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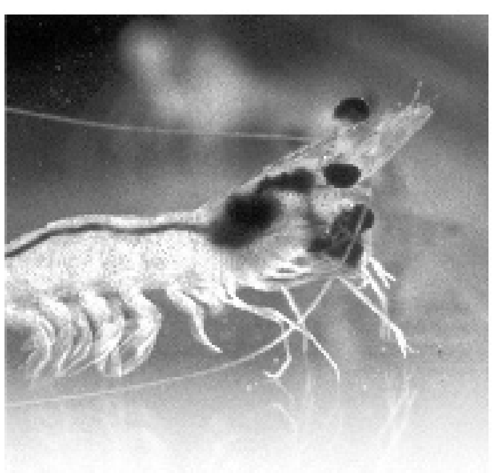
Assessing Infectious Disease Emergence Potential in the U.S. Aquaculture Industry

Phase 1: U.S. Aquaculture Industry Profile



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Project Approach

Emerging infectious diseases are diseases that have newly appeared in a population or that have existed but are evolving or increasing in incidence or geographic range. Emerging infectious diseases have affected animal and human health in recent decades, demonstrated by bovine spongiform encephalopathy, variant Creutzfeldt-Jakob disease (vCJD), Hendra virus, and Nipah virus, among others. New diseases will continue to emerge and affect animal and public health, along with the economic well-being of countries throughout the world (Brown 2004; King, Marano, and Hughes 2004).

Disease emergence can occur through the evolution of pathogens or the introduction of existing pathogens to a new location, followed by establishment and spread. Pathogen evolution is driven by biological, ecological, environmental, and societal factors, such as those that put adaptive and selective pressure on microbes. Introduction of agents, hosts, or vectors into new settings (including intracountry spread as well as transboundary spread) is promoted through ecological, environmental, and societal changes, economic forces, migration, trade, and travel (Lederberg, Shope, and Oakes 1992; Morse 1995; Smolinski, Hamburg, and Lederberg 2003).

Current methodologies for pathways analysis and risk assessment focus on predicting the likelihood of movement of known diseases to new locations. However, to be able to prevent or decrease the frequency of emerging disease occurrence, a method to predict emergence and movement of novel or evolving diseases is needed. New approaches are needed to accomplish this. Numerous authors have suggested using the biological, ecological, environmental, and societal factors associated with disease emergence to improve prediction; however, interactions among these emergence factors can be complex, making modeling difficult (Linthicum, Anyamba, Tucker, Kelley, Myers, and Peters 1990; Wilson, Levins, and Spielman 1994; Myers, Rogers, Cox, Flahault, and Hay 2000). Attempts to date have focused on predicting the potential movement of known vector-borne diseases, such as Rift Valley fever, by examining climate and ecological factors (Linthicum et al. 1990; Myers et al. 2000).

The goal of this project was to develop a method that could assess disease emergence potential for an animal industry. The method used information on disease emergence risk factors. The focus of the project was to assess an industry's overall likelihood of disease emergence rather than assessing the likelihood of emergence of a particular disease. Such a tool could be used by industry and government officials to identify vulnerable areas and to effectively target mitigation measures. The tool could be used to monitor how changes in the dynamics associated with an industry increase or could decrease the potential for disease emergence over time.

The U.S. food fish aquaculture industry was chosen for this project to provide focus and specificity during the development of the method. Aquaculture is defined as the farming of aquatic organisms in inland and coastal areas, involving intervention in the rearing process to enhance production and the individual or corporate ownership of the stock being cultivated (FAO, Glossary of Aquaculture, 2006). Food fish includes finfish and shellfish destined for direct human consumption. The food fish industry in the United States and globally has been developing rapidly. The U.S. and global industries have experienced serious disease outbreaks in recent years. For example, white spot disease, a viral disease of shrimp, first emerged in Japan in 1993 and subsequently spread to many other countries in Asia, Central and South America, and the United States (OIE, International Database on Aquatic Animal Disease, 2006).

Overview of Factors Associated with Infectious Disease Emergence in Aquaculture

Many identified drivers or factors are associated with the new appearance and evolution of aquaculture pathogens, and the spread of pathogens to new locations, including between countries (transboundary) and within countries (intracountry). These factors may overlap and interact with each other in complex ways.

