Analysis of feeds and fertilizers for sustainable aquaculture development in China

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SUMMARY

Over the past quarter-century, aquaculture in China has recorded an annual average increase in production of 13.5 percent. In 2004, total production was 32.09 million tonnes. The rapid development of the aquaculture sector has significantly stimulated the development of the aquafeed industry in China. In recent years commercially manufactured feed production has been increasing at a rate of about 20 percent annually. Developments in and expansion of the aquafeed industry has further spurred the development of aquaculture in the country. Recent trends in the intensification of aquaculture and species diversification have had significant impacts on the production and use of feeds and fertilizers, which may negatively impact on the sustainable development of the sector in China. For example, in 2004 average yields in freshwater pond culture reached 5.5 tonnes/ha, which is a 60.4 percent over average yields attained in 1994. Similarly, the number of freshwater species groups included in the national production statistics increased from 11 in 1995 to 40 in 2004.

This review summarizes the development of the aquaculture industry in China and its contribution to animal protein food supply, income and employment generation, export earnings and the national economy. Aquaculture currently supplies about 30 percent of animal food to the Chinese people. At the same time, the industry provides some 4.5 million full time and 3–4 million part-time jobs for rural communities. In 2004, the average annual income of aquaculture labour (US$1 100) was nearly double that of the income in agriculture. Aquaculture systems and practices, in particular on-farm feed management strategies and pond management techniques have been introduced to improve feed and fertilizer utilization to enhance fish and shellfish production. Research on the nutritional requirements of culture species and the development of technologies for improved pond and water quality management, the use of water quality promoting agents and improved methods of feed preparation, formulation and presentation have been the major driving forces of the sector in the recent past.

An overview is provided of the various feed ingredients, feeds and fertilizers commonly used in aquaculture in China with particular emphasis on how they are used. It was estimated that about 70 percent of the total aquafeed produced in China is used in freshwater pond culture of grass carp, common carp, crucian carp and tilapia. A significant proportion of pond aquaculture in China is dependent on farm-made feeds containing feedstuffs such as rice bran, rapeseed meal, peanut meal, soybean meal, silkworm pupae either singly or in combination with organic and inorganic fertilizers. Shrimp culture in China is mainly an earthen pond based activity using good quality industrially manufactured compounded feed with FCRs that vary between 1.2 and 1.6:1. In comparison to freshwater fish production, the output from mariculture remains very low. Marine fish culture employs net-cages, land-based tank and earthen pond systems. Marine fish cage culture largely depends on trash fish, while extruded feeds in combination with farm-made feeds are used in land-based tank culture systems and earthen ponds. It was estimated that about 4 million tonnes of trash fish are directly used as aquafeeds annually.

The development of the aquafeed industries were reviewed with emphasis on carps, tilapia, bream, eel and shrimp. In 2004, approximately 8 million tonnes of compound aquafeeds were produced and this accounted for about 8.6 percent of total animal feed production in China. Attention was also given to recent developments in aquafeed quality assurance and control standards.

The major challenges facing the aquaculture industry and its sustainable development in China are availability of and accessibility to aquaculture feed ingredients especially fishmeal, availability of organic fertilizers, economic and social constraints with respect to feed resource use, preparation of farm-made feeds, feed application and use of commercially manufactured pellet feeds by small to medium-scale farmers. In addition and as important are social and environmental impacts caused by improper use of

commercially manufactured aquafeeds. Globally, China is one the largest importers of soybean products and fishmeal. Between 2000 and 2004 soybean and fishmeal imports increased by nearly 100 percent, in comparison with an increase of only 60 percent during the preceding decade. The rapid expansion of the aquafeed industry is the principal reason for this increase in import volumes. If this trend were to continue it would seriously impact on the supply-demand balance of these two feed ingredients in world trade.

The advantages and disadvantages of the increasing dependence on commercial feeds are considered. While there are some distinct advantages the disadvantages are many and these could have serious environmental impacts and negative economic consequences for small to medium-scale farms.

Strategies and approaches to use feed ingredients, feeds and fertilizer more efficiently for sustainable aquaculture development in China are suggested. These include, among others, improving feed formulations and manufacturing technology, sourcing new and alternative feed ingredients, the important role of science and technology to improve nutrient absorption of presently used feedstuffs, particularly protein sources and improving on-farm feed management. Recommendations are provided for the implementation of these strategies, which include government incentives to promote resource efficient aquaculture systems and practices, regulating measures such as tightening the control over aquaculture effluent discharge, discouraging the inefficient use of feed ingredients and stronger support for systematic aquaculture feed and feeding related research and development activities.

1. GENERAL OVERVIEW OF AQUACULTURE PRACTICES AND FARMING SYSTEMS

1.1 History and present status of aquaculture in China

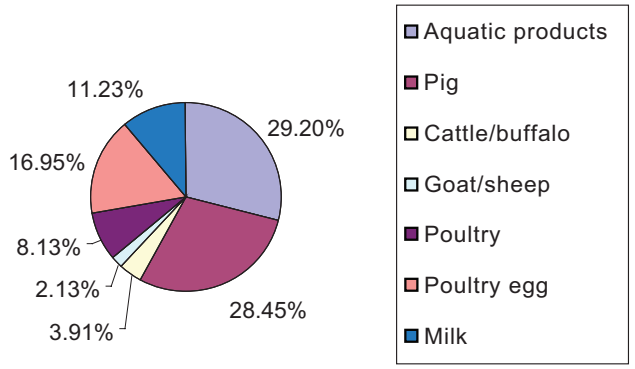
The earliest recorded history of aquaculture in China dates back over 2 500 years to the "The Treatise on Pisciculture"- the first monograph on aquaculture in the world written by Fan Li. Earliest aquaculture practices started with pond culture of common carp and continued for about 1 500 years when this practice was forbidden during the Tang Dynasty some 1 200 years ago. This led to the introduction of integrated polyculture, using four Chinese carps. Extensive fish culture practices in open-waters were initiated during more or less the same period. The traditional aquaculture practices remained virtually unchanged until the 1970s.

The development of aquaculture as a modern industry in China started in the early 1980s, after implementation of economic reforms and the "open-door" policy. The development of the sector in the last quarter of a century was characterised by rapid expansions in scope, production, technological advances, particularly with respect to seed production, diversification of species and farming systems and advances in management skills and systems. More recently there has been a trend towards greater intensification of culture systems and the introduction of new species. These factors have been the major driving forces for developments in feed technology and feeding practices. Feed and feeding have become the most important factors influencing the performance of different aquaculture practices and the development of the sector as a whole.

Within the last 20 years aquaculture has become the most important component of the fisheries sector in China. In 1988 fisheries production exceeded 10 million tonnes and for the first time aquaculture contributed over 50 percent of the total. Since 1993, the contribution by aquaculture has reached 60 percent. In 2003, aquaculture production amounted to some 30.27 million tonnes and this makes a significant contribution to the total animal protein supply, income generation of rural households and the national economy. China currently accounts for about 70 percent of global aquaculture production.

Presently, the fisheries sector provides about 30 percent of animal protein consumed in China (Figure 1), although fish consumption varies regionally. On a per capita basis people in the southeastern part of the country consume the largest quantities of aquatic products, while in the northwest consumption is much lower. By 2003, aquaculture contributed 65.5 percent to total fisheries production, provides about 20 percent of total animal food supply to the peoples of China and per capita availability of aquatic products increased from <10 kg/caput in 1980 to its present level of 37 kg/year.

FIGURE 1
Relative contribution to total animal food supply by various sectors in 2004

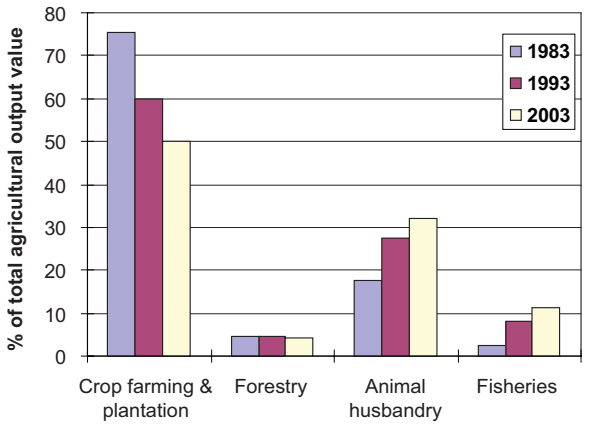


Source: MOA (2004)

Aquaculture also makes a significant contribution to the national economy. In 2004, the value of the Chinese fisheries sector amounted to about US$46.3 billion, to which aquaculture contributed 72.4 percent. In 2003, fisheries (aquaculture and capture fisheries)

comprised 11.2 percent of the total national agricultural output, of which 70.3 percent was from aquaculture and in the same year fisheries comprised 2.8 percent of GDP. As shown in Figure 2, the share of fisheries to the total value of agricultural output has increased significantly in the past 20 years.

FIGURE 2
Proportional changes in the value of agricultural outputs, 1983–2003



Source: MOA (1984, 1994, 2004)

Aquatic products have become the most important agricultural exports of China. In 2004, the total value of exported fisheries products reached US$5.49 billion with a trade surplus of US$3.01 billion. The export value of aquatic products accounted for 23.5 percent of the total agricultural export value (US$23.39 billion with a foreign trade deficit of US$4.6 billion). Although aquatic products only accounted for 0.93 percent of total national exports in 2004, the trade surplus accounted for 9.41 percent of the total national foreign trade surplus (US$32 billion). Currently the bulk of exported fisheries products are aquaculture products.

Aquaculture contributes significantly to employment, livelihoods and income of rural people in China. In 2004, the fisheries industry employed approximately 13.02 million people, of which 7.12 million were full time workers (4.49 million in aquaculture). In 2004, the average income for fisheries workers reached US$1100/year, which is about 45 percent higher than in the agricultural sector as a whole.

1.2 Aquaculture production by species and practices in China

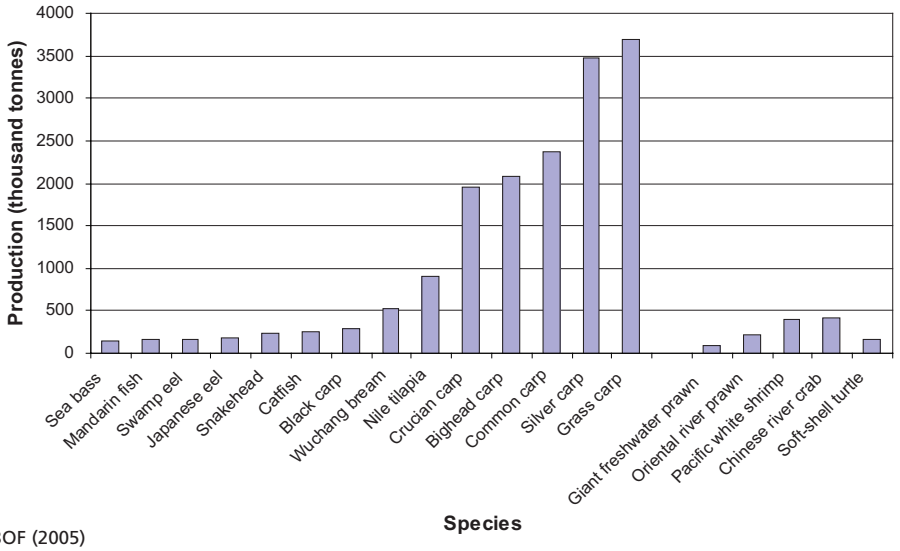
1.2.1 Production by species

Since the middle of the 1990s, changes in consumer demands and the pursuit by farmers to increase returns have stimulated the strong diversification of species in all aquaculture systems and practices. Currently, the number of species cultured in freshwater, brackish-water and marine environments exceeds 100. In 2004, about 80 different species were included in the national statistical database of aquaculture production. Production by volume and value of the major aquatic species in inland water bodies are shown respectively in Figures 3 and 4. In 2004, grass carp, silver carp, common carp, bighead and crucian carp accounted for 71.7 percent of the total inland waters aquaculture production in China. Of these species, grass carp has become the most important. Although different carp species still contribute the largest share, the contribution by other species has become significant in relation to production by value. This is mainly due to the higher market value of species such as crab, shrimps, freshwater prawns and eels.

Figure 4 shows the production of the major finfish and crustacean species in brackish-water and marine environments. In 2004, production by volume in these two environments was dominated by shrimp that account for about 37.9 percent of total production. Pacific white shrimp (*Litopenaeus vannamei*) has become the single most important culture species. The value of the major marine and brackish-water finfish and crustaceans produced in 2004 is shown in Figure 6. In terms of value this sector is dominated by shrimp and prawns.

FIGURE 3

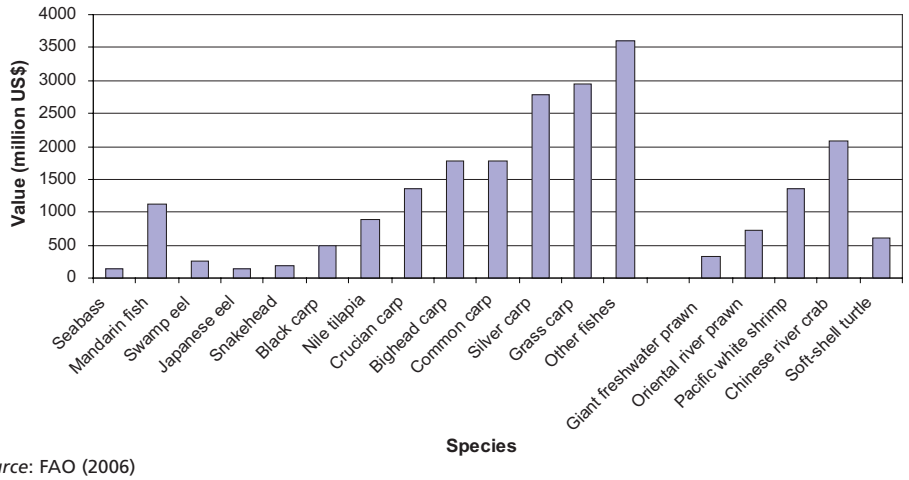
Production of major aquaculture species in inland water in China, 2004



Source: BOF (2005)

FIGURE 4

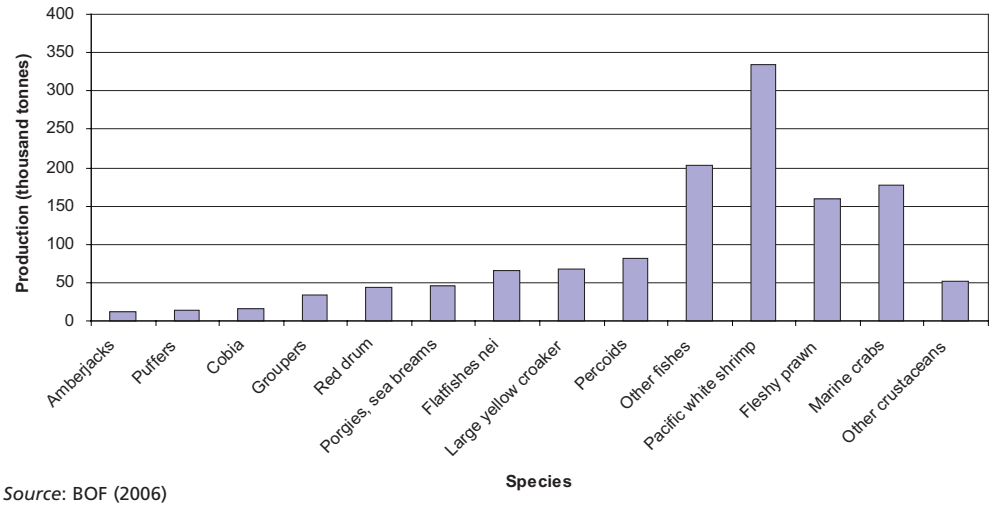
Production value of major aquaculture species in inland water in China, 2004



Source: FAO (2006)

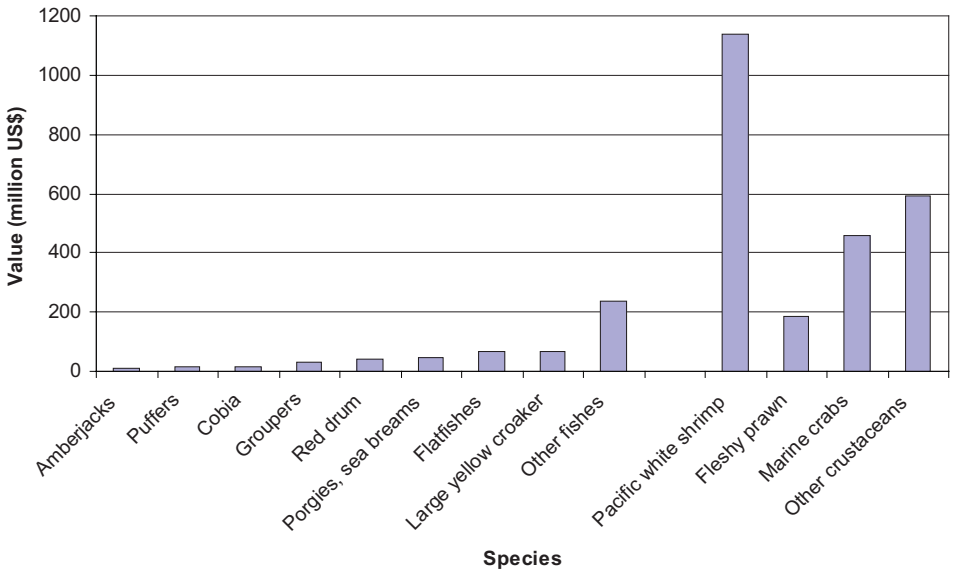
FIGURE 5

Production of major marine and brackish-water fish and crustaceans in China, 2004



Source: BOF (2006)

FIGURE 6
Production value of major marine and brackish-water fish and crustacean in China, 2004



Source: FAO (2006)

1.2.2 Production by systems and practices

Due to the organizational structure of fisheries and aquaculture statistics in China, it is not possible to provide a precise account of production by systems, although it is possible to undertake an approximate assessment of production of the different species under major culture practices. However, there is no doubt that semi-intensive pond polyculture of carp contributes the major share of inland aquaculture production. The estimated production from the major inland aquaculture practices are presented in Table 1 and Table 2 summarizes the production of marine and brackish-water species by systems. Mollusc monoculture and seaweed culture is not considered in this review.

