yellowtail	Nocardiosis
Renibacterium salmoninarum	Trout and salmon	Bacterial kidney disease
Staphylococcus spp.	Trout, tilapia, carp, perch, sea bream and yellowtail	Staphylococcosis
Streptococcus agalactiae	Tilapia Grouper, mullet and pomfret	Streptococcosis
Streptococcus ictaluri	Catfish	Streptococcosis
Streptococcus iniae	Tilapia, sea bream, red porgy, trout, flounder, barramundi, rabbitfish, hybrid striped bass, yellowtail catfish	Streptococcosis
Vagococcus salmoninarum	Trout	Hemorrhagic septicaemia
Weissella sp.	Trout	Hemorrhagic septicaemia

Table 7.3.4 Common pathogenic bacteria reported in cultured aquatic species in China.

Bacteria	Reported hosts	Symptom / Disease	Authority
Flavobacterium columnare	Channel catfish, Grass carp, koi, longsnout catfish, perch, Chinese sucker	Columnaris disease Gill-rot	(Wang *et al.* 2010)
Aeromonas salraonicid	Turtle, Frog, fish	Ulcer, Hemorrhagic septicemia	(Zhang *et al.* 2013)
Vibrio	*Epinephelus coioides* *Pseudosciaena crocea*	Lethargy, tail-rotted disease, skin hemorrhages, and death	(Zhan *et al.* 2004, Mei *et al.* 2010)
Staphylococcus sp. *Streptococcus iniae*	red sea bream, yellowtail, tilapia, sea bass silver carp, bream	Exophthalmus, corneal damage, Ulcers, skin and fin lesions	(Wang *et al.* 2014)

Table 7.3.5 List of known pathogenic fungi and aquaculture hosts.

Fungi	Reported hosts	Symptom / Disease	Authority
Cladosporium	Fish, toad, frog, mussel, crab, seahorse etc.	paralysis, anemia, gastrointestinal	(Seyedmousavi *et al.* 2013)
Exophiala	Fish, frog, toad, turtle, crab,	Systemic inflammation with a greyish to brownish color of internal mucosa	(de Hoog *et al.* 2011, Gjessing *et al.* 2011)
Paecilomyces	Fish	white fluffy appearance and bloody spot at the site of infection, caudal fins had white edges; tip of dorsal fin edges shredded with light-colored edges	(Haroon *et a*l. 2014)
Mucor circinelloides	yellow catfish	yellow mold was observed on the heads and fins of the fish and one *Mucor* spp.	(Ke *et al.* 2010)
Phoma herbarum	Fish *O. niloticus*	abnormal swimming behavior, exophthalmia, multiple rounded areas of muscle softening, protruded hemorrhagic vents, and abdominal swelling	(Faisal *et al.* 2007)
Phialemonium dimorphosporum	Fish	hemorrhagic skin ulcers, myonecrosis and the presence of mycotic granulomas	(Sosa *et al.* 2007).

Fish fungus *Saprolegnia* appears as gray or white patches on the skin/gills, and normally establishes as small, focal infections that then spread rapidly over the body or gills (Verma 2008). Different fungi were isolated form aquaculture animals (Table 7.3.6) with *Saprolegniasis* in China (Xia *et al.* 2011).

7.3.3.2 Bacterial and Fungal Diseases Detection and Control

Streptococcus are Gram-positive coccus and produce beta hemolysis. The application of colorimetric loop mediated isothermal amplification (LAMP), with pre-addition of calcein, offers simple, rapid and sensitive technique with applicability for small field laboratories. This technique explored the possible vertical transmission mode of *Streptococcus agalactiae* and *Streptococcus iniae* in natural aquatic environments. Such data can be used for screening broodstock and/or for specific pathogen-free production (Cai *et al.* 2012; Subasinghe *et al.* 2013).

Table 7.3.6 Fungal infections reported in aquaculture species.

Fungi	Reported hosts	Symptom / Disease	Authority
Saprolegnia	Perch, Acipenser Chinese giant salamander, Yellow catfish	cotton mold	(Xia *et al.* 2011)
Dematiaceae	Catfish	visceral adhesion, peritonitis	http://www.nongyie.com/view-23329-1.html
Ichthyosporidium	Flounder, Trout and whiting	Sluggishness, loss of balance, hollow belly, external cysts and sores.	

Identified biomarkers (e.g. gene) of the responses will contribute to the early-warning system of the disease (Xia *et al.* 2004; Chu and Lu 2005; Du *et al.* 2015). The complete gene sequence of the outer membrane protein W (OmpW) was amplified from the genomic DNA of *A. hydrophila* Wp3 strain, which was isolated from hemorrhaging grass carp. Studies have shown that His-W was able to efficiently induce the immunized grass carp to produce antibodies. Protection experiments showed that the immunized groups had higher survival rates than those of the control groups (57–86 percent), which suggested that the recombinant protein His-W was a candidate vaccine for grass carp against *A. hydrophila* disease (Liu *et al.* 2011).

Several strains of vibrio have been isolated from infected large yellow croaker (*Pseudosciaena crocea*), and subsequently identified as six strains of *V. harveyi*, one *V. parahaemolyticus,* and *V. alginolyticus,* by physiological, biochemical and molecular biological methods. A deduced porin from *V. alginolyticus,* and a maltoporin precursor from *V. parahaemolyticus*, were able to react with polyclonal antibodies to whole *V. harveyi,* suggesting these two proteins could act as the cross-protective antigens, and that the vaccines prepared with these porins could probably bring cross protection to three different vibrios (Zhang *et al.* 2012). DNA vaccine has developed a protective response to live *Vibrio harveyi* (Huang *et al.* 2013). Fish vibriosis occurs often in marine animals or brackish water fish. The treatment for fish vibriosis includes oral antibiotics. Kanamycin is one of the best, also chloramphenicol or furazolidone are good. Treating with antibiotics must be done in a quarantine tank rather than the main aquarium (http://animal-world.com/encyclo/fresh/information/Diseases.htm).

The method of a loop-mediated isothermal amplification (LAMP) for detection of *Saprolegnia* has been established (Wang *et al.* 2012). For fungal attacks on fish eggs, most breeders will use a solution of methylene blue (3 to 5 mg/l) as a preventive measure after the eggs are laid (Ou *et al.* 2012). Avoiding injury to cultured animals is essential, maintenance of desirable water quality, and cleanliness, are essential parts of management and disease prevention. Sifting the substrate gently to remove organic matter during weekly water changes is also important (Monks 2015).

Studies have provided an example of the link between resistant genes in strains from the environment and the accumulation of antibiotic resistance genes in bacteria isolated from fish farms (Yang *et al.* 2014).

7.3.4 Parasitic Diseases in Aquaculture

Parasites are a group of organisms that may or may not cause disease in cultured animals. Parasites are a common and natural occurrence in fish populations (Zhang *et al.* 2004). More than 40 species of marine fish are cultured in China, and a wide variety of parasites are reported as lethal pathogens of these in culture conditions (Yang *et al.* 2007). Among these are copepod parasites: *Argulus*, *Lernaea*, *Ergasilus*, trematode parasites; *Gyrodactylus* (Chen *et al.* 2011; Li *et al.* 2014), Digenetic trematodes, *Dactylogyrus*, Protozoa; Multifilis, *Chilodonella*, *Ambiphrya*, *Epistylis*, *Trichodina*, *Hexamita salmonis*, *Ichtyobodo*, *Henneguya*, *Plistophora* (Nie and Yao 2000; Li *et al.* 2008b), and examples are given in Table 7.3.7.

Table 7.3.7 Parasites reported from aquatic species cultured in China.

Parasite	Host	Symptom / Disease	Authority
Myxosporean	Fish	Liver lump and honeycomb-like cysts, destruction of liver tissue	(Zhai *et al.* 2014)
Fish louse (*Argulus*)	Fish	Extreme irritability, skin damage	(Zhang *et al.* 1999a, Alsarakibi *et al.* 2012)
Anchor Worm (L*ernaea*)	Fish	Frequent rubbing or "flashing" Localized redness Inflammation on the body of the fish, tiny white-green or red worms in wounds	(Zhu *et al.* 2010)
Flukes	Fish	rapid gill movement, mucus covering the gills or body, the gills, the skin may become reddened	(Nie and Yao 2000)

The different techniques available in diagnostic laboratories for parasitic diseases show that most base their diagnosis partly or totally on simple techniques, such as observation of clinical signs, macroscopical examination, and examination of fresh samples. Few laboratories can perform histopathological studies, and even fewer can perform more specialized techniques, such as PCR or immunohistochemistry (Alvarez-Pellitero 2004).

Used in the correct quantities, salt effectively controls protozoans on gills, skin, and fins of fish. Use of salt in ponds as a treatment is generally not recommended due to the large amount of salt required, and high cost of treatment, needed to be effective (Klinger and Floyd 2009).

The pathogenic organisms (including fish parasites) can be effectively eradicated or controlled by cleaning and disinfecting a fish pond (tank), and these methods are not only used within Chinese aquaculture but also internationally (PSBMH 2007). Such disinfecting methods are:

a) disinfecting the pond using quick lime (Calcium Oxide CaO): This is usually done about ten days prior to stocking a pond. A shallow pond is normally disinfected by splashing dissolved raw lime at a rate of 750 to 1025 kg/ha of pond area;
b) hanging bag (or basket) method: This method uses bleaching powder and prevents diseases in fish. A bamboo frame is placed at a shallow corner of the pond. Along the frame, hang several bags of bleaching powder. As soon as feeding begins, the correct amount of bleaching powder is added to each container daily;
c) use of sodium chloride (salt) for fingerling disinfection: Used as a 0.5–1 percent solution for an indefinite period as an osmoregulatory aid for the relief of stress and prevention of shock. Use a 3 percent solution for 10–30 min as a parasiticide. Sodium sulfite urea and tannic acid are used as external protozoacide for fingerling to adult fish at a concentration of 2000 mg/l for 5s.

7.3.5 Control and Prevention of Aquatic Animal Diseases

A number of technologies, methods, theories, and programs are routinely used to prevent and control aquatic animal diseases. The following are some successful cases and useful experiences of fish disease prevention and control in China.

7.3.5.1 Technologies and Methods

7.3.5.1.1 Genetically Improved Farmed Fish Disease-Resistance

Allogynogenetic gibel carp "CAS III", a third-generation new species, was bred by Professor Jianfang Gui and his research team in the State Key Laboratory of Freshwater Ecology and Biotechnology of the Institute of

Hydrobiology, CAS, after more than ten years' research. The gibel carp has demonstrated that the novel clone is a nucleo-cytoplasmic hybrid between the known clones A and D, because it contains an entire nuclear genome from the paternal clone A and an mtDNA genome (cytoplasm) from the maternal clone D (Wang *et al.* 2011). Clone D had been cultured for nearly 40 years, whereas clone A(+) was newly created. It was found that the liver lumps of heavily diseased clone-D individuals were completely composed of numerous honeycomb-like cysts, full of maturing and mature myxosporean spores, and almost all of the liver tissues were destroyed. The diseasing pathogen was identified as *Myxobolus wulii* of the genus *Myxobolus* in *Myxosporea* (Zhai *et al.* 2014). Further analysis revealed that the myxosporean resistance was much stronger in "CAS III" than in clone D (Gui and Zhu 2012).

7.3.5.1.2 Improvement of Water Quality

One or two years' culture of food fish often deposits a layer of silt and organic matter on the bottom of grow-out ponds, and various harmful bacteria and wild fish exist in the water body. Drying, dredging and exposing the bottom to atmospheric oxygen and sunlight in winter is most desirable. For disinfection of the pond bottom, the most commonly used liming compounds are quicklime (CaO), caustic lime, also called slaked lime or hydrated lime ($Ca(OH)_2$), and agricultural lime. The estimated quantities required on average is as: quicklime 7–10 kg/100 m^2, causticlime7–13 kg/100 m^2, agricultural lime 20–30 kg/100 m^2.

7.3.5.1.3 Quarantine and Disinfection of Fry and Fingerlings

For disinfecting and cleaning fish hatcheries, nets and other equipment, a range of compounds are available. For general use an iodophor, salt water and potassium permanganate are ideal. E.g. three percent salt water bath for 5–15 minutes in a clean, dark tank; 1 g/100 liters potassium permanganate bath for 90 minutes are recommended.

7.3.5.1.4 Disease Prevention Using Polyculture and/or Timely Replacement of Fish Species:

Polyculture of freshwater prawns with grass carp in southern China, improves the ecological balance of the pond water, preventing white spot syndrome virus (WSSV) in freshwater prawn, and at the same time increases total production.

7.3.5.1.5 Vaccination Used for Prevention and Control of Viral Infections:

Good husbandry, good nutrition, and high water quality are also key to avoiding disease problems. Prevention is always preferred to treatment in the control of fish diseases.

7.3.5.2 Theory and Programs

The following is a brief overview of the strategies for monitoring and preventing viral diseases, and other disease threats, to aquatic animals

7.3.5.2.1 Pathogen Detection and Identification:

In general, rapid and efficient diagnosis of the disease agent is fundamental for control and prevention of aquatic animal diseases. Research on aquatic viruses in organisms and the water environment not only allow us to better understand virus infection, morphogenesis, and transmission mechanisms, and potential treatment of viral diseases, but are also beneficial for evaluating and exploiting bio-resources, pursuing virus origins, and their relationships with the hosts, as well as realizing the significant impact and biogeochemical cycles of aquatic viruses on freshwater and marine ecosystems. A bilingual monograph, *Atlas of Aquatic Viruses and Viral Diseases* covered most of the above aspects (Zhang and Gui 2012). The book, including thirty-two charts,, is structured in six sections:

- viral disease symptoms of aquatic organisms;
- techniques in aquatic virology;

- viruses in aquatic mammals; and
- viruses in reptiles, amphibians, and fish.

The book shows viral disease symptoms in several aquatic organisms, pathological changes of host tissues and cells after infections, ultrastructure of aquatic viruses, and gene composition and function analysis of aquatic viruses with diagrams and illustrations. It can be used as reference for practitioners engaging in the prevention and control of aquatic diseases.

In early studies on the occurrence of aquatic animal viruses, cell culture was the most widely used technique for detection and isolation of infectious viruses. Other methods that have been used, included immunohistochemistry, immune electron microscopy, immunofluorescence, and enzyme-linked immunosorbent assay. The basic steps of virological analysis are sampling, virus concentration (and purification), and detection with cell culture assays or, more recently, conducting molecular methods such as PCR and Western blot analyses (Zhang and Gui 2008).

7.3.5.2.2 Increased Investments by Government to Improve Aquatic Animal Health and Disease Prevention

The Chinese Government has attached great importance to healthy and sustainable aquaculture development. The National Key Basic Research Program of China (973 Program) has successively supported seven projects since 1999, such as:

- "Fundamental research on the disease occurrence and disease resistance of the commercially important organisms in mariculture";
- "Studies on genetic and developmental biological basis for improvement of important aquaculture fishes";
- "Studies on the disease outbreak and immunological control of commercially important organisms in mariculture";
- "Investigation of crucial scientific issues in intensive aquaculture of freshwater ponds in China";
- "Basic studies on functional genomics and molecular design breeding in important cultured fish";
- "The molecular basis for the important economic traits of mollusks";
- "Study on the molecular design breeding"; and
- "Basic studies on outbreak mechanisms and immunological control of main virus diseases in marine aquaculture animals".

In addition, a series of studies on the control and prevention of aquatic animal diseases, such as, "Studies on adaptation mechanisms and immune evasion of iridovirus among aquaculture animals", and "Analysis of genomic sequences from different pathogenic grass carp reovirus strains and candidate genes associated with resistance to virus infection", have been initiated by the National Natural Science Foundation of China (NSFC). All these programs have promoted significant advances in basic studies on genetic improvement and disease control of aquaculture animals (Gui and Zhu 2012).

7.3.6 Conclusions

The increasing global human population, a massive increase in demand for animal protein, and limitations on production from capture fisheries, will inevitably lead to a continued global expansion of aquaculture, with associated risks of disease emergence and spread (FAO 2008). This Chapter summarized the state of knowledge on prevention and control of infectious diseases of aquaculture species, pathogens, including bacteria, viruses, fungi and parasites, with particular reference to Chinese aquaculture. Most of these organisms remain harmless when the cultured stocks are not stressed. However, once an outbreak occurs, prompt treatment is critical. Although nearly all reports are related to prevention and control, no single method has proved to be adequate for the effective control of these pathogens in cultured fishes (Yang *et al.* 2007).

Modern biotechnology is considered as one of the key technologies enabling the sustainable development of aquaculture. Biotechnology can not only be used to design specific and sensitive diagnostic tools, study immune systems of fish and other cultured animals, but can also help unravel the relationships between pathogens and their hosts. Biotechnology is also being used in screening of species/varieties/strains of cultured organisms for resistance to disease, and the development of efficacious vaccines and new disease-control-prevention technologies. A variety of aquatic animal diseases will gradually be controlled to a significant extent by understanding pathogen genomes, pathogen-host interactions, molecular mechanisms of pathogen pathogenesis, innovation diagnostic methods and development of the anti-pathogen technologies (such as novel vaccines). Different types of vaccine and vaccination strategies have been developed, but performance of the technology has still to be improved, and the prevention and control of disease outbreaks require a thorough understanding of the environmental and host factors.

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7.4

Development of Lake and Reservoir Aquaculture Related Practices in China

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7.4.1 Introduction

Lakes and reservoirs account for 15 percent and 24 percent of the total freshwater surface area in China, and contribute 7 percent and 12 percent to the total freshwater aquaculture production, respectively (Wang *et al*. 2015a). Both types of water bodies are used for extensive and/or intensive aquaculture. Lakes are administered by local fisheries bureaus under the Chinese Ministry of Agriculture, and reservoirs by local water resources bureaus under the Chinese Ministry of Water Resources, enabling substantial monetary gains and creating a large number of job opportunities. All of these have contributed to national food security, economic growth and social stability (Wang *et al*. 2015b). There have been plenty of successful development instances in lake and reservoir fisheries during the past few decades. Although some may be looked at rather unfavorably from today's point of view, it was still a success during the period when the primary aim was to utilize all waters for food fish production. Here we would like to share some typical success stories in lake and reservoir fisheries, and the current trends and strategies in utilization of these for food fish production.