New Appearance and Evolution of Pathogens

Some of the factors that can be associated with the new appearance of pathogens and the evolution of existing pathogens include pathogen and host factors, environmental factors, and the population dynamics of the pathogen and host (Antia, R., Regoes, R.R., Koella, J.C., and Bergstrom, C.T. 2003). An example of a pathogen characteristic related to the evolution of existing pathogens is the mutation of benign wild-type pathogens into more virulent strains, either before or after transmission to a farmed host. Infectious salmon anemia (ISA) is thought to emerge in farmed Atlantic salmon when mutated isolates are transmitted from wild salmonids or, following mutation of benign isolates in farmed salmon, after transmission of the benign isolates from wild salmonids (Nylund, Devold, Plarre, Isdal, and Aarseth 2003). Because pathogen evolution can lower the species barrier, pathogens that mutate more easily, such as RNA viruses, are at higher risk for species-crossing (Kuiken, Holmes, McCauley, Rimmelzwaan, Williams, and Grenfell 2006). Existing pathogens that are known to infect (either clinically apparent or inapparent infection) one host species may be new pathogens for another similar species. Infectious pancreatic necrosis (IPN) was first identified as a pathogen of trout, but subsequently it was found to be pathogenic for a wide range of other fish species (Murray and Peeler 2005). Host characteristics that can play a role in the appearance of new pathogens and the evolution of existing pathogens include age, physiological state, genetic strain, and immunity (Murray and Peeler 2005). Another situation in which a disease can emerge in a new species occurs when a species of fish is introduced into a new geographic area. The newly introduced species may lack the immune defense mechanisms of endemic fish species and, therefore, be more susceptible to existing pathogens (Mauel and Miller 2002).

Environmental factors that reduce immunity in the host or reduce the geographical or behavioral barriers that limit contact and potential pathogen transmission may increase risk for new pathogens or increase the evolution of existing pathogens (Kuiken et al. 2006). High densities of fish, poor management, new rearing conditions, and exposure to infectious agents in aquaculture settings can cause stress on the fish, resulting in decreased resistance to opportunistic infections and favorable conditions for the adaptation and amplification of pathogens (Mauel and Miller 2002; Mjaaland, Hungness, Teig, Dannevig, Thorud, and Rimstad 2002; Murray and Peeler 2005). Exposure to infectious agents on the farm can occur through the introduction of infected stock or contaminated water, feed, and equipment. When barriers between farmed fish and wild fish are broken, farmed fish will be exposed to pathogens infecting wild fish and vice versa. Climate change may affect the geographic range of fish species and of pathogens. For example, fish in Northern European countries are now at increased risk from two diseases, *Lactococcus garviae* and proliferative kidney disease, previously only found in warmer climates (Murray and Peeler 2005).

Species-crossing of a pathogen involves a pathogen donor host species and a pathogen recipient host species. The population dynamics of both the donor host species and the recipient host species, such as the population sizes and the degrees of mixing or interaction, influence the likelihood of a virus persisting in a new species (Kuiken et al. 2006). Three types of interactions influence the likelihood of a virus becoming endemic in a new (recipient) host species: (1) interactions between hosts of the donor and recipient species, (2) host-virus interactions within individual hosts of the recipient species, and (3) host-host interactions within the recipient species (Kuiken et al. 2006). Factors that affect these interactions will affect the likelihood of disease emergence. In addition to host population dynamics, pathogen population dynamics play a role in successful disease emergence. An example of pathogen population dynamics influencing the persistence of a pathogen is the population frequencies of different strains and their varying abilities to evade the host's immune system (Gupta, Ferguson, and Anderson 1998).

Pathways for Transboundary Spread

The factors associated with the transboundary spread of emerging and existing aquaculture diseases from one country to another are primarily related to the introduction of the pathogen through a trade pathway, including trade of live fish, fish eggs, fish products, fish feed, and equipment. Although wild fish do not respect manmade boundaries, aquacultured fish typically have a more controlled environment. This is not true, however, in all situations. For example, international trade of live fish is believed to be one of the main mechanisms contributing to the rapid global spread of koi herpesvirus (KHV) (Gilad, Yun, Adkison, Way, Willits, Bercovier, and Hedrick (2003). Trade in live ornamental fish is thought to be responsible for the spread of emerging iridoviruses. Go, Lancaster, Deece, Dhungyel, and Whittington (2006) found that trade in ornamental fish was linked to an iridovirus epizootic of an economically significant farmed finfish in Australia. Imports of salmonid eggs to Japan since the 1950s are thought to have led to outbreaks of numerous diseases on fish farms in Japan, including IPN, infectious hematopoietic necrosis (IHN), and bacterial kidney disease (BKD) (Yoshimizu 1996). Frozen shrimp imported into the United States were found to contain infectious white spot shrimp virus (WSSV) and thought to be the cause of an outbreak of WSSV in farmed shrimp in Texas (Lightner, Redman, Poulos, Nunan, Mari, and Hasson 1997; Durand, Tank, and Lightner 2000). Imported contaminated fish feed and fishing equipment can lead to outbreaks in the importing country (Murray and Peeler 2005). Wild fish and birds are a pathway for the introduction of aquaculture pathogens across country borders. Ships can move microorganisms and live animals between countries in their ballast water, because they take up ballast water in one country and release it in another (Ruiz, Rawlings, Dobbs, Drake, Mullady, Huq, and Colwell (2000).

