Aquaculture in the U.S.

James H. Tidwell

Introduction

Consumption of seafood in the U.S. has remained relatively stable at approximately 7kg/person/year for almost 20 years (NMFS 2003) (Figure 1). Compared to other countries, per capita consumption by Americans is relatively low. In the European Union per capita consumption is almost 2.5 times greater at 17 kg/person/year and Japan is over 5.5 times greater at 40 kg/person/year. The world wide average of 16 kg/person/year is over twice that of the U.S.

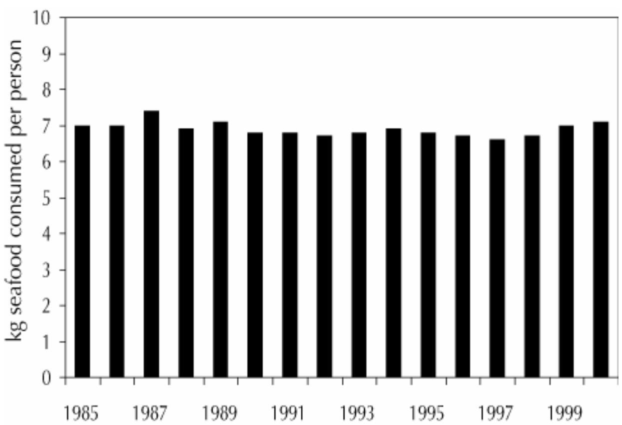

Figure 1. Per capita consumption of seafood in the United States since 1985.

Despite this fact, the U.S. represents a huge market for seafood on the world stage. The U.S. ranks as the third largest seafood consumer in the world, behind China and Japan (NMFS 2003) (Figure 2). However, China produces most of its seafood domestically, through both capture and culture. This is not true in Japan and the U.S. and these countries, along with the European Union, remain the top three import markets, accounting for more than 80% of total world imports in 2001.

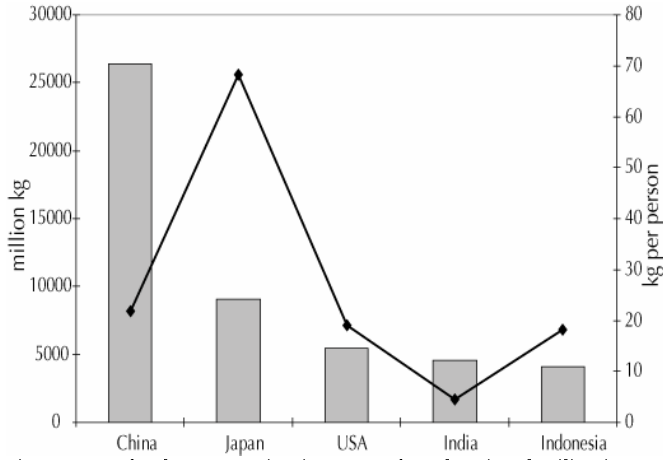

Figure 2. Seafood consumption in terms of total national utilization (x axis) vs. per capita consumption (y axis).

The balance of trade in the U.S. for seafood is an increasing concern. Over the past 10 years the amount of seafood imported into the U.S. increased 40%, from 2.6 billion kg in 1993 to over 3.6 billion kg in 2002. Today over 80% of the seafood consumed in the U.S. is imported and the trade deficit in seafood products is in excess of $7 billion/year.

The U.S. is not likely to meet these demands by increases in its capture fisheries. Since 1993 the domestic harvest of fish and shellfish actually decreased 12% (Figure 3). This leaves only two ways to decrease the trade imbalance in fish products, either decrease demand or increase domestic aquaculture production. However, demand for seafood in the U.S. is not expected to decrease, but actually to increase by 1.8 billion kg by 2020. Officials in the U.S. increasingly see the need for domestic aquaculture production to play a larger role in supplying this demand.

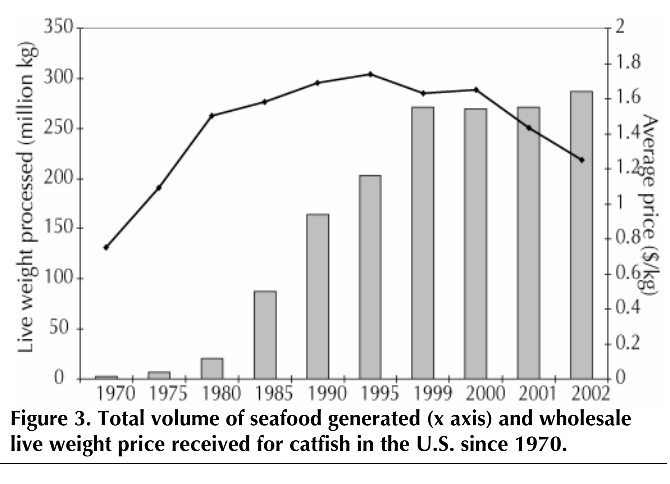

Figure 3. Total volume of seafood generated (x axis) and wholesale live weight price received for catfish in the U.S. since 1970.