7.4.2 Stock Enhancement in Yangtze Lakes with Fish Seed from Rivers

The middle and lower reaches of the Yangtze River is endowed with many lakes, which cumulatively account for 60 percent of the total area of freshwater lakes in China (Shi and Qin 2007). Culture-based fisheries in the Yangtze lakes, an indispensable extensive aquaculture practice in view of its contribution to inland fisheries, are enjoying an enhanced reputation for their ability to produce aquatic food with high nutritional quality and a high level of food safety (Wang *et al*. 2015b). Historically, almost all lakes in the middle and lower reaches of the Yangtze River were connected to the river by channels directly or indirectly, providing the Chinese major carps, silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), grass carp (*Ctenopharyngodon idellus*) and black carp (*Mylopharyngodon piceus*), with migration paths for spawning and growth between the Yangtze River and the connected lakes. These species are cultured both extensively and intensively in China, and their production ranks the highest among fish species in the world. However, all the lakes except for the Dongting Lake and the Poyang Lake were dis-connected from the river by sluice gates built primarily for flood control and irrigation purposes around the 1970s, thereby obstructing the migration

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path of major carps and affecting fish diversity in these lakes. As such, stock enhancement of major carps and other high-priced species has been widely practiced in lakes and reservoirs as a strategy known as culture-based fisheries. Successful culture-based fishery practices in Chinese lakes and reservoirs, especially the development of techniques and environmental protection based on artificial stocking of the four major carps and other aquatic species, have been well documented (Li and Xu 1995; Wang *et al.* 2015b).

Introduction of fish fry through water currents from the Yangtze River into lakes is considered as one of the most efficient means of restoring the fish communities, and improving fish production in lakes (Zhang *et al.* 1997). For example, the sluice gates of Wanghu Lake (46.2 km^2 in Hubei Province) were opened for 40 hours from 12:00 hr of June 15 to 16:00 hr of June 17, 1986. The ensuing current flow of 2.43×10^6 m^3 resulted in introducing 2.61×10^6 fish fry into the lake (Sun *et al.* 1998). More than 11 fish species were introduced into the lake (Table 7.4.1) and the survival rates ranged from 1.30–3.78 (Sun *et al.* 1998). Introduced major carps, yellowcheek (*Elopichthys bambusa*), *Ochetobius elongates*, and breams contributed to 1.32 percent of the total catch (Sun *et al.* 1998). What is more important, it also contributed to fish biodiversity and restoration of lake fisheries resources, and opening up water channels is considered as a major measure to restore river-lake connection, and biodiversity in the Yangtze basins by WWF in the 2010s.

From 1972 to 1984, sluice gates were opened six times to enable the movement of fry from the Yangtze River into Honghu Lake, the largest lake in Hubei Province, for a total of 518 hours and a total water volume 43 000 000 m^3. As a result of opening of the sluice gates 500 400 000 fry were introduced into the lake, and fry densities reached 25.9 ind./m^3 in 1972, and 5.7 ind./m^3 in 1984 (Li and Wang 1987). It is important to monitor the main spawning time and fry density in the Yangtze River to determine the most appropriate time to open sluice gates. Unfortunately, fry density in the Yangtze River has shown a sharp decline in the course of the past 40 years (Li and Wang 1987; Sun *et al.* 1998; Xie *et al.* 2007) because of disconnected sluice-gate building, damming, and over harvesting.

Water from the Yangtze River is sandy and this may accelerate the sedimentation process of lakes, and fry size is small (about 1 cm in length) and the swimming ability is poor (Table 7.4.2), which result in low survival rates (Sun *et al.* 1998). To overcome these problems, stocking of fingerlings from the Yangtze River during the autumn when water level into lakes is higher than that of the river is recommended. The principle of this practice is to make use of fingerling natural behavior of swimming against the current. When the window specially designed at the top part of the sluice gate is opened, fingerlings in the Yangtze River go into lakes against the current (Table 7.4.2).

Table 7.4.1 Species and quantity of fish fry introduced to associated lakes by the opening of sluice gates of the Yangtze River.

Species	Number (ind.$\times10^5$)	Percentage
Grass carp	2.09	8.01
Black carp	1.15	4.40
Silver carp	0.79	3.01
Bighead	0.11	0.43
Elopichthys bambusa	0.77	2.98
Breams	0.81	3.11
Mandarin fish	0.31	1.19
Coreius heterokon	0.84	3.22
Culters	1.10	4.20
Other species	10.47	40.11

Source: Modified after Sun *et al.* (1998).

Table 7.4.2 A comparison between two types of "introducing fish from rivers into lakes".

Parameter	Fry introduction with current	Fingerling introduction against current
Period	May–June	September–April
Water level of lakes and rivers	Water level of lakes is lower	Water level of lakes is higher
Current direction	River current flows into lakes	Lake current flows into the river
Water transparency	Turbid and sandy	Clear
Ages of fish introduced	A couple of weeks old	More than 5 months old
Size of fish	About 1 cm in length	5–25 cm in length
Swimming ability of fish	Low and drifting	Strong
Survival	Low	High

Source: Modified after Zhou *et al.* (1987).

7.4.3 Introduction of Wastewater and Fertilizers to Increase Productivity

7.4.3.1 Introduction of Urban Wastewater for Aquaculture in Lakes

In the late 1950s and early 1960s, China suffered from food shortages, especially from a shortage of animal protein. The introduction of urban wastewater into lakes for aquaculture started in the mid 1950s, and it was a popular and cheap means of increasing aquaculture production in lake-rich areas such as Wuhan, Changsha, Shashi, Hengyang, etc. (BDNU 1977).

This method used in lakes had the advantages of low cost, and creating a high income in a short period. It was not necessary to use feeds or fertilizers in this model, which greatly decreased production costs. Chenjia Lake, a small lake of about 400 ha near Changsha City, Hunan Province started to introduce urban wastewater for aquaculture in 1957. The yearly production exceeded 60 000 kg in 1962, and had a value of 104 000 RMB (6.0 RMB = 1 US$), and the production costs were only 18 400 RMB. Average production was about 10 000 kg/fishery worker, and the percentage of cost to income was 18.2 percent. Compared with the nearby Changsha Fish Farm, a place using conventional aquaculture practices, the production costs were was only half (He 1965).

The main stocked species were silver carp and bighead carp, together with some black carp, grass carp, common carp (*Cyprinus carpio*), Chinese bream (*Megalobrama amblycephala*), crucian carp (*Carassius auratus*), and *Xenocypris davidi*. The stocking percentages were 50–60 percent for silver carp, 25–30 percent for bighead carp, with the rest being other species (He 1965). The size of stocked fish were normally more than 250 g/ind., though small-sized fingerlings of about 15 cm were also used. The stocking density was about 2000–2500 kg/ha. Fingerlings were normally stocked in the winter, and cultured for about one year. Average fish production using waste water for aquaculture reached 5600 kg/ha, with the highest over 10 000 kg/ha (Zhang *et al.* 1983).

Urban wastewater normally comes from households and industrial sources. The former is rich in nitrogen and phosphorus, while the later may contain toxic ingredients. Therefore, the former is normally used for aquaculture. However, sometimes it is difficult to separate household wastewater from industrial sources. Use of wastewater from industrial sources for aquaculture may cause problems of food safety. It is also difficult to determine the quantity and frequency of input of wastewater into lakes. Overuse of wastewater often causes mass death of fish because of oxygen depletion brought about by the microbial flora and fauna (Luo *et al.* 1988).

Today more attention is paid to the safety of aquatic products. Currently using urban wastewater for aquaculture is discouraged if not prohibited, but in the past years of food shortages, it helped the people to get animal proteins using cheaper and easier methods.

7.4.3.2 Use of Fertilizers

During the 1980s, with increasing concerns about food safety, and the greater availability of chemical fertilizers, use of fertilizers for aquaculture in lakes and reservoirs became popular. Usage of fertilizers was widely expanded after the National Workshop on Aquaculture Using Fertilizers in Reservoirs, conducted by the Ministry of Water Resources of China in 1990. In Guanting Reservoir, a medium-sized reservoir (333.3 ha) in Hunan Province, the yearly fish production using chemical fertilizers reached 250 000 kg with a unit production of 750 kg/ha, while in Shizikou Reservoir, also a medium-sized reservoir (100 ha) in Zhejiang Province, fish production using 700 tonnes of chemical fertilizers reached 365 000 kg with a unit production of 3650 kg/ha in the year 2000, and the income was 48 times of that before fertilizers were applied (Deng *et al.* 2002).

The following techniques are normally considered for fertilizer use.

(a) ***Climate and weather conditions***: Fertilizers are normally applied on sunny days from late March to mid August in central and southern China, when water temperature is over 18°C. Application of fertilizers should start after sunrise but end before 14:00 hr, in order to enable phytoplankton photosynthesis.
(b) ***Types of fertilizers*****:** Normally, nitrogen and phosphorus fertilizers are used. The former include ammonium hydrogen carbonate and urea, and the later include calcium super phosphate. A combination of nitrogen and phosphorus fertilizers can be also used.
(c) ***Determination of nitrogen to phosphorus percentage****:* There are two methods to determine the nitrogen to phosphorus percentage. One is the Oxygen Evolution Method, a bioassay technique determining the limiting nutrients, and the optimum dosages for artificial fertilizers (Li *et al.* 1988). The other is the Water Testing and Formulated Fertilization Method, a way to determine fertilizer type and quantity, according to requirements for nitrogen to phosphorus percentage (7:1) for phytoplankton, and the basic nitrogen to phosphorus percentage in the water of a lake or reservoir (Deng *et al.* 2002). Since phosphorus is normally the limiting nutrients for phytoplankton in most lakes and reservoirs (Peng *et al.* 2004), the suggested ammonium hydrogen carbonate to calcium super phosphate ratio is 1:2–1.5 from April to August, and 1:1.5–1 from September to October (Deng *et al.* 2002; Yang *et al.* 2006).
(d) ***Determination of fertilizer quantity:*** When the nitrogen content in the water is less than 0.3 mg/l, fertilizer should be used. The quantity used each time is 2.5–3.5 kg/667m^2 for ammonium hydrogen carbonate or 1.3-1.4 kg/667m^2 for urea, and 2.0–2.5 kg/667m^2 for calcium super phosphate. The quantity of phytoplankton will peak six to eight days after fertilization (Yang *et al.* 2006).
(e) ***Methods of fertilizer application:*** When water temperature is 18–24°C, fertilizers are used every seven to ten days, and when water temperature is 25–30°C, fertilizers are used every four to six days. Fertilizers should be dissolved in water and sprayed all over the surface of the lake or reservoir using a pump. When both nitrogen and phosphorus fertilizers are used, phosphorus fertilizer should be used before nitrogen fertilizer, because of a toxic substance, metaphosphoric acid that has no fertilizer value will appear will appear if the two kinds of fertilizer are used simultaneously (Yang *et al.* 2006).

Aquaculture practices using chemical fertilizers in medium- and small-sized lakes and reservoirs were very popular in the 1980s and 1990s. For example, this technique was extended to over 80 counties in Hunan Province, covering an area of 133 000 ha, and it resulted in an increase of fish production from almost zero to 240 tonnes (Deng and Chen 1994). In the early part of the last decade, chemical fertilizers were partially or completely replaced by integrated biological fertilizers, which are fermented mixed chemical and biological fertilizers, that are four to eight times more efficient fish production than traditional chemical fertilizers (Luo and Zhu 2008). However, with increasing concerns about eutrophication and biodiversity conservation, use of fertilizers in lakes and reservoirs has been restricted or totally banned since the 2010s in China.

7.4.4 Intensive Aquaculture Using Feeds in Lakes and Reservoirs

The shortage of aquatic food products and the pursuit of economic efficiency made China develop very fast in utilizing lakes and reservoirs for intensive aquaculture in the 1980s and 1990s. Main methods of intensive aquaculture using feeds in lakes and reservoirs include cage culture and pen culture.

7.4.4.1 Cage Culture in Lakes and Reservoirs

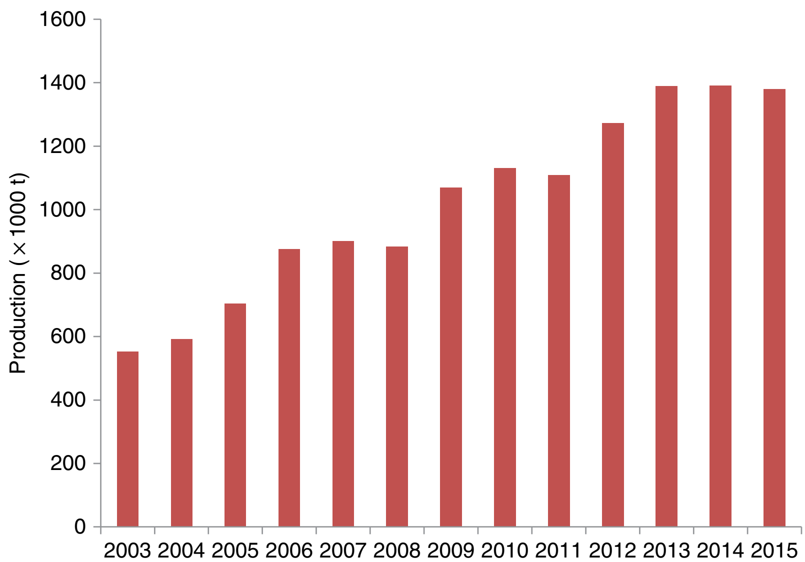
Cage culture was first introduced into China to rear fingerlings of silver carp and bighead carp through the use of natural plankton in lakes and reservoirs to meet the demands of large-sized fingerlings for stock enhancement in the early 1970s (Liu *et al.* 1997). Large-scale experiments of this kind of cage culture were carried out in the late 1970s with great success. In the summer of 1978, Bailianhe Reservoir, Hubei Province, 83 cages of total area of 1750 m^2 were stocked with silver carp and bighead fingerlings (4–5 cm in total overall length) at a density of 200 ind./m^3. In the autumn of the same year, fingerlings reached 13.3 cm in total length with a production of 249–366 ind./m^3 (Liu and He 1992). Cage culture without feeding was also used in the late 1970s for market-size fish culture of silver carp and bighead carp, and is currently extended to American paddlefish (*Polyodon spathula*) culture in many reservoirs.

Cage culture using feeds developed rapidly after the First National Experience Sharing Conference on Cage Culture in Huanggang, Hubei Province in November of 1978, and the Second National Experience Sharing Conference on Cage Culture in Shaoxing, Zhejiang Province in November 1979, under the auspices of the General Bureau of China (now the Fisheries Department of the Chinese Ministry of Agriculture). By 2014, cage culture production peaked to 1 391 651 tonnes in China (Figure 7.4.1).

The leading provinces in cage culture food fish production are shown in Figure 7.4.2. The top five provinces were Guangxi (198 031 tonnes), Hubei (190 543 tonnes), Guizhou (129 269 tonnes), Hunan (128 796 tonnes) and Yunnan (102 989 tonnes). More than 30 finfish species have been cultured in cages in China, of which the highest production of about 211.2 kg/m^2 of the omnivorous common carp (Tu *et al.* 1993), and the lowest average production of 15.4 kg/m^2 of the piscivorous mandarin fish (Qi *et al.* 1999) (Table 7.4.3). The net profit ranges from 131.0–639.0 RMB/m^2 (Table 7.4.3). The rapid development of this industry contributes to government policy aspirations, technical research and extension, and provides high profits for farmers.

However, rapid development of cage culture has been challenged by two main issues. One is the incidence of fish diseases as in grass carp (Tan *et al.* 1999), and channel catfish, resulting in large mortalities of stock (He and Pei 2007). The other is water-quality deterioration. Water-quality deterioration from cage culture caused large scale deaths of fish in Heilongtan Reservoir, Sichuan Province in the 1990s because of oxygen depletion caused by eutrophication. Currently, cage culture is facing conflicting policy challenges viz. pursuing increased production and food security, concerns about food safety, and attaining environmental integrity. Cage culture is banned in large reservoirs, especially those used for potable water supply, or which have significant social importance, such as the Danjiangkou Reservoir and the Three Gorges Reservoir, two of the largest reservoirs

Figure 7.4.1 Cage culture production from 2003–2015 in China. *Source:* China Fishery Yearbook (2016).



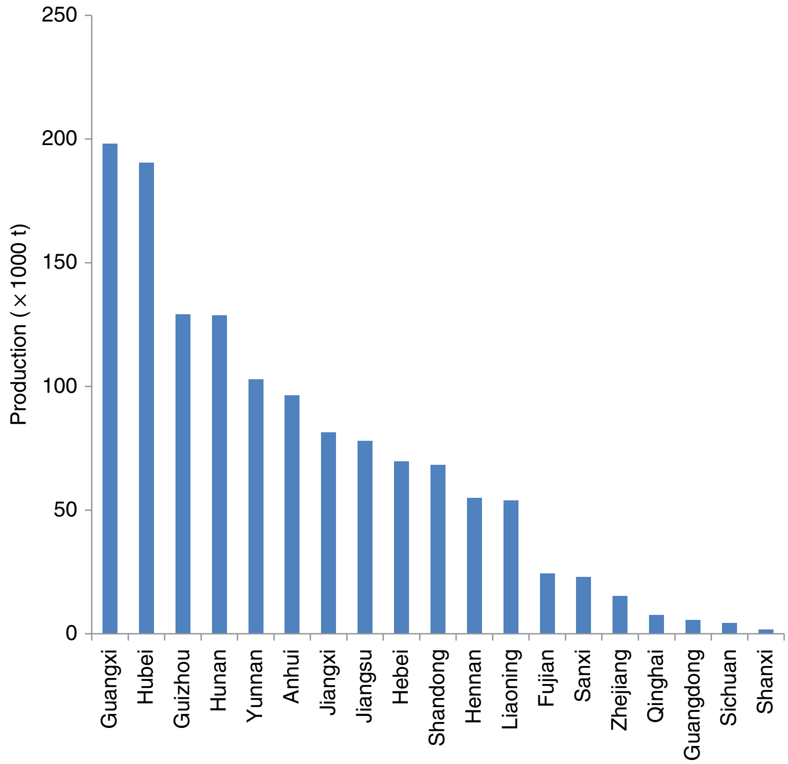


Figure 7.4.2 Mean cage-culture food fish production in the different provinces. *Source:* Data from 2015, China Fishery Statistical Yearbook (2016).

Table 7.4.3 Main cage culture fish species, mean production and net income.