TABLE 1
Estimated production from major inland aquaculture practices in China, 2004

Major practices	Estimated production (million tonnes)
Semi-intensive polyculture of carps in pond	9–10
Extensive polyculture of carps in natural water bodies	3–4
Intensive monoculture of common carp, crucian carp and tilapia	2–3
Semi-intensive/intensive monoculture of freshwater prawns and crabs in ponds	1.0
Extensive polyculture/monoculture of fish/prawn/crab in paddy fields	1.0
Semi-intensive pen polyculture of carps	0.50
Intensive cage monoculture of high valued species	0.50
Highly intensive culture of eels, soft-shelled turtle and puffer fish in indoor re-circulating systems	0.10

Source: calculated from BOF (2005)

TABLE 2
Estimated production from different marine/brackish aquaculture practices in China, 2004

Major practices	Estimated production (tonnes)
Semi-intensive/intensive monoculture of shrimp in ponds	530 000
Extensive polyculture of crab/shrimp/mollusk in ponds	190 000
Extensive culture of seabass and other species in ponds and pens	100 000
Intensive monoculture of grouper/yellow croaker and other species in cages	150 000
Semi-intensive/intensive culture of porgies/red drum/cobia/amberjack in ponds	100 000
Intensive monoculture of high valued fish in indoor re-circulating systems	80 000

Source: calculated from BOF (2005)

1.3 Aquaculture systems and practices in China

1.3.1 Aquaculture systems

The classification of aquaculture systems is usually based on the level of intensity, although the culture environment and the species composition are also often taken into consideration. Considering these aspects, the major aquaculture systems employed in China are listed in Tables 3 and 4.

1.3.2 Aquaculture practices

An important indicator of the rapid development of aquaculture in China is the rate of diversification in aquaculture practices in the past two decades. With over 100 different species that are farmed in a wide variety of environments throughout China it is very difficult to estimate and describe the various practices applied by farmers. Hence only some of the more important aquaculture practices and their major features are listed in Tables 5 and 6.

Extensive culture of carps in small lakes and reservoirs

This practice started in the 1960s and is the most extensive form of polyculture practiced in the country (Figure 7). In these water bodies the fish are entirely dependent on natural productivity. Stocking of artificially produced seed is the only material input. Bighead and silver carp are the major species and common, crucian and grass carp, wuchang

TABLE 3
Inland aquaculture systems and species in China, 2004

Culture system	Major species
Extensive polyculture in lakes/reservoirs	Wuchang bream, crucian carp, bighead carp, common carp, silver carp, grass carp, Chinese river crab
Semi-intensive polyculture in ponds	Grass carp, common carp, wuchang bream, tilapia, crucian carp, bighead carp, silver carp, largemouth bass, Mandarin fish, black carp, tilapia, giant freshwater prawn, oriental river prawn, Chinese river crab, soft-shell turtle
Intensive monoculture in ponds	Largemouth bass, Mandarin fish, Japanese eel, snakehead, catfish, tilapia, crucian carp, common carp, giant freshwater prawn, oriental river prawn, Pacific white shrimp, Chinese river crab, soft-shell turtle
Semi-intensive polyculture in cages	Wuchang bream, grass carp, tilapia
Intensive monoculture in cages	Largemouth bass, Mandarin fish, catfish, tilapia, common carp
Semi-intensive polyculture in pens	Grass carp, wuchang bream, black carp, crucian carp, bighead carp, common carp, silver carp, Mandarin fish, Chinese river crab
Extensive integrated rice-fish farming	Swamp eel, catfish, tilapia, crucian carp, bighead carp, common carp, silver carp, grass carp, oriental river prawn, Chinese river crab
Highly intensive indoor re-circulating systems	Japanese eel, soft-shell turtle, puffer fish, sturgeon

TABLE 4
Brackish-water and marine aquaculture systems and species in China, 2004

Culture system	Major species
Semi-intensive polyculture in ponds	Shrimp with molluscs, marine crabs, finfish and seaweed
Intensive monoculture in ponds	Amberjacks, red drum, black porgy, red sea breams, percoids, Pacific white shrimp, fleshy prawn, tiger prawn
Extensive culture in ponds	Percoids, mullet, crab
Intensive monoculture in cages	Amberjacks, cobia, groupers, red drum, black porgies, red sea breams, flatfishes, large yellow croaker, seabass
Extensive polyculture in pens/coves	Mullet, percoids, marine crabs
Intensive monoculture indoor re-circulating systems	Flounder, turbot, red drum, red sea breams

bream and Chinese river crab are secondary species and stocking is undertaken according to well defined schedules with respect to species composition, size and density. Depending on the size and productivity of the waterbody, stocking densities range from 150–3000 seed/ha. Care is taken to prevent the escape of fish by blocking the outlet and inlet water courses with fencing material and production ranges from 150–750 kg/ha/year without any artificial feeding and fertilization, although smaller irrigation reservoirs may be fertilized.

FIGURE 7
Harvesting of carp with combined fishing gears in Xinanjiang Reservoir, Zhejiang province

COURTESY OF FANG XIUZHEN

Semi-intensive and intensive culture of carp in freshwater ponds

Pond culture is the most traditional aquaculture practice and also the most important in terms of total fish production in China. Carp species are still used as the primary species in semi-intensive pond polyculture together with tilapia (mainly *O. niloticus*), crab, prawns and some carnivorous species such as Mandarin fish and largemouth bass as secondary species. A large variety of feeds are used, including natural feeds (aquatic weeds/terrestrial grass, benthic animals, abattoir by-products and silkworm pupae) and commercial pellets. Ponds are fertilized only during preparation and stocking density, size of seed and species composition is dependent on the production target.

Semi-intensive and intensive culture of carp in pen

Pen culture is a relative new practice that was introduced into China in the early 1980s to increase fish production in freshwater lakes. Polyculture of different carp species under semi-intensive conditions is the most common practice. Herbivorous species (grass carp and wuchang bream) are usually stocked as the primary species, while silver, bighead, common and crucian carps are used as secondary species. Commercial feeds such as soybean and rapeseed cake, pellet feeds and natural feed such as aquatic weeds/terrestrial grasses/vegetables and freshwater molluscs are commonly used. Production ranges between 10–15 tonnes/ha/year although levels of 37.5 tonnes/ha have been attained under experimental conditions.

Extensive culture of carps, tilapia and catfish in paddy field

This is a traditional aquaculture practice and is particularly popular in southern China (Figure 8). Peripheral and central crossing trenches are constructed in the paddy to maintain the required minimum water depth throughout the culture period. Fish are stocked before or after rice seedling are transplanted at very low densities. Because of the short culture period, farmers normally stock large juveniles. Supplementary feeds are applied occasionally and the application of pesticides is well managed to ensure the biosafety of the fish. Production ranges between 450–750 kg/ha/year, depending on input levels and management.

FIGURE 8
Extensive culture of fish/prawn/crab in a paddy field, Dongping, Shangdong province

Intensive monoculture of tilapia, common and crucian carp in ponds

Intensive monoculture of tilapia, common and crucian carp is a more recent practice in China. It is characterized by high stocking densities and complete dependence on pellet feeds. Production ranges between

FIGURE 9
Intensive monoculture of tilapia in cages in a reservoir, Hepu County, Guangxi Autonomous region

12–22.5 tonnes/ha/year. Tilapias are cultured mainly in southern China, while common and crucian carp are more generally produced in central and northern China.

Intensive monoculture of common carp and tilapia in cages

Intensive, cage monoculture of common carp is more popular in northern China, while intensive cage culture of tilapia is mainly practiced in southern China (Figure 9). The fish are entirely dependent on pellets and for common carp and both floating and submerged cages are used. Production of common carp in small cages can reach 200–300 kg/m^3/cycle. Tilapia are raised only in floating cages and production ranges from 50–100 kg/m^3/cycle.

Extensive culture of freshwater prawns and crabs in paddy fields

Extensive culture of freshwater prawns and crabs in paddy fields is a recent development, particularly in central and southern China. Production is basically dependent on natural food in the paddy fields. Supplementary feeds (locally available grain by-products and natural feeds) are sometimes applied. Average production is 7.5 tonnes of rice and 300–450 kg of prawns or crabs per hectare per season. Silver and/or bighead carp are occasionally also stocked into the ponds at low densities.

Semi-intensive and intensive monoculture of freshwater prawns in ponds

Semi-intensive and intensive monoculture of freshwater prawns in ponds is also a relatively new practice in China. It started with *Macrobrachium rosenbergii* and now also includes *M. nipponense* and *Litopenaeus vannamei*. *L. vannamei* is currently the most important crustacean produced in freshwater. The prawns or shrimp are fed on pellets and organic fertilizer is used to enhance natural productivity during the initial culture stages. Production levels vary by species from 1.5–3.0 tonnes/ha/cycle for *M. nipponense,* 6.0–7.5 tonnes for *L. vannamei* and 3.0–4.5 tonnes for *M. rosenbergii*.

Intensive monoculture of eels in ponds

Pond aquaculture is the most common farming practice for Japanese and European eels in China, particularly in Fujian and Guangdong provinces. Production is based on formulated feeds and organic fertilizer is only applied during pond preparation to enhance natural food production during the initial stages. Average production is around 15 tonnes/ha/cycle.

Semi-intensive and intensive culture of shrimp in brackish-water ponds

Semi-intensive and intensive brackish-water pond culture is the major culture practice for *L. vannamei*, *Penaeus monodon*, *Penaeus chinensis* and other marine shrimp species. It is mainly practiced in coastal areas and production is mainly based on use of pellet feeds. Organic fertilizer is used only in semi-intensive culture practices. Production in semi-intensive farming ranges from 1.5–2.5 tonnes/ha/cycle for *P. monodon, P. chinensis* and *P. japonicus* and between 4.5–9.0 tonnes/ha/cycle for *L. vannamei*. Intensive farming of shrimp in brackish-water ponds is normally restricted to *L. vannamei,* with production levels of 15–30 tonnes/ha/cycle.

Intensive monoculture of finfish in marine cages

Intensive, cage monoculture of large yellow croaker, grouper, cobia (Figure 10) and red drum is a relatively recent development. The most commonly used feed is trash fish, although formulated feeds have now also been developed and used for some species.

FIGURE 10
Intensive monoculture of cobia in marine cages, Shandong province

COURTESY OF LIANG MENGQUING

FIGURE 11
Intensive culture of marine fish in indoor running water system, Shandong province

COURTESY OF LIANG MENGQUING

Production varies according to species and ranges from 15–30 kg/m^3/cycle.

Intensive culture of marine finfish in indoor flow-through or re-circulating systems
The use of indoor, marine re-circulating or flow-through systems for intensive monoculture of flounder, turbot, Japanese/European eel and puffer fish is also a recent initiative (Figure 11). Only formulated feeds are used in these systems and production varies by species from 3–10 kg/m^3/cycle.

TABLE 5
Summary of major inland aquaculture practices in China, 2004

Culture environment	Polyculture/ monoculture	Major species	Intensity level	Food/feed type	Yield per cycle*
Lake/reservoir	Polyculture	Carps, Chinese river crab	Extensive	Natural food	150–750 kg/ha
Pond	Polyculture	Carps, tilapia, soft-shelled turtle, Chinese river crab, Mandarin fish	Semi-intensive	Natural food, commercial feed	7.5–15.0 tonnes/ha
	Monoculture	Common & crucian carp	Intensive	Commercial feed	15.0–22.5 tonnes/ha
	Monoculture	Tilapia	Intensive	Commercial feed	15–20 tonnes/ha
	Monoculture	Japanese/European eel	Intensive	Commercial feed	15 tonnes/ha
	Monoculture	Giant freshwater prawn	Intensive	Commercial feed	3.0–4.5 tonnes/ha
	Monoculture	Pacific white shrimp	Intensive	Commercial feed	6–12 tonnes/ha
	Monoculture	Oriental river prawn	Semi-intensive	Natural food and commercial feed	1.5–3.0 tonnes/ha
	Monoculture	Chinese river crab	Semi-intensive	Natural food and commercial feed	1.5–3.0 tonnes/ha
Cage in river/ lake/reservoir	Polyculture	Grass carp, Wuchang bream	Semi-intensive	Natural food and commercial feed	30–60 kg/m^3
	Monoculture	Tilapia	Intensive	Commercial feed	80–100 kg/m^3
	Monoculture	Common carp	Intensive	Commercial feed	100–200 kg/m^3
	Monoculture	Catfish	Intensive	Trash fish and commercial feed	60–100 kg/m^3
	Monoculture	Mandarin fish, largemouth bass	Semi-intensive	Live fish/trash fish	10–20 kg/m^3
Pen in lake/ reservoir	Polyculture	Carps	Extensive/ semi-intensive	Natural food and commercial feed	10–20 tonnes/ha
	Polyculture	Chinese river crab with carps	Semi-intensive	Natural food and commercial feed	Crab 6–9 tonnes/ha
Rice paddy	Polyculture	Carps, catfish, prawn	Extensive	Natural food and supplementary feed	450–750 kg/ha
	Monoculture	Chinese river crab, swamp eel	Extensive	Natural food and supplementary feed	225–450 kg/ha
Indoor re-circulating	Monoculture	Japanese eel/European eel	Intensive	Commercial feed	10 kg/m^3
	Monoculture	Soft-shelled turtle	Intensive	Natural food and commercial feed	5–10 kg/m^3

*Duration of a production cycle ranges from 6 months to 3 years depending upon the species and the region where aquaculture is practised. The duration of production cycle of prawn and shrimp is usually 6 months, 1.5–2.0 years for most carp species, while it is 2–3 for eel.

TABLE 6
Summary of major marine/brackish aquaculture practices in China, 2004

Culture environment	Polyculture/ monoculture	Major species	Intensity level	Food/feed type	Yield per cycle
Brackish-water ponds	Polyculture	Shrimp, mullet, tilapia, crab	Semi-intensive	Commercial feeds and natural food	4–6 tonnes/ha
	Monoculture	Shrimp	Intensive	Commercial feeds	15–20 tonnes/ha
	Monoculture	Tilapia/black porgy	Intensive/semi-intensive	Commercial feeds	15.0–22.5 tonnes/ha
	Monoculture	Shrimp	Semi-intensive	Commercial feeds and natural food	1.5–3.0 tonnes/ha
Marine cages	Monoculture	Large yellow croaker/ grouper/tilapia/red sea bream/black porgy/ seabass	Intensive	Trash fish/ commercial feeds	15–30 kg/m^3
Indoor re-circulating	Monoculture	Flounder, trout	Highly intensive	Commercial feeds, moist pellet	10 kg/m^3

2. FERTILIZERS, FEED INGREDIENTS AND FEEDS

2.1 Feed Ingredients

Aquaculture is a development priority of the government and the industry is expected to make further advances in the 21st century. The availability of feed ingredients is one of the key factors that will impact on the future development of aquaculture in China. For this reason it is pivotal to assess the future availability of feed ingredients. The chemical composition, amino acid profile, mineral and vitamin content and the apparent nutrient and amino acid digestibility of selected feed ingredients of animal and plant origin by various aquatic species are presented in Tables 7 to 18.

2.1.1 Feed ingredients of animal origin

The major feed ingredients of animal origin in China are fishmeal, hydrolyzed poultry feather meal, squid meal, fish silage, meat by-product meals, poultry by-product meal, blood products, silkworm pupae meal and shrimp meal. Many of these ingredients, especially fishmeal, are imported and efforts are being made to partially replace imported feed ingredients with locally available material.

Fishmeal

Most of the locally produced fishmeal is produced from various clupeid species such as *Engraulis japanicus*, *Sardinella longiceps*, *Coilia ectenes*, and *Sardinops sagax melanosticta*. Occasionally fishmeal from other species is also available. Approximately 400 000 tonnes of fishmeal is produced in China, of which about 70–80 percent is used in aquafeeds. The escalating cost of fishmeal is now beginning to limit its use in aquafeeds. The average optimum inclusion levels of fishmeal in feeds for carnivores is 50.0 percent, omnivores/herbivores 25.0 percent, penaeid shrimps 25.0 percent and other crustaceans 20.0 percent.

Squid meal

Squid meal is a by-product of squid processing and is an important aquafeed ingredient, particularly for shrimp. Squid meal has growth promoting properties and is a good attractant. Studies have shown that squid contains some unidentified growth enhancing factor, which presently is simply referred to as the "squid factor". Growth of Pacific white shrimp (*Litopenaeus vannamei*) is enhanced by 2.5–20 percent when the diet is supplemented with squid meal. Squid meal is produced in China and is also imported. Reliable production statistics are not available.