Intracountry Spread

Many factors associated with the establishment and intracountry spread of both emerging and existing diseases are similar to factors associated with the appearance of new pathogens and the evolution of existing pathogens. The similarities exist because the mixing of hosts and pathogens, and the stresses on each, play a key role in both processes. The rate and pattern of disease spread on a farm, between farms, and in the wild depend on the spatial distribution, movement, and mixing of the host population (Kuiken et al. 2006). The movement of live fish, including broodstock, fry, fingerlings, and fish eggs, is an important means of intracountry pathogen spread between farms, between wild fish and farmed fish, and between wild fish in different geographic areas. A qualitative risk assessment of the routes of transmission of the fish parasite *Gyrodactylus salaris* identified the anthropogenic movement of live fish as the most important route for the spread of the disease between two river catchments (Peeler, Gardiner, and Thrush 2004). The spread of IHN in Europe was aided by the fact that broodstock may act as carriers and vertically transmit the virus. The disease was introduced to several European trout hatcheries through infected eggs (Ghittino, Latini, Agnetti, Panzieri, Lauro, Ciapelloni, and Petracca 2003). Aquaculture disease control programs rely heavily on the restrictions on the movement of live fish for success (Hastein, Hill, and Winton 1999).

Host, pathogen, and environmental factors play important roles in intracountry pathogen spread. Host factors such as age, physiological state (stressed versus unstressed), and genetic strain influence the susceptibility of fish to infection and disease (Murray and Peeler 2005). Pathogen factors that affect disease spread include virulence, transmissibility, infective dose, and survivability in the environment. Environmental factors, such as the distance between farms, and biosecurity practices, such as treatment of incoming and outgoing water, and disinfection of vehicles, equipment, and personnel, have important effects on the local spread of disease (Murray and Peeler 2005). The release of untreated liquid and solid waste from fish processing plants into waterways or landfills is a mechanism for disease spread (Lightner et al. 1997). Scavenging animals such as wild birds can act as disease vectors (Peeler, Gardiner, and Thrush 2004). Severe weather events can lead to the movement of farmed and wild diseased fish. Water temperature can influence virus replication and onset and severity of mortality (Murray and Peeler 2005). The use of effective disease control and prevention meth-ods on- farms, such as vaccination and rapid removal of sick or dead stock, affect the spread of disease. For example, Norwegian farms that removed dead salmon daily throughout the summer were three times less likely to experience an ISA outbreak compared with farms that removed dead salmon less frequently (Murray and Peeler 2005).

Project Overview

Phase 1: U.S. Aquaculture Industry Profile

As a first step to building an infectious disease emergence risk assessment tool for the U.S. food fish aquaculture industry, it was necessary to develop an understanding of the dynamics associated with the industry and how those dynamics might affect disease emergence. Nine broad areas were examined: (1) agent, host, and vector biology; (2) climate, ecology, and the environment; (3) economics and industry; (4) health management; (5) international trade; (6) the political and regulatory climate; (7) production practices; (8) social and cultural issues; and (9) technology. Detailed information was gathered in each of these areas for the industry in general and for six specific aquacultured species that are important in the United States: catfish, hybrid striped bass, salmon, saltwater shrimp, tilapia, and trout. Once this initial information was gathered, the results were used for phase 2, the development and application of an infectious disease emergence risk assessment tool.

Phase 2: Infectious Disease Emergence Qualitative Risk Assessment Tool Development

Using the information about industry dynamics from phase 1, a tool was developed to help industry managers and government officials understand the "riskiness" of industry practices and the ecologic, economic, political, and social factors for disease emergence, and to identify potential opportunities to mitigate the identified risks. The risk assessment tool had to address three separate elements: disease emergence and evolution, pathways for transboundary spread, and intracountry spread. The tool is structured so that it can be used across the multiple sectors in the aquaculture industry, allowing comparisons to be made across sectors. The tool is applicable over time and capable of capturing changing industry conditions that might signal an increase or decrease in risk. Once the tool was developed, it was applied in phase 3 to four aquaculture sectors in the United States: catfish, salmon, saltwater shrimp, and tilapia.

Phase 3: Infectious Disease Emergence Qualitative Risk Assessment Tool Application and Results

The disease emergence risk assessment tool was applied to four aquaculture sectors in the United States: catfish, salmon, saltwater shrimp, and tilapia. A qualitative risk rank (high, medium, or low) was determined for each sector for each of the disease emergence elements (emergence and evolution, pathways, and spread). The results highlight areas in each sector in which risk mitigation efforts could be targeted to decrease risk.

Phase 1: U.S. Aquaculture Industry Profile

Overview

Worldwide, seafood provides approximately 16 percent of the animal protein in the human diet. The Food and Agriculture Organization (FAO) of the United Nations estimates that 43 percent of all fish and shellfish consumed globally is produced from aquaculture (FAO, World Review of Fisheries and Aquaculture 2006). A tremendous mix of species is currently farmed, including 131 finfish, 42 mollusks, and 27 crustaceans. In 2004, countries in the Asia and Pacific region accounted for 91.5 percent of food fish aquaculture production. Annual growth rates in the Islamic Republic of Iran, Myanmar, the Netherlands, Republic of Korea, Turkey and Vietnam exceeded 15 percent between 2002 and 2004. In much of the world, aquaculture is now seen as an engine for economic development and not as just an alternative food source.