Species	Cage area (m^2)	Stocking density(kg)	Stocking size(g)	Total production (kg)	Harvest size (g)	Net production (kg/m^2)	Benefit (RMB/m^2)	Source
Blunt snout bream	6	98	57.6	389.3	230	48.6	131.0	Tu *et al.* 1993
Grass carp	4	76.8	591	274.5	2408	49.4	186.7	Tu *et al.* 1993
	16	150	264	605.1	1333	28.4	107.0	Tu *et al.* 1993
Common carp	4	124	122	968.8	963	211.2	595.8	Tu *et al.* 1993
Gift tilapia	20	493.5	98.0	3533.8	727.3	152.0	525.4	Wang 2003
Nile tilapia	4	10-20	>20	500.0	0.6-1.6	125.0	250.0	Yao 2006
Large mouth bass	24	13.5	5.0	729.2	400.0	29.8	639.0	Lin *et al.* 1997
Top mouth coulter	25	60.0	40.0	814.7	580.0	30.2	420.6	Lin 2015
Channel catfish						148.1		Tang *et al.* 1994
						89.5		He & Pei 2007
						56.3		Zhang & Huang 2005
Mandarin fish	28					6.82	157.6	Xia *et al.* 2004

Figure 7.4.3 Two-layer net cages for increasing feed utilization efficiency and decreasing nutrient discharge in Geheyan Reservoir, Hubei Province. *Source:* Photo by Jiashou Liu.

in the world. By the end of 2017, a total of more than 100 000 cages with a total area of 3 000 000 m^2 will be removed from the Danjiangkou Reservoir.

In those reservoirs not supplying potable water, cage culture will be restricted. In order to reduce the effect of water-quality deterioration from cage culture, aquaculture scientists have established some standards regarding carrying capacity for cage culture (Peng *et al.* 2004). Newly designed cages, which increase feed utilization and decrease nutrient loading, are also used in reservoirs e.g. Geheyan, Hubei province. In this case of two-layered cage culture, four relatively smaller and shallower inner cages are installed in a larger and deeper outer cage, and a cross sidewalk made of steel is installed in the center of the outer cage. Inside the cage, plants are reared to absorb nutrients produced from cage culture (Figure 7.4.3). Around the edge of the outer cage, the cement sidewalks are built on cement floats, replacing the traditional floating equipment (e.g. foamed plastic materials or oil drums). The floats are connected by using seamless welding steel, and there is a 50-cm gap between adjacent floats to permit water flow. Workshops and feeding platforms are also built for cage farming operations. The cages are made of polyethylene. As for feeding, only the major cultured species in the inner cages are fed, while the co-cultured species in the outer cages are not. Compared with the traditional single-layered cage culture system, two-cage culture systems have greater resistance to wind and waves, reduce the risk of escape by cultured species, improve the efficiency of feed utilization, and reduce adverse impacts of cage farming associated with uneaten feed and feces (Wang *et al.* 2015a).

7.4.4.2 Pen Culture in Lakes and Reservoirs

Pen aquaculture in macrophytic lakes started in the early 1980s to utilize the extra plant resources. By 1992, in Taihu Lake (eastern part), the third largest freshwater lake in China, pen aquaculture had reached an area of 100.9 ha, and had a total yield of 1870 tonnes, 14 850 000 RMB in output value, and provided a profit rate as high as 45.1 percent. The main aquaculture method was to use macrophytes in lakes with a small proportion of supplemented formulated feeds. In Taihu Lake, the production from pen aquaculture reached 30 000 kg/ha. Yang *et al.* (1995) compared three modes of pen aquaculture in Taihu Lake (Table 7.4.4). It

Table 7.4.4 Comparative analysis on three types of pen aquaculture and their environmental effects in Taihu Lake.

Parameter	Low density fish culture in large-sized pens	Fish culture in small-sized pens	Mitten crab culture in pens
Average single pen area (ha)	6.12	0.51	1.24
Species cultured	Fingerlings escaped from small-sized pens	74% of grass carp; 23.6% of bream	Mitten crab
Stocking density (kg/ha)		2363.5	50.3
Food source (tonnes)	Natural feeds	Artificial feeding	Supplemental feeding
		Macrophtyes: 31 644.0, land grass: 717.3, soybean cake and grains: 2152.0	Macrophtyes: 198.0, trash fish: 120.7, soybean cake and grains: 264.0
Production (kg/ha)	351	6225	212.3
Output (RMB/ha)	1718	30 535	16 245
Profit (RMB/ha)		11781	9527
Profit rate (%)		38.6	58.6
Nutrient loading (tonnes)		N:170.73, P20.74	N:14.91, P:1.96
Nutrient load per 1000 RMB(kg)		N:54.3, P: 6.59	N:4.2, P: 0.6
Effect on macrophyte	Almost no macrophyte left	Destroyed	Lightly affected

Source: Modified after Yang *et al.* (1995).

indicates that fish culture in pens can produce better economic returns, but have worse environmental effects (Table 7.4.4). Pen aquaculture in Taihu Lake caused the disappearance of macrophytes and serious blue-green algal bloom problems in the first decade of this century (Cai *et al.* 2013). With concerns about water quality, intensive aquaculture in all large lakes and reservoirs was banned subsequently (Wang *et al.* 2017).

7.4.5 Eco-Fisheries in Lakes and Reservoirs

7.4.5.1 Replacement of Low-Valued Species with High-Valued Species

Lake and reservoir fisheries are important to food security in China, and this remains one of the most important priorities for the growing human population. But as indicated earlier, intensive aquaculture in lakes and reservoirs are perceived to cause more and more environmental problems, inducing the government to ban such activities in large water bodies. This ban on intensive aquaculture practices has encouraged the development of alternate practices that not only continue to provide food fish for a growing population but do so whilst maintaining environmental integrity, and biodiversity, and also continue to sustain farmer incomes. Thus, combining ecosystem restoration with economics is pivotal in setting successful conservation in China. In recent years, the trade-off between fisheries development and environmental protection has been supported by the replacement of low-valued species with high-valued species in lakes and reservoirs.

A trade-off study was carried out between 2006 and 2011 in Wuhu Lake, located in the middle reaches of the Yangtze River, Hubei Province, China. This is a shallow lake of 2133 ha, of mean depth of 2.6 m, disconnected by a sluice gate from the Yangtze River in 1952. It was originally covered with a large community of submersed macrophytes in 1995, but macrophytes almost disappeared in 2006 when this study began. By contrast, in 2005, the density of phytoplankton had increased from 89.3×10^4 ind/l in 1995 to 1726×10^4 ind./l in 2005. Since 1995, the lake has been managed for the culture of domesticated carp species, including grass carp, bighead carp, and silver carp, at stocking densities of 20–55 kg/ha, with the additional production of mandarin fish (*Siniperca chuatsi*). To support fish culture, plankton biomass was enhanced by the addition of inorganic fertilizers (417 kg/ha ammonium bicarbonate and superphosphate annually from 2002 to 2006), and organic fertilizers (1327 kg/ha brewer's grains and animal feces annually during 2005–2007 (Lin *et al.* 2015).

In 2008, grass carp stocking was discontinued in Wuhu Lake, the biomass of bighead carp and silver carp reduced from 8.9 ± 0.9 × 10^4 kg to 5.6 ± 1.5 × 10^4 kg, and the Chinese mitten crab (*Eriocheir sinensis*) and mandarin fish, two species of high economic value, were introduced. Fertilization in the lake was discontinued (i.e. no fertilizers or brewer's grain were used), and the lake was replanted with *Vallisneria spiralis* to re-establish the submerged macrophytes to provide refuge and food for the Chinese mitten crab. The biomass of coin-sized mitten crab (i.e. about 5 g/ind.), and mandarin fish fingerlings (about 3 cm total length) at stocking were 1.58 ×10^4 kg and 20 × 10^4, respectively (Lin *et al.* 2015).

Following the change in the fishery management in 2008, there was a significant increase in clarity and overall water quality. Macrophyte coverage increased with almost no submerged macrophytes observed in 2006, to 31 percent (mainly *V. spiralis*) coverage by summer 2010. Within four years following the start of the management change, the overall annual fish yield decreased by three percent from 785 000 kg to 763 000 kg; the Chinese carp, including grass carp, bighead carp, silver carp and common carp decreased from 630 400 kg to 477 625 kg. Following the start of the management change, the total of mandarin fish and Chinese mitten crab established a sustainable annual crop of 20 400 kg and 93 600 kg, respectively, and the overall yield of mandarin fish and Chinese mitten crab accounted for about 15 percent of the total fisheries production (Lin *et al.* 2015).

The fisheries income increased significantly following the above change of the farming method. With an annual average income of about US$ 1.83 million, 2.6 times that of 2006–2007 (about $0.70 million). During this period, mandarin fish and Chinese mitten crab alone accounted for about 48 percent of the total income generated (Lin *et al.* 2015). The differences between the traditional model and the ecosystem-based fishery model are shown schematically in Figure 7.4.4.

7.4.5.2 Eco-Fisheries Based on Aquatic Biodiversity Restoration and Water Quality Protection in Lakes and Reservoirs

China is a country with an overall shortage of freshwater resources (Zhang *et al.* 2009). As such, water-quality protection is given high priority in water supply lakes like Kuilei Lake (about 760 ha) in Jiangsu

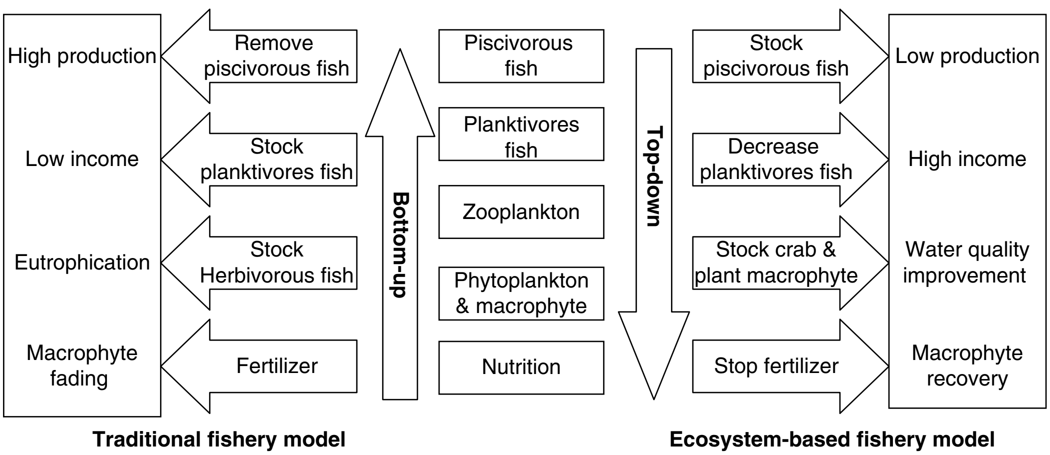


Figure 7.4.4 Comparison of measures and effects of traditional and ecosystem-based fishery management in lower and middle Yangtze River basin lakes. *Source:* From Lin *et al.* (2015).

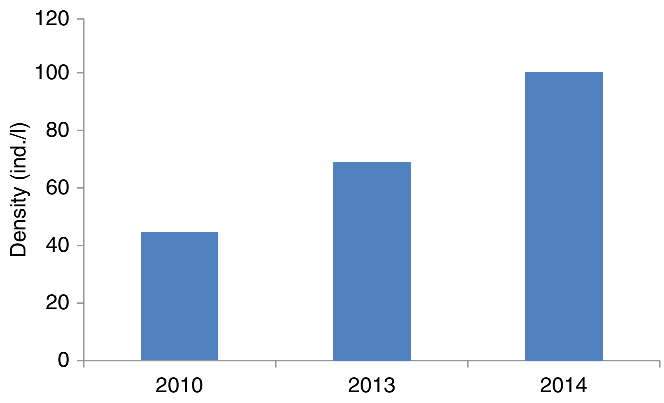


Figure 7.4.5 Change of planktonic crustaceans in Kuilei Lake. *Source:* Provided by Fengyi Chang.

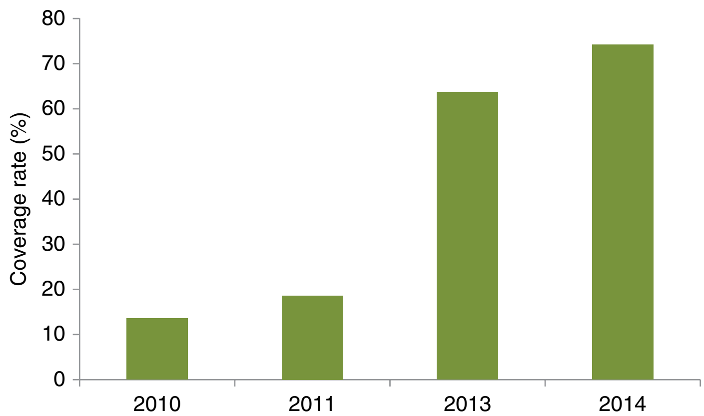


Figure 7.4.6 Change of macrophyte coverage. *Source:* Provided by Fengyi Chang.

Province. Here, prior to 2010, water quality was bad, and macrophyte coverage was very low (less than 16 percent) because of high biomass of herbivorous grass carp and benthic common carp. From 2010 on, the fisheries management strategy was changed, including stocking combinations of piscivorous mandarin fish, catfish, snakehead fish, and culters, to control both small-sized fish and common carp fingerlings as a biomanipulation tool, harvesting (removing) grass carp and common carp, and restricting stocking of silver carp and bighead carp. After two years, the biomass of planktonic crustaceans and macrophyte coverage increased significantly (Figures 7.4.5 and 7.4.6). Now the water quality and ecosystem are both in good condition, indicating that adjustment of the fish community structure is a good way to keep healthy of aquatic ecosystem.

7.4.6 Conclusions

From the narratives, "success" has to be considered in a context of time, particularly in relation to a nations' prevailing socio-economic *milieu*. A success in one period of time may not be so in another period. During the era prior to the economic upsurge commencing in the late 1980s to early 1990s, when people were hungry, production of fish was the priority. Some aquaculture methods appear ridiculous in today's context, such as using wastewater or fertilizers in lakes and reservoirs. Now, the country has progressed much further; people are environmentally conscious; more and more attention is paid to water quality protection, biodiversity conservation, and ecosystem health. It is a challenge to find a better balance between future lake and reservoir aquaculture developments, and environmental protection, and also to maintain economic viability and provide livelihoods. All in all, the endeavors in China in this regard are commendable and will continue to grow.

Acknowledgments

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7.5

In Situ Conservation of Aquatic Genetic Resources and Associated Reserves

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7.5.1 Introduction

Aquatic genetic resources are defined as comprising all genetic material of all finfish and aquatic invertebrate, and plants, and include their DNA, genes, gametes, individual organisms, wild, farmed and research populations, species and organisms as well as those that have been genetically altered.

Aquatic genetic resources in nature are free-living and minimally changed by human activities, though it is becoming difficult to find any completely unchanged wild populations in China, as in many areas of the world. Loss of habitats and degradation of the aquatic environment and capture fisheries reduce genetic diversities of aquatic populations and biodiversity.

It has been well recognized that the conservation of aquatic genetic resources is vitally important for the sustainable development of fisheries and aquaculture, globally and in China. Since aquatic genetic organisms become less natural, *in situ* conservation is considered as one of the efficient measures for protection and conservation of any population of wild organisms, and this strategy has come to the forefront in the past decade or so.

In situ conservation of aquatic genetic resources in reserves (protected areas) should meet the requirements of (1) maintaining a genetically effective population size; i.e., a number of effective breeders, so as to avoid inbreeding depression and loss of genetic variation and, (2) paying attention to the management of their habitats, so as to prevent their degradation or loss.

In situ conservation of aquatic genetic resources will guarantee that the continued presence and integrity of the waters and biological communities that host particular wild aquatic genetic resources, in the face of challenges by, *inter alias*, climate change, dam construction, droughts, floods, introduction of both alien species and diseases, over fishing, siltation and water abstraction, and so as to conserve the genetic resources (FAO 2008).

This Chapter will introduce the practices of *in situ* conservation of the aquatic genetic resources in China, and provide an account of the reserves that have been established by the Government of China for this purpose.

7.5.2 Aquaculture and Aquatic Genetic Resources

In China, there are vast inland waters (rivers, lakes and reservoir), extending from tropical to cold temperate zones. Therefore, China has abundant aquatic living resources with more than 20 000 species of aquatic living organism, and complex bio-diversity characteristics. Among these aquatic organisms, are more than 1700

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species of marine finfish, 300 decapod crustaceans, 90 cephalopods, and 744 algae. There are also more than 800 species of finfish, 62 crustaceans, 169 mollusks, 36 reptiles, and 437 water plants in inland waters (Li *et al.* 2012).

All of the above aquatic living organisms account for 30 to 40 million tonnes of the capture fisheries, and their genetic resources, with effective management, also have potential value to improve aquaculture production, efficiency and environmental sustainability. Genetically improved fish may grow faster, use food more efficiently and resist diseases (fewer pharmaceutical treatments required).

As one of the fastest growing food production sectors, aquaculture production in China reached 50 000 000 tonnes in 2014, dominated by inland aquaculture (Wang *et al.* 2015), and it helps to provide a growing human population with animal protein, since capture fisheries have reached the biological limits of production, or have been depleted through over-fishing and habitat degradation (capture fisheries production remains about 12 000 000 tonnes since the beginning of the twenty-first century).

The importance of aquaculture in food production, economic development, and food security is now well recognized worldwide. In 2004, the International Food Policies Research Institute of the United States predicted that along with the sharp increase in demand of aquatic products, 41 percent of the products would be coming from aquaculture in 2020. Indeed, we are aware now that aquaculture accounts for over 50 percent of all sea food consumed globally (Subasinghe *et al.* 2009), and as such has fallen in line with our other staples which are all farmed (De Silva 2012).

Most fish are still farmed as wild types or as undomesticated populations that are close to wild types; seaweed farming also relies heavily on the propagation of wild types (FAO 2012). Of over 230 species of farmed aquatic animals and plants (Bartley *et al.* 2009), only a few have been the subject of deliberate genetic resource managements. Channel catfish (10 varieties), Nile tilapia (10 varieties), Atlantic salmon (10 varieties), and many farmed carps (20 varieties), are cases that demonstrate the significant gains in production possible from genetic improvement.

Aquatic genetic resources are important to aquaculture development. One estimate indicated that the supply gap caused by decreasing output from capture fisheries and the increasing human population could be filled simply by incorporating genetic improvement into already existing aquaculture practices. Many cases show that aquaculture production and environmental sustainability in China were significantly improved through artificial propagation, with the effective use of aquatic genetic resources, such as the new varieties of carps, tilapia, flat fish, shrimp, mollusks and kelp. The production of the improved varieties of tilapia (Nile tilapia and Gift tilapia) in China has reached 1 450 000 tonnes in the recent years (see Chapter 4.3 for further details).

However, if the new genetically improved varieties of fish are defined as continuously controlled reproduction for more than three generations, then only 30 varieties of farmed fish, out of 152, can be termed genetically improved in China (Tables 7.5.1 and 7.5.2). There is great potential to improve the production and environmental sustainability of aquaculture in China. The numerous aquatic genetic resources of China in the wild will be the essential raw material for improvement and innovation of new varieties for aquaculture.