Fish and other marine silage

Fish and other marine silages are liquid concentrates, manufactured from trash fish and by-products and wastes of fish processing. The crude protein content (on a dry

matter basis) varies widely, although the amino acid profile is not significantly different from that of dried fish. The level of free amino acids in fish silage is high. Silage made from marine fish and crustaceans has chemo-attractant properties. In particular, shrimp silage has some feeding stimulatory properties for a variety of fish species. Fish silage may also contain unidentified growth enhancing factors.

Meat by-product meal
Meat by-products include abattoir wastes, or meat that has been confiscated and not fit for human consumption, scraps from the meat processing and canning industry, as well as processed livestock casualties. These products are reduced to either meat or meat and bone meal. The chemical composition of meat meal and meat and bone meal varies widely and depends on the quality and origin of the raw material and the rendering plant.

2.1.2 Feed ingredients of plant origin and single cell proteins
The main ingredients of plant origin that are used or have potential to be used in aquafeeds in China are cottonseed meal, rapeseed meal, soybean meal, peanut meal, sunflower meal, wheat and wheat by-products and rice by-products. Most are locally produced and the country is only partially dependent on imports.

Cotton seed meal
It is estimated that about 8–10 million tonnes of cottonseed is produced in China per annum (http://www.chinafeed.org.cn/cms/code/business/include/php/189909.htm). It is estimated that about 4–5 million tonnes of cottonseed meal is produced annually of which approximately 60 percent is used in aquafeeds.

Rape seed meal
The reported annual production of rapeseed meal is about 5 million tonnes and it is estimated that approximately 80 percent is used by the aquafeed industry.

Soybean meal
Soybean meal is the most important protein source in animal feeds. It is used for partial replacement of fishmeal in many aquafeeds and in some instances replaces fishmeal completely. It is commonly used because of its high protein content and global availability. Annual soybean meal production in China is around 15.50–17.55 million tonnes, the greater proportion of which is solvent extracted.

Peanut meal
Similarly, peanut meal is one of the most important protein sources in animal feeds and is also used as a partial or total replacement for fishmeal. About 14–15 million tonnes are produced annually, of which about 30–40 percent is used in aquafeeds and the remainder is used for livestock feed.

Wheat and wheat by-products
Available wheat by-products are wheat bran, wheat middlings, wheat germ and wheat gluten. About 100 million tonnes of wheat is produced annually in China.

Rice by-products
The most commonly used rice by-product in aquafeeds is the bran. It is used mainly as an energy source. Rice pollard is also used in aquafeeds, but to a lesser extent. Rice bran is most often used in diets for omnivorous and herbivorous fish. It is inexpensive and used mainly for species such as grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*) and Nile tilapia (*Oreochromis niloticus*).

There are several locally produced single cell protein sources that are used as aquafeed ingredients and these are brewer's yeast, molasses yeast and brewers grain.

2.2 Fertilizers

Inorganic and organic fertilizers are applied in extensive and semi-intensive pond systems to stimulate the growth of natural food, although the popularity of fertilizers use in aquaculture is declining. All fertilizers are locally produced.

Inorganic fertilizer

The most widely used inorganic fertilizers in aquaculture are mono-ammonium phosphate and di-ammonium phosphate as nitrogen and phosphorus sources, urea as nitrogen source and ammonium sulphate.

Organic fertilizer

The most widely used organic fertilizers in ponds are pig, chicken and duck manure, cow dung and green fodder.

2.3 Feeding practices in relation to farming systems and species

Grass, silver, common, bighead and crucian carp account for more than 70 percent of the total freshwater aquaculture production and of these, grass carp is the most important species. About 70 percent of aquafeeds produced annually in China is consumed by grass carp, common carp, crucian carp and tilapia.

Herbivorous fish.

The most common herbivorous aquaculture species in China are grass and silver carp. Under cage culture conditions silver carp and bighead carp are fed on compound feeds, consisting of mainly plant based ingredients with a 30–40 percent crude protein content. The commercial carp feed industry supplies pressed and extruded floating pellets and is well established in the major carp producing regions. The growout period for carp under cage culture conditions ranges from 6 months to 1 year in tropical regions and in temperate regions may range from 1–2 years.

Omnivorous fish

The most common omnivorous species produced in China are common carp, crucian carp and Nile tilapia. Omnivorous fish larvae are fed on microparticulate diets in combination with *Brachionus, Acartia* and *Pseudodiaptomus* nauplii. Tilapia are farmed in a multitude of systems and environments (ponds, cages, raceways and reservoirs, in freshwater and brackish water, under mono- and polyculture conditions and under extensive conditions with limited inputs and under semi-intensive and super-intensive stocking densities with high inputs, in static and in flow-through water and in recirculation systems using biofiltration). Under most of these conditions they are fed on compound feeds.

The main protein sources used in tilapia feeds are fishmeal, soybean meal, peanut, rapeseed and cottonseed meal as well as meat and bone meal, meat meal and feather meal. Main energy sources include animal and vegetable fats, corn, wheat and wheat by-products. Vitamins and minerals are included separately, or as combined premixes. The feeds are also supplemented with phosphate and limestone and other additives may include antioxidants and binders.

Carnivorous fish

The main carnivorous species are large yellow croaker, seabass, black rock fish, grouper, cobia, red sea bream, turbot, flounder, red drum, and puffer. Large yellow croaker, black rock fish, grouper, cobia and red sea bream are cultured in cages using

mainly trash fish. Seabass, puffer and red drum are produced in ponds with commercial feeds, farm-made feeds and trash fish. Turbot and flounder are cultured indoors in flow-through or re-circulating systems with farm-made feed and commercial feeds. Carnivorous fish feeds usually contain high levels of fishmeal and moderately low level of plant ingredients (primarily soybean meal).

Crustaceans

Shrimp are farmed mainly in ponds under semi-intensive conditions using artificial feeds. Shrimp feeds normally include moderately high levels of fishmeal, soybean meal, peanut meal, shrimp meal and wheat meal.

TABLE 7
Chemical composition (percent dry matter) of major feed ingredients of animal origin

Ingredients	Dry matter	Crude protein	Crude lipid	Ash	Crude fibre	NFE	Ca	P
Fishmeal								
Anchovy	92.0	68.2	9.3	16.9	-	5.6	-	-
Estuarine tapertail anchovy	93.1	54.9	2.4	11.3	0.2	1.9	-	-
Polack	94.0	55.1	12.8	26.7	0.8	4.6	-	-
Sardine	93.0	63.4	9.8	15.3	0.3	9.6	-	-
Sealed sardine	93.9	62.9	8.3	14.8	0.2	3.1	-	-
Mixed fish	92.6	58.3	10.0	22.5	0.6	1.2	-	-
Poultry feather meal	92.0	84.0	2.5	2.8	1.5	0.6	0.4	0.70
Squid meal	8.0–13.0	40.0–45.0	16.0–21.0	5.0–10.0	-	-	-	-
Fish silage	24.9	58.3	16.0	14.7	3.6	28.9		
Meat meal	94.6	54.0	8.8	27.5	2.4	-	8.0	3.80
Meat and bone meal	94.0	46.0	10.0	35	2.5	-	10.7	5.40
Blood meal	90.0	80.0	1.0	4.5	1.0	-	0.3	0.25
Silkworm pupae meal (full-fat)	88.9	55.1	23.2	3.8	5.5	6.4	-	-
Silkworm pupae meal (de-oiled)	91.9	72.8	2.0	5.6	6.2	7.3	-	-
Shrimp meal	92.5	37.2	1.3	38.2	21.4	-	15.0	2.20
Shrimp head meal	96.8	58.2	8.9	22.6	11.9	-	-	-
Shrimp shell meal	96.0	45.9	0.4	31.7	27.2	-	11.1	3.60

Source: Unpublished data of National Centre for Quality Supervision and Test of Aquatic Product, Qingdao, P.R. China (pers. comm.)

TABLE 8
Amino acid profile (percent dry matter) of major feed ingredients of animal origin

Amino acids	Fishmeal of different origin						Poultry feather meal	Squid meal	Fish silage	Meat meal	Meat & bone meal	Blood meal*
	Anchovy (true)	Tapertail anchovy	Polack	Sardine	Sealed sardine	Mixed fishmeal						
Arginine	3.88	6.6	6.6	6.6	5.3	5.4	5.44	2.67	4.9	3.73	3.53	3.19
Histidine	1.54	2.0	2.4	2.7	1.7	2.0	0.51	4.15	1.8	1.06	0.90	3.96
Isoleucine	4.70	4.8	4.7	4.3	5.1	4.2	3.56	1.58	3.2	1.89	1.66	0.90
Leucine	7.70	8.1	7.5	7.1	7.4	7.2	6.46	2.40	5.7	3.44	3.05	10.12
Lysine	5.87	7.2	7.7	8.0	0.2	6.9	1.63	3.09	6.6	3.43	2.98	5.99
Methionine	2.90	3.0	2.8	2.4	2.6	2.9	0.48	0.63	2.5	0.76	0.66	0.91
Phenylalanine	4.20	3.8	3.9	3.4	3.2	3.5	3.14	1.58	2.9	1.93	1.73	5.47
Threonine	4.40	5.2	4.2	4.0	4.2	4.1	0.38	1.64	3.1	1.79	1.69	1.02
Tryptophan	-	-	-	-	-	-	0.52	0.90	1.1	0.87	0.77	1.73
Valine	5.40	5.3	5.8	4.9	-	4.6	6.03	2.04	4.3	2.64	2.38	6.41
Tyrosine	1.20	1.0	1.1	0.7	0.9	-	-	-	-	-	-	-

*Percent of crude protein

Source: Unpublished data of National Centre for Quality Supervision and Test of Aquatic Product, Qingdao, P.R. China (pers. comm.)

TABLE 9
Apparent nutrient digestibility (%) of various ingredients of animal origin by various aquatic species

Feed ingredients/aquatic species	Dry matter	Crude protein	Crude lipid	Gross energy	P
Fishmeal (local)[1]					
Seabass	62.03	92.30	89.40	83.96	85.52
Grass carp	81.51	84.04	83.83	-	-
Chinese long-snout catfish	-	90.91	83.00	-	-
Black carp	68.17	88.38	81.65	79.16	12.62
Fishmeal (imported)[1]					
Grass carp	83.06	87.54	80.56	-	-
Nile tilapia	-	92.21	-	-	-
Fleshy prawn	-	91.47	-	-	-
Blunt nose black bream	64.20	83.90	98.10	-	-
Black carp	77.35	89.30	100.00	91.54	-
Poultry feather meal[2]					
Nile tilapia	-	93.36	-	-	-
Fleshy prawn	-	76.42	-	-	-
Blunt nose black bream	62.20	86.90	-	-	-
Meat & bone meal[3]					
Seabass	58.62	77.39	88.31	67.94	53.39
Blunt nose black bream	70.00	89.10	91.80	-	15.00
Black carp	71.39	88.00	97.00	79.66	25.42
Grass carp	59.13	79.21	81.36	-	-
Fleshy prawn	-	81.35	-	-	-
Meat meal[3]					
Seabass	70.10	87.30	82.80	-	-
Pacific white shrimp	76.00	90.00	-	-	-
Blood meal[4]					
Nile tilapia	-	91.58	-	-	-
Blunt nose black bream	88.00	83.38	0.22	-	0.24
Black carp	85.42	92.19	-	86.62	-
Chinese long-snout catfish	-	85.93	-	82.27	-
Fleshy prawn	-	73.47	-	-	-

Source: [1] Chang *et al*. (2005); Lei, Yang and He (1996); Lin, Luo and Ye (2001); Liu, Zhu and Chen (1990); Rong, Liang and Yue (1994); Ye, Lin and Luo (2003); You *et al.,* (1993); Wu *et al.,* (1995); Wu *et al.,* (2000), [2]Rong, Liang and Yue (1994); Wu *et al,* (1995); Wu *et al,* (2000); [3]Chang *et al.* (2005); Lin, Luo and Ye (2001); Liu, Zheng and Zhao (2004); Rong, Liang and Yue (1994); [4]Lei, Yang and He (1996); Liu, Zhu and Chen (1990); Rong, Liang and Yue (1994); You *et al*. (1993); Wu *et al.* (1995); Wu *et al.* (2000)

TABLE 10
Apparent amino acid digestibility (%) of various ingredients of animal origin by various aquatic species

Ingredients/species	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Try	Val	Tyr	Cys
Fishmeal (local)[1]												
Seabass	94.37	83.32	91.41	90.53	89.03	89.58	90.85	93.63	-	92.34	-	-
Grass carp	84.90	93.10	87.50	85.50	90.50	93.80	74.9	90.10	-	89.80	-	-
Fishmeal (imported)[1]												
Grass carp	86.70	90.00	98.90	87.30	91.30	90.90	98.10	85.30	-	88.60	-	-
Nile tilapia	94.90	93.60	92.10	91.30	93.20	94.60	90.50	92.30	-	90.80	92.70	85.90
Fleshy prawn	90.91	91.02	90.96	90.92	90.91	60.91	90.92	90.82	-	90.84	-	-
Poultry feather meal[2]												
Nile tilapia	94.50	59.30	96.20	94.20	56.50	89.90	93.60	92.50	-	95.80	91.50	90.80
Fleshy prawn	76.42	77.95	76.43	76.39	76.61	76.49	76.41	76.42	-	76.37	-	-
Meat & bone meal[3]												
Seabass	82.79	81.41	75.47	79.12	82.57	79.03	75.28	74.57	-	77.95	-	-
Meat meal[3]												
Grass carp	80.40	87.00	74.00	84.60	79.00	88.50	71.00	84.20	-	81.40	-	-
Fleshy prawn	81.47	81.34	81.37	81.35	81.89	81.18	81.30	81.35	-	81.35	-	-
Blood meal[4]												
Nile tilapia	93.90	95.50	-	91.90	90.40	78.10	92.30	87.20	-	90.60	-	-
Fleshy prawn	49.70	40.49	49.57	49.30	50.32	49.45	49.27	49.76	51.56	49.70	-	-

Source: [1]Chang *et al.* (2004); Liu, Zheng and Zhao (2004); Rong, Liang and Yue (1994); Wu *et al.* (2000), [2]Rong, Liang and Yue (1994); Wu *et al.* (2000), [3]Chang *et al.* (2004); Rong, Liang and Yue (1994); Ye, Lin and Luo (2003), [4]Rong, Liang and Yue (1994); Wu *et al.* (2000)

TABLE 11
Chemical composition (percent dry matter) of major plant feed ingredients and single cell proteins

Ingredients	Dry matter	Crude protein	Crude lipid	Ash	Crude fibre	NFE	Ca	P
Plant based feed ingredients								
Rape seed meal	89.0	36.5	3.5	4.8	11.7	20.5	0.68	1.17
Soybean meal, solvent extracted	89.5	44.5	1.0	6.0	6.5	-	0.25	0.60
Soybean meal, expeller	89.0	42.0	4.0	6.0	6.0	-	0.25	0.60
Peanut meal, solvent extracted	91.0	47.0	1.0	5.5	-	-	0.20	0.60
Peanut meal, expeller	91.0	45.0	5.0	5.5	4.2	-	0.20	0.55
Peanut meal with hull	88.6	29.3	9.9	6.3	27.9	-	0.26	0.29
Wheat flour	89.0	13.0	2.0	1.8	3.0	-	0.05	0.40
Wheat bran	87.5	15.5	4.0	6.0	10.5	-	0.10	1.15
Wheat middling	87.5	15.5	4.0	4.5	7.5	-	0.10	0.90
Wheat germ	89.5	25.0	8.0	4.5	3.0	-	0.05	1.00
Rice bran, de-fatted	89.0	15.5	1.0	8.0	8.5	-	0.10	1.40
Rice bran, full-fat	89.5	13.0	14.0	16.7	12.0	-	0.10	1.60
Rice hull	91.5	3.0	0.7	22.8	39.3	-	-	-
Single cell protein								
Brewer's yeast	91.7	51.4	0.6	8.4	2.0	29.3	-	-
Torula yeast	91.7	47.1	1.1	6.9	2.0	34.6	-	-
Molasses yeast	95.5	42.5	2.8	8.8	0.5	47.2	-	-
Brewers grain	92.5	25.0	6.0	4.0	15.0	-	0.25	0.48

Source: Unpublished data of National Centre for Quality Supervision and Test of Aquatic Product, Qingdao, P.R. China (pers. comm.)

TABLE 12
Amino acid profile (percent dry matter) of major plant feed ingredients and single cell proteins

Amino acids	Cotton seed meal, solvent extracted	Cotton seed meal, expeller	Rape seed meal	Soybean meal, solvent extracted	Soybean meal, expeller	Peanut meal, solvent extracted	Peanut meal, expeller	Wheat bran	Wheat middling	Wheat germ	Rice bran, full-fat	Brewer's yeast	Torula yeast	Molasses yeast	Brewers grain
Arginine	4.47	4.51	2.23	3.07	2.93	4.62	4.05	0.87	1.21	1.88	0.85	2.46	2.60	2.27	1.22
Histidine	1.04	1.07	1.09	0.86	1.00	0.93	0.85	0.36	0.45	0.65	0.32	1.00	1.40	1.11	0.49
Isoleucine	1.28	1.39	1.46	1.70	1.74	1.69	1.70	0.70	0.57	0.88	0.51	2.94	2.90	2.70	1.47
Leucine	2.23	2.35	2.71	3.05	3.07	2.61	2.62	1.09	1.09	1.56	0.90	3.56	3.50	3.89	1.89
Lysine	1.81	1.64	2.15	3.53	2.27	1.62	1.33	0.67	0.81	1.54	0.57	3.70	3.80	3.76	0.87
Methionine	0.52	0.57	0.77	0.65	0.46	0.42	0.50	0.20	0.28	0.44	0.24	1.0	0.80	0.84	0.45
Phenylalanine	2.21	2.18	1.54	1.89	1.94	1.99	1.95	0.64	0.67	0.94	0.58	2.77	3.00	2.46	1.38
Threonine	1.23	1.36	1.71	1.00	0.66	-	-	0.53	0.60	0.97	0.47	2.41	2.60	2.82	0.97
Tryptophan	0.47	0.53	0.49	1.37	1.46	1.09	1.17	0.39	0.23	0.30	0.10	0.73	0.50	0.59	0.37
Valine	1.82	1.97	1.94	0.93	1.78	1.79	1.89	0.68	0.83	1.17	0.76	2.90	2.90	2.97	0.40

Source: Unpublished data of National Centre for Quality Supervision and Test of Aquatic Product, Qingdao, P.R. China (pers. comm.)