In 2004, the $71.5 billion value of global fish and shellfish exports (wild-caught and farmed, including fresh, chilled, frozen, canned, dried, salted, and smoked fish, and shellfish) (FAO, World Review of Fisheries and Aquaculture 2006) greatly exceeded global exports of fresh, frozen, dried, canned, and prepared bovine meat ($20 billion) or poultry meat ($15 billion) (FAOSTAT 2007). Fish and shellfish products are predominantly traded in processed form; however, the share of live, fresh, or chilled fish and shellfish trade increased slightly from the 1990s to the early 2000s, reaching 10 percent in 2004. Technological developments have allowed this increase in live, fresh, and chilled fish and shellfish trade. Developing countries continue to improve processing capabilities and increasingly export high-value live fish or value-added processed products.

Expansion of aquaculture production has been challenged by concerns about environmental impacts and sustainability. Standards for effluent discharge are being established in many countries. Improvements in feed and feeding efficiency have reduced nutrient loads emitted from fish farms. Research on additional or alternative feed sources could reduce dependency on fishmeal in diets of farmed fish.

Another challenge in aquaculture is the health care system. In general, the aquaculture industry does not rely on veterinarians to provide health management for their animals. The system has evolved without veterinarians because of several different factors. Historically, veterinarians were not trained to deal with aquatic animals. The use of veterinarians and health care experts varies by industry. Many of the industries use fish pathologists or manage many health problems mainly through husbandry techniques. Few approved drugs are available for use in the aquaculture field, which limits treatment options. There have been recent advances in this area, particularly given the passage in 2001 of the Minor Use and Minor Species Animal Health Act by the Food and Drug Administration (FDA). This act allows a mechanism for “minor” species such as fish to be treated with FDA-approved drugs that are not specifically approved in that species. The FDA has designated certain drugs as having low regulatory priority in aquaculture species, which allows more flexibility in the treatment of aquaculture species. The lack of availability of approved drugs is a frequent issue brought up by the aquaculture industry. Aquaculture species must undergo drug withholding before slaughter.

Finfish have a functioning immune system, which enhances disease management. The skin of finfish, with fast-healing properties and a layer of protective mucus, is an important immune component. Some crustacean species have rudimentary immune capabilities. Environmental stressors such as temperature, pollutants, and handling can all affect the immune status of aquatic animals.

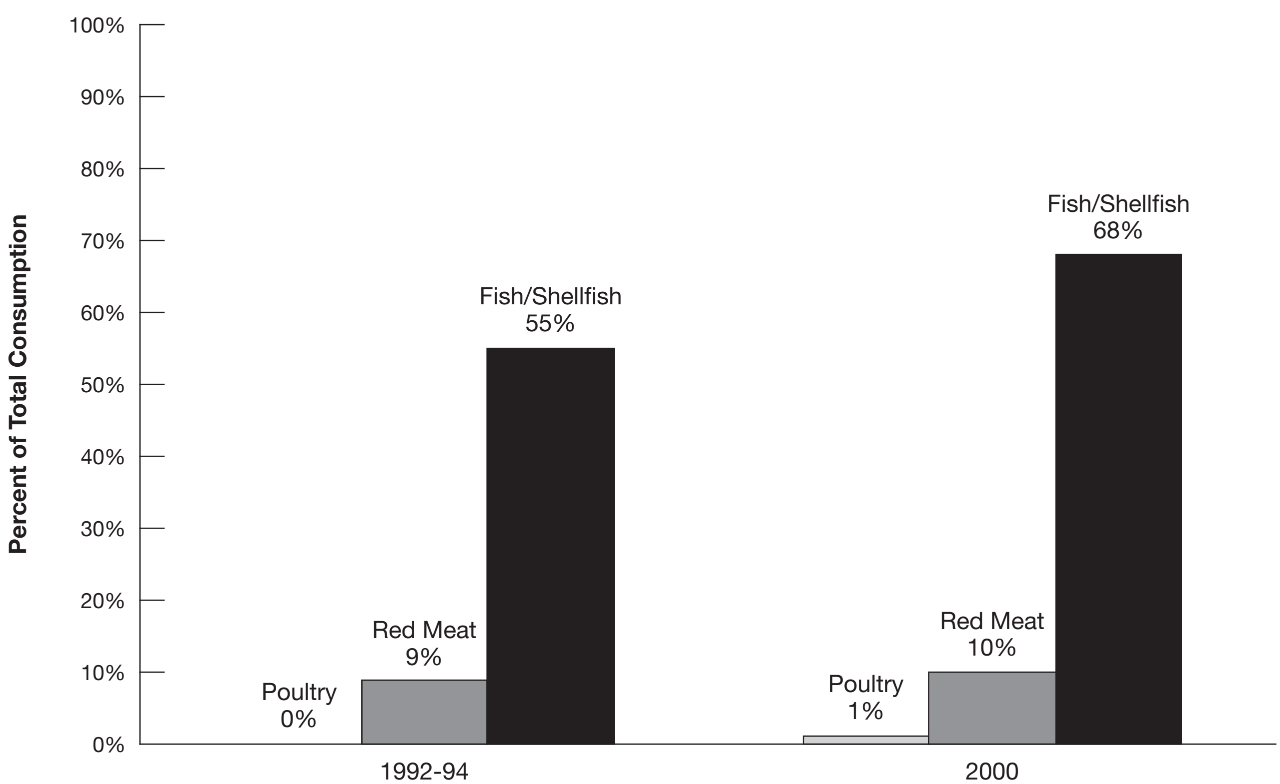
The United States is the third largest consumer of fish and shellfish worldwide, although U.S. per capita consumption falls far below per capita consumption in many other parts of the world, including Asia and Oceania (NOAA 2004). On a per capita basis, fish and shellfish consumption within the United States has increased slowly over recent years, going from 11.2 pounds (edible weight) in 1910 to 16.6 pounds in 2004 (NOAA 2004). Unlike the situation for beef, pork, or poultry consumption, the United States relies on imports for much of its fish and shellfish supply (see figure 1). Nearly 70 percent of the fish and shellfish consumed in the United States is imported and, of those imports, it is estimated that more than 40 percent is supplied through aquaculture.