It is obvious that management of aquatic genetic resource is necessary for more than just to improve production. Besides being essential for genetic improvement in aquaculture, genetic resources are the necessary raw ingredients that allow species to adapt to short-term and long-term environmental changes; they provide species, populations and individuals with the flexibility and stress tolerance of dealing with and adapting to changes to their environment, changes both from humans and from natural causes.

7.5.3 Present Status of National Aquatic Genetic Resource Reserves (NAGRR)

7.5.3.1 Legislation

Article 29 of the Fisheries Law of the People's Republic of China (Standing Committee of the National People's Congress, PRC 2000) has clearly recommended that "The State should protect the aquatic genetic resources

Table 7.5.1 List of fresh water aquatic species cultured in China. The data have been compiled from a variety of sources.

No.	Common English/ Chinese name	Species
Finfish		
1	鲢 Silver Carp	*Hypophthalmichthys molitrix*
2	鳙 Bighead Carp	*Aristichthys nobilis*
3	草鱼 Grass Carp	*Ctenopharyngodon idellus*
4	青鱼 Black Carp	*Mylopharyngodon piceus*
5	鲤 Carp	*Cyprinus carpio haematopterus*
6	鲫 Crucian	*Carassius auratus auratus*
7	银鲫 Silver Prussian Carp	*Carassius auratus gibelio*
8	彭泽鲫 Pengze Crucian Carp	*Carassius auratus var.pengzenensis*
9	白鲫 Japanese Crucian Carp	*Carassius auratus cuvieri*
10	鲮 Mud Carp	*Cirrhinus molitorella*
11	鳜 Mandarin Fish	*Siniperca chuatsi*
12	日本鳗 Japanese Eel	*Anguilla japonica*
13	欧洲鳗 European Eel	*Anguilla anguilla*
14	美洲鳗 American Eel	*Anguilla rostrata*
15	尼罗罗非鱼 Nile Tilapia	*Oreochromis niloticus*
16	奥利亚罗非鱼 Blue Tilapia	*Oreochromis aureus*
17	虹鳟 Rainbow Trout	*Salmo gairdneri*
18	斑点叉尾鮰 Channel Catfish	*Ictalurus punctatus*
19	云斑鮰 Brown Bullhead	*Ameiurus nebulosus*
20	淡水白鲳 Black Pacu	*Colossoma brachypomum*
21	大盖巨脂鲤 Cachama	*Colossoma macropomum*
22	中华鲟(保护种类) Chinese Sturgeon	*Acipenser sinensis*
23	达氏鲟(保护种类) Acipenser Dabryanus	*Acipenser dabryanus*
24	施氏鲟(保护种类) Amur Sturgeon	*Acipenser schrenckii*
25	匙吻鲟(保护种类) Paddlefish	*Polyodon spathula*
26	圆吻鲴 Distoechodon Tumirostris	*Distoechodon tumirostris*
27	银鲴 Xenocypris Argentea	*Xenocypris argentea*
28	细鳞斜颌鲴 Smallscale Yellowfin	*Xenocypris microlepis*
29	团头鲂 Bluntnose Black Bream	*Megalobrama amblycephala*
30	广东鲂 GuangDong Black Bream	*Megalobrama hoffmanni*
31	三角鲂 Triangular Bream	*Megalobrama terminalis*
32	胭脂鱼(保护种类) Chinese Sucker	*Myxocyprinus asiaticus*
33	卷口鱼 Ratmouth Barbel	*Ptychidio jordani*
34	长臀鮠 Helmet Catfish	*Cranoglanis bouderius*
35	长吻鮠 Longsnout Catfish	*Leiocassis longirostris*
36	黄颡鱼 Yellow Catfish	*Pelteobagrus fulvidraco*
37	大口鲶 Southern Catfish	*Silurus soldatovi*

(*Continued*)

Table 7.5.1 (Continued)

No.	Common English/ Chinese name	Species
38	胡子鲶 Slender Walking Catfish	*Clarias nieuhofii*
39	革胡子鲶 Clarias Lazera	*Clarias lazera*
40	卡特拉鲃 Catla	*Catla catla*
41	露斯塔野鲮 Rohu Carp	*Labeo rohita*
43	印度鲮 Indian Pangolin	*Cirrhina mrigala*
44	白鲑 Whitefish	*Coregonus lavaretus*
45	加州鲈 Largemouth Bass	*Micropterus salmoides*
46	蓝鳃太阳鱼 Bluegill Sunfish	*Lepomis macrochirus*
47	条纹鲈 Striped Perch	*Morone saxatilis*
48	美国红鱼 Red Drum	*Sciaenops ocellatus*
49	大眼狮鲈 Walleye Larvae Eyed	*Stizostedion vitreum*
50	大口胭脂鱼 Bigmouth Buffalo	*Ictiobus cyprinellus*
51	暗纹东方鲀 Pufferfish	*Takifugu obscurus*
Shrimp and Decapod Crabs 虾蟹类		
52	梵纳对虾 White-leg Shrimp	*Penaeus vannamii*
53	罗氏沼虾 Giant River Prawn	*Macrobrachium rosenbergii*
54	中华绒螯蟹 Chinese Mitten Crab	*Eriocheir sinensis*
55	日本沼虾 Oriental River Prawn	*Macrobrachium nipponense*
Shellfish 贝类		
56	三角帆蚌 Hyriopsis Cumingii	*Hyriopsis cumingii*
57	褶纹冠蚌 Cockscomb Pearl Mussel	*Cristaria plicata*
Reptiles 爬行类		
58	中华鳖 Soft-shelled Turtle	*Trionyx sinensis*
59	乌龟 Turtle	*Chinemys reevesii*

and their habitats and establish aquatic genetic resources reserves (protected areas) in the key areas where aquatic genetic resources are of high economic and hereditary breeding value".

In Section 3 of the Fishery Resources Protection and Enhancement Act on "Program of Action on Conservation of Living Aquatic Resources of China" (State Council, PRC 2006) promulgated by the State Council in 2006, aquatic genetic protection were described as being "in key growing and breeding places of aquatic living organisms and these organisms may have high economic and breeding values, aquatic genetic resources reserves should be demarcated, relevant management measures should be established, and the management of reserve should be regulated and strengthened" (State Council, PRC 2006).

In January 2011, the Ministry of Agriculture of PRC formally published "Management Interim Procedures of Aquatic genetic Resources Reserves" (Ministry of Agriculture, PRC 2011a) in the form of a ministerial decree in accordance with the Fisheries Law of the People's Republic of China, and the Action Plan on the Conservation of Living Aquatic Resources of China, which stipulated the issues of demarcation and management of aquatic genetic resources reserves.

All of above indicate that the practices for the demarcation, establishment and management of aquatic genetic resources reserves in China are covered by legal authority and policy support.

Table 7.5.2 List of marine species cultured in China. The data have been obtained from various sources.

No.	Common English / Chinese name	Species
Algae 藻类		
1	石花菜 Gelidium	*Gelidium amamsii*
2	真江蓠 Gracilaria Asiatica	*Gracilaria asiatica*
3	坛紫菜 Porphyra Haitanensis	*Porphyra haitanensis*
4	凤尾菜 Vegetable Fern	*Gracilaria eucheumoides*
5	异形石花菜 Gelidium Vagum	*Gelidium vagum*
6	扁江蓠 Gracilaria Textorii	*Gracilaria textorii*
7	海南江蓠 Gracilaria Hainanensis	*Gracilaria hainanensis*
8	条斑紫菜 Porphyra Yezoensis	*Porphyra yezoensis*
9	细基江蓠 Gracilaria Tenuistipitata	*Gracilaria teruistipitata*
10	裙带菜 Sea Mustard	*Undaria pinnatifida*
11	大石花菜 Gelidium Pacifium	*Gelidium pacifium*
12	匍匐石花菜 Gelidium Pusillum	*Gelidium pusillum*
13	细毛石花菜 Gelidium Crinale	*Gelidium crinale*
14	红毛藻 Bangia Fusco-purpurea	*Bangia fusco-prupruea*
15	江蓠 Gracilaria	*Gracilaria verrucosa*
16	麒麟菜 Eucheuma	*Eucheuma muricatum*
17	小石花菜 Divaricate Gelidium Thallus	*Gelidium divaricatum*
18	脆江蓠 Gracilaria Bursa-pastoris	*Gracilaria bursa-pastoris*
19	海带 Kelp	*Laminaria japonica Aresch*
Shellfish 贝类		
20	褶牡蛎 Ostrea Plicatula	*Ostrea plicatula*
21	西施舌 Coelomactra Antiquata	*Mactra antiquata*
22	马氏珠母贝(合蒲珠母贝) Pinctada Martensii (Akoya pearl oyster)	*Pinctada martensii*
23	菲律宾蛤仔 Short Necked Clam	*Ruditapes philippinarum*
24	虾夷扇贝 Patinopecten Yessoensis	*Patinopecten yessoensis*
25	栉江珧 Comb Pen Shell	*Pinna pectinata*
26	毛蚶 Ark Clam	*Scapharca subcrenata*
27	泥蚶 Ark Shell	*Tegillarca granosa*
28	海湾扇贝 Bay Scallop	*Argopecten irradians*
29	紫石房蛤 Saxidomus Purpuratus (“Washington” clams)	*Saxidomus purpuratus*
30	魁蚶 Blood clam	*Scapharca broughtonii*
31	华贵栉孔扇贝 Noble scallop	*Chlamys nobilis*
32	密鳞牡蛎 Lamellated Oysters	*Ostrea denselamellosa*
33	厚壳贻贝 Hard-shelled Mussel	*Mytilus coruscus*
34	翡翠贻贝 Green mussel	*Mytilus smaragdinus*
35	大珠母贝 Pearl Oyster	*Pinctada maxima*
36	文蛤 Hard Clam	*Meretrix meretrix*

(*Continued*)

Table 7.5.2 (Continued)

No.	Common English / Chinese name	Species
37	蝾螺 Turban Shell	*Turbo cornutus*
38	栉孔扇贝 Chinese scallop	*Chlamys farreri*
39	缢蛏 Chinese Razor Clam	*Sinonovacula constricta*
40	四角蛤蜊 Mactra Yeneriformis	*Mactra veneriformis*
41	日本日月贝 Amusium Japonicum Formosum	*Amusium japonicum formosum*
42	贻贝 Mussel	*Mytilus edulis*
43	长牡蛎 Pacific Oyster	*Crassostrea gigas*
44	青蛤 Chinese Venus	*Cyclina sinensis*
45	皱纹盘鲍 Pacific Abalone	*Haliotis discus hannai*
46	近江牡蛎 Southern Oyster	*Crassostrea rivularis*
47	杂色鲍 Haliotis Diversicolor	*Haliotis diversicolor*
Shrimp and crabs 虾蟹类		
48	日本对虾 Kuruma Prawn	*Penaeus japonicus*
49	中国龙虾 Chinese Spiny Lobster	*Panulirus stimpsoni*
50	锦绣龙虾 Ornate Spiny Lobster	*Panulirus ornatus*
51	南美白对虾 White-leg Shrimp	*Penaeus vanmamei*
52	刀额新对虾 Greasy-back Shrimp	*Metapenaeus ensis*
53	脊尾白虾 Ridgetail Prawn	*Palaemon carincauda*
54	中国对虾 Chinese Shrimp	*Penaeus chinensis*
55	锯缘青蟹 Mud Crab	*Scylla serrata*
56	三疣梭子蟹 Swimming Crab	*Portunus trituberculatus*
57	墨吉对虾 Banana Prawn	*Penaeus merguiensis*
58	斑节对虾 Giant Tiger Prawn	*Penaeus monodon*
59	中国对虾 Chinese Shrimp	*Penaeus orientalis kishinouye*
Finfish 鱼类		
60	斑鰶 Spotted Gizzard Shad	*Clupanodon punctatus*
61	日本鳗鲡 Japanese Eel	*Anguilla japonica*
62	黄鳍东方鲀 (条纹东方鲀) Yellowfin Puffer	*Fugu xanthopterus*
63	日本海马 Japanese Seahorse	*Hippocampus japonicus*
64	欧洲鳗鲡 European Eel	*Anguilla anguilla*
65	虱目鱼 Milkfish	*Chanos chanos*
66	蜂巢石斑鱼 Mottled Grouper	*Epinephelus merra bloch*
67	小齿石斑鱼 Smalltooth Grouper	*Epinephelus microdon*
68	花鲈 Japanese Sea Perch	*Lateolabrax japonicus*
69	梭鱼 So-iuy Mullet	*Mugil soiuy*
70	赤点石斑鱼 Hong KongGrouper	*Epinephelus akaara*
71	美国红鱼(眼斑拟石首鱼) Red Drum	*Sciaenops ocellatus*
72	黄鳍鲷(黄鳍棘海鲷) Yellow-fin sea bream	*Acanthopagrus latus*
73	鲻 Grey Mullet	*Mugil cephalus*

Table 7.5.2 (Continued)

No.	Common English / Chinese name	Species
74	三斑海马 Flatfaced or Longnosted seahorse	*Hippocampus trimaculatus*
75	日本黄姑鱼 Japanese Croaker	*Nibea japonica*
76	青石斑鱼 Indigo Hamlet	*Epinephelus awoara*
77	条纹狼鲈(条纹石鮨、美洲条纹鲈) Striped Bass	*Morone saxatilis*
78	美国大口胭脂鱼 Bigmouth Buffalo	*Ictiobus cyprinellus*
79	大黄鱼 Large Yellow Croaker	*Pseudosciaena crocea*
80	褐牙鲆(牙鲆) Olive flounder	*Paralichthys olivaceus*
81	乌塘鳢(中华乌塘鳢) Chinese Gudgeon	*Bostrichthys sinensis*
82	鲑点石斑鱼 Rock Cod	*Epinephelus fario*
83	白星石斑鱼 Edgeblack Grouper	*Epinephelus summana*
84	刺海马 Spiny Seahorse	*Hippocampus histrix*
85	大海马(克氏海马) Great Seahorse	*Hippocampus kelloggi*
86	大弹涂鱼 Mudskipper	*Boleophthalmus pectinirostris*
87	黑鲷 Black Sea Bream	*Sparus macrocephalus*
88	宽带石斑鱼 Striped Grouper	*Epinephelus latifasciatus*
89	云纹石斑鱼 Kelp Grouper	*Epinephelus moara*
90	真鲷 Genuine Porgy	*Chrysophrys major*
91	宝石石斑鱼 Areolate Grouper	*Epinephelus areolatus*
92	赤石斑鱼 Blacktip Grouper	*Epinephelus fasciatus*
93	六带石斑鱼 Sixbar Grouper	*Epinephelus sexfasciatus*
94	管海马 Spotted Seahorse	*Hippocampus kuda*

7.5.3.2 Development Process

In order to implement the Fisheries Law of the People's Republic of China, the "Program of Action on Conservation of Living Aquatic Resources of China", as well as the Management Interim Procedures of Aquatic Genetic Resources Reserves, the Ministry of Agriculture of PRC issued the Notification to accelerate the demarcation of Aquatic Genetic Resource Reserves on June 8 2007. To this end it published, "The specification of aquatic genetic resources reserves demarcation" (Ministry of Agriculture, PRC 2007a). These legislative enactments indicate the official beginning of demarcation of aquatic genetic resources reserves in China. From 2007 to 2014 (Ministry of Agriculture, PRC 2007b; 2008a, b; 2009a, b; 2010a, b; 2011b, c; 2012a, b; 2013a, b; 2014a, b; 2015), the Ministry of Agriculture of PRC published eight batches of reserves, establishing a total of 464 National Aquatic Genetic Resources Reserves.

7.5.3.3 Present Status of NAGRR

7.5.3.3.1 Types and Numbers

Up to 2014, there were eight batches of reserves, with a total number of 464 National Aquatic Genetic Resources Reserves demarcated. Of these reserves, there are 293 river-based (63 percent), 111 lake-based (24 percent), nine reservoir-based (two percent), six estuary-based (one percent), and 45 marine reserves (ten percent) (Table 7.5.3).

Table 7.5.3 Types of National Aquatic Genetic Resources Reserves.

Batch (year)	Rivers	Lakes	Reservoirs	Estuaries	Marine	Total
No. 1 (2007)	20	10	0	0	10	40
No. 2 (2008)	34	18	1	3	7	63
No. 3 (2009)	34	14	2	0	7	57
No. 4 (2010)	35	15	1	1	8	60
No. 5 (2011)	42	13	2	2	3	62
No. 6 (2012)	59	18	1	0	8	86
No. 7 (2013)	42	14	2	0	2	60
No. 8 (2014)	27	9	0	0	0	36
Sum	293	111	9	6	45	464
Percentage	63%	24%	2%	1%	10%	100%

7.5.3.3.2 Distribution

The distribution by administrative regions, most of the provinces and municipalities of China (not including Taiwan, Hong Kong, and Macao) have established aquatic genetic resources reserves, except Beijing, Shanghai and Tianjin. There are 62 aquatic genetic resources reserves in Hubei province, and it is ranked top most, followed by Shandong province (38 NAGRRs) (details in Figure 7.5.1 and Table 7.5.4).

In relation to the distribution by drainage basins, there were 169 aquatic genetic resources reserves in the Yangtze River Basin, 44 in the Yellow River Basin, and 41 in the Songhua River Basin. As far as marine-based NAGRR are concerned, there are 17 aquatic genetic resources reserves in the Bohai Sea, 23 in the Yellow Sea, five in the East China Sea, and seven in the South China Sea (details in Table 7.5.5).

According to location and jurisdiction, most of the NAGRR positions fall inside a single province and they will be administrated by their relevant provincial fishery administration agencies. However, there are still some NAGRRs which may fall into more than two provinces, and these NAGRRs will be governed by a joint fishery administrative agency committee of the relevant provinces.

7.5.3.4 Areas

The total area of the eight batches of aquatic genetic resources reserves is about 154,681 km^2. Of this, the river basins, lake-based and reservoir-based NAGRRs account for 80 058 km^2, occupying over 45 percent of all freshwater areas in China. Areas of sea- and estuary-based NAGRRs in total account for 74 624 km^2, occupying over one percent of sea areas of China.

7.5.3.5 Main Species Protected in the NAGRRs

7.5.3.5.1 Protected Species Categories

In all of the National Aquatic Genetic Resources Reserves, there are 453 species of aquatic living organisms protected, including 348 fish (76.8 percent of the total protected organisms); the other protected categories include crustaceans (4.6 percent), shellfish (6.8 percent), aquatic plants (3.1 percent), and the other aquatic animals account for 8.6 percent; 98 species in the 453 protected species are in the National Wildlife Protection List, the rest are important economic aquatic species or endemic species (Table 7.5.6).