James H. Tidwell
Aquaculture Research Center
Kentucky State University
Frankfort, KY 40601

Email: jtidwell@gwmail.kysu.edu

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History

Aquaculture is quite old in other parts of the world. Carvings in Egyptian pyramids show Tilapia being harvested from ponds over 4500 years ago. In China carp are known to have been spawned and reared over 2500 years ago, and possibly much earlier (Landau 1992). However, in the United States aquaculture has a much shorter history. Early efforts In the United States began only in the nineteenth century. Most of the early work was associated with salmonids, such as Atlantic salmon, rainbow trout, and brook trout, and was directed toward public stocking programs. However, as early as 1864 there were private commercial hatcheries operating (Stickney 2000).

What many think of as commercial aquaculture began only in the 1950's. At Auburn University Dr. Homer Swingle began performing controlled experiments on fish in ponds both in terms of management and production. As farmers became interested in the potential of an entirely new crop, federal labs in Marion, Alabama and Stuttgart, Arkansas began to conduct research in support of this fledgling industry. From these humble beginnings Aquaculture has become the fastest growing segment of U.S. agriculture (OFA and Tidwell 2003). Fish are raised in many ways. The following sections will provide a short overview of major production systems and the primary species used in commercial production in the U.S. The last section will summarize new or emerging species.

Major Production Systems

Pond Production Systems

Ponds are the oldest, most natural, and usually the most economical, production system for most aquaculture species. All production systems must be able to provide oxygen for the fish and remove toxic waste products produced by the fish. A pond's ability to accomplish these actions is based on naturally occurring processes and the fact that a pond is a small semi-closed ecosystem (Tidwell 1999a).

Oxygen production in a pond is primarily based on photosynthesis by the microscopic algae (phytoplankton) floating in the pond. Diffusion from the atmosphere contributes very little oxygen to a pond. The ability to reliably provide oxygen is the first limiting factor in the production capacity of ponds. Without aeration production is limited to approximately 1,300 kg/ha. With aeration provided, production is increased to 3,500-5,000 kg/ha.

When fish are fed prepared diets, much of the nitrogen in the feed protein is excreted through the fish's gills into the surrounding water in the form of ammonia. This ammonia is either removed from the water by the phytoplankton, or converted to less toxic forms by naturally occurring bacteria in the pond through a process known as nitrification. The efficiency of nitrification within the pond is currently the primary constraint on the production capacity of ponds for most species.

Types of ponds include watershed and levee style ponds. Watershed ponds are most practical in hilly areas and are constructed by building a dam across a draw or valley. Watershed ponds are sited so that the smallest dam impounds the most water. Because of hilly terrain, watershed ponds can be quite deep near the dam, affecting their use for some species. Construction prices vary based on terrain and dam size. Major considerations are suitability of soils, sufficient water supply based on watershed, ability to handle excess water during heavy rain and rainy periods, proximity to electricity for aeration, and accessibility for daily feeding and maintenance.

Levee style ponds are constructed in flat terrain by shallow excavation, and then the excavated soil is used to construct levees around all four sides. Leveed ponds have no watershed so a clean dependable water source must be available. Possible sources are streams or wells, which also allow better control over filling and draining. Leveed ponds are normally more productive per unit of size than watershed ponds because of shallow, uniform depth, and better manageability. Construction costs will vary based on location.

Raceway and Flow-through Fish Production Systems

Raceways are large concrete or earthen troughs with a constant flow of water, usually from springs. These are primarily used for coldwater species, such as trout (Wynne 1999). Large volumes of water must flow via gravity through a series of terraced raceways and are discharged into a receiving stream with little or no wastewater treatment. Raceways have a length to width ratio of approximately 6:1 and hold a water depth of 1-1.25 m. Typically, raceways are built in pairs and share a common interior wall. Raceways that are 11 m x 2 m may have a floor and walls that are 15 cm thick. Larger units may be constructed of poured concrete 20 cm or more in width depending on raceway length and water volume.

Aeration occurs between sequential raceways as the water flows over a screened outfall and pours into the head of the raceway below. Water volume is exchanged approximately every hour. Gravity flow from the water source is essential as the cost of pumping such large volumes of water (1,500-15,000 liters/minute) would be prohibitive in most cases. Nitrogenous wastes are removed from the raceways by flushing or dilution before toxic levels of ammonia gas can concentrate in the water. The serial reuse of spring water is usually limited to 6 to 8 raceway passes with hard water and 3-5 passes with soft water. The water flow rate, water chemistry, temperature, size of fish, and the rate of feeding determines the volume of fish which can be produced in a particular raceway system. Generally, rainbow trout can be grown at an annual rate of 3-6 kg per liter per minute of water flow.

Net Pens

Net pens are large floating "cages" which allow fish to be raised in natural bays, protected near-shore waters, and increasingly in open ocean environments. Modern net pen designs probably originated in Japan in the 1950's (Fairgrieve 2000). Today, net pens are the main production system used for the industrial scale farming of Atlantic salmon, which is described later. Net pen design has progressed rapidly in recent years and some units are extremely high tech with amazing engineering and materials incorporated in their design. Net pens are usually separated into four classifications.

Class I: Gravity Pens. These net pens are basically flexible net bags supported by a floating collar with the bag held open by weights. Round pens are 15-30 min diameter and separated while rectangular pens can be 30 m on the long axis and grouped together with catwalks in between. They are relatively inexpensive but not well suited to high-energy environments.