Fish and shellfish aquaculture production in the United States grew at more than 3.6 percent annually between 1995 and 2004 (see table 1) with total production reaching nearly 900 million pounds in 2004 (NOAA 2004). Catfish production accounted for 72 percent of this total production in 2004. Annual growth rates between 1995 and 2004 were highest for shellfish, notably clams (38.5 percent) and shrimp (37.7 percent). Additional species farmed in the United States, but not included in the production statistics (table 1), include abalone, largemouth bass, red drum, sturgeon, yellow perch, and walleye.

In the next section of this document, detailed profiles are provided for U.S. production of catfish, hybrid striped bass, salmon, shrimp, tilapia, and trout.

Within the United States, several steps have been taken to promote aquaculture. The National Aquaculture Act of 1980 provided a national policy to encourage the domestic aquaculture industry and established the interagency Joint Subcommittee on Aquaculture (JSA). The JSA is a statutory committee that reports to the National Science and Technology

Figure 1: Import Share of Total U.S. Consumption



Source: USDA, Economic Research Service 2005.

Table 1: Fish and Shellfish Aquaculture Production

U.S. Aquaculture Production (1,000 pounds)

	1990	1995	2000	2004	Rate of Change 1995–2004
Finfish:					
Catfish	360,435	446,886	593,603	630,450	41%
Salmon	9,069	31,315	49,372	33,416	7%
Striped Bass	1,590	8,315	11,237	11,500	38%
Tilapia	—	15,075	20,000	20,000	33%
Trout	56,816	55,934	59,164	54,976	–2%
Shellfish:					
Clams	3,680	4,325	9,929	20,967	385%
Crawfish	71,000	58,146	17,025	70,383	21%
Mussels	607	410	424	593	45%
Oysters	22,192	23,221	16,822	26,214	13%
Shrimp	1,984	2,205	4,782	10,513	377%
Total	**527,373**	**645,832**	**782,358**	**879,012**	**36%**

Source: NOAA, National Marine Fisheries Service 2004.
Note: — = not available.

U.S. Aquaculture Production (1,000 dollars)

	1990	1995	2000	2004	Rate of Change 1995–2004
Finfish:					
Catfish	273,210	351,222	445,919	439,158	25%
Salmon	26,341	75,991	99,208	56,679	–25%
Striped Bass	—	21,156	29,513	31,353	48%
Tilapia	—	22,613	30,000	40,000	77%
Trout	64,640	61,447	63,690	57,082	–7%
Shellfish:					
Clams	13,486	19,709	32,595	73,339	272%
Crawfish	34,000	34,714	27,626	42,836	23%
Mussels	1,173	1,221	525	3,956	224%
Oysters	77,949	70,628	42,419	80,075	13%
Shrimp	10,344	8,818	14,559	21,280	141%
Total	**501,143**	**667,519**	**786,054**	**845,758**	**27%**

Source: NOAA, National Marine Fisheries Service 2004.
Note: — = not available.

Council Committee on Science and serves as a Federal Government-wide coordinating group.

The JSA has commissioned a National Aquatic Animal Health Task Force, which includes representatives from the Animal and Plant Health Inspection Service (U.S. Department of Agriculture), the Fish and Wildlife Service (U.S. Department of the Interior), and the National Oceanic and Atmospheric Administration National Marine Fisheries Service (U.S. Department of Commerce). One of the assignments of this task force is to develop a National Aquatic Animal Health Plan (NAAHP) that provides for efficient, safe, and effective national and international commerce of aquatic animals; requires the protection of cultured and wild aquatic animals from foreign pests and diseases; calls for the U.S. Government to meet its legal trade obligations; and ensures the availability of diagnostic and certification services for public, private, and tribal entities (National Aquatic Animal Health Task Force 2003). The task force has established a number of working groups to examine various components of the plan. It is anticipated that a draft of the full plan will be completed by 2007 and will cover a wide range of issues, including diseases of concern, disease prevention, surveillance, disease control and management, commerce, education and training, research and development, and roles and responsibilities of Federal agencies.