7.5.3.5.2 Geographical Distribution of Protected Species

Geographically, NAGRRs of China are distributed in 28 provincial and municipal administrative regions and the Bohai Sea, Yellow sea, East China Sea, South China Sea. Table 7.5.7 lists the number of protected species

Figure 7.5.1 Distribution Map of NAGRRs in China.

in each provincial administrative region and sea area, which show that most species distributed in the provinces located in the middle and lower reaches of Yangtze River, such as Hubei (71 species), Hunan (68 species), Jiangxi (50 species), Jiangsu (50 species) are protected; in Shandong province, located in the Yellow River basin, 50 species are protected.

7.5.3.5.3 Main Protected Species in Different Regions

The main protected species in different administrative regions are given in Tables 7.5.8 and 7.5.9. Table 7.5.8 lists the statistical count of the conservation areas which contain the top ten main protected fishes in each region. The top ten list contains shorthead catfish, mandarin fish, topmouth culter (*Culter alburnus*), carps – grass carp, goldfish, silver carp and bighead carp, argus snakehead, and catfish. These fish have been

Table 7.5.4 Numbers of NAGRRs in Different Administrative Regions (YRFAC –Yellow River Fishery Administrative Committee; MOA – Ministry of Agriculture).

	Number of National Aquatic genetic Resources Reserves								
Region	**No. 1**	**No. 2**	**No. 3**	**No. 4**	**No. 5**	**No. 6**	**No. 7**	**No. 8**	**Sum**
Beijing	0	0	0	0	0	0	0	0	0
Tianjin	0	0	0	0	0	0	0	0	0
Hebei	0	1	3	5	3	2	3	0	17
Shanxi	0	1	1	0	0	0	0	0	2
Neimeng	2	2	0	1	0	2	1	1	9
Liaoning	0	1	0	1	0	1	2	0	5
Jilin	3	3	1	3	3	3	3	3	22
Heilongjiang	2	3	2	4	4	4	3	1	23
Shanghai	0	0	0	0	0	0	0	0	0
Jiangshu	6	5	5	1	3	5	3	2	30
Zhejiang	0	1	2	1	0	1	0	0	5
Anhui	0	5	4	4	3	4	4	1	25
Fujian	1	0	0	1	3	0	2	1	8
Jiangxi	1	5	4	2	0	4	3	2	21
Shandong	6	5	5	5	3	6	5	3	38
Henan	2	2	2	3	3	3	1	0	16
Hubei	2	5	4	6	6	16	12	11	62
Hunan	3	2	2	2	3	5	4	6	27
Guangdong	4	3	2	2	2	2	1	0	16
Guangxi	0	1	1	0	1	0	0	0	3
Hainan	0	1	1	0	0	0	0	0	2
Chongqing	0	1	1	0	0	0	0	0	2
Sichuan	0	4	3	6	11	5	0	1	30
Guizhou	0	0	2	0	1	5	2	2	12
Yunnan	2	3	3	2	2	2	1	0	15
Xizhang	0	0	0	1	0	1	1	0	3
Shanxi	0	2	2	2	3	6	2	1	18
Gansu	1	3	3	3	3	2	3	1	19
Qinghai	1	2	1	1	2	3	2	0	12
Ningxia	2	0	0	1	0	1	0	0	4
Xinjiang	0	0	2	2	2	1	2	0	9
YRFAC	1	0	0	0	1	1	0	0	3
MOA (Bohai Sea and Yellow Sea)	1	0	0	0	0	0	0	0	1
MOA (the East China Sea)	0	1	1	0	0	1	0	0	3
MOA (the South China Sea)	0	1	0	1	0	0	0	0	2
Total	40	63	57	60	62	86	60	36	464

Table 7.5.5 Distribution of aquatic genetic resources reserves in different river basins and seas.

River Basin/Sea	Numbers
Songhuajiang River Basin	45
Liao River Basin	7
Hai River Basin	17
Yellow River Basin	47
Huai River Basin	33
Yangtze River Basin	193
Pearl River Basin	22
South-east Rivers Basin	22
South-west Rivers Basin	12
North-West Rivers Basin	14
Bohai Sea	17
Yellow Sea	23
the East China Sea	5
the South China sea	7
Total	464

Table 7.5.6 Categories of the Protected Species in NAGRRs.

Category	Fish	Crustaceans	Shellfish	Others	Aquatic Plants
Number	348	21	31	39	14
Percentage	76.8	4.6	6.8	8.6	3.1

protected in 347 NAGRRs (74.7 percent of the total number of NAGRRs). Table 7.5.9 lists the conservation areas which contain the top three main protected crustaceans, shellfish, the other aquatic animals and aquatic plants in each region, the numbers respectively are 43, 18, 25 and 6, in turn accounting for of 9.3 percent, 3.9 percent, 5.4 percent and 1.3 percent in total.

Most of the top ten main protected fish are cyprinid fish, which are protected in 177 NAGRRs (38.1 percent of the total NAGRRs). These NAGRRs are distributed all over China. There are 76 NAGRRs that protect the shorthead catfish (*Pelteobagrus eupogon*), which is the top most protected species, accounting for 16.4 percent of the total NAGRRs. The NAGRRs that protect the shorthead catfish are distributed across most of China, except the western provinces, for example Xinjiang, Qinghai and Gansu.

The 62 NAGRRs in Hubei province contain all ten top main protected fish, two main protected crustaceans, one main protected shellfish, and one main protected aquatic plant. Dozens of NAGRRs in other provinces protect nine top main protected fishes, they are 30 in Jiangsu, 21 in Jiangxi, 16 in Henan, and 16 in Hunan. Some NAGRRs in Hebei province contain five main protected crustaceans, and Jiangsu province contains four.

Most of the NAGRRs in which the main protected shellfish are protected are located in the coastal zone and inland large fishery provinces, such as Liaoning, Shandong, Jiangsu and Hubei, Hunan, Jiangxi, and Anhui. The NAGRRs in which the other aquatic animal and aquatic plants are protected are located in three regions: first, some coastal zone provinces, such as Hebei, Liaoning, Shandong, containing mainly the *Apostichopus japonicas* (sea cucumber); second, some provinces located in the middle and lower reaches of the Yangtze

Table 7.5.7 The Number of Protected Species in Different Administrative Regions.

Administrative Region	Number protected	Administrative Region	Number protected
Beijing		Hainan	13
Tianjin		Chongqing	5
Hebei	28	Sichuan	36
Shanxi	4	Guizhou	21
Inner Mongolia	13	Yunnan	44
Liaoning	14	Tibet	8
Jilin	39	Shaanxi	23
Heilongjiang	36	Gansu	42
Shanghai		Qinghai	30
Jiangsu	50	Ningxia	4
Zhejiang	7	Xinjiang	16
Anhui	39	Henan, Shaanxi, Shanxi*	10
Fujian	13	Henan, Shandong	10
Jiangxi	50	Gansu, Sichuan, Qinghai	7
Shandong	55	Yangtze River between Anqing and Shanghai	1
Henan	29	Bohai Sea	12
Hubei	71	Yellow Sea	8
Hunan	68	East Sea	9
Guangdong	36	South Sea	6
Guangxi	17		

Note: The NAGRR located over Henan, Shanxi and Shaanxi three provinces, similarly hereinafter.

River, contain mainly aquatic plants, such as Hubei, Hunan, Jiangxi, Anhui; third, some provinces located in the rugged hilly areas contain mainly the other main protected aquatic animals (Chinese giant salamander and tortoise), such as in Sichuan, Yunnan, Shaanxi and Gansu.

7.5.4 Regulations of National Aquatic Genetic Resource Reserves

The Ministry of Agriculture of China promulgated the regulation for the supervision and administration of Aquatic Genetic Resource Reserves in 2011 (Ministry of Agriculture, PRC 2011a). This regulation of Aquatic Genetic Resource Reserves was based on the Law of Fishery, and other relevant regulations of China.

In this regulation, Aquatic Genetic Resource Reserves were defined as the protected areas which are the habitats of high-economic and genetically valued aquatic living organisms, and they may include waters, mudflats and adjacent island and land territory. Special management and protection measures according to the relevant Chinese Laws will be applied to Aquatic Genetic Resource Reserves, in order to protect the aquatic genetic resources and the habitats thereof.

The Ministry of Agriculture of China is in charge of the supervision and management of Aquatic Genetic Resource Reserves. The local government of county, and/or above county level, will engage in the regular daily obligations of the Aquatic Genetic Resource Reserves within their jurisdiction.

Table 7.5.8 The distribution of the NAGRRs containing the main protected fish species.

Species / Region	Fish									
	Shorthead Catfish (*Pelteobagrusfulvidraco*)	Mandarin Fish (*Sinipercachuatsi*)	Topmouth Culter (*Erythroculterilishaeformis*)	Carp (*Cyprinuscarpio*)	Grass Carp (*Ctenopharyngodonidellus*)	Goldfish (*Carassiusauratus*)	Silver Carp (*Hypophthalmichthysmolitrix*)	Bighead Carp (*Aristichthysnobilis*)	Argus Snakehead fish (*Ophiocephalusargus*)	Catfish (*Siluriformes*)
Total	**76**	**48**	**41**	**34**	**26**	**26**	**25**	**25**	**23**	**23**
Beijing										
Tianjin										
Hebei	5	2		1		3			2	
Shanxi									1	1
Inner Mongolia	1									
Liaoning										
Jilin	2	4	1	2	2	1	2			
Heilongjiang	3	2	2	2	2		2	2		1
Shanghai										
Jiangsu	4	2	2	2	1	3	1	1	4	
Zhejiang			1							
Anhui	2	3	3	2	1		1	1		
Fujian	1									
Jiangxi	6	5	2	2	4	2	3	3		2
Shandong	2	1	2	3	1	1	1	1	2	
Henan	1	1	1	1	1	2	1	1		1
Hubei	14	17	18	2	6	2	5	6	8	3
Hunan	8	2	4	4	4	3	4	5		1
Guangdong	1	1		4	2	2	3	3		2

(*Continued*)

Table 7.5.8 (Continued)

Species / Region	Fish									
	Shorthead Catfish (*Pelteobagrusfulvidraco*)	Mandarin Fish (*Sinipercachuatsi*)	Topmouth Culter (*Erythroculterilishaeformis*)	Carp (*Cyprinuscarpio*)	Grass Carp (*Ctenopharyngodonidellus*)	Goldfish (*Carassiusauratus*)	Silver Carp (*Hypophthalmichthysmolitrix*)	Bighead Carp (*Aristichthysnobilis*)	Argus Snakehead fish (*Ophiocephalusargus*)	Catfish (*Siluriformes*)
Guangxi										
Hainan										
Chongqing					1		1	1		
Sichuan	10	6	4	1		2			1	
Guizhou	7	2								2
Yunnan										
Tibet										
Shaanxi	8			7		3			3	9
Gansu				1	1	2	1	1		
Qinghai										
Ningxia										
Xinjiang										
Henan, Shanxi and Shaanxi	1								1	
Henan and Shandong			1						1	1

Table 7.5.9 The distribution of the NAGRRs containing the main protected crustacean, shellfish, other main protected aquatic animal and aquatic plants.

Species / Region	Crustacean					Shellfish			The other main protected aquatic animal			Aquatic plant		
	Oriental River Prawn *(Macrobrachiumnipponense)*	Chinese White Prawn *(Leander modestus)*	Red Tail Prawn *(Penaeuspenicillatus)*	Chinese Mitten Crab *(Eriocheirsinensis)*	Swimming Crab *(Portunustrituberculatus)*	Disk Abalone *(Haliotis discus hannai)*	Asian Clam *(Corbiculafluminea)*	Trigonioides *(Hyriopsiscumingii)*	StichopusJaponicus *(Apostichopusjaponicus)*	Chinese Giant salamander *(Andriasdavidianus)*	Tortoise *(Chinemysreevesii)*	Bulrush *(Phragmitesaustralis)*	Lotus *(Nelumbonucifera)*	Water Shield *(Braseniaschreberi)*
Total	**26**	**5**	**2**	**8**	**2**	**7**	**6**	**5**	**10**	**9**	**6**	**3**	**2**	**1**
Beijing														
Tianjin														
Hebei	5	1		1	1				1					
Shanxi														
Inner Mongolia														
Liaoning				1		4			4					
Jilin														
Heilongjiang														
Shanghai														
Jiangsu	7	3		5			4	1						
Zhejiang	1									1				
Anhui	4	1					1				1	1	1	
Fujian														
Jiangxi							1	1			1			
Shandong	4					3			5					
Henan				1										
Hubei	2							1					1	1
Hunan	2							2			2			

(*Continued*)

Table 7.5.9 (Continued)

Species / Region	Crustacean					Shellfish			The other main protected aquatic animal			Aquatic plant		
	Oriental River Prawn (*Macrobrachiumnipponense*)	Chinese White Prawn (*Leander modestus*)	Red Tail Prawn (*Penaeuspenicillatus*)	Chinese Mitten Crab (*Eriocheirsinensis*)	Swimming Crab (*Portunustrituberculatus*)	Disk Abalone (*Haliotis discus hannai*)	Asian Clam (*Corbiculafluminea*)	Trigonioides (*Hyriopsiscumingii*)	StichopusJaponicus (*Apostichopusjaponicus*)	Chinese Giant salamander (*Andriasdavidianus*)	Tortoise (*Chinemysreevesii*)	Bulrush (*Phragmitesaustralis*)	Lotus (*Nelumbonucifera*)	Water Shield (*Braseniaschreberi*)
Guangdong			1								1			
Guangxi														
Hainan														
Chongqing														
Sichuan										4	1			
Guizhou														
Yunnan										1				
Tibet														
Shaanxi	1									2		1		
Gansu										1		1		
Qinghai														
Ningxia														
Xinjiang														
Bohai sea					1									
south China sea			1											

The provincial-level fishery administrative agencies implement the action plans for the Aquatic Genetic Resource Reserves within their jurisdiction, and promote the establishment of the Aquatic Genetic Resource Reserves according to the national development plan.

All levels of the fishery administrative agencies shall actively find support, including financial assistance, from different levels of government, and improve the daily supervision and management of the Aquatic Genetic Resource Reserves.

All organizations and individuals have the responsibility to report illegal damage and/or occupation of the Aquatic Genetic Resource Reserves to the to the relevant fishery administrative authorities in the province or the Aquatic Genetic Resource Reserves administrative agencies. The fishery administrative authorities or the Aquatic Genetic Resource Reserves administrative agencies should take necessary actions, including investigation.

The Aquatic Genetic Resource Reserves are classified as national level and provincial level reserves, and both of these can demarcate the core functional zones and experimental zones according to the status of the aquatic resource, environment, and purpose of the protection.

Expert committees with backgrounds in fishery, environmental protection, hydrology, transportation, oceanology and bio-protection will evaluate the necessity of newly established Aquatic Genetic Resource Reserves. The name, location, extension, and main protected species of newly established Aquatic Genetic Resource Reserves should be publicized.

The established Aquatic Genetic Resource Reserves will be supervised and managed by the fishery administrative agency of the local county where the reserve is located, and the agency should assign a special reserve management organization, necessary staff and equipment, to carry out regular daily management.

The duty of the reserve management organization is mainly to implement the specific management routines of the reserve; maintain the protection establishments; carry out investigation, resource restoration and habitat rehabilitation; rescue injured aquatic animals; publicize the importance of aquatic genetic resource protection; carry out law enforcement, and report the overall situation to the fishery administrative agencies.

The Ministry of Agriculture and the provincial fishery administrative agencies should take part in the environment impact assessment of construction projects which involve Aquatic Genetic Resource Reserves, organize experts to examine the thematic impact report on Aquatic Genetic Resource Reserves, and provide an official observation to the project owner, based on the examination of expert groups. The project owner should adopt this official comment as one part of the environment impact assessment report, and take necessary actions.

Any organization or individuals who intend to conduct aquatic living resource surveys, scientific research, education and training, visiting and site-seeing, or photographing, should abide by the relevant laws and regulations enacted by the specific Aquatic Genetic Resource Reserve, and make sure that these activities are not harmful to the aquatic living resource and the habitat.

Reclaiming of lakes or seas for land is prohibited within Aquatic Genetic Resource Reserves; construction of waste water outlets into Aquatic Genetic Resource Reserves is also prohibited, and reconstructing and expending the wastewater outlets must ensure that the water in the reserves is not being polluted.

Withdrawal or adjustment of Aquatic Genetic Resource Reserve must be gone through with the Expert Committee, and approved by the national or provincial fishery administrative agencies.

Any organization or individuals, found to have violated the regulation of Aquatic Genetic Resource Reserves, and results in damage to the aquatic living resource(s) and habitats, will be punished by the fishery administrative or fishery law enforcement agency, or the organization of Aquatic Genetic Resource Reserves according to Chinese laws and regulations.

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Section 8

Development Strategies and Prospects

8.1

Development Strategies and Prospects – Driving Forces and Sustainable Development of Chinese Aquaculture

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8.1.1 Introduction

China has been responsible for most of the growth in food fish availability worldwide during the last twenty or so years, owing to the dramatic expansion in its aquaculture (FAO 2014a). Since China's opening up to the world in the early 1980s, Chinese aquaculture has undergone unprecedented development due to increased market demand and investment. As a result of thirty year's expansion and growth, China has become the top aquaculture producer in the world, and a country whose aquaculture production exceeds its capture fisheries (Figure 8.1.1). In 2014, total production of Chinese aquatic products was slightly over 64.6 million tonnes, of which 47.5 million tonnes came from aquaculture, and these were about one third and two thirds of the world total fisheries production and total aquaculture production, respectively. Freshwater aquaculture and mariculture production in China in 2014 were 29 360 000 tonnes and 18 130 000 tonnes, respectively. At the same time, capture fisheries production in China was only 17 100 000 tonnes, and the percentage of capture fisheries and aquaculture products in total fishery products was 26.5 percent and 73.5 percent, respectively. Chinese capture fisheries was less than one fifth of the world's total capture fisheries in 2014, of which 86.6 percent was marine (14 800 000 tonnes), and 13.4 percent was freshwater products (2 300 000 tonnes) (FAO 2014b).

However, more than 60 years ago, in the early 1950s, the total fishery production in China was only slightly over 1 000 000 tonnes, of which about 100 000 tonnes was from aquaculture, and accounted for only eight percent of the total fisheries products. The development of fisheries in China can be divided into two periods: slow development before 1985, and rapid development after 1985. During the first period, freshwater and marine aquaculture production grew at annual rates of 6.7 percent and 6.5 percent, respectively, as freshwater aquaculture rose from 270 000 tonnes in 1954 to 2 380 000 tonnes in 1985, and mariculture rose from 150 000 tonnes in 1954 to 1.25 million tonnes in 1985. Both underwent rapid expansion over the last thirty or so years, at an annual growth rate of 7.9 percent and 9.6 percent, respectively (Figures 8.1.2 and 8.1.3). Consequently, the growth of total fisheries products rose by 3.6 percent prior to 1985, to 6.7 percent after 1985. This was in spite of the rapid growth in aquaculture but impaired by the relatively slow growth of capture fisheries at around 3 percent. The proportion of freshwater and marine aquaculture in China rose from 29.7 percent and 15.5 percent in 1985 to 45.4 percent and 28.1 percent in 2014. The rapid growth of Chinese aquaculture is also reflected in the proportion of Chinese aquaculture products in the global total, which rose from 31.9 percent in 1985 to 46.7 percent in 2013.