Class II: Anchor-Tensioned Pens. This design is better suited to high-energy environments with high winds. With this design the net enclosure is held in place by a system of floatation buoys and bottom anchors.

Class III: Semi rigid Pens. These pens differ in having their own internal support system to hold the bag enclosure open. Many have a hub and spoke type arrangement. This allows the net enclosure to be fully sealed (instead of open at the top like Class I and Class II). Because of this these systems can actually be lowered under the surface to escape bad weather.

Class IV: Rigid Pens. Rigid pens are inflexible frames usually with welded wire netting. They can be grouped in floating barges and some systems actually extend out the bottom of a ship so the system can move around. Rigid systems are also utilized when predation by marine mammals is a problem.

Recirculating Production Systems

A recirculating system is the most intensive system of fish production. This type system, through water treatment and water reuse, can use less than 10 percent of the water required by ponds to produce similar fish yields (Losordo *et al.* 1992a). Many fish species grown in ponds, raceways and floating pens could be reared in commercial-scale recirculating systems. Therefore, with increasing concern for resource conservation and demand for high quality aquacultured products, there is a great deal of interest in recirculating systems in the United States and other parts of the world. Though there have been a few reports of profitable commercial-scale recirculating systems, economic viability of growing most commonly cultured species in these systems has not been proven. Recirculating systems have generally been expensive to build and operate. These systems will not be used on a wide scale basis until total costs of producing fish is comparable to the cost of production in ponds and other similar systems. The challenge to designers of recirculating systems is to develop systems that maximize production capacity per unit of capital invested but will maintain reliability of the controlled environment. Currently, recirculating systems have a great value in educational and research labs.

The major advantages in using recirculating aquaculture systems are 1) low water requirements, 2) low land requirements, 3) the ability to control water temperature, 4) the ability to control water quality, and 5) independence from adverse weather conditions. Therefore, the aquaculturist has the ability to measure and control most variables, which make up the environment of the recirculating system and maximize fish production per unit.

Numerous technologies are available for recirculating systems. However, there are four basic components to these systems: solid waste removal, ammonia and nitrite control, dissolved gas control, and disinfection (Losordo *et al.* 1992b). Solid waste includes settleable and suspended solids. Settleable solids sink to the bottom of the tanks and are siphoned and discarded from the system. Suspended solids are removed with screen or sand filters. Ammonia and nitrite control is accomplished with a biofilter that relies on bacteria to remove these nitrogenous waste products. Some of the common biofilters are rotating biological contactor (RBC), expandable media filters, fluidized bed filters, and packed tower filters. Dissolved gas control involves adding dissolved oxygen and removing carbon dioxide. Some common dissolved gas components include diffuser aeration, mechanical aeration, packed column aerators, counter current diffusion column, pressurized spray tower, and pressurized packed column. The last component to be considered for a recirculation system is disinfection of pathogenic organisms, which can be accomplished with ozone or ultraviolet irradiation.

Most reports of successful production have been from small (less than 100,000 pounds per year), recirculating systems supplying fish to local niche markets at high prices. These high priced markets are necessary for financial success because of high cost of fish production in recirculating systems. Typically, the fixed cost of developing a recirculating system is higher than that for an equivalent pond production system. Given this fact alone, a producer should not try to compete with pond-raised products. Instead, the producer should target high value markets, such as gourmet food, tropical or ornamental fish, or year around supply of fresh product. As with other aquaculture production systems, the size of the recirculating system and decision to become involved should be market driven.

Major Species

Channel Catfish

The catfish industry really began in the 1960's and the first commercial processing plant opened in 1969. Since that time catfish has been one of the most rapidly expanding agriculture industries in the U.S. (Figure 4). Today the channel catfish industry is by far the largest aquaculture industry in the U.S. In the early years catfish ponds were extremely large (> 30 ha). Over the years average pond sizes have decreased (8 ha) due to management considerations. Much of the current production is concentrated in the Deep South, with Mississippi, Arkansas, Alabama, and Louisiana being the top four states. Currently, there are over 60,000 ha of catfish production ponds. About 60% are located in Mississippi, along the fertile Delta region in the old Mississippi River flood plain. When production on the west side of the river, in Arkansas, is included approximately 80% of catfish production occurs in this Delta region.

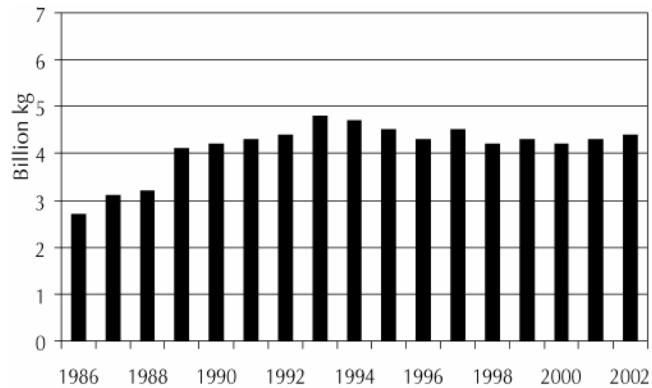

Figure 4. Volume of domestic commercial landings.