TABLE 13
Apparent nutrient digestibility (%) of major plant feed ingredients by various aquatic species

Feed ingredients/ aquatic species	Dry matter	Crude protein	Crude lipid	Carbohydrate	Crude fibre	Gross energy	P
Cotton seed meal[1]							
Seabass	40.59	76.79	80.46	-	-	16.99	-
Grass carp	59.49	75.22	51.16	-	-	-	8.50
Blunt nose black bream	43.80	81.20	90.40	23.4	-	-	-
Black carp	64.60	85.50	57.00	60.0	18.0	-	-
Fleshy prawn	-	83.14	-	-	-	-	-
Rapeseed meal[2]							
Seabass	58.66	81.30	86.09	-	-	68.01	-
Grass carp	68.62	77.81	81.33	-	-	-	-
Blunt nose black bream	49.30	80.70	85.70	45.7	-	-	8.20
Black carp	61.59	86.42	98.80	63.0	18.0	65.93	43.41
Chinese long-snout catfish	-	89.87	-	-	-	79.07	-
Nile tilapia	-	86.57	-	-	-	-	-
Fleshy prawn	-	80.16	-	-	-	-	-
Soybean meal[3]							
Seabass	66.00	90.60	86.70	-	-	76.20	47.50
Grass carp	75.40	87.50	82.20	-	-	-	-
Blunt nose black bream	77.80	95.70	-	74.4	-	-	39.70
Black carp	79.30	96.80	-	67.1	-	81.30	64.40
Chinese long-snout catfish	-	76.30	-	-	-	61.40	-
Fleshy prawn	-	92.00	-	-	-	-	-
Peanut meal, solvent extracted[4]							
Seabass	64.40	87.05	87.21	-	-	73.16	59.20
Blunt nose black bream	-	95.70	-	74.4	-	-	39.70
Peanut meal with hull[4]							
Blunt nose black bream	29.50	86.20	-	45.3	-	-	11.50
Black carp	46.04	88.93	-	51.3	-	51.44	22.27
Nile tilapia	-	89.87	-	-	-	-	-
Fleshy prawn	-	86.94	-	-	-	-	-

Source: [1] Chang *et al.* (2005); Lin, Luo and Ye (2001); Liu, Zheng and Zhao (2004); Rong, Liang and Yue (1994); You *et al.* (1993); Wu *et al.* (1995); Wu *et al*. (2000 [2]Chang *et al.* (2005); Lei, Yang and He (1996); Lin, Luo and Ye (2001); Liu, Zhu and Chen (1990); Rong, Liang and Yue (1994); You *et al.* (1993); Wu *et al.* (1995); Wu *et al.* (2000), [3] Chang *et al.* (2005); Lei, Yang and He (1996); Lin, Luo and Ye (2001); Liu *et al.* (1990); Rong, Liang and Yue (1994); You *et al.* (1993); Wu *et al*. (1995), [4]Chang *et al.* (2005); Liu, Zhu and Chen (1990); Rong, Liang and Yue (1994); You *et al.* (1993); Wu *et al.* (1995)

TABLE 14
Apparent nutrient digestibility (%) of major plant feed ingredients and single cell protein by various aquatic species

Feed ingredients/aquatic species	Dry matter	Crude protein	Crude lipid	Carbohydrate	Gross energy	P
Wheat flour						
Grass carp	59.97	87.06	82.49	-	-	-
Chinese long-snout catfish	-	94.17	-	-	48.43	-
Wheat bran[1]						
Grass carp	62.61	73.20	52.42	-	-	-
Black carp	42.81	87.16	99.30	37.45	33.95	33.96
Nile tilapia	-	91.54	-	-	-	-
Wheat middling[1]						
Grass carp	61.64	71.53	53.22	-	-	-
Nile tilapia	-	89.03	-	-	-	-
Barley flour[1]						
Grass carp	59.97	59.36	50.09	-	-	-
Black carp	66.90	74.60	82.80	71.50	-	-
Rice bran, de-fatted[2]						
Grass carp	47.41	76.36	56.99	-	-	-
Rice bran, full-fat[2]						
Nile tilapia	-	60.48	-	-	-	-
Blunt nose black bream	61.00	74.90	86.80	65.10	-	3.00
Brewer's yeast[3]						
Nile tilapia	-	91.69	-	-	-	-
Grass carp	64.24	85.04	82.53	-	-	-
Fleshy prawn	-	84.75	-	-	-	-
Torula yeast[3]						
Fleshy prawn	-	87.63	-	-	-	-
Molasses yeast[3]						
Fleshy prawn	-	74.22	-	-	-	-
Brewers' grain[4]						
Grass carp	71.71	68.47	69.09	-	-	-

Source: [1]Lei, Yang and He (1996); Liu, Zhu and Chen (1990); Lin *et al.* (2001); You *et al.* (1993); [2]Lin *et al.* (2001); Wu *et al.* (1995); Wu *et al.* (2000), [3]Lin, Luo and Ye (2001); Rong, Liang and Yue (1994); Wu *et al.* (2000), [4]Lin, Luo and Ye (2001)

TABLE 15
Apparent amino acid digestibility (%) of major plant feed ingredients by various aquatic species

Feed ingredients/ aquatic species	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Try	Val
Cotton seed meal[1]										
Seabass	93.59	83.97	80.82	82.89	77.32	60.30	86.46	79.25	-	76.99
Grass carp	89.20	73.70	89.50	84.10	87.80	86.10	65.30	87.2	-	88.50
Nile tilapia	94.70	89.90	80.20	82.90	75.20	59.90	89.90	85.4	-	87.20
Fleshy prawn	83.11	83.19	83.08	83.14	83.23	82.97	83.12	83.08	83.21	83.27
Rape seed meal[2]										
Seabass	91.87	91.64	82.55	84.32	89.93	75.95	88.09	83.62	-	81.72
Grass carp	84.80	88.30	81.60	83.60	91.50	87.60	72.70	83.00	-	81.80
Nile tilapia	94.90	93.70	86.90	83.90	78.80	89.30	86.40	80.20	-	81.80
Fleshy prawn	80.28	80.34	80.25	80.20	80.21	80.60	80.15	80.07	80.93	80.32
Soybean meal[3]										
Seabass	97.34	97.89	92.35	90.66	93.96	70.05	91.72	91.49	-	88.10
Grass carp	84.90	88.50	66.50	83.60	90.50	85.60	64.90	82.10	-	82.80
Nile tilapia	99.40	98.20	94.20	96.40	96.30	94.90	96.40	96.90	-	94.20
Fleshy prawn	92.13	92.22	92.07	92.11	92.06	92.25	92.12	91.90	92.06	92.11
Peanut meal, solvent extracted[4]										
Seabass	97.34	97.89	92.35	90.66	93.96	70.05	91.72	91.49	-	88.10
Peanut meal, expeller[4]										
Fleshy prawn	87.00	87.16	87.06	87.02	87.14	87.06	86.96	86.97	87.34	87.01
Peanut meal with hull[4]										
Nile tilapia	97.00	87.20	80.10	86.20	95.20	85.70	87.80	85.70	-	
Wheat flour[4]										
Grass carp	93.00	90.40	82.90	89.60	90.10	87.80	83.60	80.20	-	86.30
Wheat bran[4]										
Grass carp	76.20	91.10	94.80	87.10	86.90	90.00	77.20	85.40	-	79.30
Nile tilapia	97.80	97.40	94.10	92.70	93.50	88.20	91.10	94.20	-	87.10
Fleshy prawn	72.34	73.68	73.00	72.46	72.75	72.05	73.13	75.03	73.34	72.46
Wheat middlings[4]										
Grass carp	75.90	82.20	82.90	79.40	89.80	90.20	84.60	71.00	-	87.10
Nile tilapia	99.10	100.00	92.50	94.90	96.10	88.20	95.60	-	-	91.80

Source: Chang *et al.* (2004); Lin *et al.* (200); You *et al.* (1993); Wu *et al.* (2000), [2] Chang *et al.* (2004); Lin *et al.* (200); Rong, Liang and Yue (1994); Wu *et al.* (2000), [3] Chang *et al.* (2004); Lin *et al.* (2000); Rong, Liang and Yue (1994); Wu *et al.* (2000), [4] Chang *et al.* (2004); Rong, Liang and Yue (1994); Wu *et al.* (2000)

TABLE 16
Apparent amino acid digestibility (%) of major plant feed ingredients and single cell proteins by various aquatic species

Single cell protein/aquatic species	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Val	Tyr	Cys
Barley flour[1]											
Grass carp	82.8	82.3	84.5	82.9	80.2	79.2	74.5	74.9	-	73.0	-
Rice bran, full-fat[2]											-
Grass carp	88.2	90.9	87.7	88.4	90.0	88.6	73.4	84.1	-	90.0	-
Nile tilapia	74.2	84.8	89.0	63.6	60.4	72.9	76.6	62.5	-	67.3	-
Brewer's yeast[3]											
Nile tilapia	93.3	88.9	82.4	89.3	76.2	92.4	90.3	85.9	86.4	86.6	81.9
Grass carp	87.9	38.1	25.1	60.1	94.8	31.6	67.9	54.9	85	35.0	-
Fleshy prawn	84.8	84.8	84.8	84.8	84.8	84.8	84.8	84.9	84.3	-	-
Torula yeast[3]											-
Fleshy prawn	87.6	87.8	86.7	87.7	87.7	88.2	87.6	87.8	87.7	-	-
Molasses yeast[3]											-
Fleshy prawn	74.3	74.2	74.2	74.3	74.5	74.1	74.3	74.2	74.4	-	-
Brewers' grain[4]											-
Grass carp	83.4	86.1	86.8	85.6	84.7	88.0	75.8	74.6	78.1	-	-

Source: [1]Liu *et al.* (2000); Rong, Liang and Yue (1994); Wu *et al.* (2000), [2]Liu, Zheng and Zhao (2004); Wu *et al.* (2000), [3]Rong, Liang and Yue (1994); Ye *et al.* (2003); Wu *et al.* (2000), [4]Liu, Zheng and Zhao (2004)

TABLE 17
Mineral content of major feed ingredients

Minerals	Unit	Meat meal	Meat & bone meal	Blood meal	Soybean meal, solvent extracted	Soybean meal, expeller	Peanut meal, solvent extracted	Peanut meal, expeller	Wheat middling	Wheat germ
Calcium	%	7.96	10.16	0.27	0.25	0.33	0.20	0.16	0.11	0.07
Phosphorus	%	4.00	4.86	0.26	1.71	0.62	0.63	0.56	0.83	0.64
Sodium	%	1.31	0.73	0.32	0.12	0.24	0.42	0.41	0.20	-
Potassium	%	0.57	1.58	0.14	0.07	0.02	1.14	1.13	0.97	0.83
Magnesium	%	0.27	1.13	0.22	0.28	0.25	0.04	0.32	0.24	0.23
Chlorine	%	1.20	0.74	-	0.60	1.91	-	0.03	0.08	-
Sulphur	%	0.50	0.26	0.34	0.22	0.33	26.8	0.29	0.24	-
Manganese	mg/kg	9.6	13.3	5.3	29.9	32.3	0.03	25.4	112.2	-
Iron	mg/kg	0.044	0.050	0.307	0.008	0.0016	32.7	-	0.008	-
Zinc	mg/kg	104.4	95.3	4.4	-	-	15.3	-	150.2	-
Copper	mg/kg	9.8	1.5	13.3	15.8	18.0	-	-	18.3	-
Selenium	mg/kg	0.420	0.262	-	-	-	0.065	-	-	-
Iodine	mg/kg		1.313	-	-	-	-	-	0.109	-

Source: Unpublished data of National Centre for Quality Supervision and Test of Aquatic Product, Qingdao, P.R. China (pers. comm.)

TABLE 18
Vitamin content of major feed ingredients

Vitamins	Unit	Blood meal	Soybean meal, solvent extracted	Soybean meal, expeller	Peanut meal, solvent extracted	Peanut meal, expeller	Brewer's yeast	Torula yeast
A (Retinol)	IU/g	-	0.7	0.3	-	0.4	-	-
E (α-tocopherol)	mg/kg	-	-	6.6	-	-	-	-
B_1 (Thiamine)	mg/kg	0.4	1.5	4.0	5.7	7.1	90.3	6.2
B_2 (Riboflavin)	mg/kg	2.5	4.0	3.5	10.9	5.2	36.4	49.2
B_3 (Nicotinic acid)	mg/kg	31.0	14.1	14.9	172	166	458	499
B_5 (Pantothenic acid)	mg/kg	2.9	14.1	14.9	50.2	47.2	109.0	83.1
B_6 (Pyridoxine)	mg/kg	4.43	-	-	-	-	43.24	29.54
B_7 (Biotin)	mg/kg	0.08	0.73	0.30	0.33	-	0.96	1.39
B_9 (Folic acid)	mg/kg	0.10	-	6.60	0.65	-	9.42	22.4
B_{12} (Cyanocobalamin)	mg/kg	44.3	-	-	-	-	-	-
Choline	mg/kg	729	2 551	2 763	1 963	1 650	4 075	2 887

Source: Unpublished data of National Centre for Quality Supervision and Test of Aquatic Product, Qingdao, P.R. China (pers. comm.)

3. FEED MANAGEMENT STRATEGIES AND POND MANAGEMENT TECHNIQUES

Enhanced levels of intensity in virtually all aquaculture sectors have led to enormous increases in the demand for feeds. Moreover, price escalations of feed ingredients have also increased the share of feed cost in the total production costs.

To ease the problems of feed supply and to minimize feed costs, various management strategies and pond management techniques have been developed and adopted. These have made a significant contribution to the sustainable development of the industry.

3.1 Nutritional requirements of major aquaculture species in China

Understanding the nutritional requirements of cultured animals is the fundamental basis for good feed management practices at the industrial and small-scale level. Intensive research on the nutritional requirements of common aquaculture species was undertaken during 1980–1990s and this was strongly driven by the early developments in compound aquafeed production. Many of these findings are still used by the feed industry and are presented in Tables 19 to 23.

TABLE 19
Nutritional requirements (percent dry matter) of important aquacultures species in China

Species	Crude protein			Crude lipid	Carbohydrate	Crude fibre
	Fry	Juvenile	Adult			
Common carp	43–47	37–42	28–32	4.6	38.5	3.7–7.0
Black carp	33–41	29.5–40.9	35	4.6	25–38.5	
Grass carp	25–30	28–32		4.2–4.8	36.5–42.5	12.0
Wuchang bream	25.6–41.4	21.1–30.6		4.5	25–28	36.5–42.5
Crucian carp	40.0	30.0	28	5–8	36.0	12.2
Rainbow trout	43.0	36–40	35–40	8.5	20–30	3.0
Nile tilapia	48.5			12–15	30–40	5–20
Japanese eel	48.5	45.0	44	5–8	18.3–27.3	
Channel catfish	35–40	30–35	28–35	5–12	40.0	
Black porgy	40–45			10–14	15.0	6.25

Source: modified after Li (1996)

TABLE 20
Nutritional requirements (percent dry matter) of fleshy prawn, *Penaeus chinensis* and black tiger shrimp, *Penaeus monodon*

Species	Crude protein			Crude lipid	Carbohydrate	Crude fibre	Ca	P	C/P ratio
	Post larvae	Juvenile	Adult						
Fleshy prawn	40	42	44	4–6	20–26	3.7–7.0	1.0–1.5	1.7–2.5	1:1.7
Tiger shrimp	40–44	40	35–38	4		3–5	3.5–4.5	3.5–4.5	

Post larvae 0.7–1.0 cm, juvenile 3.0–6.0 cm and adult >6 cm.

Source: modified from Li, Song and Lou (1986), Li (1990) and Li (1996)

TABLE 21
Nutritional requirements (percent dry matter) of giant freshwater prawn, *Macrobrachium rosenbergii*

Nutrient	Juvenile (1–4 cm)	Early growout (4–6 cm)	Late growout (>6 cm)
Crude protein	40–45	35–40	28–35
Crude lipid	7–9	5–7	4–5
Carbohydrate	20–24	24–30	30–35
Crude fibre	4	5	6
Crude ash	10–12	12–14	14–16
Calcium	0.9–1.1	1.8–2.2	1.8–2.2
Phosphorus	0.9–1.1	1.8–2.2	1.8–2.2

Source: adapted from Li (1996)

TABLE 22
Nutritional requirements (percent dry matter) of soft-shelled turtle

Crude protein		Crude lipid	Carbohydrate	Crude fibre
Juvenile	Adult			
47.4–49.1	43.3–45.1	6–7	22.7–25.3	<10

Source: adapted from Li (1996)

TABLE 23
Nutritional requirements (percent dry matter) of Nile tilapia

Fish weight (g)	Crude protein	Crude lipid	Carbohydrate
0.1–2.5	56–40	<12	40–50
2.5–7.5	40–36	<10	-
7.5–30.0	36–30	<8	-
> 30.0	32–25	<5	-

Source: Unpublished data of YSFRI (Yellow Sea Fisheries Research Institute, Chinese Academy of Fisheries Sciences)

Since the mid-1990s, there has been a rapid diversification in aquaculture species to meet the changing preferences of consumers and to increase profits. Unfortunately since that time government has reduced the level of funding for aquaculture nutrition research. As a consequence, research on the nutrient requirements of many new species

is lagging behind. The feed additive industry in China is very profitable and is driving research towards understanding the amino acid, vitamin and mineral requirements of aquatic species and hence much of the research is focused on these aspects. See Annexure 1 for information on the amino acid, mineral and vitamin requirement of the major aquaculture species. The current lack of systematic research on the nutritional requirements of aquaculture species will certainly impact on development of compound aquafeeds.