In the vast areas of inland China, the volume of freshwater aquaculture (29 400 000 tonnes) was almost 13 times of capture fisheries in 2014, much higher than the ratio of marine sector (1.42:1) (Figure 8.1.2).

Aquaculture in China: Success Stories and Modern Trends, First Edition.
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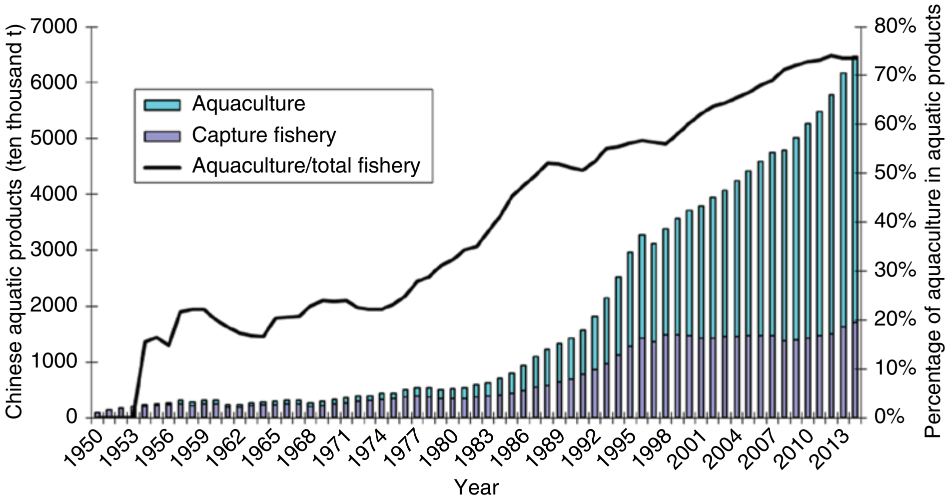

Figure 8.1.1 Trends in the growth of Chinese aquaculture and capture fisheries 1950–2014. *Data source:* China Fishery Statistical Yearbook.

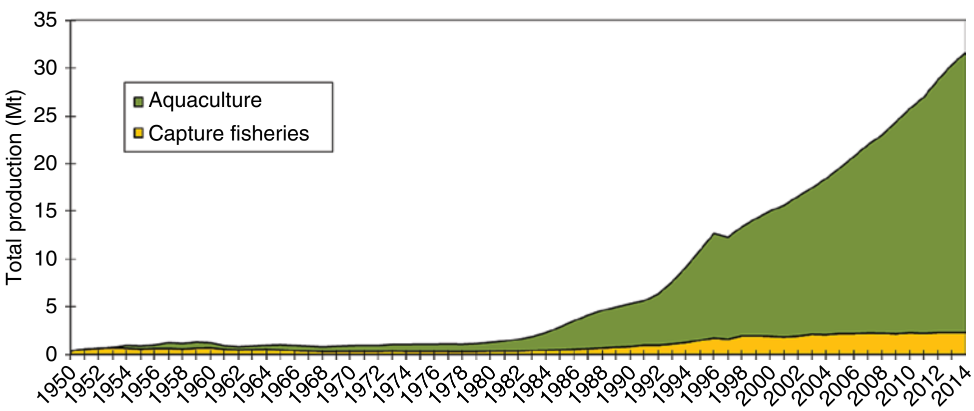

Figure 8.1.2 Trends in the growth of freshwater aquaculture and capture fisheries 1950–2014. *Data source:* China Fishery Statistical Yearbook.

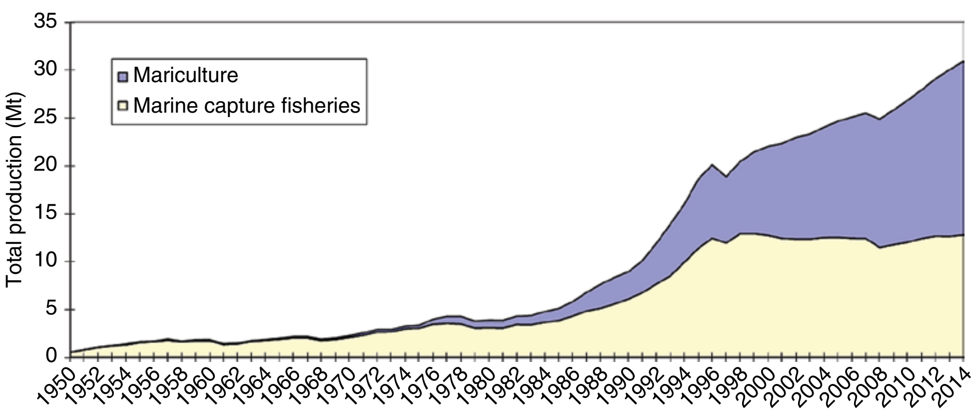

Figure 8.1.3 Trends in the growth of mariculture and capture fisheries 1950–2014. *Data* sources: China Fishery Statistical Yearbook.

Inland populations rely mainly on freshwater aquaculture for aquatic food, particularly finfish species of the carp family, which make up over 60 percent of China freshwater aquaculture production (Wang *et al*. 2015). Since fish of the carp family are mainly filter-feeders and/or omnivorous, they are less costly and easier to raise. In 2014, freshwater aquaculture exceeded mariculture in production by 11 230 000 tonnes, and the predominance of the former sector will probably be maintained throughout the next decades, as freshwater fishes such as carp will remain an important food for the inland populations.

For decades, Chinese aquaculture has played a significant role in meeting market demand, increasing fishery worker incomes, and contributing to the export of agricultural commodities. Furthermore, aquaculture has also enhanced the nutrition of the people, and contributed towards ensuring food security for Chinese people. At the same time, China has been evaluating the integration of aquaculture practices in the context of aquatic ecosystem health, particularly examining the best aquaculture structure and practices, and output from an ecosystem services perspectives (including food provision, climate modulation and culture/esthetics). As a result, China has become a world leader in a range of aquaculture practices, in the extension of aquaculture technologies, the number of species cultured, and the scale of the aquaculture industry. With the current global advocacy for Blue Growth (FAO 2014a) and sustainable aquaculture development, Chinese aquaculture will effectively promote the shift in fishery growth modes, transforming it into a new mode of economic growth. It will also help to bring the ecosystem services of aquaculture fully into play.

In the light of this background information two questions arise: how did Chinese aquaculture develop so rapidly and to such a scale to become predominant in global aquaculture, and second, how can this development be maintained sustainably well into the future? To understand these questions, the driving forces behind the rapid development of Chinese aquaculture are analyzed in this Chapter, then the significance and possibility for further development of Chinese aquaculture and its development strategies are discussed. Based on these evaluations, recommendations for guaranteeing the future sustainable development of Chinese aquaculture are proposed.

8.1.2 Major Driving Forces Leading to the Rapid Development of Chinese Aquaculture

The success of aquaculture in China is the collective reflection of favorable national policies, progress in related sciences and technologies, an expanded market and, in particular, complementarity in aquaculture practices, some of which, such as polyculture of Chinese major carps, have been ongoing for millennia, and finally, a dependence on a wide range of cultured species.

8.1.2.1 Correct Decision-Making

From 1957, there was controversy in the then Ministry of Fisheries over whether to prioritize capture fisheries or aquaculture development. In 1959, the then the central government made a decision, "to promote capture fisheries and fish farming simultaneously". By the end of the 1970s, in order to solve the problem of "the difficulty in providing sufficient food fish for the Chinese people", a high-level discussion was conducted again, focusing on the development of either aquaculture or capture fisheries. In 1980, in his "Opinions on formulating long-term development planning", the general designer for China's reform and opening up, Mr. Deng Xiaoping reiterated, "(We) should develop many kinds of sideline industries, including fishery and husbandry. For development of fishery, we need a guideline; to deem aquaculture primary or supplementary? We should deem aquaculture the primary way of fishery, and to use all kinds of water areas and ponds for aquaculture" (CPGC 2006). After lengthy deliberations the Fishery Law of PRC was enacted in 1986, and "aquaculture primary" was legally established and enforced all over China. Although not everyone understood and accepted this policy, it placed a clear emphasis on aquaculture. The logic behind this is the fact that nature alone would not be able to meet the demand for all aquatic food needs, and the realization that the gap in food fish needs would have to be met from aquaculture. The consequent debates and opinions at a high-level of policy making lead to the national policy on the effective promotion of aquaculture.

After China's economic reform and opening-up in the early 1980s, "aquaculture-centered or aquaculture primary" fishery development policy was rapidly confirmed and officially established through a series of regulations and provisions issued by the State Council or the Ministry of Agriculture. Both the domestic and the world markets were open to Chinese aquaculture products, so that trade and capital investment in aquaculture increased. These markets again became stimuli and driving forces for the establishment of the 'aquaculture primary' policy.

8.1.2.2 Progress in Science and Technology

The development of Chinese aquaculture is a result of many factors, among which the contribution of science and technology is estimated to have contributed about 58 percent to its development (Niu 2014), which is higher than that for Chinese agriculture in general (50 percent). As a result of positive national policies, progress was continuously made in aquaculture science and technology, including hatchery techniques for the main cultured, freshwater finfish species, and the successful trial on seaweed artificial breeding in the 1950–1960s, breakthroughs in artificial seed production of scallop in the 1970s, and the success of land-based shrimp artificial reproduction in 1980s (SDCA 2013). Through this, solid foundations and preparations were laid for rapid development in marine and freshwater aquaculture. Advances in science and technology gradually made Chinese aquaculture both reliable and profitable, and were successful in drawing increasing investment from both the public and private sectors.

It is worth noting that major breakthroughs in the artificial propagation and grow-out of a number of aquatic species brought about "aquaculture upsurges" at intervals of roughly once every ten years. From the 1950 onwards, there were, consecutively, upsurges in seaweed culture, bivalve culture, shrimp culture, and fish culture. A total of 156 new genetically improved aquaculture varieties bred by Chinese researchers were officially approved for dissemination during 1996–2014; these include 76 selectively bred varieties, 45 crossbred varieties, five varieties bred using other biotechnologies, and 30 introduced species. The speed of artificial propagation in aquaculture has accelerated during the last decade. During 1996–2005, 34 new varieties (including 28 freshwater species and six marine species) were bred, and 27 species were introduced from abroad; during 2006–2014, 92 new varieties (including 38 freshwater species and 54 marine species) were bred, and only three species were introduced from abroad (NCCAV 2015). At the same time, major innovations were also made in disease control and the use of prophylactics in aquaculture, in aquaculture technology and facilities, feed production and aquatic food processing, and remediation and conservation of fishery resource. It is important to note that, quite a number of aquaculture modes or practices have been developed and established in China, to fit into different environmental conditions, or meet different social and/or ecological needs.

Farming practices are an important factor in promoting the scientific and technological progress of Chinese aquaculture. Since China adopted a policy of prioritizing aquaculture in the mid 1980s, the sector developed very rapidly. However, in early 1990s, disease outbreaks continued to spread in freshwater and marine aquaculture. These incidents taught a lesson to farmers and managers, and alarmed the researchers. Thereafter, the concept of 'healthy aquaculture' took shape, and became the fundamental policy for present-day aquaculture in China.

In 1994, Chinese scientists introduced from Canada the principles of trophodynamics for studying carrying capacity in aquaculture. In particular, systematic studies were carried out in coastal seas of China, and modes of polyculture and modern integrated multi-trophic aquaculture (IMTA) were explored. These applications were also extended to large-scale and different practices, so that the mode of 'ecological aquaculture' became accepted. In the 2009 Xiangshan Science Conferences (no. 340), it was proposed that an "ecosystem approach for aquaculture is the new direction for basic research on sustainable development of mariculture" (Tang *et al.* 2009). This is when the concept of ecosystem-based management (EBM) was introduced to aquaculture. In a way, the concept of EBM is embodied in the technology of IMTA, which is an ecosystem approach for aquaculture, because it exploits integrated ecosystem services (including food provision, atmospheric modulation and culture services). In 2010, the concept of 'carbon fishery' was proposed (Tang 2010).

It was pointed out that currently about 3 000 000 tonnes of carbon is removed annually from Chinese waters through aquaculture. Its contribution to atmospheric CO_2 reduction is equivalent to afforestation of more than 1 000 000 ha. In 2012, UNEP UN Environment Program) and GEF (Global Environment Facility) recommended China's IMTA to the United Nations Conference on Environment and Development (UNCED) Rio+20. It was pointed out that the pilot IMTA project had proved to be highly energy efficient, and optimized the carrying capacity of coastal bays while improving water quality, increasing protein yields, and through carbon capture, contributing to mitigation of the effects of climate change (Sherman and McGovern 2012). In the context of such a development, it is natural and logical to put forward an action plan for developing environmentally friendly aquaculture, which also meets the new requirements of green, low carbon, and sustainable social-economic development.

Scientific and technological progress in Chinese aquaculture has begun to focus on the improvement of theory, so that development has a better scientific basis. In recent years, a series of monographs have been published, and many research results published in international, peer-reviewed, science journals, including work on stress adaptation of oysters and shell formation (Zhang *et al.* 2012), the genome sequence of flatfish revealing ZW sex chromosome evolution and adaptation to a benthic lifestyle (Chen *et al.* 2014), genome sequence and genetic diversity of the common carp (Xu *et al.* 2014), epigenetic modification and inheritance in sex reversal of fish (Shao *et al.* 2014), and genome-explained evolution and vegetarian adaptation in grass carp (Wang *et al.* 2015).

8.1.2.3 Importance of Cultured Species and Their Structure

The structure of Chinese aquaculture is remarkable and unique in the world in both its species composition and the ratio of their outputs. Most of the species cultured do not rely on artificial feed or feeding; these species feed low in the trophic chain, and depend on natural phyto- and zooplankton production, and in some cases detritus. Carnivorous and omnivorous finfish and shrimp have food conversion ratios (FCRs) between 1–1.2/1, which is much lower than that of livestock (2.5–7.0/1). This low trophic aquaculture production not only saves costs, but also requires lower investment, and lower resource consumption; management of these operations is relatively simple and easy to replicate, and as a result, these kinds of aquaculture production practices can be quickly scaled up during the early stages of expansion. From an ecosystem services perspective, low trophic aquaculture equates to more carbon sequestration, and higher eco-service value. The production of non-fed aquaculture species in 2010 was about 59 percent of total aquaculture production in China (SDCA 2013); but the percentage was much higher for mariculture species, which was 87.4 percent (Figure 8.1.4). Only 39.1 percent of Chinese aquaculture products come from fish and crustaceans which rely on fishmeal. The ratio of non-fed aquaculture species in Chinese aquaculture is much higher than the world average of 30 percent. This is why China produces more than 60 percent of aquaculture products in the world, with only 25 percent of global fishmeal production (Han *et al.* 2016).

In 2014, freshwater aquaculture generated 61.8 percent of the total aquaculture products in China, of which 88.7 percent was finfish (Wang *et al.* 2015). More than 82 percent of cultured freshwater finfish in China are filter-feeding, herbivorous or omnivorous fish, which have very low requirement for fishmeal. For example, finfish of the carp family make up 67.6 percent of all cultured freshwater finfish, including silver carp and bighead carp, which are filter-feeders, and grass carp, which feeds on grass, and their feed (including formulated feed) contains almost no fishmeal. In mariculture, non-fed species, including bivalves (72.6 percent) and seaweeds (11.1 percent), account for 83.7 percent of the total production. Specifically, total output of cultured seaweeds and marine bivalves was 15 170 000 tonnes in 2014, while the total production of cultured marine fish and crustaceans was 2 620 000 tonnes (China Fishery Statistical Yearbook 2015). As a result, the ratio of marine non-fed species to fed species was about 85:15 (Figure 8.1.5).

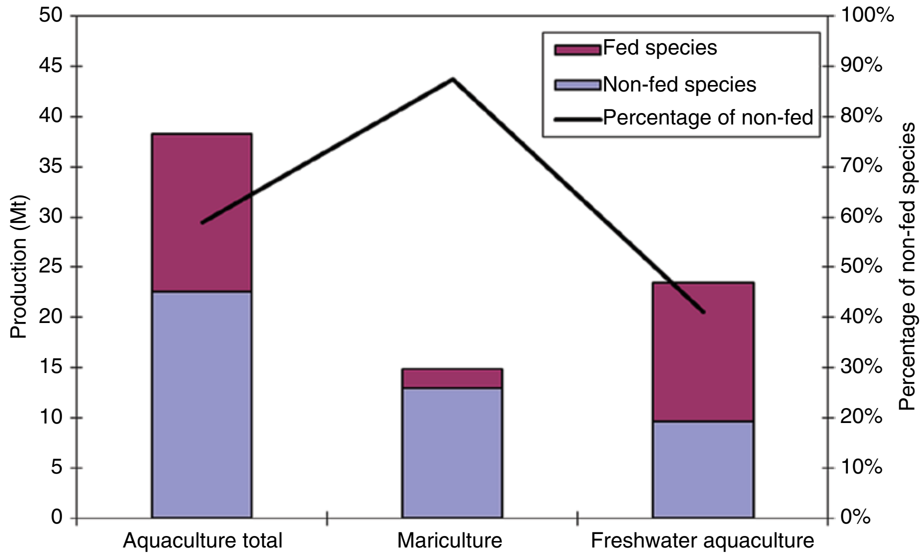

Figure 8.1.4 Aquaculture output of non-fed and fed species in 2010. *Data source:* SDCA (2013.)

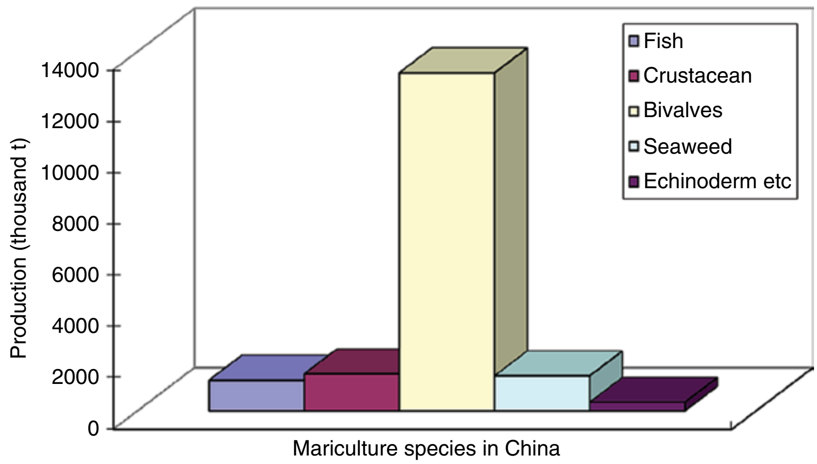

Figure 8.1.5 Cultured marine species groups and production in 2014. *Data source:* China Fishery Statistical Yearbook (2015.)

