# USE AND FUTURE PROSPECTS FOR USE OF SOY PRODUCTS IN AQUACULTURE

**Michael C. Cremer, Ph.D.**
**Technical Director – Aquaculture**
**American Soybean Association**
**Room 902 China World Tower 2**
**No. 1 Jianguomenwai Avenue**
**Beijing 100004, P.R. China**

## ABSTRACT

Aquaculture has been the fastest growing agricultural sector for more than a decade and has become a significant contributor to global fisheries production. In 1996 aquaculture supplied approximately 73% of freshwater fish, 57% of mollusc, 43% of diadromous fish, and 17% of crustacean production worldwide. Projected population growth and static landings of capture fisheries indicate a need for aquaculture production to double by 2025 from its 1996 output of approximately 26 mmt.

Industry use of feed-based production technologies is anticipated to rapidly increase demand for manufactured aquafeeds. Production of manufactured aquafeeds grew in excess of 30% annually in recent years. Growth in manufactured aquafeeds has been particularly strong in China, where aquafeeds are forecast to increase to 20% of market share of 100 mmt of premixed animal feed production by 2005. It is expected that strong demand for feed resources by the aquaculture industries of Asia, and particularly China, will significantly impact future world commodity markets and feed prices.

Soybean products have become the focus of protein substitution in aquafeeds for every fed aquaculture species. Soybeans have the best amino acid profile of all protein-rich plant feedstuffs for fish. Soybean production can be structured to meet demand, and soybean meal is considerably less expensive and more consistent in quality than traditionally used marine animal meals. Research has demonstrated that soybean products can supply a major portion of the feed protein for nearly every fed aquaculture species around the world. Inclusion rates of up to 50% in aquafeeds for freshwater fish are projected to stimulate a demand for more than 6 mmt of soybean meal in China alone by 2005.

The use of soy products in aquaculture is projected to increase significantly. Aquaculture will benefit from genetic improvements in soybeans and advances in feed processing and related technologies. High lysine, methionine and phytase soybean varieties currently under research will allow greater inclusion levels of soybean meal in aquafeeds. Processing advances in the removal of anti-nutritional factors will improve soybean utilization by aqua species. Research on attractant additives and synthetic flavorings will broaden opportunities for soybean product use in aquafeeds. Collectively these advances will result in greater demand for soybean products in all sectors of the aquaculture industry.

## INTRODUCTION

Aquaculture has been the fastest growing agricultural sector globally for more than a decade. Its global growth has outstripped that of livestock husbandry by a factor of two to four. In 1985, the International Aquaculture Foundation forecast that aquaculture production would increase from 12 million metric tons (mmt) to 18 mmt by the year 2000[1] (IAF 1985). In fact, production surpassed 18 mmt in 1994 and is now forecast to exceed 30 mmt by 2000.

Aquaculture will play an increasingly significant role in supplying fishery products to global consumers in the future. Demand for fishery products continues to increase. Global per capita consumption of fishery products has increased approximately 10% since 1985 to its current level of about 13.5 kg per annum (New 1997). If per capita consumption remains static at 13.5 kg, population growth alone will require an additional increase in global fishery production of approximately 34 mmt by 2025.[2] Each 1.0-% increase in per capita consumption over the current level will increase demand by an additional 1.1 mmt.

Where will this additional 34+ mmt of annual fishery production come from? The long-term sustainable harvest from ocean capture fisheries is estimated to have peaked at its current level of about 100 mmt annually, 60% of which is fish for human consumption. There is little expectation that capture fishery landings will increase in the future. Some capture fisheries have already surpassed maximum sustainable yield and are in decline from excessive fishing pressure, pollution and other factors. With minimal opportunity to expand capture fishery landings, the increased production can only come from aquaculture. Meeting this demand will require a doubling of current aquaculture production (Figure 1). This offers tremendous opportunities for aquaculture producers, feed manufacturers and associated product suppliers. It also presents significant challenges to all sectors of the industry.

## AQUACULTURE PRODUCTION

Aquaculture has become a significant contributor to total global fisheries production, supplying approximately 73% of freshwater fish, 57% of mollusc, 43% of diadromous fish, 17% of crustacean, and 0.7% of marine fish production in 1996 (Figure 2). Global aquaculture production for 1996, the latest year for which data is available, was reported by FAO to be 26.4 mmt, not including aquatic plants (Tacon 1998). Asia produced nearly 90% of this aquaculture production, followed by Europe (5.4%), Latin America (2.0%), North America (1.8%), Africa and the Middle East (0.6%), and Oceania (0.3%)(Figure 3).

Nine of the top ten aquaculture producing nations in the world are within Asia (Table 1). China is the largest producer of aquaculture products by a large margin (18.6 mmt in 1996), supplying over 70% of Asian and 63% of global production. China leads in both freshwater and marine aquaculture production. Growth within China's freshwater aquaculture industry averaged 18.4% annually for the past 5 years (1993-1997)(Table 2), and production is expected

[1] Production excluding aquatic plants

[2] The United Nations projects an increase in global population from 5.7 billion in 1995 to 8.3 billion in 2025 (New 1997).

to reach 20 mmt by 2005 (Cremer et. al 1998). India, the second largest aquaculture producer, Thailand and Bangladesh had average annual aquaculture growth rates in excess of 10% for the period 1984 to 1996 (Table 1). Growth rates for two other top-ten producers, the Philippines and Indonesia, were 6.7% and 8.1%, respectively, for the same period.

Global aquaculture is currently dominated by the production of freshwater carps in Asia. Silver, grass, common, bighead, crucian, roho, catla and mrigal carps comprise eight of the top eleven aquaculture species worldwide (Table 3)(Tacon 1998). Production of fed fish species is increasing as a percentage of total production, while production of filter feeding species is declining. Annual production increases for the filter feeding species (primarily silver and bighead carps) for the period 1984 to 1996 averaged 10.6%, while increases in fed species production for the same period exceeded 17%. Feed-based production of carps, tilapias and other species is expanding rapidly in China in particular, in response to increases in living standards, changes in consumer product preference, and sustainability issues related to the environment. The Indian major carps (roho, catla and mrigal) are largely still cultured using fertilizers and feed ingredients as the nutrient base, but all three of these species can be fed.