3.2 Farm-made feeds

Traditional fish farming practices mainly relied on natural food organisms, enhanced by organic fertilization and supplementary feeds such as aquatic weeds, terrestrial grasses, naturally collected molluscs and by-products/wastes from agricultural production and processing activities. Due to the intensification of fish farming and the introduction of new species, aquaculture has become more dependent on artificial feeds. The use of commercially manufactured pellets is becoming more popular, although farm-made feeds still play and enormously important role in Chinese aquaculture.

Because of the diversity of farmed species there are many different types of farm-made feeds. In general, farm-made or processed feeds can be classified into several categories.

3.2.1 Simple processed raw feed ingredients and natural food organisms

These feeds are commonly used in semi-intensive farming of marine fish, crabs and prawns and may include soaked soybean, maize and soybean/rapeseed cake, crushed molluscs, chopped trash fish or mussel meat, germinated barley, soybean milk and dregs.

3.2.2 Compound farm-made feeds

Some farmers produce a compound pellet using on-farm produced ingredients according to several formulations. Most of these feeds are nutritionally unbalanced. On the other hand, some very well balanced feeds are produced, especially for high value species such as eel, puffer fish and some marine fish species.

3.2.3 Custom made compound pellets

These feeds are made by small and medium-scale feed manufacturers who have specialized their operations such that they can make smaller quantities of feeds according to their own or their clients' formulation and specifications.

3.2.4 Comparison between farm-made feeds and industrially manufactured pellets

There are no statistical data on the proportional use of farm-made and commercially manufactured feeds in China. However, it is estimated that just less than 8 million tonnes of commercially manufactured aquafeeds were used in 2004. Farm-made feeds (all types, including the feeds made by small and medium-scale processors) therefore play a far more important role in aquaculture than industrial aquafeeds. It is not possible to provide an estimate of annual farm-made feed production and use. Export of aquafeeds from China is very limited and imports mainly comprise starter feeds for shrimp and eel. However, it is difficult to estimate total exports and imports.

In comparison to commercially manufactured feeds, farm-made feeds have certain advantages and disadvantages. The manufacture of farm-made feed usually requires more time because of primitive equipment with a limited production capacity. Most commercial feed manufacturers have established convenient retailing chains for farmers, except in remote areas with poor transport facilities. Farm-made feeds are often in the form of moist pellets, paste/dough or fresh or in other forms that can not be stored for as long as sinking or expanded (floating) pellets.

Farm-made/processed feeds and commercially manufactured feeds are often used for different species or in different practices. Practical feed conversion ratios of different

farm-made feeds are seldom compared and because of the different formulations and ingredients used it is difficult to compare the biological and economic efficiency of these feeds with commercially manufactured feeds.

3.3 Pond management techniques

As mentioned earlier, pond aquaculture is the most important practice in terms of aquaculture production. Many practical techniques to minimise feed costs have been developed by scientists and farmers and in particular these have focused on reducing feed use and improving feed utilization.

Fertilization

Pond fertilization throughout the culture cycle was a common practice in extensive and semi-intensive polyculture of carp species and, if applied appropriately, this practise can reduce feed requirements to a minimum. However, the trend of increasing intensification has led to significant increases in the use of artificial feeds, such that the role of fertilizers in pond aquaculture has become less important than before, especially during growout. However, fertilization is still the major approach to provide food during seed production operations of many species. The fertilization of ponds during the preparation phase is also still commonly practiced in carp and shrimp/prawn culture. Commonly used fertilizers in ponds include pig, chicken, duck manure, cow dung and green fodder. During pond preparation the base quantity is between 2 250–3 750 kg pig manure/ha and if ponds are fertilized during the production cycle then quantities ranging from 1 500–2 250 kg/ha are used for each application.

Inorganic fertilization is commonly practiced in many small irrigation reservoirs to enhance natural productivity and to increase fish production. N and P fertilizers are commonly used and the recommended dose is usually 0.5 mg/l for N and 0.05 mg/l for P.

Pond substratum management

Improving the pond substratum is another important management technique, which is directly related to feed management strategies. It usually consists of three activities, total drainage, sun drying and liming. These practices promote the decomposition of organic matter in the bottom soil and accelerate the release of nutrients soon after filling, leading to enhanced production of natural food organisms and a reduction in artificial feed requirements. Managing the pond substratum also results in improved water quality during the production cycle, particularly higher DO levels and this contributes to improved feed utilization and growth. Excessive bottom silt is mechanically removed. This minimises the accumulation of organic matter leading to improved water quality.

In super-intensive systems, especially for shrimp, the bottom is lined with plastic and central draining pipes are installed that enables the removal of all wastes produced during the culture cycle. Bottom aeration systems have also been introduced into super-intensive shrimp culture ponds (up to 20–30 tonnes/ha/cycle)

Water quality maintenance: aeration and water exchange

Feed utilization efficiency is highly influenced by water quality, especially DO levels. Aeration is the most commonly used method to maintain good water quality in semi-intensive and intensive culture practices. Three different types of aerators are commonly used in China, paddle-wheels, turbines and water jets. The former is commonly used in shrimp ponds and the latter two types are commonly used in fishponds. These range from modern types that are internationally available to ingenious home made devices (Figures 12, 13 and 14).

FIGURE 12
Paddle wheel aerators in freshwater semi-intensive culture pond of Pacific white shrimp, Suzhou city, Jiangsu province

FIGURE 13
Farm-made paddle wheel aerator used in brackish-water, semi-intensive shrimp culture, Beihai city, Guangxi Autonomous Region

FIGURE 14
Turbine type aerators and water pump in a freshwater semi-intensive culture pond of giant freshwater prawn, Gaoyou city, Jiangsu province

Water exchange is practiced only when water quality can not be effectively maintained through aeration or other methods and this is because it requires more energy and is subject to availability.

Use of beneficial micro-organisms

Since the late 1990s, new methods for water quality maintenance have been widely adopted in China and this involves the use of beneficial micro-organisms. Two types are commonly used, viz. photosynthetic bacteria and EM (effective micro-organisms). The micro-organisms have two major functions, viz. improvement of water quality and prevention of disease by decreasing the levels of NH_3 and NO_2 and increasing DO levels in the water. Some bacteria also directly improve feed utilization.

3.4 Feed formulation

Increased intensification in aquaculture has significantly increased the quantity of feed used. Many aquaculture practices are now entirely dependent on artificial feeds. To improve feed utilization, traditionally used raw feed stuffs (mostly by-products from grain processing and oil extraction) are being replaced by commercially manufactured compound feeds. Many of the formulations are considered confidential, although some commonly used ones are listed in Tables 24 to 34.

TABLE 24
Practical feed formulation for Nile tilapia

Ingredients	Ingredient composition (% dry matter)		
	Fry (0.1–1.0 g)	Fingerling (10–50 g)	Growout (>50g)
Fishmeal	50.0	12.0	4.0
Soybean meal	17.0	46.0	34.0
Wheat middling	4.0	30.0	30.0
Wheat meal	4.2	-	-
Corn	-	6.2	22.1
Corn gluten meal	12.0	-	-
Poultry by-product meal	2.0	-	6.0
Vegetable oil	-	3.6	0.5
Fish oil	1.0	-	-
Fish protein hydrolysate	4.0	-	-
Phosphate	-	1.4	2.6
Vitamin & mineral premix	0.5	0.5	0.5
Binder	-	-	0.01
Methionine	-	-	0.01
Proximate composition (% dry matter)			
Dry matter	91.0	90.0	88.3
Crude protein	49.5	35.0	28.5
Crude fat	13.0	12.4	11.9
Approximate cost (US$/tonne)	400	300	250

Source: You Yang, Jiangnan Feed Co. Ltd., Changshu city, Jiangsu province (pers. comm.)

TABLE 25
Practical feed formulation for grass carp and wuchang bream

Ingredient	Ingredient composition (% dry matter)	
	Fingerling	Growout
Corn	8.95	12.95
Wheat bran	10.0	11.0
Low-grade wheat flour	18.8	16.8
Soybean cake	14.0	5.0
Rape seed cake	41.0	51.0
Fishmeal	4.0	-
Binder	1.0	1.0
Growth and immune enhancing additive mix	1.25	1.25
Coarse powder*	1.0	1.0
Approximate cost (US$/tonne)	300	

*Mineral powder for better pelleting and ingredient mixing

Source: You Yang, Jiangnan Feed Co. Ltd., Changshu city, Jiangsu province (pers. comm.)

TABLE 26
Practical feed formulation for common carp, crucian carp and Nile tilapia

Ingredient	Ingredient composition (% dry matter)	
	Fingerling	Growout
Corn	6.9	10.0
Wheat bran	-	4.0
Low grade wheat flour	11.85	11.75
Soybean cake	32.0	27.0
Rape seed cake	40.0	41.0
Fishmeal	6.0	3.0
Binder	1.0	1.0
Growth and immune enhancing additive mix	1.25	1.25
Coarse powder*	1.0	1.0
Approximate cost (US$/tonne)	300	250

*Mineral powder for better pelleting and ingredient mixing

Source: You Yang, Jiangnan Feed Co. Ltd., Changshu city, Jiangsu province (pers. comm.)

TABLE 27
Practical feed formulation for turbot, flounder and red sea bream (growout)

Ingredient	Ingredient composition (percent dry matter)		
	Turbot[1]	Flounder[1]	Red sea bream[2]
Fishmeal	45.0	42	30
Hydrolyzed protein	5.0	10	
Blood meal	5.0		
Silage			4.0
Yeast	5.0	10	5
Groundnut/peanut meal	10.0	10	16
Soybean cake	10.0	10	16
Wheat flour	15.5	13	
Wheat middling			15
Fish oil	1.0		4
Calcium diacid phosphate	2.0	2	
Dicalcium monophosphate			2
Phosphatid	1.0	1.5	
Phospholipid			1.5
Choline	0.5	0.5	0.5
Vitamin mix	0.5	0.5	1.0
Mineral mix	0.5	0.5	1.0
Proximate composition (% dry matter)			
Dry matter	87.3	84.22	
Crude protein	47.6	45.5	
Crude lipid	7.1	7.03	
Ash	10.7	10.37	
Approximate cost (US$/tonne)	800–900	800–900	

Source: [1]Yellow Sea Fisheries Research Institute Feed Company, Qingdao, Shandong Province (pers. comm.); [2]Lei (2005)

TABLE 28
Practical feed formulation for eel (percent dry matter)

Ingredient	Glass eel 0	Glass eel 1	Black eel	Juvenile	Growout
White fishmeal	68.0	68.0	66.0	60.0	52.0
Red fishmeal	2.0	2.0	2.0	5.0	10.0
Popped soybean	-	-	-	4.7	7.2
Potato starch	20.0	20.0	10.0	-	-
Cassava starch	-	-	12.2	2.25	23.0
Hydrolyzed protein	1.2	1.2	3.5	3.5	3.5
Yeast	2.0	2.0	2.0	2.0	2.0
Calcium diacid phosphate	0.2–0.3	0.2–0.3	0.2–0.3	0.2–0.3	0.2–0.3
Vitamin	0.3	0.3	0.25	0.2	0.15
Mineral mix	1.0	1.0	1.0	1.0	1.0
50% chloridised choline	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5	0.3–0.5
Salt	0.2	0.2	0.2	0.3	0.3
Lysine	0.2	0.2	0.15	0.15	0.125
Methionine	0.1	0.1	-	0.1	0.075
Lysine	0.15	0.15	0.1	0.1	0.1
Growth enhancing agent	0.05	0.05	0.05	-	-
Casein		4.0	-	-	-
Fish meat protein	4.0	-	2.0	-	-
Approximate cost (US$/tonne)	1500–1600	1500–1600	1250–1400	1050–1200	950–1050

Source: He Yijing, feed manufacturer in Guangdong province (pers. comm.)

TABLE 29
Practical feed formulation for Pacific white shrimp, *Litopenaeus vannamei*

Ingredient	Ingredient composition (% dry matter)		
	Starter	Growout 2	Growout 3
Wheat meal	29.5	28.6	30.6
Soybean cake	15.0	15.0	15.0
Groundnut cake	11.0	16.0	16.0
Fishmeal	30.0	25.0	23.0
Squid meal	3.0	2.0	2.0
Shrimp bran*	0	1.0	1.0
Yeast	3.0	3.0	3.0
Bone meal	1.1	-	-
Calcium phosphate	2.0	2.0	2.5
Calcium diacid phosphate	1.5	1.5	2.0
Binder	1.2	1.2	1.0
Growth and immune enhancing additive mix	1.0	1.0	1.0
Fish oil	1.0	1.0	1.0
Sea salt	1.5	1.5	1.5
Lure agent	0.1	0.1	0.1
FRC**	0.1	0.1	0.1
Polysaccharide	0.1	0.1	0.1
High stability Vitamin C	0.1	0.1	0.1
Approximate cost (US$/tonne)	850–950	750–800	650–700

*By-product from shrimp processing industry; **a commercial herb additive for increasing resistance to disease and stress.

Source: You Yang, Jiangnan Feed Co. Ltd., Changshu city, Jiangsu province (pers. comm.)

TABLE 30
Practical feed formulation for flounder, shrimp, Nile tilapia and carp (percent dry matter)

Ingredient	[1]Flounder	[2]Shrimp	[3]Tilapia	[4]Carp
Fishmeal	45	27	12	6
Fish hydrolysates	5			
Blood meal	5			
Squid meal		3		
Shrimp bran		10		
Yeast	5	5		
Soybean meal	10	20	46	32
Peanut meal	10	20		
Rapeseed meal				40
Corn meal			3.5	8
Low grade wheat flour	13			11.5
Wheat middlings			30	
Wheat gluten meal		10		
Vitamin mix	0.5	1.0	1.0	1.0
Mineral mix	0.5	0.5	0.5	0.5
Lecithin		1.5		
Fish oil	5	2		
Vegetable oil			3.6	
Dicalcium phosphate	1		1.4	
Binder				1.0
Proximate composition (%)				
Crude protein	45.0	40.0	28.6	

Source: [1,2]Jin Haili Feed Co. Ltd, [3]You Yang Feed Co. Ltd, [4]Ying Hui Feed Co. Ltd (pers. comm.)

TABLE 31
Practical feed formulation for fleshy prawn, *Penaeus chinensis*

Ingredients	Ingredient composition (% dry matter)		
	Juvenile	Middle stage	Adult
Fishmeal	27	25	25
Soybean meal	40	40	40
Yeast	5	7	6.5
Shrimp bran*	10	10	12
Squad meal	3	3	1.5
Fish oil	2	2	2
Wheat gluten meal	10	10	10
Lecithin	1.5	1.5	1.5
Vitamin mix	1	1	1
Mineral mix	0.5	0.5	0.5
Approximate cost (US$/tonne)	470	460	450

*by-product from shrimp processing industry.

Source: Yellow Sea Fisheries Research Institute Feed Company, Qingdao, Shandong Province (pers. comm.)

TABLE 32
Practical feed formulation for giant freshwater prawn, *Macrobrachium rosenbergii*

Ingredient (%)	Ingredient composition (% dry matter)		
	Juvenile	Early growout	Late growout
Wheat bran	0	7.85	9.35
Low grade wheat flour	14.35	14.5	18.0
Soybean cake	32.0	23.2	22.5
Rape seed cake	15.2	22.0	21.6
Fishmeal	33.8	22.5	17.5
Coarse fishmeal	0	5.3	6.0
Shell meal	1.0	1.0	1.6
Binder	1.2	1.2	1.0
Moult promoting agent	0.2	0.2	0.2
Growth and immune enhancing additive mix	1.25	1.25	1.25
Coarse powder*	1.0	1.0	1.0
Average cost (US$/tonne)	850–1000	600	

*Mineral powder to improve pelleting and ingredient mixing

Source: You Yang, Jiangnan Feed Co. Ltd., Changshu city, Jiangsu province (pers. comm.)

TABLE 33
Practical feed formulation for oriental river prawn, *Macrobrachium nipponense*

Ingredient	Ingredient composition (% dry matter)		
	Juvenile	Early growout	Late growout
Wheat bran	-	6.95	10.0
Low grade wheat flour	19.25	18.5	15.75
Soybean cake	29.4	21.0	19.5
Rape seed cake	16.0	20.6	26.0
Fishmeal	23.3	19.0	11.3
Coarse fishmeal	5.4	6.5	4.2
Shell meal	3.2	3.8	4.8
Binder	1.2	1.2	1.0
Moult inducing agent	0.2	0.2	0.2
Growth and immune enhancing additive mix	1.25	1.25	1.25
Coarse powder*	1.0	1.0	1.0
Approximate cost (US$/tonne)	500	400	350

*Mineral powder to improve pelleting and ingredient mixing

Source: You Yang, Jiangnan Feed Co. Ltd., Changshu city, Jiangsu province (pers. comm.)