In summer 2005, the National Offshore Aquaculture Act was proposed by the Bush administration and was issued in response to the 2004 report from the U.S. Commission on Ocean Policy, "An Ocean Blueprint for the 21st Century." A revised version of this Act was introduced in the U.S. House of Representatives and in the U.S. Senate in the spring of 2007. The National Offshore Aquaculture Act of 2007 would provide the necessary authority to the Secretary of Commerce for the establishment and implementation of a regulatory system for aquaculture in Federal waters, also known as the U.S. Exclusive Economic Zone (EEZ). The revised Act includes additional environmental requirements, changes to permits and the role of States, and provisions for research for all marine aquaculture, including research on alternative feed formulas to reduce the use of wild fish in aquaculture feeds. A number of offshore aquaculture demonstration projects are currently ongoing for blue mussels, cobia, moi, and cod/haddock.

Sector-Specific Profiles

This section provides brief summaries of the dynamics associated with six food fish and shellfish sectors in the United States (catfish, hybrid striped bass, salmon, shrimp, tilapia, and trout), including forces for change within each sector. These sectors were chosen to showcase the range of production taking place in the United States from catfish aquaculture, which is a relatively well-established industry, to hybrid striped bass, tilapia, and the freshwater segment of the shrimp industry, which are all younger industries.

Catfish

U.S. Production

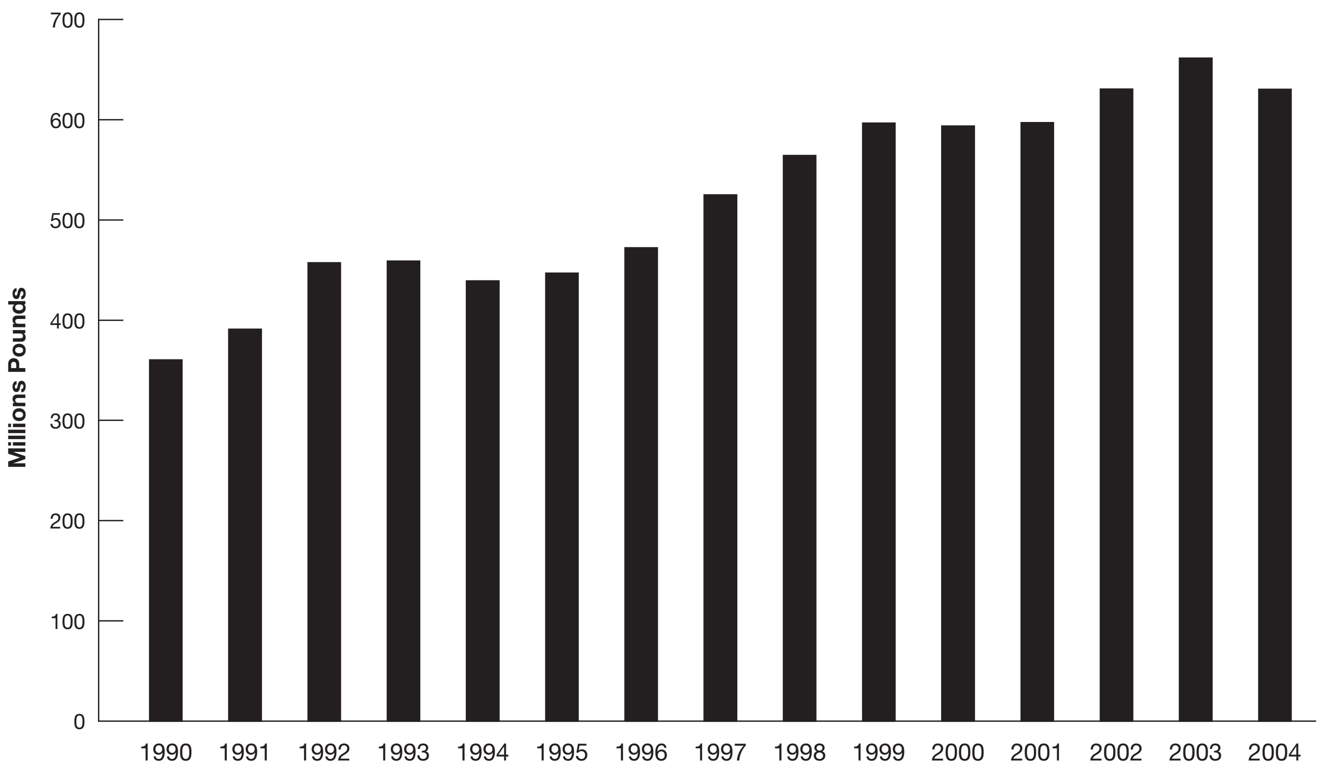
Catfish culture is the most economically important food fish aquaculture sector in the United States. Catfish cultivation techniques were first developed in the early to mid-1900s when catfish were being propagated to stock U.S. waterways. Between 1970 and 1990, catfish production for food grew rapidly with the quantity of processed farmed catfish increasing more than tenfold. The rate of growth in catfish production has slowed since 1990, but production has generally increased annually. Between 2000 and 2004, U.S. catfish production grew by approximately 6 percent (see figure 2).