In the regions outside of Asia, salmon, catfish and a variety of mussels, clams, oysters and other molluscs are the dominant culture species. Aquaculture in Europe is dominated by salmon production in Norway and the UK (424,000 mt combined), and mollusc production in France, Spain and Italy (557,000 mt combined). North American production is led by catfish and trout culture in the U.S. (231,000 mt), and mollusc production in the U.S., Mexico and Canada (155,000 mt combined). Within Latin America, Chile leads with its production of salmon (199,000 mt), followed by shrimp production in Ecuador (109,000 mt). Egypt is the leading producer of aquaculture products in Africa and the Middle East with 76,000 mt of freshwater and marine fish. Oceania production is dominated by mollusc culture in New Zealand (68,400 mt). All production figures are for 1996 (Aquaculture Magazine 1999).

## AQUAFEED PRODUCTION

The production of manufactured aquafeeds has been one of the fastest growing agribusiness sectors in the world, with growth rates in excess of 30% annually in recent years (Tacon 1998). This is largely the result of a growing trend in Asia toward the adoption of feed-based technologies for the production of high demand food fish for domestic markets. There has also been steady growth in feed-based production of high value species for niche and export markets.

Growth in manufactured aquafeeds has been particularly strong in China. China was the world's second largest manufacturer of animal feeds in 1996. Aquafeeds accounted for an estimated 9% of total premixed animal feed production of 55 mmt in 1996, and are forecast to grow to 20% of market share of 100 mmt by 2005 (PROMAR et al. 1996; Zhang 1996). Freshwater aquaculture producers in China are rapidly shifting to feed-based production technologies, both in response to increasing market demand for feed-taking species and as a means to increase profitability. Traditional polyculture, backyard fish culture and similar production systems that depend on manures and low-grade nutrient inputs are expected to contribute very little to future growth in the China aquaculture industry. It is expected that the trend to manufactured feeds will also quickly transfer to the coastal aquaculture sector in China. Demand for cultured marine products is growing rapidly. China's coastal aquaculture sector currently utilizes wild caught marine fish as food for 90% or more of cultured fish, and for up to 50% of cultured shrimp. An estimated 3 mmt of wild caught fish, representing more than 20% of China's total marine capture production of 13.9 mmt, were used in 1997 by the coastal aquaculture industry to produce 358,000 mt of fish and shrimp (Schmittou 1998). The use of wild caught fish by this industry is not sustainable. A shift to manufactured feeds will be essential in the near future in response to issues of disease, economics and environmental impact.

No organization collects data on global aquafeed production, and feed production estimates have varied considerably. The most recent report from FAO estimated compound aquafeed production for 1995 at 8.6 mmt, and projected aquafeed production would increase to 15.6 mmt by 2000 (Tacon 1998). These estimates were extrapolated from global aquaculture production statistics. The present author estimates aquafeed production in China will exceed 21 mmt by 2005. This projection is based on the use of manufactured aquafeeds to produce 49% of 20 mmt of freshwater aquaculture and 90% of 1.8 mmt of coastal aquaculture production by this date. Irrespective of the accuracy of these projections, it is expected that strong demand for feed resources by the aquaculture industries in Asia, and particularly China, will significantly impact future world commodity markets and feed prices.

The primary consideration of any farmer is profitability, and for aquaculturists, the primary cost of production is feed. Aquafeeds have traditionally used high levels of fish and other marine animal meals to meet the protein requirements of aquaculture species. Pike (1998) estimated the percentage of fishmeal in aquafeeds in the mid-90s for the major species groups to be 4-5% for catfish, 15% for carp, 25-30% for shrimp, 35-40% for trout, 45-55% for salmon, 50% for eels and 60% for marine species. However, static supply of marine animal meals has driven costs ever higher and made them the most expensive component of aquafeeds. The economic impact has been significant, as the above species groups collectively account for over 52% of global aquaculture output and utilize essentially all of the world's current aquafeed production.

To maintain profitability, a common goal in the production strategy for every fed aquaculture species has become the replacement of expensive marine animal proteins in feeds with more cost efficient plant proteins. Soybean protein has been identified as having the best amino acid profile of all protein-rich plant feedstuffs for meeting the essential amino acid requirements of fish (Lovell 1991). Soybean meal is considerably less expensive than marine animal meals, can be made consistent in quality, and production can be structured to meet demand.

## SOY PRODUCTS IN AQUACULTURE

Demand for soybean meal for livestock, poultry and aquaculture feeds has become the most important factor impacting global soybean production and prices (Baize 1998). For aquaculture, soybean meal has become the focus of protein substitution for every fed species.

Research and practical field tests have shown that soybean meal can be used as the primary protein source for most freshwater fish species, and as a significant protein source for nearly every fed aquaculture species around the world. Following is a synopsis of soybean utilization opportunities for the major aquaculture species groups.

**Carps**

Studies by the American Soybean Association (ASA) in China have demonstrated that soybean meal can fully replace fishmeal in growout feeds for a variety of omnivorous carp species, and that it can be incorporated at up to 50% in properly formulated rations (Schmittou et al. 1995a/1995d/1995e; Cremer et al. 1997a/ 1997b/1998a/1998b/1998c). ASA field tests conducted from 1995 to 1998 showed all-plant protein growout diets with 50% soybean meal produced equivalent or better growth and higher economic return than comparative diets containing 5-10% fishmeal with the common (*Cyprinus carpio*), crucian (*Carassias auratus gibelio*), grass (*Ctenopharyngodon idella*), black (*Mylopharyngodon piceus*) and wuchang (*Megalobrama amblycephala*) carps. Together these five species accounted for 5.8 mmt, or 47%, of China's 12.4 mmt of freshwater fish production in 1997. Production of freshwater carps in China currently offers the largest single potential market in the world for soybean-based aquafeeds. Chinese producers are rapidly shifting to feed-based production technologies and feed manufacturers are gradually replacing fishmeal-based diets with soybean-based diets based on cost efficiency. Full replacement of fishmeal with soybean meal generated savings of more than 30% in ingredient costs in a 32% protein carp diet in China, based on October 1998 ingredient costs (Figure 4).