Production occurs in static water ponds of 2-8 ha approximately 1.5 m deep. Fish are stocked at 10,000-30,000 fish/ha and average about 15,000 fish/ha. Fish are usually raised in an "understocking" system, where harvest size fish (0.45-0.9 kg) are selectively removed then replaced with stocker size fish. This is a "continuous" production system, which keeps the pond at a relatively high percentage of capacity at all times. Another method is the "clean-harvest" or "batch" culture system where fish are all stocked at the same time and size, grown out to harvest size, and then they are all completely removed. With this system the production unit is not operating at a high percentage of capacity much of the year. However, the producer has better inventory control and a large diversity of ages and sizes are not mixed in the same pond.

Catfish are fed feeds of approximately 28-32% crude protein. Feeds are composed of primarily soybean meal, corn, and in the past, fish meal. Over the past 15 years fish meal levels have been reduced from about 8% to • 2%. Feeds based entirely on plant products are now more common as are lower protein diets (26-28%). Catfish are usually fed once per day and feed conversion ratios are usually 1.5-1.75/l.

Catfish are harvested and transported to the processing plants alive where they are processed in modern state-of-the-art facilities. This allows the industry to ensure consumers of a very high quality product at all times. Although much of the processing is still done by hand, there has been a trend toward increased automation. A variety of products are marketed including fillets, steaks, and whole dressed fish. Processed catfish are available as fresh, ice-packed, or frozen. The preferred product mix has shifted over the years. Fresh whole dressed fish was the preferred product form in early years. Frozen fillets now account for the largest portion (~1/3) of sales.

Processing yields in channel catfish are approximately 60% for whole dressed and 40% for fillet. Catfish is relatively high in crude protein (16.3%) and low in fat (5.4%). The four major fatty acids, which account for about 75% of the total fatty acids in fillets, are 16:0, 18:0, 18:1, and 18:2 n-6. Concentrations of saturated fatty acids are about 24%, monenes, 44%, dienes, 15%, and trienes, 4%. Muscle tissue typically contains about 4% n-3 fatty acids and 22% n-6 fatty acids.

Rainbow Trout

The primary species of trout raised commercially is the rainbow trout (*Oncorhynchus mykiss*). The trout industry is about one-sixth the size of the catfish industry by weight, but one-fourth by value. Similar to catfish, one state accounts for a large percentage of trout production. Idaho produces approximately 50% of U.S. farmed trout, with the next closest state being North Carolina at about 9%. In Idaho much of the production is concentrated in or near the Snake River valley, where there are abundant spring resources of suitable temperature and water quality.

Production systems for rainbow trout are similar around the world. Fish are raised in large flowing water earthen or concrete raceways. Stocking densities are based on flow rate, water quality (pH and dissolved oxygen), fish size, etc. Harvest size is 450-600 g and usually requires 10-15 months of growth. Trout are sold not only as food fish but also for recreational fishing.

Trout are by nature carnivores so feeds formulated for trout contain higher protein levels and high fish meal levels than feeds for catfish, which are omnivores. Trout feeds usually contain 42-45% protein and 15-20% lipid. To meet essential fatty acid requirements, lipid is usually supplied as 4-5% marine fish oil and the remainder from animal or plant oil sources. Trout are fed several times per day and feed conversion ratios range from 1.2/l to as low as 0.8/l.

Trout are usually processed within minutes of harvest. Trout are processed into head-on gutted (60-70% of the production mix), fillets, or "butterflied." Edible yield is about 50%. Trout fillets typically contain 19% protein and 5-7% fat. The omega-3 fatty acid content of trout fillets averages 22% of fillet fat.

Developing Culture Species

Hybrid Striped Bass

Hybrid striped bass (HSTB) are produced by crossing striped bass (*Morone saxatilis*) with white bass (*M. chrysops*). There are two crosses produced: the original cross (also called palmetto bass) is made by using female striped bass and male white bass; the reciprocal cross (also called sunshine bass) is made when female white bass and male striped bass are used. Hybrid striped bass require warm temperatures (20-28ºC) for rapid growth and thus, many pond-based farms have been located in the southern United States (Webster 1999).

Hybrid striped bass culture can be divided into three phases of production. Phase I is the hatchery phase and fry stage which last for 30-60 days and fish reach 2.5-7.5 cm. In Phase II Phase I fish are grown for between 5 to 9 months to grow to 7.5-35 cm fingerlings. Phase III culture is basically a grow-out of fish to market-size (0.7-1.1 kg) or to adult fish.

For Phase I culture, 5 to 10 day old fry (post-hatch) are stocked into ponds at rates of 250,000-500,000 fry/ha. For commercial food-fish production, a lower stocking rate allows for more rapid growth. Survival of fry-to-fingerlings can be low (less than 20%), however, values between 25-60% are typical. The ponds are generally fertilized one to two weeks prior to stocking with inorganic or organic fertilizers to aid in the growth of zooplankton, which the fry eat. Fry generally will eat the zooplankton in the pond, but supplemental feeding may allow for increased growth and survival of fry. When fish are about 21 days old, a high protein salmon starter diet is fed 1 to 3 times per day, 7 days per week, at a rate of between 0.9-4 kg/ha/day for the first week, and increased up to, thereafter. It is generally recommended not to exceed 30 kg/ha per day.