Catfish prefer warm water, with optimal growth achieved at 85 degrees Fahrenheit. Most catfish production in the United States (98 percent) takes place in unheated earthen ponds. Given these current production methods, catfish cultivation is limited to southeastern areas of the United States with an appropriate climate. More than 90 percent of U.S. production of food-size catfish takes place in Alabama, Arkansas, Louisiana, and Mississippi, with production of fingerlings concentrated in Mississippi (90 percent of production). According to USDA:National Agricultural Statistics Service (NASS) data for 2004, 1,147 total farms were producing catfish in 13 states; 35 percent of these farms were located in Mississippi. Acreage devoted to catfish has remained static or has dropped slightly in the four major production states, while acreage in Florida, Georgia, Kentucky, and North Carolina increased. Catfish farms averaged 160 acres in 2002, an increase of 25 acres over average size in 1999.

Channel catfish (*Ictalurus punctatus*) is the most common species raised in the United States; other catfish species produced on a limited basis include the blue catfish and the channel-blue hybrid. Polyculture is used in the industry with approximately half of all operations maintaining catfish plus another species. Polyculture in this case is used to control algal species or aquatic weeds rather than to produce another marketable product. Grass carp, fathead minnows, and threadfin shad are some of the species currently being used in polyculture with catfish. Of these several species, grass carp is the only one that is actually harvested and marketed. Grass carp are sometimes grown with catfish for weed control; however, the use of grass carp and other carp in catfish production is prohibited in some states because of invasive species concerns.

Catfish production involves four stages. Catfish are spawned in specialized ponds, because they typically do not reproduce in growout ponds. The eggs are then collected and hatched in indoor tanks or troughs. After two weeks, the resulting fry are stocked in nursery ponds. Fingerlings are moved from the nursery ponds into growout ponds. The catfish industry includes producers who combine all stages of production within their operation and producers who specialize in fry, fingerlings, or food-size fish production. Specialized fry and fingerling producers are more common in western Mississippi and Arkansas.

Figure 2: U.S. Farmed Catfish Production



Source: NOAA, National Marine Fisheries Service 2004.

Until recently, brood fish were sourced from food fish growout ponds or from existing high-performing broodstock. Efforts to improve genetics within the industry have led to more selectivity in broodstock. Most catfish produced are of an unknown breed, although the USDA:APHIS:National Animal Health Monitoring System (NAHMS) 2003 Catfish study reported that 40 percent of respondents stock at least some branded fingerlings. Additionally, the USDA Agriculture Research Service (ARS) released an improved strain of brood fish in 2001.

Traditionally, catfish producers have maintained growout ponds with fish of varying ages, enabling them to harvest fish year-round. In this manner, ponds were kept in production continuously for a number of years with a high stocking density. Catfish production in some areas is moving to all-in/all-out or single-batch production; however, according to the NAHMS 2003 catfish study, more than 80 percent of fingerlings stocked were placed in ponds already containing fish. In addition to single-batch production, some producers are using pond sorting. In pond sorting, fish are harvested multiple times to ensure that only the most desirable product is harvested and at the most profitable level. Current technology may limit the growth of pond sorting because the costs associated with sorting and movements of fish between ponds are still relatively high. Extension projects at research facilities continue to experiment with other production changes, such as varying pond depth, temperature, and chemical usage.

Catfish require a diet containing 28 to 30 percent protein in the growout phase. Fry require a diet with higher protein content. In the United States, this protein requirement is met largely with vegetable-based proteins, principally soybean meal. Fishmeal and fish oil account for an average of 2 percent of catfish diets. Although that percentage is declining, fishmeal is still an important component in the diets of fry. Worldwide, however, less than 1 percent of all fishmeal is fed to catfish. Meat and bone meal, blood meal, and poultry meal are sometimes used in catfish diets.

Biosecurity practices on catfish farms vary. Because catfish are raised in open water ponds, they are exposed to birds and other animals. Catfish have relatively little exposure to wild aquatic species and the pathogens they may carry, because the water used to fill the ponds is generally pumped from groundwater. The exception to this is that in some parts of Alabama ponds are constructed by initially damming small streams and diverting water into the pond. Water for hatchery facilities is often sourced from groundwater as well. Once filled, seepage from the clay-bottomed ponds is minimal and, in most production areas, rainfall is sufficient to maintain pond levels. Contact with pathogens can occur from water contamination, introduction of new stock, and agricultural effluent run-off during extreme weather events, and movement of equipment, personnel, and wildlife. Health certificates are required to move fish between some states.