TABLE 34
Practical feed formulation for Chinese river crab

Ingredient	Ingredient composition (% dry matter)	
	Juvenile	Adult
Wheat bran	4.75	8.5.5
Wheat flour	13.5	17.5
Soybean cake	28.0	22.0
Rape seed cake	15.0	20.0
Fishmeal	26.0	20.0
Coarse fishmeal	6.0	4.5
Shell meal	3.1	4.0
Binder	1.2	1.0
Moult promoting agent	0.2	0.2
Growth and immune enhancing additive mix	1.25	1.25
Coarse powder*	1.0	1.0
Approximate cost (US$/tonne)	500	400

*Mineral powder to improve pelleting and ingredient mixing

Source: You Yang, Jiangnan Feed Co. Ltd., Changshu city, Jiangsu province (pers. comm.)

3.5 Feed preparation/manufacturing techniques

Farm-made feeds are commonly used in many kinds of aquaculture practices in China, especially in extensive and semi-intensive aquaculture systems. It is estimated that farm-made feeds account for about 40 percent of the country's aquaculture production and the remaining 60 percent are accounted for by natural feeds and by commercially manufactured feeds. This provides some measure of the importance of farm-made feeds. Although the use of commercially manufactured feeds is becoming more popular, farm-made feeds or feeds supplied by small producers are likely to continue to play a very important role in aquaculture in China for a long time to come.

Farm-made feeds have distinct advantages in that they are normally made from locally available ingredients, although this also has serious shortcomings. Many farm-made feeds are unbalanced and are presented in an unsuitable form, which usually results in poor ingestion, nutrient utilization, reduced production efficiency and deterioration of the culture environment. Moreover, due to limited on-farm storage facilities ingredients are not always properly stored, leading to rancidity and mould formation. Using such ingredients in feeds affects the growth and the health of fish.

Various traditional and recently improved techniques are used for the preparation and manufacturing of aquafeeds to enhance quality and water stability. Most feed ingredients are ground to a required particle size and mixing is normally carried out using specialized equipment that meet required mixing standards. Wheat and potato starch are generally used as binders to improve water stability, although special binders may also be used. After compounding the feed the mixture is normally steamed and if required this is done under pressure, particularly in the process of manufacturing floating feeds. Steaming (or cooking as practised by farmers) is very important for binding the feed and for improved nutrient utilization.

Many feed companies sell premixed formulations that are used by farmers either as is or are mixed with other ingredients such as trash fish and then processed into a suitable form. Micronutrient premixes are commercially available in China. In recent years, many special feed additives have been developed. These provide additional properties, e.g. a moult stimulating agent that has been developed for crustaceans. Immuno-stimulants are popularly used in feeds for species that are susceptible to diseases. Presently used immuno-stimulants include Chinese herb extracts and various polysaccharides. Growth enhancement agents are also used in aquafeeds for certain species.

FIGURE 15
Chopped trash fish for making compound feed for Chinese river crab, Suzhou city, Jiangsu province

FIGURE 16
Cooking of feed ingredient for preparation of farm-made feed, Dongping County, Shandong province

FIGURE 17
Commercial dry pellet used for giant freshwater prawn, Gaoyou city, Jiangsu Province

Various techniques are used to improve nutrient utilization of farm-made aquafeeds. Many feed stuffs such as trash fish and pumpkin are chopped (Figure 15) to make them more palatable. Trash fish and mussel meat (frozen or fresh) is minced, particularly for the early stage rearing of fish, shrimp/prawns and crabs. Minced fish is sometimes mixed with other feed ingredients and minced fish is also commonly used in the preparation of moist pellets or paste feeds.

Cooking is a commonly used method to improve the biological quality of certain feed stuffs, especially maize, barley and pumpkin (Figure 16). Cooked feed stuffs are often mixed with other ingredients such as trash fish.

Molluscs such as snails and clams are commonly used as feeds for crustaceans and some fish species such as black carp. The shells are usually crushed by special crushing/grinding machines prior to feed application. This process is often omitted for fish that are able to crush the shell without difficulty.

Many ingredients are ground to a fine powder for nursery operations and growout. The most typical example is grinding soybean or soybean cake to make soybean milk or a granular paste for nursery operations for several fish species. Grain feedstuffs (e.g. maize, barley, wheat bran, soybean/soybean cake) are usually soaked in water before they are fed to the fish or soaked and cooked to improve feed utilization.

The practice of germinating certain grains before application as feeds is most commonly used to meet the special requirement of certain species, e.g. germinated barley sprouts are fed to grass carp broodstock in early spring.

3.6 Feed presentation methods

Feed presentation methods in China are as diverse as the sector itself and vary with species, systems and the level of intensity. Some of the presentation methods are shown in Figures 18–23.

Commercially manufactured feeds are applied in the form of dry pellet (sinking or floating) or moist pastes (such as for eel) (Figure 17). In recent years, the use of floating pellets in intensive culture systems has become more popular. This is mainly because waste and environmental impacts are minimised and nutrient utilization is optimized.

Farm-made feeds are presented in different forms. Some feed stuffs are presented in their original form, such as aquatic weeds, terrestrial grasses and vegetables (Figure 18). Alternatively the ingredients are mixed and processed prior to feeding (Figures 20–22). Moist pellets are also used on some relatively large farms. The extruded moist pellets are usually kept at low temperatures before use. Live food fish are also used for some of the highly carnivorous species such as Mandarin fish. Live food fish such as mud carp and juvenile wuchang bream are either produced in the same waterbody or supplied to the target fish on a regular basis.

FIGURE 18
Green fodder grown on pond dyke for herbivorous fish, Gaoyou city, Jiangsu province

FIGURE 19
Trash fish used as feed for marine fish, Shandong province

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FIGURE 20
Cooked maize used as feed for Chinese river crab, Suzhou city, Jiangsu province

FIGURE 21
Paste feed for intensive culture of eel

COURTESY OF HE YIJING

Feed particle size varies according to the requirements of the life history stage or the species. Table 35 lists pellet sizes for some of the important aquaculture species at different stages.

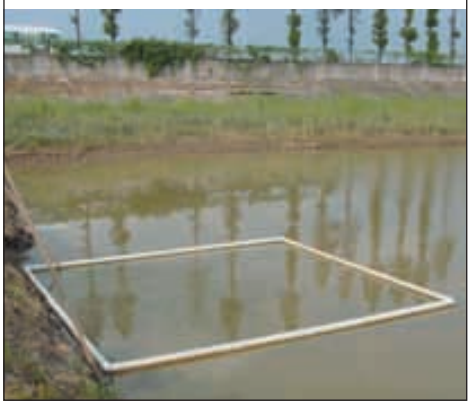
TABLE 35
Feed pellet size for some important aquaculture species in China

Species	Stage	Size standard	
		Diameter (mm)	Length (mm)
Common carp/ crucian carp	Fingerling	1.0–2.0	2.0–4.0
	Growout	2.0–4.0	4.0–7.0
Wuchang bream/ grass carp	Fingerling	1.0–2.0	2.0–4.0
	Growout	2.0–4.0	4.0–7.0
Nile tilapia	Fingerling	1.0–2.0	2.0–4.0
	Growout	2.0–4.0	4.0–7.0
Chinese river crab	Juvenile	1.0–2.0	2.0–3.0
	Growout	2.0–5.0	4.0–7.0
Oriental river prawn	Juvenile (crumble)	0.3–1.0	0.3–1.0
	Juvenile (pellet)	0.5–1.5	1.5–3.0
	Middle stage	1.0–2.0	2.0–5.0
	Adult	1.8–2.5	4.0–7.0
Giant freshwater prawn	Juvenile (crumble)	0.3–1.0	0.3–1.0
	Juvenile (pellet)	0.5–1.5	1.5–3.0
	Middle stage	1.0–2.0	2.0–5.0
	Adult	1.8–2.5	4.0–7.0
Pacific white shrimp	Juvenile (crumble)	0.3–1.0	0.3–1.0
	Juvenile (pellet)	0.5–1.5	1.5–3.0
	Middle stage	1.2–2.0	3.0–4.0
	Adult	1.0–2.0	2.0–5.0
Swimming crab	Growout	4.8–5.6	12–19

Source: various feed manufacturers (pers. comm.)

FIGURE 22
Preparation of semi-moist feed for crab by mixing cooked maize and chopped fish, Suzhou city, Jiangsu province

FIGURE 23
Floating feeding frame for application of green fodder in a pond, Gaoyou city, Jiangsu province



The feeding rate is very much dependent on the type of feed, water temperature and culture stage of the stock. Dry pellets are normally fed to finfish at 2–5 percent of body weight per day. Feeding rates for shrimp are much higher and usually range from 4–8 percent of body weight, while the feeding rate of herbivorous fish with green fodder can be as high as 10–20 percent of body weight per day. Daily rations are controlled through different means in the various culture practices. Although the daily ration is generally determined according to average fish weight and temperature, the actual amount is often adjusted according to the feeding behaviour and intensity of the fish. This is often assessed by checking the feed left over in feeding areas or on feed trays at a certain time after feeding. A commonly used feeding schedule for Nile tilapia is illustrated in Table 36, which also shows that ration is determined by the level of intensity.

Feeding frequency is dependent on the feeding habit of the species and the feed application method. In shrimp/prawn culture, animals are fed 4–6 times daily in the early stage of culture and later reduced to 3–4 times per day. If manual feeding is practiced then fish are normally fed 2–3 times per day. If automatic feeders are used then fish are normally fed 4–6 times a day. Frequent feeding can improve feed utilization.

Several feed application methods are illustrated in Figures 23–27. A floating frame is usually used in ponds for feeding with aquatic weeds, terrestrial grasses or vegetable leaves (Figure 23). The frames are commonly made of bamboo and confine the floating feed. Residues and uneaten material are concentrated on the bottom, under the frame, which facilitates easy removal. Feeding trays are also traditionally used for the application of sinking pellets and are also useful to monitor feeding intensity, adjusting the daily ration and to monitor fish health Figure 24).

TABLE 36
Feeding recommendations for different size classes of tilapia under different farming conditions

Fish weight (g)	Feed particle size (mm)	Feeding rate (% wet body weight)		Feeding frequency (time/day)
		Semi-intensive (<20 000/ha)	Intensive (>20 000/ha)	
<1	<0.5	30–10	-	To satiation
1–5	0.5–1.0	10–6	-	6
5–20	1.0–2.0	6–4	-	4
20–100	3.2	4–3	-	4
100–250	3.2–4.6	3	-	3
250–500	4.6	3–2	2–1.5	3
>500	4.6	2–1.5	1.5–1.3	3–2

Source: Yellow Sea Fisheries Research Institute, Chinese Academy of Fisheries Sciences (pers. comm.)

FIGURE 24
Feeding tray used for sinking feeds in a semi-intensive fish pond, Suzhou city, Jiangsu province

FIGURE 25
Semi-automatic feeder used in intensive fish pond, Gaoyou city, Jiangsu province

FIGURE 26
Feeding by broadcasting for tilapia in freshwater cage culture, Hepu County, Guangxi Autonomous Region

FIGURE 27
Broadcasting of trash fish in marine cages, Shandong province

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Feeding shelves are usually used in indoor re-circulating systems for application of dough or paste feeds, e.g. for eels. Semi-automatic and automatic feeders for dry sinking or floating pellets are now commonly used in intensive pond culture and cage culture (Figure 25). The feeders are set to deliver a certain amount of feed at pre-determined times. Broadcasting of feed over the water surface is a common feeding method used in intensive shrimp and prawn culture and during the early stages of fish nursery operations (Figures 26 and 27). It is performed by hand either from the pond dyke or from a boat.

4. THE DEVELOPMENT OF AUQAFEED INDUSTRIES IN CHINA

4.1 Background and historical development

China is currently the world's largest producer of industrially compounded aquafeeds. The bulk of the feed is manufactured for freshwater cyprinids. It is estimated that 40–45 percent of farmed fish in China are fed on industrially manufactured compound aquafeeds and about 8.0 million tonnes of commercial aquafeeds are produced annually. Currently, there are over 360 large and medium scale aquaculture feed manufacturers with an annual production of about 2.7 million tonnes. There are also a large number of small aquafeed mills that produce feeds on demand. Local and international research results provide the basic reference points for formulating commercial aquafeeds. Aquafeed technologies were introduced from Taiwan Province of China, Europe and the United States of America. Presently, aquafeed machinery is manufactured in China.

The development of China's animal feed industry started in the late 1970's. In May 1984, the State Council promulgated the "1984–2000 Outline of China's Feed Industry Development". This plan resulted in China's feed industry growing from practically nothing in 1975 to one of the worlds largest within two decades. The number of mills expanded to over 14 000 in 1985. State owned and managed mills constituted over 60 percent of all feed mills at the end of the 1980's. However, this has changed and most are now owned and operated by the private sector or by public/private joint venture companies. In 1976 the total annual output of compound animal feeds was 0.6 million tonnes. By 2002 production had increased to 56 million tonnes and by 2004 to 93 million tonnes.

Since the late 1980's the demand for compound aquafeeds has increased rapidly. At present there are more than 10 000 large, medium and small aquafeed mills to include that produce different feeds and additives. Most of the feed mills are located in coastal areas such as Guangdong, Fujian, Hainan, Guangxi, Zhejiang, Shandong, Liaoning, Shanghai and Tianjin and the feed output of these provinces account for more than 50 percent of total aquafeed production. Feed mills producing feeds for common freshwater fishes are located mainly in Sichuan province. By 2004, China produced over 8 million tonnes of compounded aquafeeds, which then accounted for 8.6 percent of total compound animal feed production. The aquafeed industry is the fastest expanding agricultural industry in China and is currently growing at over 30 percent per annum. The industry is also becoming more efficient as old and inefficient mills are closed and new mills are opened.

During the 1980s the Customs Bureau of China removed import levies on feed milling equipment and reduced the levies on many feedstuffs. By 1990 there were over 270 factories that manufactured feed milling equipment. The reduction in levies on feed stuffs led to the formation of joint ventures and the entry of foreign owned feed manufacturing firms from Thailand, United States of America, Japan, United Kingdom, Hong Kong and Taiwan Province of China. These changes have significantly influenced the industry by introducing new milling techniques, feed formulations, management methods and marketing practices. The competition within the aquafeed industry has also made the sector more efficient. Initially, aquafeeds were produced as a special feed line in existing livestock feed mills. This has obviously changed and extruded and floating aquafeeds made by specialist aquafeed mills have been commercially available since 1996. While compound feeds were initially only fed to high value export species such as marine shrimp, producers are expanding the use of compound feeds for other species as well.

Aquafeeds are manufactured in different forms and the nutrient composition depends on the species and stage of growth. Feed cost varies with quantity, quality and type of product (sinking or floating pellets, powder for soft feeds or microparticulate feeds for fry). At this juncture the bulk of the microparticulate feeds used in marine finfish aquaculture is imported. There are only five aquafeed mills that produce microparticulate diets for marine fish and output does not meet the demand.

4.2 Quality assurance and feed standard

The sharp increase in demand for aquafeeds in the 1980s and 1990s resulted in the shortage of feed ingredients and poor feed quality. Poorly formulated feeds and or improper manufacturing processes also resulted in low digestibility and poor water stability. Furthermore, the use of feed additives such as growth promoters, hormones and antibiotics was uncontrolled. To resolve these problems the Ministry of Agriculture now supports the National Center for Quality Supervision and Test of Aquatic Products and the aquafeed industry associations in feed quality assurance.

Under the new regulations, feed mills must secure a license before they are allowed to operate and must register the nutritional composition and value of their formulations.

Feed processing plants are inspected by the feed industry associations and by the National Center for Quality Supervision and Test of Aquatic Products. Sanitary tests are conducted and mills are inspected to ensure proper storage and use of raw materials and hygiene during the manufacturing process. Feeds are tested randomly to ensure that they meet the stipulated minimum and advertised standards. Products are also tested for antibiotic levels and hormone residues. Some feed standards are shown in Tables 37 to 40. To facilitate inspection and quality control of aquafeeds, national, provincial and district centres of feed quality control have also been established.