When Phase I fingerlings are ready to be grown to larger fish, they are harvested from the nursery ponds and stocked into ponds for Phase II production. Stocking density for Phase II production for commercial food-fish production ranges from 25,000-35,000 fish/ha should be used. The diet should be a high protein (35-50%) floating diet with a pellet size that will allow for consumption by the fish. Feeding rates can be as high as 20% of body weight (BW) for the first 30 days after stocking, but decreased monthly until harvest so that fish should be fed 3-4% BW at that time. The average culture period for Phase II fingerlings is 150 days and should reach a size of 40 grams per fish and be 15 cm in length. However, there have been reports that fish can reach a weight of greater than 90 grams in a growing season.

Production of Phase III fish involves the growing of hybrid striped bass to market-size on to adults that can be used as broodstock (Hodson and Hayes 1989). Phase II fingerlings to be stocked for grow-out should weigh 100-250 grams and stocking density should be between 7,000-10,000 fish/ha. A floating diet with between 38-40% protein should be fed, and fish should be all they will eat once or twice daily, 7 days per week. A standing crop of HSTB at harvest ranges between 1,800-4,500 kg/ha with average weights of 0.45-1 kg and feed conversions of 1.5-2.3. Hybrid striped bass are often marketed gutted on ice or live to ethnic Asian Markets.

Freshwater Prawns

The freshwater shrimp, or more properly, freshwater prawn is a member of a large group of freshwater crustaceans found in many parts of the world. There are several species found native to the U.S., but most aquaculture efforts have concentrated on the Giant Malaysian Prawn (*Macrobrachium rosenbergii*), which is a native of southern Asia. Culture efforts in the U.S. were initiated in Hawaii in 1960's, South Carolina in the 1970's, and Mississippi in the 1980's. Despite these efforts, substantial concentrated production of this species has not developed. Large-scale production has been hindered by relatively low production rates, size variability at harvest, and a relatively demanding process for producing seedstock (Tidwell 1999).

Over the past five years interest in production of this animal has again increased due to an increasing demand for shrimp products, reduced supplies of shrimp (especially large sizes) due to serious disease problems in saltwater shrimp production, and increases in production rates for prawns based on new management and production practices. Other factors producing increased interest in production include identified markets for live and fresh prawns in inland locations, the growing trend among consumers wanting to know how their food was produced, and the discovery that prawns actually grow more rapidly at cooler temperatures.

Seedstock production for prawns normally begins with selection of broodstock at the harvest production ponds in the fall. The number of females is based on anticipated production needs. Broods must be overwintered in tanks at greater than or equal to 24ºC. In the U.S., production ponds are stocked in late May-early June with what are known as 60 day nursed juveniles (0.3-0.5 gram average weight). That is they have been grown for 30-60 days in freshwater after completing 30 days of larval development in brackish (salty) water. This means prawns should be hatched from mid-February to mid-March to allow sufficient nursery time prior to pond stocking.

Nursery tanks are normally much larger than larval tanks as stocking rates are reduced from approximately 50/l in the larval tanks to 5/l in the nursery tanks. These tanks must also be provided with mesh substrate structures sufficient to produce 450 post larvae per square meter density. In the nursery phase, water temperatures are maintained at 24-28ºC and the prawns are fed trout starter feeds at a declining percentage of body weight.

Production ponds should be properly prepared before juvenile prawns are transferred from the nursery. Most ponds used are 0.2 - 0.5 ha in size. This catch basin is 0.5 - 0.75 m deeper than the adjoining pond bottom and about 2.5 m. Ponds are equipped with either paddlewheel or turbo aspirator type aerators which also mix and destratify the pond. The number of prawns to be stocked depends primarily on marketing considerations. The higher the stocking density the greater the production (kg/ha) but the smaller the average prawn. The other factor affecting stocking density is whether artificial substrate is added to the pond. To produce very large prawns, stocking densities of 20,000 - 30,000/ha will produce about 550 - 625 kg/ha with an average weight of 40-45 grams (10 prawns per pound). At 40,000 prawns/ha without substrate, about 900 kg/ha of prawns are produced averaging 30-35 grams (12-15 prawns per pound). With artificial substrate added, the density can be increased to 60,000-65,000/ha with production of 1,400-1,500 kg/ha at this same average size of 35 grams. Prawns are fed a 32% protein-sinking pellet at 3-7% of estimated biomass.

To harvest the prawns, the pond is drained down to concentrate prawns in the harvest basin. Adding freshwater or providing aeration in the catch basin during harvest will reduce stress. Prawns are removed from the basin using a small seine than transferred to clean, aerated water (purging tanks) to allow them to remove mud and debris. If prawns are to be marketed live, they can be held in tanks for transport or sold directly to consumers on-farm. If prawns are to be sold on ice or processed, they should be removed from purging tanks and immersed in ice water for 15-30 minutes to rapidly chill the prawns. They can then be held on drained ice until processed or sold. Maximum holding time is approximately five days for whole (head-on) prawns and 8-10 days for tails.