Soybean meal can also serve as the primary protein source in fingerling diets for carp. Field tests in China in 1994, 1997 and 1998 with diets containing 37-45% soybean meal and 10% fishmeal produced excellent growth for advanced fry to fingerlings of black, common, crucian, grass and wuchang carp (Schmittou et al. 1995b/1995c; Cremer et al. 1998d/1998e; Cremer et al. 1999a/1999b/1999c). Field tests underway in 1999 will determine if fingerlings of these species can be weaned to an all-plant protein diet with 50% soybean meal at an intermediate stage in the fingerling production cycle, i.e. at approximately 20-25 g for fingerlings targeted to be grown to 50-100 g. This would offer significant feed cost savings to fingerling producers.

It is probable that the three Indian major carps can also be produced with soybean-based aquafeeds. With an annual production exceeding 1.3 mmt, the Indian carps may represent a significant potential market for soybean meal through the application of feed-based technologies following a model similar to that being adopted in China. Such a transition to feed-based aquaculture may become critical to India in the future as they face mounting water availability and environmental degradation issues. Properly applied feed-based aquaculture can result in significant improvement and sustainability of water quality within aquaculture systems in comparison to traditional, low-grade nutrient culture techniques.

**Tilapias**

Nile tilapia and its hybrids are the sixth ranking aquaculture production species in the world (Table 3), although numerous species of tilapia are cultured worldwide. China, Southeast Asia, and Egypt are the largest producers of nile tilapia, with China producing approximately 65% of global output in 1996. Like the carps, omnivorous tilapia can be cultured with all-plant protein feeds containing up to 50% soybean meal. ASA/China field trials conducted from 1993 to 1997 demonstrated high production and economic returns with soybean based diets (Schmittou et al. 1995d/1995e/1995f; Cremer et al. 1997a/ 1997b/1998f/1998g).

**Catfish**

The omnivorous freshwater catfishes are able to effectively utilize soybean meal as the primary protein ingredient in manufactured feeds. Soybean meal has steadily replaced fishmeal in channel catfish feeds in the United States, and most catfish rations now contain less than 5% fishmeal. Robinson et al. (1998) demonstrated that animal protein was not required in channel catfish diets containing 28% or more crude protein and 35% to 56% dehulled soybean meal. Channel catfish pond and cage studies conducted by ASA in China during 1997 and 1998 also demonstrated that soybean meal could fully replace fishmeal in extruded, growout rations for this species (Cremer et al. 1998h; Cremer et al. 1999d/1999e). Soybean meal now comprises 50% of ASA catfish rations in China. Other studies by ASA have demonstrated rapid fry to fingerling growth, high survival and good feed conversion for channel catfish and Yangtze River longnose catfish (*Leiocassis longirostris*) with a diet containing 45% soybean meal and 10% fishmeal.

**Salmonids**

Salmonids differ from the omnivorous carps, tilapias and catfishes in that they are typically carnivorous and have higher protein and amino acid requirements. As a result, most efforts to replace marine animal meals in salmonid diets focus on the use of soy protein concentrate (SPC). SPC has excellent potential as a fishmeal substitute due to its high protein content, good amino acid profile, negligible levels of indigestible soybean carbohydrates, and low phosphorus content (Weede et al. 1997). The aqueous alcohol leaching method to manufacture SPC removes or significantly reduces anti-nutritional and heat stable saponins, oligosaccharides and lectin. The low phosphorus content of SPC may be of particular value in the future to help reduce the pollutant content of aquatic effluents. SPC proved to be an acceptable substitute for up to 75% of menhaden fishmeal in diets for rainbow trout when supplemented with essential amino acids (Harold et al. 1998).

Dehulled, solvent-extracted soybean meal has a digestion coefficient equal to or greater than whole fishmeal protein, and is reported to be 85% digestible by rainbow trout (Lovell 1991). However, it lacks sufficient energy to be used in large quantities in salmonid diets. Extruded, full fat soybean meal has been used successfully in some trout diets (Chin et al. 1997). The additional fat in full fat soybean meal is probably more beneficial to salmonids than standard plant protein meals, as salmonids do not utilize the less expensive carbohydrates from grains well for energy (Lovell 1991). Trials with enzyme modified soybean meals or soy flour where the carbohydrates were either removed or made more digestible have also given encouraging results with salmonids.

**Marine Shrimp**

In 1996, shrimp farms provided approximately 30% of world shrimp production and utilized an estimated 1.1 mmt of aquafeed. This industry has depended heavily on marine capture fisheries to supply the protein and lipid components of commercial shrimp feeds. An estimated 20-25% of most commercial shrimp feeds are in the form of marine fishery products, including fish, shrimp and squid meals, and fish oil. Increasing concern about the long-term availability and cost of these ingredients strongly suggests that second generation shrimp feeds will need to reduce their dependence on these feed ingredients (Tacon et al. 1998).

Soybean meal can be an effective replacement for at least a portion of marine animal meals in shrimp feeds. Soybean meal has higher protein and amino acid digestibility values for shrimp than fish, squid or shrimp meal, but its lower levels of energy restrict its use for full replacement of marine animal products (Akiyama 1991a). Akiyama (1991b) reported that *Penaeus monodon*, *P. japonicus* and *P. vannamei* are able to digest soy protein very efficiently, and that soybean meal is palatable to these shrimp species. Tests with marine shrimp feeds for *P. monodon* showed equivalent growth performance with a feed formulated with 40% of protein from soybean meal and 28% from animal meals compared to a 50% animal protein feed with only 20% soybean meal (Akiyama 1991a).