The tradition of 'low trophic aquaculture' has in fact been practiced in China for thousands of years, along with the techniques of maintaining fish on silkworm fields or in orchards. This mode of low-trophic aquaculture was renamed IMTA by Canadian researchers in 2004, and it is well-known for its combination of species from multi-trophic levels, as well as its relatively low cost and high productivity (Chopin *et al.* 2010). It is remarkable that, even now most of the species used in Chinese aquaculture continue to be non-fed species (Figures 8.1.4 and 8.1.5), and for many years, their aquaculture production was about six times that of fed species. It is estimated that the mean trophic level (TL) of Chinese aquaculture is around 2.2 (Han *et al.* 2015, 2016), which is very close to the ideal level of 2.0 (Olsen 2011). In an ecosystem pyramid, if a species has a TL of 2.0 and production of 100, when its TL rises to 3 then its production will be only 10. This characteristic indicates that Chinese aquaculture has a high-output production structure.

Studies on trophodynamics have shown that there is a negative relationship between ecological conversion efficiency and trophic level at the higher trophic levels (Tang *et al.* 2007). By integrating low trophic-level

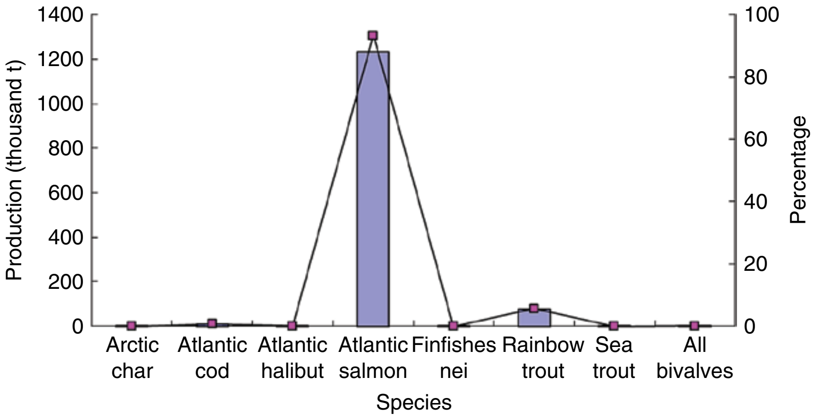

Figure 8.1.6 Production of aquaculture species in Norway 2012. *Data source:* FAO (2014b).

species, IMTA seeks a low-trophic approach for the culture of fed species, so that its general performance y is greatly improved. In this way, IMTA is more efficient economically and ecologically than other modes of aquaculture.

Compared to China, the aquaculture structure of many other countries is generally at higher trophic levels. In Norway, for example, there are about 15 aquaculture species (FAO 2014b), including eight finfish species and several bivalves. However, more than 99 percent of Norwegian aquaculture production is carnivorous finfish, with a TL estimation of over 3.0, while bivalves contribute only about 0.15 percent of the total output, and there is no seaweed aquaculture (Figure 8.1.6).

8.1.3 Significance and Potential Developments in Chinese Aquaculture

It is estimated that when the global population peaks in 2030, the demand for aquatic food in China will increase to about 80 000 000 tonnes, almost 20 million tonnes more than the current output (SDCA 2013). Therefore, the next ten to twenty years will see a continuous rapid growth in Chinese aquaculture, driven by market demand, and facilitated by progress in science and technology. Accompanied by major changes in national economic expansion, this development facilitates will trigger the re-invigoration and growth in the fisheries sector. These changes will go hand in hand with a boost in low-carbon fishery growth, reduce CO_2 emissions, and alleviate eutrophication, and produce aquatic food of high quality at greater quantities. All these facets will contribute to ensure national food security, and promote the progress of ecosystem-based fisheries science and technology in China

8.1.3.1 Significance of Aquaculture Development in China

8.1.3.1.1 Meet Market Demands and Guarantee Food Security

Chinese aquaculture has played an important role in supplying domestic and international markets with a broad array of fish products. Export of Chinese aquatic products has been the highest in value among major Chinese agriculture export commodities for 12 successive years, and greater in volume than that of any other country for ten successive years. Aquatic food has long been an ordinary part of the diet of the Chinese people; in 2010, the annual fish consumption was 35.1 kg for the Chinese, while annual per capita fish supply in the rest of the world was about 15.4 kg (FAO 2014a). The per capita availability of aquatic product in China has risen rapidly in the last few years, reaching 47.2 kg in 2014 (China Fishery Statistical Yearbook 2015).

Aquaculture has generated high-quality proteins and vital nutrition for Chinese people; aquatic products account for about 20 percent of Chinese intake of animal protein. The consumption of aquatic food has significantly improved Chinese dietary intake, and guaranteed food security. As such, the experience of Chinese aquaculture has been applauded by FAO as a success story, which can be replicated in other developing countries worldwide.

Aquaculture also helps to increase employment and maintain social equity. The continuous growth of aquaculture during the last 40 years has brought about rapid expansion of related industries, and increased of income of fishery workers. In 2013, the total employment of the fishery industry was 14 400 000, of which more than 5 00 000 worked in aquaculture and 6 500 000 worked in related industries or employed part-time. The average annual net income of a Chinese fishery worker also rose rapidly from 626 RMB in 1985, to 14 426 RMB (6 RMB = 1 US$) in 2014 (China Fishery Statistical Yearbook 2015).

8.1.3.1.2 Promote Low-Carbon and Blue Growth in Food Production

From an ecological perspective, Chinese aquaculture has brought about a transformation of growth mode and industry structure of fisheries, not only in China but also globally. Because of its low trophic-oriented species usage, Chinese aquaculture incorporates a significant carbon sink function, and as such it has played a distinct role in reducing CO_2 emission and ameliorating eutrophication.

These new perspectives bring about fresh hope for Chinese aquaculture. At the beginning of this century, there were reports lamenting the unsustainability of modern fisheries (Pauly *et al.* 1998; Watson and Pauly 2001), and declaring that aquaculture should not be a solution for the problem of degradation of world capture fisheries (Pauly and Alder 2005). However, just like capture fisheries, aquaculture is a source of both health and wealth, providing high employment and livelihoods for hundreds of millions of people (FAO 2014a). World food fish aquaculture production was 70 500 000 tonnes in 2013, with production of farmed aquatic plants at 26 100 000 tonnes; and China alone produced 43 500 000 tonnes of food fish and 13 500 000 tonnes of aquatic algae (FAO 2014a). Chinese experience in aquaculture has stood the test of time, has provided a template that can be copied elsewhere in the world, and has won wide acknowledgement and attention. FAO has been recommending Chinese experience, and has been promoting it in developing countries, especially in South-east Asia (FAO 2012).

Besides food provision, aquaculture obviously has eco-service functions. Studies on the biogecochemical cycle in mariculture systems have revealed that, shellfish and seaweed mariculture in China has increased atmospheric CO_2 absorption by coastal ecosystems. It was estimated that on average 3.79±0.37 million tonnes C yr^{-1} was utilized by these organisms, and 1.20±0.11 million tonnes C yr^{-1} were removed from coastal ecosystems by harvest of these products during 1999–2008 (Tang *et al.* 2011). A physiological study on scallops provided evidence on their carbon sequestration. One scallop (*Chlamys farreri*) may absorb 10 170 g carbon (C) during a 500-day farming cycle, at the same time, it may release 3110 g C by respiration and calcification, and deposit 3985 g C via feces and excretion. Finally, 3075 g C will be removed by the scallop at harvest (Figure 8.1.7). These findings indicate that cultivated shellfish and seaweeds have become a "removable carbon sink", which has played an important role in carbon sequestration. If this mode of aquaculture is extended globally, it will surely improve the coastal ecosystems' capacity to absorb atmospheric CO_2.

Chinese aquaculture of bivalves and seaweeds removed 1 380 000 tonnes C from seawater in 2010, while filter-feeding fish and other non-fed freshwater aquaculture species removed 1 300 000 tonnes C from inland waters (Xie *et al.* 2013). If we sum up the CO_2 reduction of the two components, then it equals to an annual forestation of 1 000 000 ha. Especially in China, where IMTA is widely practiced, both mariculture and freshwater aquaculture have increased the carbon sink function of aquatic ecosystems. Recognition of the contribution of Chinese aquaculture has provided further motivation for industry development. Driven by national policies on ecosystem conservation enacted in the last few years, the aquaculture sector is now paying more attention to the environment, and efforts are being made to develop carbon sink fishery under this premise.

8.1.3.2 Future Aquaculture Developments in China

Consumer demand is the key driving force for aquaculture development in China. As the Chinese population is set to peak in 2030, the demand for aquatic products until then will increase by a further 20 000 000 tonnes,

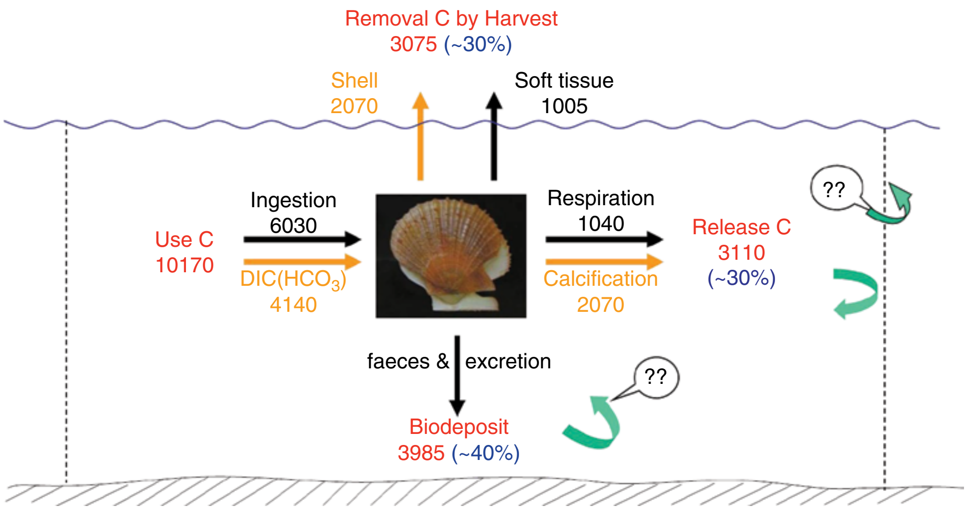

Figure 8.1.7 Carbon budget of scallop *Chlamys farreri* in a culture system during a farming cycle (unit: mg C/ind./500 days). *Source:* From Tang *et al*. (2013).

which can only be met by aquaculture. In addition to favorable national policies and management systems, further development of Chinese aquaculture will be facilitated by progress in science and technology, the application of new culture practices, and the expansion of marine and freshwater aquaculture areas to include deep sea areas and terrestrial "wasteland", such as saline-alkaline fields.

8.1.4 Development Strategy for Chinese Aquaculture

8.1.4.1 Developmental Philosophy and Goals

Facing a shortage of resources and the need for rapid economic development, a philosophy of "ecological harmony" has evolved in China, which calls for resource-saving and environmentally friendly development. To realize the goals of "eco-harmony", aquaculture development should also be highly energy and resource efficient and sustainable, and embrace principles of high quality, health, and safety, and be eco-friendly.

Aquaculture ecosystems are controlled by multiple factors, leading to complexity and uncertainty in ecosystem changes that are difficult to identify and manage, particularly in China where human impacts on the ecosystem are unprecedentedly high. Facing the impacts of multi-stressors and multi-control mechanisms, the best option is to develop an adaptive strategy by implementing ecosystem-based management (EBM), for which one option is to develop 'carbon-sink fisheries'. Carbon-sink fisheries are the embodiment of green and low-carbon development in fisheries. They are an effective way to realize the three development strategies of aquaculture, namely 'conservation, extension and high-technology'; they are also a reliable approach to achieving 'high-efficiency, high-quality, eco-friendly, health and safety'. Carbon-sink fisheries better reflect the two functions of fisheries, food provision and ecosystem services, and fulfill multiple purposes.

The two main developmental strategies for carbon-sink fisheries are: to develop resource-conservation-based capture fisheries, and to develop environmentally friendly aquaculture (Tang 2014). The main measures for developing resource-conservation-based capture fisheries are seasonal fishing closures, and reduced fishing efforts. Since 1995, China has initiated steps towards natural fishery resource recovery by mandating 60–90 day closures on fishing in the Bohai Sea, Yellow Sea, East China Sea and South China Sea during the summer months (MOA 2009). Meanwhile, the number of fishing boats has been actively reduced by 30 percent in the last decade. Great efforts were also made to promote stock enhancement programs in many waters. The experimental release of penaeid shrimps in the Bohai Sea, the north Yellow Sea and the southern waters off the Shandong Peninsula had been carried out for many years since 1984 (Deng 1983; Ye *et al.* 1999). Then in 2006, the State Council promulgated a program of action on the conservation of living aquatic resources of China. This program provided guidance for the conservation of living aquatic resources. Now, stock enhancement has become a public activity for marine fishery resource conservation and management, and about 158.35 billion seed of several commercially important aquatic species were released in Chinese coastal waters from 2011 to 2015, with a total investment of nearly 5 billion RMB (China Fishery News 2015). Consequent to the release of penaeid shrimps in north Yellow Sea and Bohai Sea, the capture fishery yield of Liaoning Province has resulted in remarkable economic benefits for the local fishers with an input-output ratio of 1:6.5–1:9.2 (China Fishery News 2015). However, recovery of biological resources is a slow and complex process, especially for those migrant species for which the result of stock enhancement is difficult to evaluate, and the development of resource-conservation-based capture fisheries will be a long-term and an arduous task.

To develop environmentally friendly aquaculture, innovations in science and technology should be continued, by optimizing aquaculture practices such as IMTA (Figure 8.1.8). IMTA is an adaptive, efficient, and sustainable way to respond to multiple stressors for coastal ocean ecosystems. It not only generates more output of a diverse range of products, but also directly or indirectly sequesters atmospheric CO_2 and nutrients, which may help to increase the social acceptability of aquaculture systems. IMTA is practiced in China in different combinations. For example, in Sanggou Bay, north-eastern China, there are long-line culture of finfish, abalone, bivalves, and seaweed, and IMTA of bottom culture of abalone, sea cucumber, clam, and seaweed. In general, the value of food provision service and climate regulating service provided by IMTA is much higher than that of monoculture (Table 8.1.1).

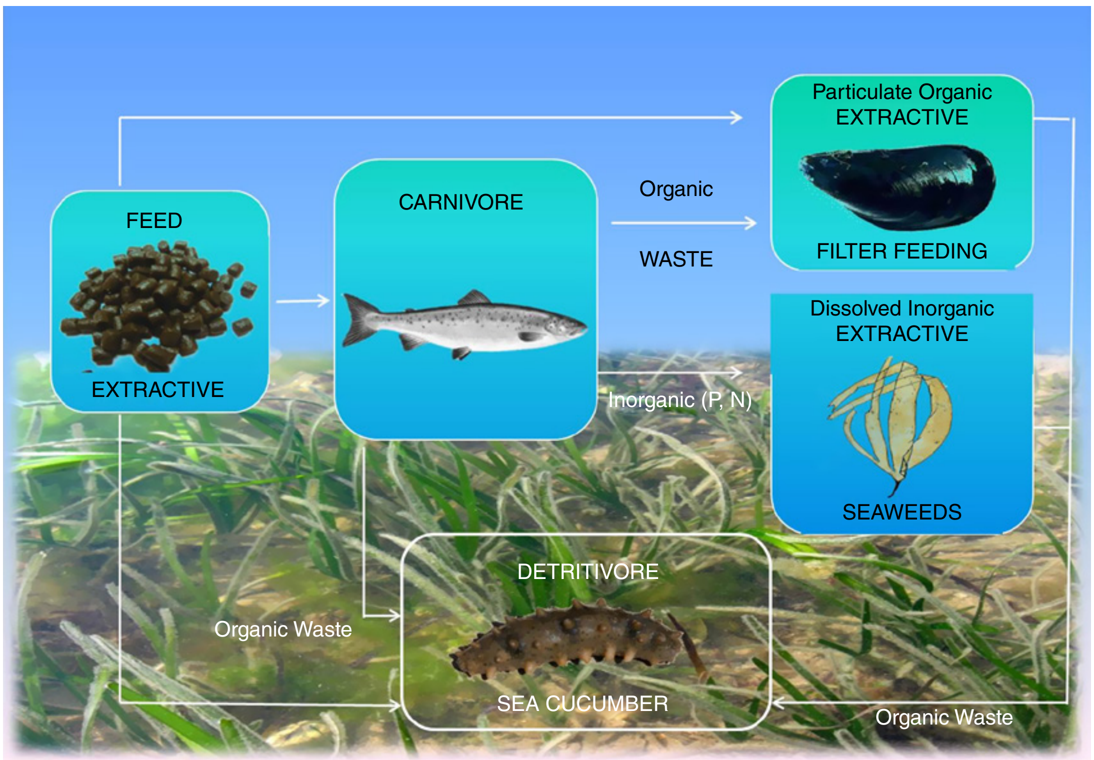

Figure 8.1.8 Structure of an inshore IMTA system. *Source:* From Fang *et al.* (2009).

Table 8.1.1 Ecosystem services of different types of mariculture in Sanggou Bay, northeastern China.

Mariculture practice	Value of food provision (RMB/ha/yr)	Value of climate regulation (RMB/ha/yr)
Kelp monoculture	49 219	4859
Abalone monoculture	235 409	8215
IMTA of abalone and kelp	325 553	13 591
IMTA of abalone, sea cucumber, and kelp	483 918	13 833

Source: Adapted from Liu *et al.* (2013).

8.1.4.2 Strategic Countermeasures and Development Modes

To achieve sustainable Blue Growth in aquaculture, China needs to pursue a new round of modernization through innovation, and application of high-tech and resource-conservation measures (Moffitt and Cajas-Cano 2014). The concept of conservation, technology intensiveness, and eco-friendly growth has been widely accepted in recent years, creating an impetus for further growth of aquaculture. During this advancement in technology, traditional aquaculture modes and/or practices have to be upgraded in terms of standardization and production scales, and mechanization and automation techniques will need to be widely extended, so that the ratio of output to input is raised significantly. In this context, new aquaculture modes such as reinvigorated IMTA, recirculating aquaculture systems (RAS), etc. will have to be extended rapidly across China.