Proximate composition of prawn tail meat is approximately 78% moisture, 20% protein, 0.4% fat, and 1.2% ash. They have about half the fat of saltwater shrimp and about half the cholesterol. Many people with seafood allergies are actually allergic to iodine. Iodine concentrations in freshwater shrimp (0.14 mg/l) are less than 1/6 those of saltwater shrimp (0.80 mg/l). The fatty acid composition of lipids in prawn tails is 38% saturated, 39% monounsaturated, and 26% polyunsaturated. Omega-3 fatty acids are about 10% of total.

Paddlefish

Paddlefish, spoonfish, spoonbill cat, and Polyodon spathula are among several names given to this unique prehistoric fish. The paddlefish is the largest (over 900 kg, 1.75 m long) freshwater fish in the United States and is found in 26 states that have large streams, rivers, and impoundments within the Mississippi River basin and adjacent Gulf Coastal drainages. Paddlefish are highly valued for their black eggs (roe), which are processed into caviar and also for its boneless, firm, white meat (Mims 1999). However, they are currently available only from the wild populations. Overexploitation and contamination by organochlorine pollutants (i.e. PCB) have required that many state agencies close down the wild harvest of paddlefish.

Paddlefish have many characteristics for aquacultural development as a food fish. Paddlefish filter feed on zooplankton throughout life, are long-lived (greater than 20 years), and grow rapidly (up to 10 pounds per year). They can be harvested by selective gill nets or by seining. Paddlefish can be propagated artificially and fingerlings raised intensively up to 5.5 cm in ponds, then grown for meat and roe intensively in ponds with catfish or extensively in reservoirs. Paddlefish meat is firm and boneless with a beef or pork-like texture, and it is also similar to sturgeon in taste and texture.

Currently, broodstock are obtained from wild sources. Typically, males are smaller (by one-third to one-half in weight) than females, and have tubercles on their head and opercular flaps that feel like sandpaper. In contrast, mature females have few, to no tubercles, and the abdomen is round and distended during the pre-spawning period. Broodstock must be held in circular tanks (2.4 m) in the hatchery. Water temperature of 15.5-18ºC, flow rate of 7.5 l per minute and water saturated with oxygen are optimal conditions. Broodstock should be injected with hormones to induce spawning. For milt collection, tubing attached to a syringe is inserted into the urogenital pore. Milt can be collected several hours before use and stored in sealed containers on wet ice.

For collection of eggs, any one of several methods can be used: hand-stripping, caesarian section, or the Minimally Invasive Surgical Technique, MIST. The eggs should be fertilized using the “wet-method.” The eggs are then loaded into McDonald jars at about 9,000 eggs/l. Larvae hatch in approximately 6 days when eggs are incubated at 18ºC. Larvae must be held for another 5 to 6 days before they will consume food.

Larvae can be grown in fertilized earthen ponds or in tanks. In ponds, live food such as Daphnia spp. must be present in order for the paddlefish larvae to have appropriate food until they are large enough to accept extruded pellets. Once the fish reach about 9 cm, they can be trained to eat a 1.5 mm extruded pellet (45% protein). Survival rates can range from about 50 to 80%. It takes approximately 6 weeks for the paddlefish to reach about 12 cm, at which time they are able to filter feed. If fish are trained on a prepared diet, they can remain in the ponds and will continue to grow up to 0.2 kg and 35 cm in about six months.

Reservoir ranching and polyculture with catfish are two potential systems to raise paddlefish for caviar and meat. Production of paddlefish in these systems relies on the filter feeding of naturally produced food organisms; therefore requiring no feed cost and little management. Reservoir ranching is an extensive method for producing paddlefish. Fish are stocked at low densities (4-8 fish/ha) and can reach 4.5 kg per fish in about 18 months and can be sold for their meat or permitted to grow until maturity, and then harvested for their roe. Fish are captured with gill nets with nearly 90% efficiency. Survival of greater than 50% is expected in reservoirs. Use of all-female paddlefish for caviar production would be most beneficial in this system.

Polyculture of paddlefish with catfish is a more intensive system than reservoir ranching. Paddlefish stocked at 75-200/ha with catfish can reach up to 3-4.5 kg in about 12 months, with survival of greater than 90%. Fish can be harvested by seining and sorted by hand from the catfish. This system is best for paddlefish meat production or for grow-out of paddlefish fingerling to sizes required for stocking into reservoir ranching systems.

Paddlefish meat is firm and boneless and is very similar to sturgeon in taste and texture. Processing yields for paddlefish are about 45% whole dressed and 34% fillet. Proximate composition of fillet is 82% moisture, 1.5% fat, 16% protein and 0.9% ash. Fatty acid composition is approximately, 28% saturated, 56% monounsaturated, and 15% polyunsaturated. The omega-3 fatty acid concentration is about 10% of total (Decker *et al.* 1991).

Largemouth Bass

The largemouth bass (*Micropterus salmoides*) is a member of the Sunfish Family (*Centrarchidae*). Members of the *Micropterus* genus are known as black bass and share the sunfish family with the bream (*Lepomis* spp.), crappies (*Poxomis* spp.) and several other genera. The largemouth bass is native to the midwestern and southeastern United States and northeastern Mexico. At present, largemouth bass have been introduced throughout the United States and many other countries worldwide. Interest in the commercial culture of largemouth bass is due to the great demand and high selling price compared to other cultured species (Tidwell *et al.* 2000).