A variety of factors hinder complete replacement of marine animal meals in shrimp diets. Marine meals contain higher levels of energy, essential amino acids, essential fatty acids, phospholipids, cholesterol, minerals and attractants, in comparison to plant protein meals. Many of the nutrient differences between plant and animal protein meals can be resolved by supplementation with synthetic amino acids, trace minerals and oils. However, the nutritional requirements of the various shrimp species and the impact of age, size, and environment on these nutritional requirements are currently poorly understood and complicate the formulation of shrimp diets. Of critical concern when using supplements is their water stability in pelleted feeds. While fish may consume pelleted feeds within minutes, shrimp feeds may be immersed for one to several hours before consumption. The longer the feed immersion before consumption the greater the reduction in nutritional value, as a result of leaching of critical vitamins, minerals and free amino acids. This is a particular problem with starter feeds because the greater surface to volume ratio of small feed particles accelerates diffusion. Improvements in the water stability of feeds containing costly supplements and technology advances that reduce the cost and increase the availability of synthetic amino acids will facilitate the increased use of soy products in shrimp diets (Chamberlain 1995). Current soybean meal inclusion rates of 15-20% will likely increase by 50% or more in the future as the dietary requirements of shrimp under practical farming conditions become better understood.

**Marine Fish**

The production of marine fish in coastal aquaculture systems will likely be the fastest growing sector of the global aquaculture industry in the future. Coastal aquaculture will gain in importance both because of increasing demand for marine products and because suitable land and water resources associated with freshwater environments will become increasingly scarce (Stickney 1998). Doubling of current aquaculture production to meet global fishery demand by 2025 will depend heavily on the ability of the industry to expand marine fish production.

Aquafeeds are currently not widely used to culture marine fish species. However, rapid growth in the demand for marine fish species will see a corresponding increase in demand for aquafeeds. It is probable that manufactured feeds will replace wild caught fish as food for all or nearly all cultured marine fish species in the near future. Issues of sustainability, disease transmission and environmental impact will necessitate this shift to manufactured feeds.

Development of aquafeeds for marine fish species is hindered by poorly researched and understood nutrient requirements for and nutrient availability to the numerous marine species targeted for culture. Most marine culture species are similar to salmonids and/or marine shrimp in that they are predominantly carnivorous, have high protein and amino acid requirements, and can more effectively utilize marine animal proteins than plant proteins. Many marine diets are currently formulated with high protein (40-50%) and fishmeal levels (≥50%).

Recent studies have indicated that soy products may be incorporated in marine fish diets at significant levels. Tests with hybrid striped bass, which can be cultured in both fresh and saline waters, indicated 25% of dietary protein could be replaced by soybean meal in feeds for 5 g fish, 75% for 100-150 g fish, and 100% for ≥200 g fish (Gallagher 1994). Brown et al. (1997) reported that solvent extracted soybean has the potential of supplying the majority of crude protein in diets fed to juvenile hybrid striped bass. Tests with red drum demonstrated that fish fed with diets containing 90% of protein from soybean meal gained as much weight as fish fed a diet with 100% of protein from fishmeal, and that soybean meal inclusion could be extended to 95% with supplementation of 2% glycine (McGoogan et al. 1997). Watanabe (1998) reported that soybean meal could replace up to 50% of fishmeal in yellowtail diets. Current field studies in China are testing practical diets with up to 40% soybean meal inclusion rates in diets for sea bream and sea bass.

## FUTURE PROSPECTS FOR SOY PRODUCTS

There is little doubt that the use of soy products in aquaculture will increase significantly in the future. Demand will increase especially for soybean meal. The development and application of feed-based production technologies and the need for practical and economic aquafeeds is projected to stimulate a demand for more than 6 mmt of soybean meal in China alone by 2005. Dehulled soybean meal will rapidly replace standard soybean meal as farmers realize the cost benefits associated with the higher protein and amino acid contents of dehulled meal. Growth in the cultured fish and shrimp industries in other parts of Asia could also add significantly to demand for soy products. If fed fish and shrimp maintain their current position as 52% of global aquaculture output, demand for these products could approach 30 mmt by 2025. Incorporation of soy products in aquafeeds at currently acceptable rates would require an estimated 20 mmt of soybean meal annually for fish and shrimp production by 2025.

Aquaculture in general, and particularly the marine shrimp and fish culture industries, will benefit from genetic improvements in soybeans and advances in feed processing and other technologies. High lysine, high methionine and high phytase soybean varieties currently under research and commercial development will allow higher inclusion levels of soybean meal in marine fish diets. Improved technology for removal of anti-nutritional factors from plant protein meals is greatly increasing their usage opportunities in aquafeeds. Many of the anti-nutritional factors that limit soybean use are destroyed by heat treatment, including protease inhibitors, lectins, goitrogens, anti-vitamins and phytates. Improved extrusion technologies effectively reduce trypsin inhibitor and antigenicity (Endres 1995). Further nutritional improvements are expected with new processing techniques to remove all or portions of heat stable anti-nutritional factors such as saponins, estrogens, lysinolanine and oligosaccharides (Chamberlain 1995). Only about one-third of the phosphorus content of soybeans is currently available to fish, but development of phytase enzymatic treatments may improve phosphorus release from the non-digestible phosphorus component in soybeans. Palatability of soy products is problematic for some aquaculture species. Research on attractant additives for recreational fishing and synthetic seafood flavors for human consumption will have applications in the aquaculture industry by improving or masking palatability problems of soy products. Collectively these advances will permit greater use of soybean products in all sectors of the aquaculture industry.

Commensurate with improvements in soybean quality and processing technologies is the need for critical research in aquaculture nutrition and improvement in feed manufacturing capability. Establishing the dietary nutrient requirements of the many species of cultured fish and shrimp and the nutrient availability of feed ingredients for these species is critical to expanding aquaculture production and aquafeed applications. It is also an immense task. Unlike the swine, poultry and other animal husbandry industries that deal with a limited number of species or varieties of a single species, aquaculture is characterized by the production of dozens of species with widely varying feeding habits and nutritional needs. The aquafeed industries in many of the largest aquaculture producing nations are largely rudimentary and need to greatly improve feed manufacturing capabilities. Quality aquafeed availability is constrained by limited manufacturer knowledge and/or application of fish nutritional requirements, quality control standards, and feed pelleting and extrusion technologies. The soybean industry will realize significant growth in marketing opportunities by supporting development of advances in fish nutrition research and technical support to the aquafeed industry.