Resource conservation is the foundation to sustainable aquaculture development. Germplasm is the basis of this and is the key prerequisite for aquaculture sustainability; at the same time, ample space and clean water are indispensable for aquaculture success. Blue Growth of aquaculture also relies on the continuous expansion of the range of species cultured, of culture mode and practices, and scales of production. This multi-dimensional expansion should nonetheless center around high-efficiency, high-quality, eco-friendly, and health and safety practices, so that aquaculture in China will move from a quantity-oriented approach and towards quality-oriented, responsible and ecosystem-based development.

High-technology is a driving force for aquaculture growth. High-tech plays important roles in both modernization and upgrade of traditional aquaculture operations, and nurtures strategic new industries or modes of aquaculture, such as the hatchery industry, land-based industrialized aquaculture, deep-sea aquaculture, and the culture of raw materials for biofuel. High-tech will bring new life to aquaculture and stimulate a new round of improvement.

8.1.5 Tasks and Measures for Green and Sustainable Development of Chinese Aquaculture

To realize the strategic goal of 'high-efficiency, high quality, eco-friendly, health and safety', the tasks and relevant safeguard measures are identified for green and sustainable development of Chinese aquaculture (SDCA 2013).

8.1.5.1 Key Tasks

8.1.5.1.1 Accelerate Establishing the Hatchery Sector for Genetically Improved Strains/ Varieties in Modern Aquaculture

Research and development of technology systems for culture and breeding of eugenic aquaculture varieties should be accelerated. Efficient and safe application of heterosis technologies should be integrate and innovated, and other breeding technologies for main aquaculture species should be improved. Cell engineering breeding and other new techniques form the frontier of this subject. For the breeding of new varieties, the genes governing high quality, high production, and stress-resistance traits need to be integrated, so as to produce new breeding materials, with clear target properties and outstanding general properties.

In addition, China will have to improve the development of genetically improved varieties/strains and hatchery systems. Based on advanced facilities and technologies, a series of national, provincial or ministerial level 'Aquaculture Original and Genetically Improved Species Propagation Centers' need to be established, so as to enhance artificial propagation technology, and increase the introduction, testing, demonstration, and geographical spread of genetically improved varieties.

8.1.5.1.2 Plan for the Growth of Modern Aquaculture Practices

China has adopted the code of conduct for responsible fisheries (CPGC 2006) by enacting fisheries policy and legislation that are consistent with the code. Yet more effort is needed to fully implement the code. First, aquaculture planning should be established based on environmental carrying capacity. To meet the requirement of environmentally friendly development of aquaculture, baseline surveys of aquaculture areas are needed. Second, assessment systems for carrying capacity of water bodies need to be set up, and assessments of aquaculture carrying capacity, ecological capacity and environmental carrying capacity undertaken. Third, aquaculture development plans should be made according to the result of these assessments, by implementing regional planning or provincial planning, identifying functions and keystones, and applying modern aquaculture practices adapted for various aquaculture areas, production methods, and species.

Modern aquaculture production modes should be nested within existing aquaculture planning, or be included as major components when a plan is made. One choice is to develop new mariculture modes such as IMTA and RAS. New modes of modern aquaculture are usually constructed in such a way so as to meet the requirements of high-efficiency, high-quality, to be eco-friendly, and facilitate sustainable development.

- IMTA: Based on carrying capacity assessments, this aquaculture system consists of aquaculture species of different trophic levels, thereby significantly improving the energy efficiency of the aquaculture system. Diversified IMTA modes are currently used in China, including three-dimensional IMTA, and bottom-IMTA farming practices/models (SDCA 2013).
- RAS: Using biological purification techniques, RAS as a new mode of aquaculture stands out in terms of resource conservation, efficiency, and productivity. RAS has been extended rapidly in China during the last decade, with diversified system designs, and cultured species (Zhu *et al*. 2012).
- Improved ecological engineering has greatly enlarged the geographical and physical area of aquaculture, with varied modes and functions in accordance with different water depths or bottom topography. These new modes include deep-sea cages, multi-functional artificial reefs, and marine ranches. These have won increasing recognition in China because of their semi-natural products, and reduced competition with other aquaculture modes for resources.

8.1.5.2 The Advancement of Modern Aquaculture Instruments and Facilities

Facilities are important factors influencing aquaculture modes, patterns, species, and production. China will need to extend efforts in improving the standardization and scale of development of traditional aquaculture modes, including inland pond culture and inshore raft culture. It is expected that aquaculture levels of mechanization and automation will need to be increased significantly, and the application of information technology (the 'Internet +' mode), and capacity for aquaculture disaster such as major disease outbreaks, degradation of water quality or extreme weather events, or climate change impact mitigation be tangibly improved in the near future (Tang and Fang 2012). Special emphasis will need to be given to integrated co-culture and healthy culture modes, land-based industrialized aquaculture and RAS, and deep-sea cages or deep-sea culture platforms, so that the scale of these aquaculture modes will be significantly expanded, and major breakthroughs achieved on key technology research and development.

At the same time, unparalleled importance should be attached to the application of energy-saving and ecosystem-conserving technologies in aquaculture. Emphasis should be given to research and development of energy-saving new materials and new instruments, online-monitoring systems, disease diagnosis and control techniques, and aquaculture wastewater reuse techniques.

8.1.5.3 Strengthening Modern Aquaculture and Product Quality Monitoring

Disease and pollution control are closely related to product quality in aquaculture. Continued use of banned antibiotics, albeit at much reduced levels, and other bactericides in China has posed new challenges for the aquaculture industry; alternative methods for disease control or prevention must be developed and put into practice as soon as possible. Both basic research and application are urgently needed for establishing disease prevention and control systems, including pathology and epidemiology, evaluation of ecological factors influencing disease outbreaks, and disease prevention technologies such as vaccines, probiotics, and rapid test methods, all have to be developed. In addition, national and local aquaculture disease reference laboratories, aquatic animal disease monitoring and early warning systems, and a series of aquatic medicine and immunotherapy agent manufacturers should also be established.

Besides aquaculture diseases and drug control, control of aquaculture practices is also important to ensure aquatic food safety. Water-quality control is vital for aquaculture development, especially in China where aquaculture facilities are usually located near agricultural and industrial establishments. The development of healthy aquaculture is heavily dependent on clean air, clean water and high quality feed, thus enforcement of environmental protection laws and regulations is of the first order of importance. Aquatic product quality and traceability systems covering the chain of production are currently being established in China. Such traceability systems rely on rapid information release, and the sharing and management of data. They also call for risk assessment and rapid response for aquatic product safety accidents.

8.1.5.4 Active Promotion of Aquaculture Feeds and Food Processing

Digestible feeds with high utilization rates are important for the modern aquaculture industry. Further studies are recommended on nutritional physiology and metabolism of aquatic animals, so as to provide the basis for formulating low-cost, low-polluting and high-quality aquatic feeds.

Adequate processing and distribution of aquatic products are the basis of a successful and profitable aquaculture industry. Lack of technological sophistication in these sectors has seriously limited the profits of the Chinese aquaculture industry. Improvements in information dissemination are important for the development of trade of aquatic food, along with the establishment of modern logistics, wholesale markets, and electronic trade networks.

8.1.5.5 Scaled Up Production Systems of Modern Aquaculture

For sustainable development of modern Chinese aquaculture, we need to integrate all of the above-mentioned aspects, and scale up production systems in the following ways. First, steady development of production systems for major aquatic products steadily. Second, acceleration of the development of production systems for valuable and rare aquatic products. Third, the expansion of the production systems for export-oriented aquatic products. Fourth, strengthening the development of production systems for recreational and ornamental aquatic products.

8.1.6 Safeguard Measures and Policies

8.1.6.1 Highlighting the Need for Space of Aquaculture, and Maintaining the Output of Aquatic Products

As a fundamental means of food provision, aquaculture needs adequate space and water, the quality of which is most important. Due to rapid social and economic development in China, there is increasing competition for these primary resources. It is recommended that zoning of basic aquaculture areas in China is implemented, just like the “red line” for crop lands, so as to provide the minimum space needs for aquaculture.

At the same time, it is necessary to exploit remaining untapped water resources, such as deep-sea areas, and saline and alkaline inland water bodies, for potential aquaculture development.

8.1.6.2 Establishing Modern Aquaculture Systems and Scaling Up Development, Based on Carrying Capacity Evaluation

There is a need to conduct carrying capacity evaluations for all major aquaculture areas in China, in order to set up a modern aquaculture planning system, and promote in a rational way large-scale development.

Developing ecosystem-based aquaculture is important and should be prioritized. Other priorities should be, further strengthening the building of marine protected areas (MPA) and special protected water areas (SPWA), and progressively establishing self-sustaining aquaculture ecosystems. The transformation of operation modes should be accelerated, and progress guided towards large-scale and sustainable development. By promoting the concept of carbon-sink fisheries, it will be necessary to actively explore popularization of ecosystem-based aquaculture and, to search for new routes for upgrading extensive aquaculture, as well as increase per-unit productivity, so as to fully display the food provision and eco-service functions of aquaculture systems, and create a modern aquaculture production system.

8.1.6.3 Improve the *Milieu* for Aquaculture Science and Technology Innovation

The main measures for improving aquaculture science and technology innovation include: implementing aquaculture innovation programs and consolidating the construction of science and technology platforms and teams; implementing key programs for aquaculture science and technology innovation; emphasizing education and training in fisheries sciences, strengthening the training of specialized technical experts and innovation teams; and, improving the building of aquaculture technology extension systems.

8.1.6.4 Strengthening Modern Aquaculture Governance and Law-Enforcement

A good system of governance and law-enforcement are vital for the development of aquaculture in China. We need to improve the operability and effectiveness of the laws and regulations for Chinese aquaculture; accelerate the renovation of operational rights for water areas, and streamline aquaculture permit systems; speed up the protection of aquaculture water bodies, and establish aquaculture ecosystem compensation mechanisms; and fully promote law enforcement and governance of aquaculture.

8.1.7 Concluding Remarks

Blue Growth is is set to be a significant part of the future of China, and will bring about historic changes in the mode of aquaculture development. In a report to Vice Premier Wang Yang of the State Council (China Fishery News 2015) on new achievements of aquaculture development strategy study in China, Feb. 21, 2014, three points were raised:

- New knowledge: Chinese aquaculture has not only an important food supply function, but also a significant ecological service function;
- New model: Vigorously develop carbon-sink fisheries, and promote the construction of environmentally friendly aquaculture and resource-conservation-based capture fisheries;
- New solutions: A series of measures for safeguarding green and sustainable development of aquaculture have already been confirmed.

Therefore, we believe that Chinese aquaculture will continue to follow the principle of green, low-carbon and sustainable development. China will vigorously implement conservation, expansion and adoption of high technology strategies for the future development of aquaculture, and encouraged a new round of modernization of aquaculture. As such, Chinese aquaculture is destined to make even greater contributions to ensuring the supply of aquatic products, food security and ecological wellbeing, not only for China but the world as a whole.

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Index

Aquaculture in China: Success Stories and Modern Trends, First Edition.
Edited by Jian-Fang Gui, Qisheng Tang, Zhongjie Li, Jiashou Liu, and Sena S. De Silva.

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Figure 2.1.4 Green-grass aquaculture model of grass carp culture, in which the grass replaces the bulk need of compounded pellet feed. *Source:* Photo by Xiaodong Sun.

Figure 2.1.7 Biological floating-beds in grass-carp culture ponds that help in maintaining water quality.

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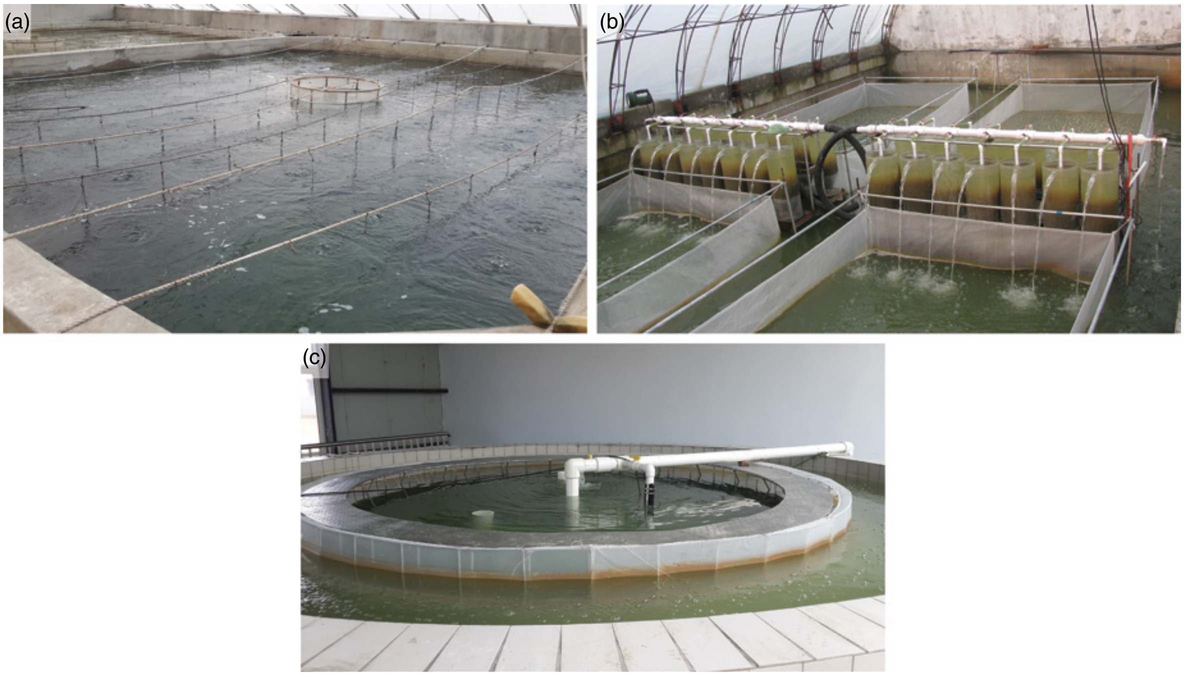

Figure 2.3.5 Hatching containers for common carp eggs. (a) cement tanks; (b) incubation jars; (c) circular incubation pools.

Figure 2.3.11 Removal of snow from overwintering ponds of common carp culture ponds in northern China.

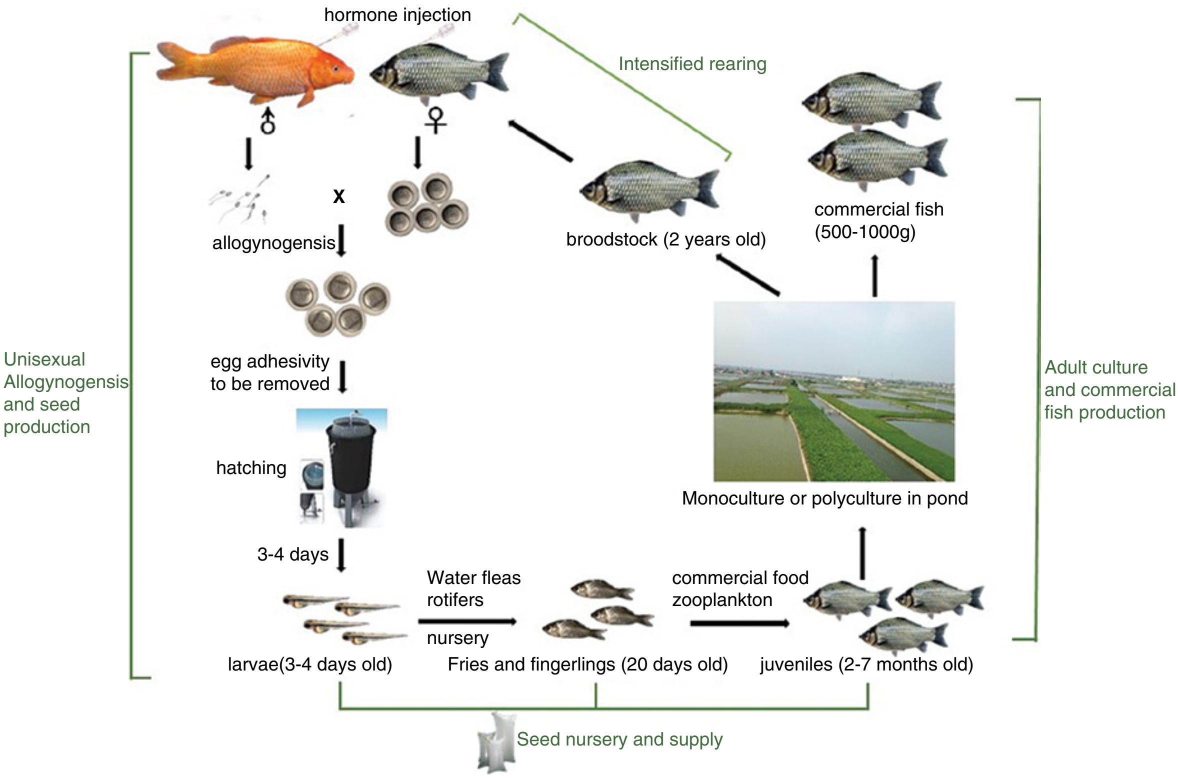

Figure 2.4.4 The allogynogenesis, seed production, and commercial fish culture of allogynogenetic gibel carp "CAS III".

Figure 2.6.6 Large-scale rice crayfish aquaculture in Qianjiang, Hubei Province. *Source:* Photo by Zhonghu Tao.

Figure 2.6.7 Integrated rice field aquaculture with crayfish (right) and the fyke net (left) for harvest in Jianli County, Hubei Province. *Source:* Photo by Qidong Wang.

Figure 3.1.3 Cage-hanging cultivation of freshwater pearl mussels.

Figure 3.2.5 Typical juvenile crab pond in China (Jintan crab farm, Jiangsu Province, China, 2015). Note the macrophyte beds in the ponds.

Figure 3.2.7 The bottom aeration system using micropore used in juvenile rearing ponds of *E. sinensis* (Jintan crab farm, Jiangsu Province, China, 2015).

Figure 3.5.6 Ponds farming of sturgeon of Hubei Yangtze River Aquatic strains testing station.

Figure 3.6.5 Snakehead at a wholesale market in Wuhan, Hubei Province.

Figure 3.8.1 Yellow catfish, *Pelteobagrus fulvidraco. Source:* Photo by Dapeng Li.

Figure 3.9.2 Cage culture in ponds (CCP) of *M. albus*.

Figure 3.9.4 *M. albus* cage culture in plastic greenhouses.

Figure 3.13.4 A pond culture facility (shows the fencing on the far side and structures provided for the turtles to bask in the sun).