The largemouth bass is one of the most popular sport fish in the United States. Although there has been extensive research on largemouth bass for many years, this work has almost exclusively addressed hatchery production and fisheries management. Amazingly little research has been conducted on growth of bass to larger sizes, their nutritional requirements, or suitability as an aquaculture species.

In the 1960's, Dr. Snow at Auburn University conducted a series of studies on raising largemouth to sizes of 2.5-3.0 cm on feed as a method of increasing and intensifying hatchery production for sportfish stocking. During the 1980's a number of federal and state hatcheries refined feed training techniques, again to maximize hatchery production. In recent years aquaculturist have become interested in the culture of feed trained largemouth to larger sizes. This interest is based on an increasing demand for large bass for remedial stocking in sportfish ponds, their use in commercial "trophy" lakes, and a demand for live bass as food fish among ethnic Asians.

The production of largemouth bass fry follows well-established procedures dating back to the 1930's. Largemouth bass are usually pond spawned and do not require hormone or photoperiod manipulations. Broodfish of greater than or equal to 2 years of age and 0.6 kg in weight are stocked into 0.2-0.4 ha spawning ponds at125 brood pair per hectare. Spawning ponds are normally not fertilized so that spawning behavior, eggs, and fry can be observed easily and more easily harvested. Broods may be stocked when temperatures reach 18ºC and spawning should begin soon after.

Since spawning ponds are not fertilized, a nursery pond should be prepared as soon as spawning begins using organic and inorganic fertilization so as to contain large numbers of food items (zooplankton) for the bass fry. When large numbers of fry can be seen in the spawning pond, fry should be transferred from the spawning to the nursery pond and stocked at 100,000-200,000 fry/ha. After 3-4 weeks in a properly prepared nursery pond bass should reach 0.6-0.8 cm in length and be ready for feed training.

To feed train largemouth bass (and several other species) the basic concept is to remove the fish from the natural source of food, crowd them at high densities, and present them with highly palatable prepared foods at frequent and regular intervals. For feed training, fingerlings (0.6-0.8 cm) are seined from the nursery pond, graded to uniform sizes, and stocked in flow through tanks (round or rectangular) at a high density, which is based on water flow. Fish are then offered freeze-dried krill, ground fish flesh, or fish eggs. Freeze dried krill is especially effective, commercially available, and easy to feed and store. These highly palatable products are then gradually mixed in with a high quality salmonid diet. With fish flesh and eggs a semi-moist diet is produced. Over a series of about a week, each day's feed ration should be increasingly comprised of the manufactured feed. By Day 7 the fish should be consuming straight feed. Fish that have trained to take the feed will by this time be thick bodied, with large tank or compartment and maintained on feed for several more days before pond stocking. Fish that haven't obviously trained can be left in the tank and the use of moist training diets or krill may be repeated. After an additional week most of these fish should adapt to the diet. With good results about 80-90% of the fish originally stocked should train to accept artificial diets. Recent studies have shown that offspring from second or third generation feed-trained fish train easier than those from forage fed fish indicating improvements from domestication.

After the fish have been feeding actively in tanks for at least 2 weeks, fish can be stocked into ponds at 50,000-75,000/ha and fed 2-3 times per day using a 40-48% protein salmonid diet with 8-10% fat. Feed the fish all they will readily consume at each feeding. Largemouth will feed voraciously on some days and not so actively on others, this is probably associated with temperature, sunlight, and/or water quality changes. A floating diet is desirable as it allows the person feeding to more easily observe the fish feed to satiation. Bass should attain sizes of 15-20 cm (with some larger individuals) by the following fall. This size is well suited for pond stocking.

To produce fish of greater than or equal to 1 pound will require at least one additional year of growth. Fish can be thinned to grow-out densities either in the fall or spring, however fish should not be handled when water temperatures are below 13ºC due to fungal infections. Some papers have recommended a grow-out density of 5,000/ha. However, research at KSU found no difference in average weights of fish stocked at 12,000 or 6,000/ha, while the higher density produced double the amount of fish per unit of pond. Production was best in bass stocked at 12000-15,000/ha and fed a 46-48% protein diet with 6-8% lipid. Fish were fed once daily to satiation and produced approximately 4000 kg/ha of fish which averaged 400 g. Bass can be harvested by seine similar to catfish. They are actually easier to catch, but will jump over the seine if edges aren't held high.

Water quality tolerances in largemouth bass vary with age and other culture conditions. Data indicate that feed conversion efficiencies are reduced at oxygen concentrations below 4 milligrams per l, avoid D.O. levels less than 3 milligrams per liter and can tolerate a D.O. of 1.4 milligram per liter at 25ºC. Ammonia tolerance is similar to or slightly less than channel catfish with a 24-hour un-ionized ammonia LC50 value of 1.69 milligram per liter. However, centrarchids appear to be very tolerant of high nitrite concentrations due to an ability to prevent absorption. The 96-hour LC50 for nitrite is 24.8 milligram per liter in channel catfish but 460 milligram per liter in largemouth bass.