TABLE 37
Feed specification for fleshy prawn (*Penaeus chinensis*)

Number	Feed type/ class	Shrimp size (cm)	Pellet diameter (mm)	Pellet length (mm)
01	Starter	1.0–3.0	0.5–1.5	1.5–3.0
02	Grower	3.1–8.0	1.2–2.0	2.0–5.0
03	Finisher	>8.0	1.8–2.5	4.0–8.0

Source: MOA (2002)

TABLE 38
Guaranteed analysis of feed for fleshy prawn (*Penaeus chinensis*)

Parameters			Index
Pellet diameter	≤	0.425 mm	3
		0.250 mm	20
Degree of homogenity of mixing	≤		10
Water stability (leaching rate) (%)	≤		12
Moisture (%)	≤		11
pH			5.0–8.5
Crude protein (%)	≥		38
Crude lipid (%)			3–8
Crude fibre (%)	≤		5
Ash (%)	≤		16

Source: MOA (2002)

TABLE 39
Guaranteed analysis (%) of feed for flounder

Parameters		Starter pellet	Juvenile	Adult
Fish length (cm)		<5.0	5.0–15.0	>15.0
Leaching rate (%)	≤	4.0	4.0	4.0
Crude protein (%)	≥	50	45	40
Crude lipid (%)	≥	6.5	5.5	4.5
Crude fibre (%)	≤	1	2	3
Ash (%)	≤	15	16	16
Moisture (%)	≤	10	10	10
Ca (%)	≤	4	4	4
P (%)	≥	1.5	1.5	1.5

Source: MOA (2002)

TABLE 40
Technical specifications for formulated feed of eel

Feed grade		White eel	Black eel	Juvenile	Growout
Fish size, weight (g)		<0.5	0.5–2.0	2.1–15.0	>15
Physical and chemical characteristics (%)					
Mesh size (μm)	≤	200		250	
Degree of homogenity of mixing	≤	5.0	8.0	10.0	10.0
Leaching rate (%)	≤	4.0			
Crude protein (%)	≥	52.0	47.0	46.0	45.0
Crude lipid (%)	≥	3.0			
Fibre (%)	≤	0.8		1.0	
Moisture (%)	≤	10			
Ash (%)	≤	18			
Ca (%)	≤	4.6			
P (%)	≤	1.5			
Sand (%)	≤	2.0			
Sensory characteristic					
General appearances		Uniform color, without mould, deterioration, blocking and insects growth			
Visco-elasticity		Good extensibility after stirring	Good extensibility and visco-elasticity after stirring		

Source: MOA (2002)

TABLE 41
Fishmeal imports and exports for 1995–2004 (tonnes)

Year	Export	Import	Consumption
1995	3 367	690 050	686 683
1996	778	882 476	881 698
1997	1 488	985 234	983 746
1998	1 474	416 188	414 715
1999	1 308	631 271	629 963
2000	1 718	1 185 713	1 183 994
2001	1 690	901 696	900 007
2002	3 767	958 151	954 384
2003	4 160	800 251	796 090
2004	5 026	1 123 082	1 118 056

4.3 Exports and imports of feed ingredients and additives

As the aquaculture industry expanded imports of feed ingredients, mainly fishmeal, soybean meal and amino acids increased proportionally. Export and import volumes of fishmeal for 1995–2004 and soybean and three amino acids (glutamine, lysine and methionine) for 2000–2004 are shown in Tables 41 and 42. To promote the development of the aquaculture feed industry, relatively low tariffs are levied on the major imported raw materials in China.

TABLE 42
Soybean and amino acid imports and exports for 2000 to 2004 (tonnes)

Year	Soybean		Glutamic acid		Lysine		Methionine	
	Export	Import	Export	Import	Export	Import	Export	Import
2000	215 265	10 419 368						
2001	261 177	13 939 933	17 607	24 460	782	73 601	275	57 674
2002	305 365	11 315 348	37 167	14 757	974	81 351	186	53 805
2003	294 790	20 741 111	44 135	5 661	8196	75 488	263	72 867
2004	348 648	20 229 940	34 101	2 865	22954	76 475	454	85 819

For example, in 1999 import tariffs on fishmeal intended for aquafeeds was 3 percent, compared to 30 percent for aquatic products imported for human consumption. Similarly, import duties for soybean meal used for feed production were 40 percent, compared to 114 percent for soybean products imported for other uses. The import duty on fish oil is 30 percent. The preferential duties on important protein sources for animal feeds have had a positive effect on the availability and quality of feeds for aquaculture as well as for animal husbandry.

Presently China imports about 1.2 million tonnes of fishmeal per year, mainly from Peru, Chile and Russia to sustain its feed industry. About 75 percent of the imported fishmeal is used for aquafeeds. The annual local soybean production is about 15.5–17.55 million tonnes and China imports more than 20 million tonnes of soybean from the United States of America and Canada.

Additives such as vitamin and mineral premixes, stable vitamins, amino acids, chelated trace elements, mixed enzymes, phytase, probiotics, prebiotics, immunity stimulants, attractants, antioxidants and binders are ether locally produced or imported. Generally, most of the additives are produced in China although amino acids, such as glutamic acid, lysine, methionine and some vitamins are imported.

4.4 Shrimp feed industry

Rapid developments in the shrimp feed industry have contributed to the substantive harvests in recent years, particularly in the southern coastal regions of China. Shrimp farming in China was initially facilitated by breakthroughs in larval rearing technologies and latterly through the development of appropriate feeds. Early rearing stages depend on single cell algae (*Phaeodactylum tricornutum, Nitzschia closterium, Chaetoceros muelleri, Platymonas* spp. among others) and minced egg yolk and soybean milk are also used for larval rearing, followed by rotifers and *Artemia* nauplii. Most hatcheries are equipped with live feed culture facilities. Dried and powdered *Spirulina* is used in some hatcheries to substitute or supplement live microalgae. Other feeds, such as minced clam meat and yeast powder are also used separately or mixed. Presently, microparticulate and microencapsulated feeds are widely used in Chinese shrimp hatcheries.

Before the advent of compound feeds shrimp were fed on fishery by-products, such as low-value fresh trash fish, invertebrates and shellfish. These were abundant in the intertidal zone and shallow coastal waters and where fed either directly or after being chopped or crushed. Presently, all shrimp farmers use compound feeds with food conversion ratios of 1.2–1.6:1.

4.5 Freshwater fish feed industry

Approximately 70 percent of all aquafeed production in China is used for pond culture of grass carp, common carp, crucian carp an Nile tilapia. Many other feedstuffs such as rice bran, rapeseed meal, peanut meal, soybean meal and silkworm pupae are also used in earthen pond systems in combination with organic or inorganic fertilization. However, it is estimated that only 30 percent of carp are now reared on "traditional" feeds. As a consequence of the switch to compound feeds the carp production cycles are 20–25 percent shorter than they were 10 years ago and average FRCs are 1.5:1. Given the relatively low value of carp, feed formulation has become of pivotal importance in this highly competitive sector. The current carp growout formulations contain a variety of ingredients such as fishmeal, peanut meal, soybean meal, rapeseed meal and cotton seed meal. To remain competitive the feed manufacturing sector is very aware of the need to be flexible and to further reduce the fishmeal component of carp feeds. This will ensure the continued and long term sustainability of the sector.

4.6 The marine fish feed industry

Compared with freshwater fish production total marine fish aquaculture production is relatively small, but all are high value species. Marine fish in cages and in ponds are fed mainly on trash fish, farm-made feeds and extruded pellets, while large-scale industrial systems exclusively use extruded pellets. Farm-made feeds are made from commercial feed premixes (60–70 percent) that is mixed with trash fish (30–40 percent) to form soft pellet or dough. The moisture content of soft feeds is 25–30 percent.

As mentioned above, the type of feed is largely determined by the culture system. For example, since the 1960s aquaculture of olive flounder expanded rapidly and the species is now farmed intensively in land based flow-through systems, in cages as well as in ponds. In flow-through systems and to some extent in cages the fish are fed on pellets, while farm-made feeds consisting of premixed feed powders and a high proportion of trash fish are predominantly used in cages and in ponds. The high cost and reduced availability of trash fish is becoming problematic and the environmental impacts of using trash fish are well recognised and hence it is important to develop species specific feeds for the intensive production of marine fish. The detailed nutritional requirements of olive flounder have only recently been defined (Lei, 2005) and these findings provide the basis upon which a specific extruded flounder feed can be developed. Despite the absence of a specific formulated feed for flounder, over 40 percent of flounder is produced using formulated feeds. Olive flounder readily accept dry formulated feeds and FCRs of 1.2:1 have already been achieved. The development of specific formulated feeds will go a long way to ensure the future sustainability of the marine fish farming sector in China.

As with flounder, the farming of large yellow croaker (*Pseudosciaena crocea*), mainly in cages, is also largely dependent on the use of trash fish based farm-made feeds. Recent studies have shown that the use of trash fish affects flesh quality in yellow croaker. The basic nutritional requirements of large yellow croaker are known (Duan *et al.*, 2001) and an extruded diet for this species has been developed and is now widely used, with FCRs of 1.5:1. These two examples illustrate the changes that are occurring in the feeding of marine fish in China.

5. PROBLEMS AND CONSTRAINTS OF AQUACULTURE FEEDS AND FEEDINGS

The main trends in aquaculture development in China over the past two decades have been described in the preceding sections and can briefly be summarized as follows:

- There is a general trend towards intensification of farming systems. This is driven by the need to limit resource use and simultaneously to maximize production and return on investment.
- There is a clear trend towards greater species diversification. This is in response to changes in consumer preferences and the farmers' pursuance of better margins. Most of the species that have recently been introduced into aquaculture are generally dependent on artificial feeds.
- These trends have led to the increasing dependence on and demand for formulated feeds.

The overall growth of the sector and the trends described above have given rise to several major problems and constraints and these are:

- Availability and accessibility of aquaculture feed ingredients will become a major constraint, particularly in view of expected increases in production and the increasing use of artificial feeds.
- Accessibility to aquafeed ingredients (e.g. fishmeal, trash fish, soybeans) may become a limiting factor under certain circumstances.
- Reduced integration of fish with animal husbandry may create problems with respect to the availability of organic fertilizers.
- Because of competition for feed resources, aquaculture may become less competitive in relation to other sectors with higher economic returns.
- Poor quality farm-made feeds may affect feed utilization and efficiency.
- Improper feed application affects feed utilization and profit margins and has negative environmental impacts.
- Small and medium-scale farmers are affected by the increasing dominance of feed manufacturing companies and suppliers.

If these problems and constraints are not appropriately addressed they may negatively impact on the growth of the aquaculture sector and its sustainable development.

5.1 Availability and accessibility of feeds, feed ingredients and fertilizers

The most pressing constraint facing Chinese aquaculture is the future availability of and accessibility to feed ingredients. This constraint is fuelled by two major factors. First, while the growth rate of Chinese aquaculture has slowed down in recent years it is inevitable that production will and has to increase significantly in the coming years. According to the national fisheries development plan, by 2010 the per capita availability of aquatic products is expected to reach 44 kg. To meet this target, total fisheries production must reach 57.2 million tonnes, an increase of 8 million tonnes over the 2004 national production figure. Considering the stagnant or even slightly declining catches from capture fisheries, the increasing demand for aquatic products can only be met by aquaculture. For various reasons as outlined above, aquaculture will become more dependent on artificial feeds hence increasing the demand for core ingredients. By 2010, it is estimated that the demand for commercially produced aquafeeds will be 15–20 million tonnes, excluding farm-made aquafeeds. This is a 46–60 percent increase over the 2004/05 production of 8 million tonnes.

Secondly, China has a population of 1.3 billion people, increasing by approximately 17 million annually. It is an onerous task for China to meet the basic grain demands of its increasing population. It is also unlikely that the increasing demand for aquafeed ingredients can be met by national agriculture and fisheries production capacity. In addition, competition for feed ingredients of plant origin from the expanding animal husbandry sector will intensify and this will put further pressure on the supply side.

The future supply of fishmeal for the Chinese aquaculture industry will become increasingly problematic. In recent years the inclusion rate of fishmeal in aquafeeds has increased substantially to improve feed efficiency. This, coupled with the increased production levels of shrimp, prawns and fish, all of which have a high protein demand of animal origin has increased the demand for fishmeal significantly. National production of fishmeal is limited and most of the fishmeal used in China is imported. Presently, world fishmeal production is maintained at around six million tonnes. The increasing demand for fishmeal by China will therefore have a major and very significant impact on the balance of demand and supply in the world market.

Traditional aquaculture practices were closely linked to animal husbandry. Hence organic fertilizer was a very important input in production systems. This was convenient and practical in that it provided a means of increasing farm production through recycling of biological wastes. In recent years aquaculture has become more isolated from animal husbandry for various reasons. Most importantly the poor economic returns from improperly managed animal rearing activities have made these practices unviable. Moreover, small-scale animal rearing is gradually being replaced by large-scale, industrial operations. This reduces the traditional linkage between aquaculture and animal husbandry and also impacts on the supply of organic fertilizers. The inconvenience and additional transport costs in acquiring adequate quantities of manure is to now limiting the use of organic fertilizers in fish culture.

5.2 Economic and social constraints of feed resource use

Due to the rapid expansion of the animal feed industry, including the aquafeed industry, the increase in demand for feed ingredients has pushed market prices steadily upwards. According to data released by the Ministry of Agriculture, between 2002 and 2004 the price of maize increased by nearly 30 percent, soybean meal price by about 90 percent (up to US$360/tonne in 2004) and fishmeal by 10–15 percent in the same period. These significant price increases over a relatively short time period have impacted on the economic returns of farmers as well as feed manufacturers.

Despite concerted efforts by all role players to improve the quality of aquafeeds and their application, utilization efficiency is far from satisfactory and this results in excessive discharge of nutrients into the environment. The increasing use of commercial feeds in aquaculture has also resulted in greater public concern on the pollution of aquatic environments by aquaculture.

Improving the quality of aquafeeds to achieve greater feed efficiency, higher returns and reduced environmental impacts has become an urgent issue for the sustainable development of aquaculture in the country. The major challenge lies in improving feed quality without increasing costs. Major technical breakthroughs in the nutrition of cultured animals and feed manufacturing technology are, therefore, urgently needed.

5.3 Use of commercially manufactured pellet feeds by small and medium-scale aquaculture

The recent trend towards greater use of manufactured feeds has advantages and disadvantages. The advantages include greater convenience and offer farmers a greater choice with respect to species selection and also improved production efficiency and yield. On the other hand, the disadvantages of industrially manufactured feeds, especially for small and medium scale farmers, must not be overlooked and these are:

- reduced the usage of locally available resources, which are usually cheaper;
- increasing number of farmers abandoning traditional semi-intensive polyculture systems, which usually and often have sound ecological and economic benefits;

- breacking of the traditional linkage between aquaculture and other agricultural activities such as animal husbandry and horticulture, which promotes recycling of wastes and by-products;
- increasing dependence of farmers on feed manufacturers and retailers influences their production goals and decisions; and
- high input-high output production systems using pelleted feeds increases market risks to the farmers, especially when they are mislead by feed suppliers.

6. RESOURCE AVAILABILITY AND THE EXPANSION OF THE AQUACULTURE INDUSTRY

During the period 1980–1990 the average annual growth rate of aquaculture was around 10 percent and from 1999–2000 it was 11.1 percent. The future expansion of the aquaculture industry in China will largely depend on available resources (feed and fertilizers) and support facilities (science, technology, feedmills and improved life support systems).

6.1 Ingredient requirements

Because of their high nutrient density, formulated aquafeeds are among the most expensive animal feeds in the market. Their high cost is also largely attributable to the liberal use of expensive ingredients such as fishmeal and fish oil. Due to an increasing demand for aquafeeds and overfishing, the demand for fishmeal will exceed supply in the very near future. Hence there is a desperate need to assess and exploit new protein sources to replace fishmeal in artificial feeds as much as possible. This is particularly important for China, which has the largest aquaculture industry in the world but only produces a very limited quantity of fishmeal.

According to the China Fisheries Yearbook (2001) the total aquaculture production of 25.8 million tonnes in 2000 (excluding aquatic plants and seaweeds) consisted of 52.1 percent filter feeders, 26.4 percent omnivorous species, 12.3 percent herbivorous species and 4.5 percent carnivorous species. The production subtotal for omnivorous, herbivorous and carnivorous species therefore amounted to approximately 11.2 million tonnes (Table 43). If all of the former had been produced using compound feeds at a FCR of 1.5:1 then approximately 16.7 million tonnes of artificial feeds would have been required. At present, China has to import about 1.2 million tonnes of fishmeal a year for the animal feed industry and of which, aquafeeds use approximately 70 percent. If the annual production of aquafeeds reaches 16.7 million tonnes as calculated above, then China would need approximately 3.64 million tonnes of fishmeal per annum to sustain its current production of fish and crustaceans (Table 43). The carnivorous species consumed the largest proportion of the available fishmeal (71.1 percent of the total used in aquafeeds), followed by omnivorous species (17.3 percent), and herbivorous species (9.3 percent). In addition, about 4 million tonnes of trash fish are used as feed for marine finfish. To meet this theoretical demand is, quite frankly, impossible. The only way to sustain the required level of growth of aquaculture in China is to exploit new protein sources and reduce the fishmeal inclusion levels in feeds. However, significant reductions in dietary fishmeal inclusion levels will result in reduced feed palatability and production. It is therefore important for science to consider not only the possible essential amino acid imbalances but also to pay particular attention to feed attractants.

In 2004, freshwater fish were the biggest consumers of commercial feeds (accounting for approximately 70 percent of total aquafeed usage), followed by shrimp (10 percent). The main ingredients in freshwater fish and shrimp feeds are soybean meal, peanut meal and rape seed meal and on a combined basis their total inclusion level amounts to about 50 percent In 2003, the total production of common carp, crucian carp, tilapia, wuchang bream, black carp and grass carp was about 9.15 million tonnes. On the basis

of a FCR of 1.5:1 these fish consumed an approximate amount of 13.7 million tonnes of feed. Similarly, the production of 1.3 million tonnes of crustaceans in 2003 at a FCR of 1.5:1 would have consumed approximately 2.0 million tonnes of feed. This suggests that about 15.7 million tonnes of feed were consumed by freshwater fish and crustacean alone. However, in 2003 total commercial aquafeed production only amounted to some 7.8 million tonnes. Notwithstanding the fact that marine fish were not considered in this calculation it is clear that there is a substantial gap between the requirement for commercial feeds and actual production.

To predict the future feed requirements of the aquaculture industry we used data provided by the National Feed Industry Office (Table 44). It was calculated that freshwater fish will have the highest requirement and that marine fish species like flatfish, grouper, cobia, large yellow croaker, seabass and shrimp will eventually require substantial amounts of artificial feeds because of increasing production. It is also predicted that trash fish will be gradually replaced by artificial feeds in the coming ten years. At current growth rates the predicted total feed requirement for all sectors by 2015 is approximately 54 million tonnes (Table 44). Because not all fish farmers will be using artificial feeds by 2015 and because FCRs are expected to improve this estimate is considered as the upper maximum, but gives some inkling of the magnitude of the challenges faced by Chinese aquaculture.