## LITERATURE CITED

Akiyama, D.M. 1991a. The use of soy products and other plant protein supplements in aquaculture feeds. Pages 199-206 *in* Proceedings of the Aquaculture Feed Processing and Nutrition Workshop, Thailand and Indonesia, September 1991. American Soybean Association, Singapore.

Akiyama, D.M. 1991b. Soybean meal utilization by marine shrimp. Pages 207-225 *in* Proceedings of the Aquaculture Feed Processing and Nutrition Workshop, Thailand and Indonesia, September 1991. American Soybean Association, Singapore.

Aquaculture Magazine. 1999. Status of world aquaculture. Pages 6-38 *in* Aquaculture Magazine Buyer's Guide '99 and Industry Directory, Asheville, North Carolina, USA.

Brown, P.B., R. Twibell, Y. Jonker and K.A. Wilson. 1997. Evaluation of three soybean products in diets fed to juvenile hybrid striped bass *Morone saxatilis x M. chrysops*. J. World Aquac. Soc. 28(3):215-223.

Chamberlain, G.W. 1995. Utilization of vegetable proteins in aquaculture feeds: nutritional issues. Pages 66-74 *in* Expanding Agriculture Co-Product Uses in Aquaculture Feeds: Workshop Proceedings. The Midwest Feeds Consortium, Des Moines, Iowa, USA.

Chin, K. and Y.K. Joon. 1997. Recent advances in aquaculture nutrition. American Soybean Association Seminar for the China Feed Industry. American Soybean Association, Beijing, China.

Cremer, M.C., H.R. Schmittou and J. Zhang. 1997a. 80:20 pond field trials with crucian carp, pacu, tilapia and wuchang carp, 1995-1996. Publication AQ13-97, American Soybean Association, Beijing, China.

Cremer, M.C., H.R. Schmittou and J. Zhang. 1997b. LVHD cage field trials with nile tilapia, common carp, crucian carp, wuchang carp and channel catfish, 1995-1996. Publication AQ12-97, American Soybean Association, Beijing, China.

Cremer, M.C. and J. Zhang. 1998a. Feed-based 80:20 growth performance of crucian carp on soybean meal-based diets. Publication AQ9-98, American Soybean Association, Beijing, China.

Cremer, M.C. and J. Zhang. 1998b. Feed-based 80:20 growth performance of wuchang carp. Publication AQ10-98, American Soybean Association, Beijing, China.

Cremer, M.C. and J. Zhang. 1998c. Feed-based 80:20 growth performance of grass carp. Publication AQ10-98, American Soybean Association, Beijing, China.

Cremer, M.C. and J. Zhang. 1998d. Fry to fingerling growth performance of three strains of crucian carp. Publication AQ8-98, American Soybean Association, Beijing, China.

Cremer, M.C. and J. Zhang. 1998e. Feed-based 80:20 production of black carp fingerlings. Publication AQ12-98, American Soybean Association, Beijing, China.

Cremer, M.C. and J. Zhang. 1998f. Production of red tilapia in 1-$m^3$ cages with soybean meal-based diets. Publication AQ15-98, American Soybean Association, Beijing, China.

Cremer, M.C. and J. Zhang. 1998g. 80:20 pond growth performance of hybrid tilapia on soybean meal-based diets. Publication AQ13-98, American Soybean Association, Beijing, China.

Cremer, M.C. and J. Zhang. 1998h. Growth performance of channel catfish in 1-m3 cages with three soybean meal-based diets. Publication AQ14-98, American Soybean Association, Beijing, China.

Cremer, M.C., B. Zhu, H.R. Schmittou and J. Zhang. 1998. Status and forecast for the freshwater aquaculture production and feed industries in China. International Aquafeed Directory and Buyer's Guide 1999, Turret RAI, Middlesex, UK.

Cremer, M.C. and J. Zhang. 1999a. Fry to fingerling growth performance of crucian carp at different stocking rates with a soybean-based diet. In print. American Soybean Association, Beijing, China.

Cremer, M.C. and J. Zhang. 1999b. Fry to fingerling growth performance of grass carp at different stocking rates with a soybean-based diet. In print. American Soybean Association, Beijing, China.

Cremer, M.C. and J. Zhang. 1999c. Fry to fingerling growth performance of wuchang carp at different stocking rates with a soybean-based diet. In print. American Soybean Association, Beijing, China.

Cremer, M.C. and J. Zhang. 1999d. pond and cage production performance of select strains of channel catfish with soybean-based diets. In print. American Soybean Association, Beijing, China.

Cremer, M.C. and J. Zhang. 1999e. Growth performance of channel catfish on an all-plant protein, soybean-based diet with a protease enzyme additive. In print. American Soybean Association, Beijing, China.

Endres, J.G. 1995. Soybean products. Pages 114-129 *in* Expanding Agriculture Co-Product Uses in Aquaculture Feeds: Workshop Proceedings. The Midwest Feeds Consortium, Des Moines, Iowa, USA.

Gallagher, M.L. 1994. The use of soybean meal as a replacement for fish meal in diets for hybrid striped bass (*Morone saxatilis x M. chrysops*). Aquaculture 126:119-127.

Harold, R.L. and K.B. Koch. 1998. Substitution of soybean and sunflower protein concentrates for fish meal in diets for rainbow trout *Oncorhynchus mykiss*. Paper presented at the World Aquaculture Society Conference 1998, Las Vegas, Nevada, USA.

IAF. 1985. The future of aquaculture: profile of a growth industry. The International Aquaculture Foundation, Virginia, USA. 120 pp.

Lovell, R.T. 1991. Use of soybean products in diets for aquaculture species: revised. Pages 173-187 *in* Proceedings of the Aquaculture Feed Processing and Nutrition Workshop, Thailand and Indonesia, September 1991. American Soybean Association, Singapore.