Nutritional research on largemouth bass is extremely limited. Pond studies raising second year fish to approximately 0.3 kg demonstrated that diets containing 42-48% protein could be advantageous. Most largemouth bass in commercial production are currently fed high protein (greater than 40%) salmonid diets based primarily on ready availability. However, reported problems concerning pale, fatty livers and mortality have been thought to be nutritionally related. Liver problems may reflect a skewed protein/energy ratio or excess carbohydrates in the diet. Winter mortality in pellet fed fish has also been reported and could be related to nutrition, especially vitamin deficiencies. Additional nutrition research is sorely needed as an essential component to the development of the efficient aquaculture production of this fish.

Asian consumers appear to desire live largemouth bass above all other freshwater fish. They desire fish of 0.7-0.9 kg, which may require third year growth. Processing of largemouth has not been reported. However, the basses tend to have a relatively round body profile, and may become quite thick in body confirmation at large sizes. Preliminary data from Kentucky State University (KSU) indicated dress-out values similar to catfish (60% whole dress, 40% filet), relatively high protein levels, and extremely high levels of omega-3 fatty acids. These are the "heart healthy" fatty acids reported to be so advantageous for human health.

Tilapia

Several species of tilapia and their hybrids are farmed throughout the world. There is evidence to suggest the Egyptians raised tilapia in ponds over 3000 years ago. Tilapia are also called "Saint Peter's Fish" because it has been said that they were the fish Peter caught when Christ told him to cast out his nets in the Sea of Galilee.

Tilapia have several attributes which make them attractive as a culture species: high tolerance of poor water quality and crowding, good performance on commercial catfish feed (32% protein), a high degree of disease resistance, and a mild flavored, white flesh. Because of their tolerance to crowding and poor water quality, tilapia are well suited to cage culture and recirculating systems. Research has also shown that in addition to controlling filamentous algae, tilapia stocked in channel catfish ponds can help control off-flavors by eating blue-green and other large planktonic algae.

Tilapia have a good growth rate. A 50-100 g tilapia fingerling can reach 0.3 kg by the end of a temperate growing season. Tilapia performance is best in a temperature range of 22-32ºC. Growth and feeding slow when temperatures drop below 21ºC. However, tilapia are cold intolerant and die when water temperatures drop below 8ºC.

Tilapia produce a mild flavored flaky white flesh which lends itself to many preparations. They are relatively low in fat (< 4%). However, their fillet yield is relatively low (33% for 500 g fish and less for smaller).

Red Claw Crayfish

Red claw crawfish (Australian crayfish; *Cherax quadricarinatus*) should be very similar in culture methods to the freshwater shrimp (*Macrobrachium rosenbergii*) that were described earlier. However, there are several differences. One difference between the two species is that red claw seedstock will cost more. Another difference is that red claw can spawn in freshwater, not brackish water as the freshwater shrimp does. Thirdly, red claw do not undergo larval stages like freshwater shrimp and can eat a pelleted diet after being released from the female. These last two characteristics of red claw make them easier for a producer to establish his/her own hatchery. A drawback to red claw juvenile production is their much lower fecundity rate compared to the freshwater shrimp. Red claw females generally produce from 100 to 1000 juveniles per female; however, survival is high because they do not have larval stages. Like the freshwater shrimp, red claw die when water temperatures decline to 10ºC; therefore, they should not pose a threat to native crayfish species.

Bluegill and Bluegill Hybrids

In recent years the interest in culture of bluegill hybrids has increased greatly. Much of the attention has been focused on the hybrid produced when male bluegill (*Lepomis macrochirus*) are crossed with green sunfish (*L. cyanellus*). This hybrid has been singled out among the many "bream" species based on its' aggressive nature, willingness to accept artificial diets, and skewed sex ratio (greater than or equal to 90% male). This has resulted in substantial production for stocking into recreational ponds. Hybrid bluegill have been evaluated, and show promise, for use in pay lakes (fee fishing). In the north central region of the U.S., hybrid bluegill have also been identified as a species of primary interest for food fish production.

Compared to other interspecific hybrids, such as hybrid striped bass, hybrid bluegill are relatively easy to produce. No hormone treatments are required and pond spawning is relatively productive and reliable. One of the most important factors in the production of hybrid bluegill is proper identification of both sexes used in the cross. Improper sexing of even one or two fish can ruin the production of an entire pond. Spawning usually occurs at 25-27ºC. Fry should be observable soon after hatching. Broodfish may be selectively removed by using a large mesh seine (based on brood size). A powder trout starter diet should be fed around the edges of the pond. Once feeding is observed particle sizes can be increased accordingly. Approximately 250,000 fry/ha may be produced. Fingerlings can reach a stocker size of 5-75 cm in 60-100 days. Transport of 5-7.5 cm fish is usually less stressful once temperatures cool in the fall. For pond stocking fish are now ready to sell. For use in pay lakes, or possibly as food fish, at least a second year of growth is required. Fingerlings are thinned or stocked in the fall or spring at 12,000-24,000/ha and fed a 32-36% protein-floating pellet until harvest.

Conclusions

As can be seen, aquaculture is a diverse industry both in terms of technologies used and species raised. While competition from low cost imports represent a serious concern to industry growth, development of unique product forms and initiatives related to food security for the U.S. will likely contribute to continued growth.

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