To evaluate whether the available raw materials can sustain the requirements for the projected production increases, the feedstuff requirements and available resources are compared. The projected potential annual demand for feed ingredients by the animal feed industry is shown in Table 45, which shows that there will be a 43.2 million tonne shortfall for energy sources and a 25.2 million tonne shortfall for protein sources.

TABLE 43
The potential annual demand of fishmeal for aquaculture feeds in China (based on aquaculture production in 2000)

Feeding habits	Estimated production (million tonnes)	FCR (approx)	Feed production (million tonnes)	% fishmeal in feed	Requirement of fishmeal (million tonnes)
Carnivorous	1.16	1.5	1.74	40	0.70
Omnivorous	6.81	1.5	10.22	25	2.56
Herbivorous	3.17	1.5	4.76	8	0.38
Total	**11.14**		**16.7**		**3.64**

TABLE 44
Predicted production and feed requirement of major aquaculture species by 2015 (million tonnes)

Species	2004	2015	FCR	Feed requirement by 2015
Freshwater aquaculture	18.92	20.0	1.5	30.0
Mariculture	13.17	16.0	1.5	24.0
Total	**32.09**	**36.0**		**54.0**

Source: National Feed Industry Office, MOA, Beijing (pers. comm.)

TABLE 45
Projected potential annual demand of feed resources for animal feeds including aquafeeds by 2015

Source	2015		
	Requirement (million tonnes)	Available resources (million tonnes)	Demand shortfalls (million tonnes)
Cereals/energy sources	320.5	277.3	43.2
Protein sources	50.0	24.8	25.2

Source: National Feed Industry Office, MOA, Beijing (pers. comm.)

6.2 Fertilizer requirement

The role of fertilizers in pond culture has become less important than before, especially during growout. Fertilizers are still needed in extensive and semi-intensive ponds where natural food is required. It is predicted that the total pond surface area will remain relatively constant over the next 10 years and because fertilizer requirements

are calculated on the basis of surface area it is predicted that adequate quantities of organic and inorganic fertilizers will be available for the foreseeable future.

7. RECOMMENDATIONS FOR IMPROVED UTILIZATION OF FERTILIZERS AND FEED RESOURCES

Aquaculture has many advantages over other animal production sectors, such as high food conversion efficiencies, low surface area requirements and relatively high economic returns. Aquafeeds, in particular as well as fertilizers are among the most important limiting factors that will affect the expansion and sustainable development of the industry in the future. Greater efficiency in the use of feed and fertilizer resources is therefore required. The industry already faces several problems and constraints and others will emerge with time. Based on the preceding review, it is recommended that the following strategies and policy guidelines be implemented to address the challenges.

7.1 Development of new feed ingredient resources

China is a country with a huge population and relatively limited land resources. Competition for feed ingredients (especially for fishmeal and grains) will no doubt increase in the foreseeable future. Therefore, it is very important to develop new resources for aquafeeds.

In addition to commonly used feed ingredients such as maize, barley, soybean and groundnut cake, China currently produces over 50 million tonnes of rice bran and wheat bran, over 20 million tonnes of residues from distiller and brewery waste and over 30 million tonnes of potato, sweet potato and cassava. With appropriate technologies the use of high quality feed ingredients such as grains and oilseed cakes can be significantly improved. The utilization of plant proteins by aquatic animals is still inefficient, e.g. only 50 and 70 percent of the proteins in rapeseed and soybean cake are utilized. By improving the protein utilization of these ingredients by 20–30 percent would, for example, provide an additional supply of 1 million tonnes of high value ingredients.

In addition, by changing agricultural systems, special feed ingredient crops should be cultivated increase production within the existing constraint of available farm land. For example, growing green fodder on pond dykes and other scattered and unused land areas within farm boundaries can replace commercial feeds for herbivorous species.

7.2 Promote fish farming systems and practices that increase the efficient use of feeds and fertilizers

The Chinese aquaculture sector is characterised by highly diversified culture systems and practices. There is a growing tendency for farmers to abandon traditional and highly efficient aquaculture systems and practices in favour of simpler feed based systems with higher production levels. This is especially the case in relatively well developed areas where the use of fertilizers and locally available resources is decreasing and the use of commercial feeds is increasing. Farmers are not always aware of the fact that these changes have, in many instances, led to reduced feed efficiency and increased production costs. A typical example is that the FCR in super intensive shrimp farming systems is usually 20 and 10 percent higher than under semi-intensive and intensive farming conditions, respectively.

The adoption of aquaculture systems and practices with optimum feed and fertilizer utilization efficiency is a strategy that should be vigorously promoted. Practices that should be promoted include semi-intensive, pond based multi-species polyculture, integrated aquaculture in paddy fields, integrated fish farming (fish-crop-animal) and semi-intensive polyculture of shrimp, finfish, seaweed and molluscs in brackish-water ponds. Where monoculture is undertaken, farmers should be encouraged to use semi-intensive instead of intensive or super-intensive practices.

7.3 Promoting improved management practices

Improving the culture environment can play a significant role in improving feed utilization. For example, the FCR of grass carp under pond culture conditions at optimum temperatures increases 1.34 fold at DO levels below 3.4 mg/l compared with DO above 3.5 mg/l and feed intake is reduced by 35 percent compared with DO levels above 7 mg/l (source: http://www.china-fisheries.com/zhuanlan/displaytech.asp?sort=feed&id=3313, 2004).

Some new approaches have recently been adopted, such as the use of beneficial micro-organisms and aerators. However, some traditional and very effective methods, such as pond draining, sun-drying of the substratum, removal of excessive silt and clearing before restocking have been abandoned by many farmers due to various reasons. It is very important to encourage farmers to retain traditional pond management techniques to maintain good culture environments, especially with respect to the improvement of pond bottom conditions. In addition, other modern techniques and equipment should be more efficiently used to maintain water quality above certain standard thresholds. For example, aerators should not only be used in emergencies when DO levels are critically low but should be used to improve oxygen distribution when surface oxygen levels are high. The relatively higher cost of power is compensated for by the comprehensive benefits generated by improved feed utilization.

An approach that is currently receiving attention is the biological treatment of intensive aquaculture effluents that will enable water re-use. This may have significant future implications.

7.4 Strengthen scientific research and technology development

By improving feed manufacturing technologies and feed application techniques, it is possible to maximise the utilization of available feed resources. The following research and development priorities have been identified.

Comprehensive nutrition research

The industrial aquafeed industry in China is relatively new and is a sector that has to provide appropriate products for a hugely diverse and rapidly growing production sector. The absence of detailed research on the nutritional requirements of culture species imposes enormous challenges on the industry. Research is required on the nutritional requirements of cultured species at different stages of ontogeny and under different environmental and culture systems and practices. In particular, it is important to understand the utilization efficiency of different ingredients at different life history stages of the species, such that the most appropriate feeds can be formulated. Moreover, there is a need to better understand the feeding behaviour of fish and shrimp species under different culture practices and systems and ontogenetic stages.

Development and adoption of technology to improve the utilization of different feed ingredients

Feed manufacturing technologies have to be developed to improve nutrient utilization of different feed ingredients. Advanced processing technologies can significantly improve the acceptability and digestibility of feeds by altering the internal structure and providing appropriate physical features to the feed. These need to be developed.

Research on feed additives to improve feed utilization must also be promoted. In particular this research should focus on enzymes, essential amino acid, fatty acids, vitamins, minerals, immuno-stimulants and growth enhancing agents.

Although feed manufacturers produce over 100 different types of feeds for cultured species at different culture stages, the formulations are based on limited scientific research. In most instances the available feeds are simple adaptations of the formulations for similar species with minor modifications. Hence, more resources

should be invested by both the public and the private sector to strengthen the scientific basis of feed formulation and to develop new and innovative ingredient processing technologies

7.5 Improve on-farm feed application technologies

When aquafeeds are applied under certain conditions, the utilization of the feed is highly dependent on the application schedules and methods. While less wasteful feeding methods have been adopted by farmers in recent years, their feeding schedules are largely based on tradition and lack a scientific basis. Hence feeding rates, frequencies and feeding times vary greatly among and between farms and is manifest in highly variable production levels. There is a very real need to establish standard feeding schedules for various species at various life history stages under specific culture practices and environmental conditions.

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REFERENCES

BOF. 2005. 2004. China Fisheries Statistic Yearbook. Bureau of Fisheries. Beijing, Ministry of Agriculture. 122 pp.

Chang, Q., Liang, M., Wang, J. & Zhai, Y. 2004. Available amino acid and phosphorus of various feed ingredients for Japanese sea bass (*Lateolabrax* sp). *Marine Fisheries Research*, 2(25): 35–40.

Chang, Q., Liang, M., Wang, J., & Zhai, Y. 2005. Apparent digestibility coefficients of various feed ingredients for Japanese sea bass (*Lateolabrax Japonicus*). *Acta Hydrobiological Sinica*, 2(29): 172–175.

China Fisheries Yearbook. 2001. *China Fisheries Yearbook*, Vol. 8. Beijing, Chinese Aquaculture Publishing Company. pp. 243–247.

Duan, Q., Mai, K., Zhong, H., Si, L., Wang, X. 2001. Studies on the nutrition of the large yellow croaker, Pseudosciaena crocea R. I: growth response to graded levels of dietary protein and lipid. *Aquaculture Research*, 32 (Suppl., 1): 46–52.

FAO. 2006. FAO Fisheries Department, Fishery Information, Data and Statistics Unit. Fishstat Plus: Universal software for fishery statistical time series. Aquaculture production: quantities 1950-2004, Aquaculture production: values 1984-2004; Capture production: 1950-2004; Commodities production and trade: 1950-2004; Total production: 1970-2004, Vers. 2.30 (available at: http://www.fao.org/fi/statist/FISOFT/FISHPLUS.asp).

Fred, H. 2001. Feeding tilapia for sweet-tasting flesh and ready marketability. *International Aqua Feed*, 4(4): 12–19.

Lei, J. 2005. Marine fish culture theory and techniques. Beijing, China Agriculture Press, pp. 463–465.

Lei, W., Yang, Y. & He, X. 1996. Apparent digestibility coefficient of crude protein and energy for six commercial feed ingredients for Chinese long-snout catfish. *Acta Hydrobiological Sinica*, 2(20): 113–118.

Li, A., Song, X. & Lou, W. 1986. Effect of different protein level in feed of growth of fleshy prawn *Fenneropenaeus chinensis. Qilu Fisheries*, 3: 19–23

Li, A. 1990. Research progress on nutritional physiology of flesh prawn *Fenneropenaeus chinensis. Feed Industry*, 6: 25–29.

Li, A. (ed). 1996. Nutrition and feed of aquatic animals. China Agricultural Press, Beijing.

Lin, S., Luo, l. & Ye, Y. 2001. Apparent digestibility of crude proteins and crude fats in 17 feed ingredients in grass carp. *Journal of Fishery Sciences of China*, 3(8): 59–64.

Liu, Y., Zhu, Y. & Chen, H. 1990. Digestibility of black carp to fourteen fish feeds. *Fishery Information*, 6: 166–169.

Liu, L., Zheng, S., Zhao, B. 2004. Effects of different levels of squid viscera meal in practical feeds on growth performance of shrimp *Litopenaeus vannamei*. A Collection of the 3rd China Symposium on Aqua-animal Nutrition and Feed. pp. 98–105.

MOA. 1984. China Agricultural Year Book. Beijing, China Agricultural Press. 490 pp.

MOA. 1994. China Agricultural Year Book. Beijing, China Agricultural Press. 513 pp.

MOA. 2004. Analysis on situation and prospect of feed market in China in the 1st half of 2004 (available at http://www.agri.gov.cn/xxfb/t20040812_231786.htm).

MOA. 2004. China Agricultural Year Book. Beijing, China Agricultural Press. 508 pp.

MOA.2002. A collection of standard in feed industry. Beijing, China Standard Press. 387 pp.

Rong, C., Liang, S. & Yue, B. 1994. Protein and amino acid digestibility of sixteen feed ingredients for *Penaeus orientalis*. *Journal of Fisheries of China*, 2(18): 132–137

Wang, Q. & Wang, M. 2001. Feeds and feeding of Chinese shrimp. *International Aqua Feed*, 2(4): 11–14.

Wu, J., Yong, W., You, W., Wen, H. & Liao Z. 2000. Nutritional value of proteins in 13 feed ingredients for *Oreochromis niloticus. Journal of Fishery Sciences of China*, 2(7): 37–42.

Wu, J., Yong, W., You, W., Wen, H. & Liao, Z. 1995. Apparent digestibility and digestible energy of 12 feedstuffs for bluntnose black bream *(Megalobrama amblycephala* Yih). *Journal of Fishery Sciences of China*, 3(2): 55–62.

Ye, Y., Lin, S. & Luo, L. 2003. Apparent digestibility coefficient of 27 feed ingredients for grass carp. *Journal of Fishery Sciences of China*, 1: 60–64.

You, W., Yong, W., Wu, D., Wu, J., Liao, Z. & Wen, H. 1993. Evaluation of nutritive value of 11 feed ingredients for black carp (*Mylopharyngodon piceus*). *Freshwater Fishery*, 23: 8–12.

APPENDIX

Appendix A. Aquaculture species in China

A.1. List of major aquaculture species in China

Common name	Scientific name
Amberjacks	*Seriola spp*
Bighead carp	*Aristichthys nobilis*
Black carp	*Mylopharyngodon piceus*
Black tiger shrimp	*Penaeus monodon*
Catfish	*Clarias leather*
Channel catfish	*Ictalurus punctatus*
Chinese long-snout catfish	*Leiocassis longirostris*
Chinese river crab/Chinese mitten-handed crab	*Eriocheir sinensis*
Cobia	*Rachycentron canadum*
Common carp	*Cyprinus carpio*
Crucian carp	*Carassius carassius*
Estuarine tapertail anchovy	*Coilia ectenes*
Fleshy prawn	*Penaeus chinensis*
Giant freshwater prawn/giant river prawn	*Macrobrachium rosenbergii*
Goldfish	*Carassius auratus auratus*
Grass carp/white amur	*Ctenopharyngodon idella*
Grouper	*Epinephelus spp.*
Japanese eel	*Anguilla japonica*
Japanese shrimp/kuruma prawn	*Penaeus japonicus*
Large yellow croaker	*Pseudosciaena crocea*
Largemouth bass	*Micropterus salmoides*
Mandarin fish/Chinese perch	*Siniperca chuatsi*
Mozambique tilapia	*Oreochromis mossambicus*
Mud crab	*Scylla serrata*
Nile tilapia	*Oreochromis niloticus*
North African catfish	*Clarias gariepinus*
Olive flounder	*Paralichthys oliuaceus*
Oriental river prawn	*Macrobrachium nipponense*
Pacific white shrimp/white-leg shrimp	*Litopenaeus vannamei*
Polack/pollack bone frame	*Pollachius pollachius*
Puffer fish	*Fugu spp*
Red drum	*Sciaenops ocellatus*
Red sea bream/sea bream	*Pagrus major*
Seabass/Japanese seaperch/perch	*Lateolabrax japonicus*
Silver carp	*Hypophthalmichthys molitrix*
Snakehead	*Ophicephalus argus, Channa spp.*
Soft-shell turtle	*Trionyx sinensis*
Swamp eel/mud eel	*Monopterus albus*
Swimming crab/gazami crab	*Portunus trituberculatus*
Turbot	*Psetta maxima*
Walking catfish	*Clarias batrachus*
Wuchang bream/white amur bream/bluntnose black bream	*Megalobrama amblycephala*

Appendix B. Nutrient requirements of selcted aquaculture species

B.1. Dietary essential amino acid requirements of fleshy prawn and red sea bream (g/kg diet)

EAA	Fleshy prawn	Red sea bream
Methionine	12.4	5.3
Threonine	17.8	4.1
Valine	21.4	8.0
Isoleucine	17.6	2.0
Leucine	29.3	10.5
Phenylalanine	14.7	33.7
Lysine	31.0	23.9
Tryptophan	3.2	-
Histidine	8.6	4.0
Arginine	40.0	4.7

Source: Wang and Wang (2001) for fleshy prawn and Lei (2005) for red sea bream

B.2. Dietary vitamin and trace mineral requirement for fleshy prawn *P. chinensis* (mg/kg of diet, unless otherwise specified)

Vitamin	Requirement
A	12 000-18 000 IU
D	6000 IU
E	36–44
K	3.2–3.6
B_1 (Thiamine)	6
B_2 (Riboflavin)	10-20
B_3 (Nicotinic acid)	40
B_5 (Calcium pantothenate)	10
B_6 (Pyridoxine)	14
B_7 (Biotin)	0.08
B_9 (Folic acid/pteroylglutamic acid)	0.5
B_{12} (Cyanocobalamin)	0.001–0.002
C (LAPP 15%)	400
Inositol	400
Choline chloride	400
Trace mineral	
Selenium	20
Copper	30
Cobalt	30
Zinc	100–200
Iodine	30
Manganese	60–80

Source: Wang and Wang (2001)

B.3. Dietary vitamin and mineral requirements of Nile tilapia (mg per kg diet unless otherwise specified)

Vitamin	Amount
B_2 (Riboflavin)	5–6
B_3 (Niacin)	6–10
B_{12} (Cyanocobalamin)	NR
C	40–125
D	375 IU
E	25–100
Choline	NR
Mineral	
Calcium	0.7%
Manganese	2.5
Phosphorus	0.45–0.9%
Zinc	20–30

NR = no requirement established.

Source: Fred (2001)