McGoogan, B.B., and D.M. Gatlin III. 1997. Effects of replacing fish meal with soybean meal in diets for red drum *Sciaenops ocellatus* and potential for palatability enhancement. J. World Aquac. Soc. 28(4):374-385.

New, M.B. 1997. Aquaculture and the capture fisheries: balancing the scales. World Aquaculture 28(2):11-30.

Pike, I. H. 1998. Future supplies of fish meal and fish oil: quality requirements for aquaculture. Pages 39-49 *in* 1997/8 International Aquafeed Directory, Turret RAI, Middlesex, UK.

PROMAR and CIEC. 1996. China, the world's largest food market: A strategic assessment of the Chinese food chain to 2005. PROMAR, Alexandria, Virginia and China International Economic Consultants Co., Ltd., Beijing, China.

Robinson, E.H. and M.H. Li. 1998. Comparison of practical diets with and without animal protein at various concentrations of dietary protein on performance of channel catfish *Ictalurus punctatus* raised in earthen ponds. J. World Aquac. Soc. 29(3):273-280.

Schmittou, H.R. and J. Zhang. 1995a. 80:20 pond culture of crucian carp in five locations in the Yangtze River delta, 1994. Publication AQ17-95, American Soybean Association, Beijing, China.

Schmittou, H.R. and J. Zhang. 1995b. 80:20 pond culture of common carp fry to grow-out on Lichen Regional Fish Farm, Jinan, Shandong, 1994. Publication AQ11-95, American Soybean Association, Beijing, China.

Schmittou, H.R. and J. Zhang. 1995c. 80:20 pond culture of common carp fry to fingerlings on Jin Shan Bao Fish Farm, Harbin, Heilongjiang, 1994. Publication AQ18-95, American Soybean Association, Beijing, China.

Schmittou, H.R. and J. Zhang. 1995d. Comparison of production and economic data per cage volume for trial and commercial productions of fishes in low volume cages. Publication AQ7-95, American Soybean Association, Beijing, China.

Schmittou, H.R. and J. Zhang. 1995e. Comparison of production performances of common carp and nile tilapia raised in 1 cubic meter cages with either opaque or transparent covers. Publication AQ12-95, American Soybean Association, Beijing, China.

Schmittou, H.R. and J. Zhang. 1995f. Comparison of production performance of nile tilapia fed either two or four times per day in low volume cages in Qian Dao Reservoir, Zhejiang, 1993. Publication AQ13-95, American Soybean Association, Beijing, China.

Schmittou, H.R. 1998. Status and trends assessment of the coastal fish and shrimp farming industries in China. Report for the American Soybean Association, Beijing, China.

Stickney, R.R. 1998. Mariculture at a crossroads. World Aquaculture 29(3):8-10; 70-72.

Tacon, A.G.J. 1998. Trends in global aquaculture and aquafeed production: 1984-1996 highlights. Fisheries Department, FAO, Rome, Italy.

Tacon, A.G.J., W. G. Dominy and G.D. Pruder. 1998. Global trends and challenges in aquafeeds for marine shrimp. Pages 28-35 *in* International Aquafeed Issue 4 1998.

Watanabe, T. 1998. Protein sources for marine feeds. Paper presented at the World Aquaculture Society Conference 1998, Las Vegas, Nevada, USA.

Weede, N.E., F.M. Dong and R.W. Hardy. 1997. Growth, feed utilization, and fillet sensory characteristics of rainbow trout fed diets containing soy protein concentrate. Paper presented at the World Aquaculture Society Conference 1997, Seattle, Washington. University of Washington School of Fisheries, Seattle, Washington, USA.

Zhang, Y. 1996. Developments in China's feed industry. International Milling Flour and Feed 190(8):22-27.

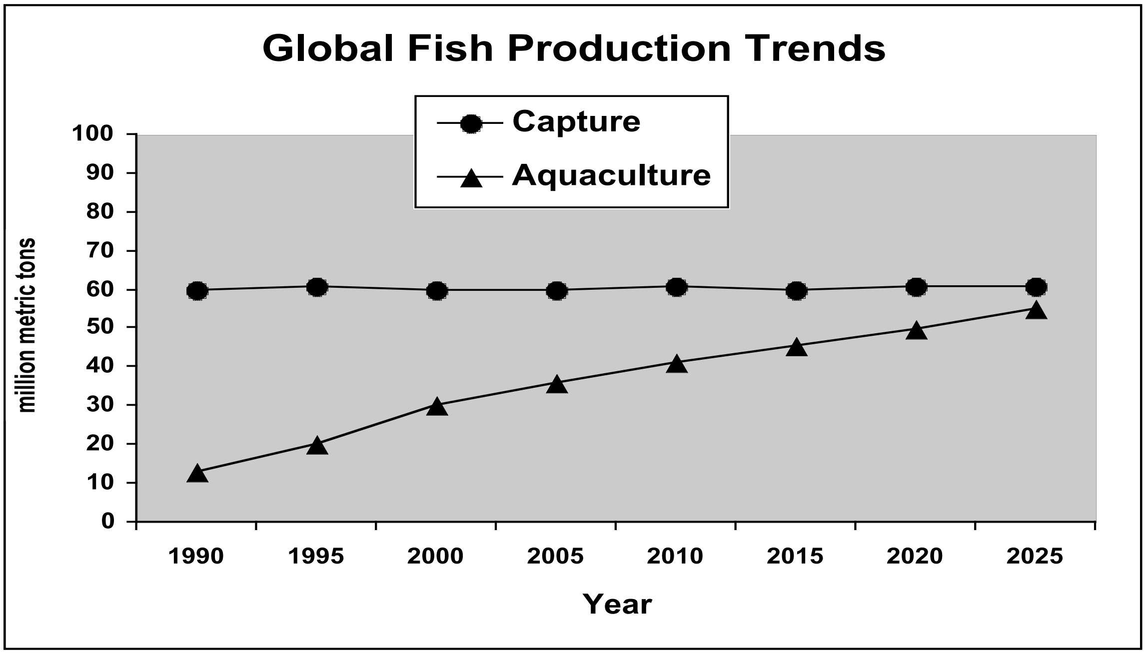


Figure 1. Projected demand for fishery products will require aquaculture to double from its current production level by 2025, as capture fisheries landings of food fish are projected to stabilize at approximately 60 mmt.

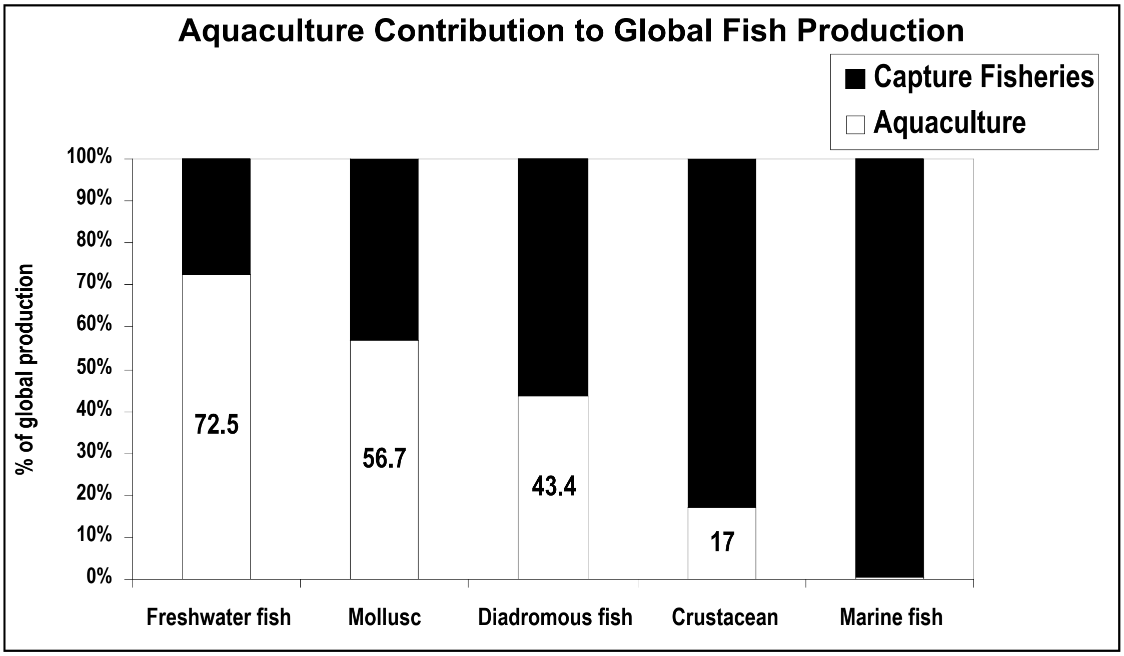


Figure 2. Aquaculture contributed significantly to global production of freshwater fish, molluscs, diadromous fish and crustaceans in 1996. Aquaculture production of marine fish is forecast to increase substantially in the future.

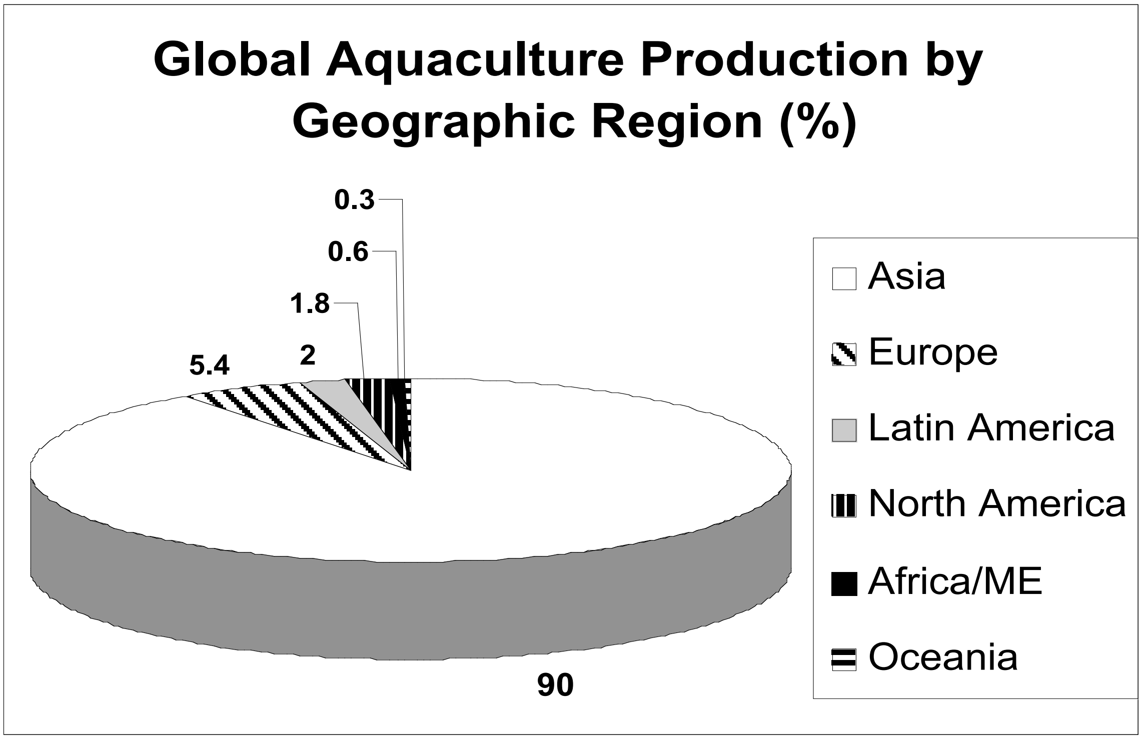


Figure 3. Aquaculture production is dominated by Asia, which produces approximately 90% of global production, by weight.

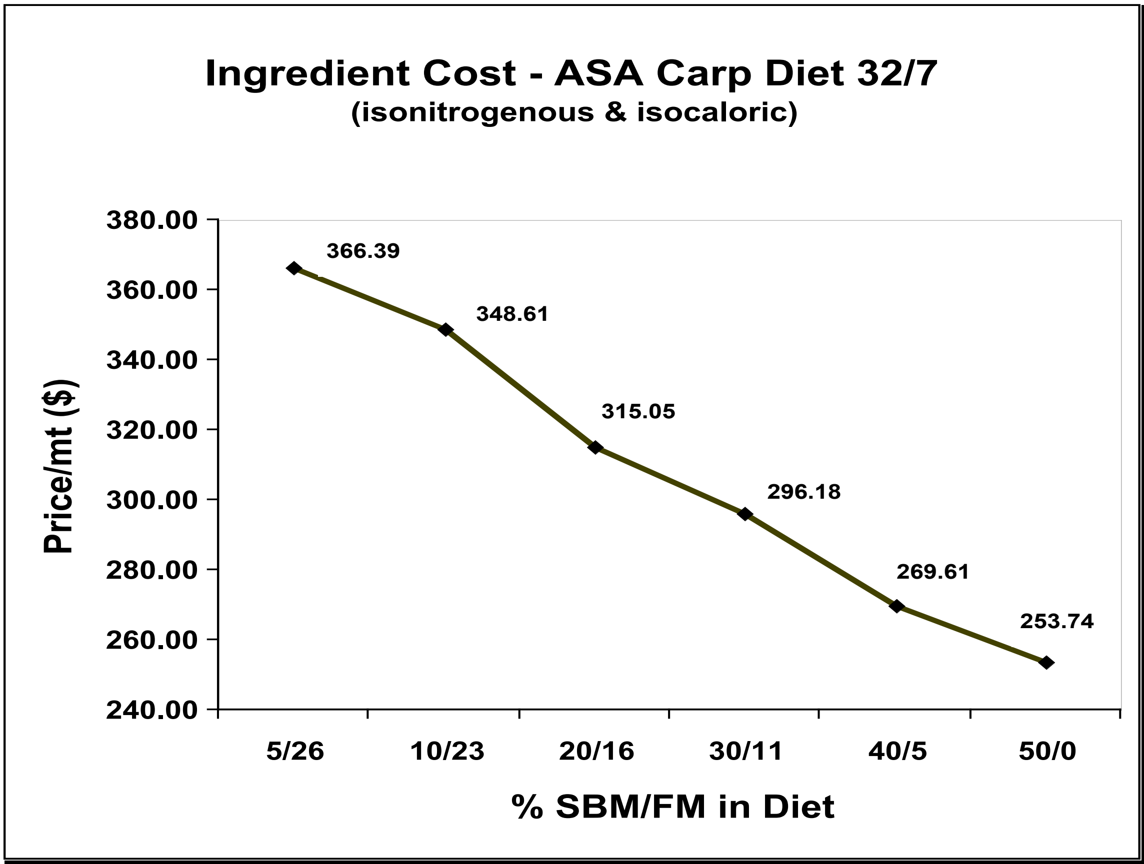


Figure 4. Full replacement of fishmeal with soybean meal generated savings of more than 30% in ingredient costs in a 32% protein carp diet in China, based on October 1998 ingredient costs.

Table 1. Aquaculture production, percentage of global aquaculture production, and percentage annual growth from 1984 to 1996 for the top ten aquaculture producing countries in the world. Nine of the top ten nations are in Asia.

| TOP AQUACULTURE PRODUCING COUNTRIES - 1996 | | | | |
|---|---|---|---|---|
| Rank | Country | Production (mt) | % of Global | Growth (APR 84-96, %/yr) |
| 1 | China | 18,628,500 | 62.9 | +17.8 |
| 2 | India | 1,768,422 | 6.0 | +12.0 |
| 3 | Japan | 1,349,405 | 4.6 | +1.0 |
| 4 | Philippines | 974,065 | 3.3 | +6.7 |
| 5 | Korea, Rep. | 896,998 | 3.0 | +2.6 |
| 6 | Indonesia | 780,130 | 2.6 | +8.1 |
| 7 | Thailand | 509,656 | 1.7 | +14.8 |
| 8 | Korea, DPRP | 456,000 | 1.5 | -3.3 |
| 9 | United States | 393,331 | 1.3 | +1.7 |
| 10 | Bangladesh | 390,088 | 1.3 | +11.6 |

Table 2. Growth of the China freshwater aquaculture industry averaged 18.4% annually during the 5-year period 1993-1997.

| Year | Freshwater aquaculture production (mmt) | Percent increase over the previous year |
|---|---|---|
| 1993 | 6,441 | 20.8 |
| 1994 | 7,850 | 21.9 |
| 1995 | 9,408 | 19.8 |
| 1996 | 10,937 | 16.2 |
| 1997 | 12,367 | 13.1 |
| Average annual increase | | 18.4 |

Table 3. Top ranking aquaculture species and their production, annual growth and major producing countries/regions for 1996. Annual production increases for feed taking species for the period 1984-1996 averaged 19.2%.

| TOP AQUACULTURE SPECIES 1996 | | | | |
|---|---|---|---|---|
| **Rank** | **Species** | **Production (mt)** | **Growth (APR 84-96, %/yr)** | **Major producing country/region** |
| 1 | Silver Carp | 2,877,529 | +9.4 | China |
| 2 | Grass Carp | 2,437,600 | +21.4 | China |
| 3 | Common Carp | 1,991,981 | +11.9 | China/SE Asia |
| 4 | Bighead Carp | 1,418,351 | +12.8 | China |
| 5 | Crucian Carp | 692,980 | +25.1 | China |
| 6 | Nile Tilapia | 603,034 | +22.2 | China/SE Asia/Egypt |
| 7 | Atlantic Salmon | 555,643 | +31.5 | Europe/Americas |
| 8 | Tiger Prawn | 532,322 | +22.2 | SE Asia/India |
| 9 | Roho Carp | 493,393 | +12.4 | India/Myanmar |
| 10 | Catla Carp | 419,456 | +11.3 | India |
| 11 | Mrigal Carp | 412,313 | +15.1 | India |