A number of important diseases affect catfish production in the United States. In 2002, the most frequent disease problems reported by food-size catfish operations were as follows: enteric septicemia of catfish (ESC) (reported by 61 percent of operations), columnaris disease (50 percent), and winter kill (33 percent). Additional disease issues reported by catfish producers in 2002 included the following: anemia (14 percent of operations), proliferative gill disease (PGD) (13 percent), visceral toxicosis of catfish (10 percent), trematodes (4 percent), and *Ichthyophthirius multifilis* ("ich") (4 percent). Of the food-size catfish operations surveyed, 17 percent vaccinate for ESC.

Although catfish can accommodate a range of environmental conditions and crowding, catfish producers report significant losses over the production cycle. Annual losses are routinely between 15 and 20 percent of total fish stocked. Producers report that infectious diseases account for the largest percentage of losses, with catfish fry and fingerlings being especially vulnerable to infectious diseases. Approximately 65 percent of the fry and fingerlings lost during production are believed to be lost because of infectious diseases, especially ESC and columnaris.

The catfish industry utilizes veterinarians on a limited basis, and producers tend to provide much of their own health care. Three antibiotics are approved for use in catfish: ormetroprim (Romet-30), oxytetracycline (Terramycin), and florfenicol (Aquaflor). In addition, formalin, which is used to control protozoan parasites, is also approved for use in catfish production. Diagnostic laboratory support is readily available to producers, and 34 percent of producers reported submitting samples in the NAHMS catfish study. Two of the major laboratories supplying services to catfish farmers are located at the Thad Cochran National Warmwater Aquaculture Center at Mississippi State University and the Aquaculture/Fisheries Center at the University of Arkansas at Pine Bluff.

Research on catfish is funded collaboratively by the industry, State governments, and the Federal Government. In 2000, the catfish industry was the second largest beneficiary of USDA Cooperative State Research, Education and Extension Service (CSREES) aquaculture research funds (the shrimp sector received the most funding). The principal catfish research institutions in the United States include Auburn University; Mississippi State University; the USDA ARS Regional Aquaculture Center at Stoneville, Mississippi; and the University of Arkansas at Pine Bluff. Issues being researched include emerging diseases, hybrids, genetics, and production.

Marketing

Between 2000 and 2003, catfish remained the fifth most consumed seafood in the United States with consumption at approximately 1 pound per person per year. Catfish is a popular fish with African-American and Asian populations.

More than 90 percent of catfish are marketed directly to large, year-round processing plants. The remaining small percentage of fish (less than 10 percent) are processed on-farm and sold directly to restaurants and grocery stores, or are sold live to stock fee-based fishing ponds. In 2004, 16 processors were listed on the Catfish Institute Certified Processor List.

In 2003, processors sold 60 percent of their product as fillets, 18 percent as whole dressed fish, and 22 percent as other products. Catfish processors now require larger fish to meet increasing demand for portion control and standardized fillets.

Less than 40 percent of each individual catfish is used to produce the fillets and other primary products marketed to consumers. Currently, catfish by-products are used in fishmeal, fish oil, and pet food. Significant effort is under way, however, to develop additional uses for catfish by-products, including catfish mince to produce catfish nuggets, patties, and sausages.

International Production and Trade

Among all catfish species produced in 2005, the United States accounted for 18 percent of worldwide production (see table 2). Other major producing countries include China (32 percent), Vietnam (25 percent), Thailand (9 percent), Indonesia (7 percent), and India (3 percent). Between 2003 and 2005, production in Nigeria grew 234 percent while production in Vietnam grew 131 percent. China experienced a 50 percent growth over the same time period.

The United States is the principal producer of channel catfish worldwide; other catfish species are produced in numerous countries. Growers in Vietnam produce basa, swai, and tra (*Pangasius* spp.), which they began marketing as catfish in significantly increased quantities to the United States beginning in 1997 and peaking in 2001. U.S. catfish producers argued that the Vietnamese fish were not catfish and should not be allowed to be marketed as catfish. Producers also argued that the Vietnamese fish were being marketed in the United States at unfair prices, which amounted to dumping. The U.S. catfish industry received protection in 2002 from the International Trade Commission when it imposed tariffs on species imported from Vietnam. Nonictalurid fish are now prohibited from being labeled as catfish. Country-of-origin labeling has also gone into effect for food fish. In 2003, China began exporting catfish fillets to the United States. U.S. imports from China in 2003 and 2004 were 326 and 347 metric tons, respectively. Guyana exports more than 100 metric tons of catfish fillets to the United States annually. No live catfish are imported into the United States.

Table 2: Top 10 Farmed Catfish-Producing Countries, 2005

Catfish	
Country	**Production in 1,000 pounds**
China	956,008
Vietnam	752,000
United States of America	551,508
Thailand	261,568
Indonesia	204,180
India	88,106
Nigeria	71,338
Malaysia	49,378
Netherlands	8,400
Brazil	7,464
World Total	**3,026,644**

Note: Catfish include the following species: African catfish, Amur catfish, Asian redtail catfish, Atipa, Bagrid catfish, Barred sorubim, Bayad, Black bullhead, Black catfishes nei, Blue Catfish, Catfish, hybrid, Catfishes nei, Channel catfish, Chinese longsnout catfish, Duckbill catfish, Flathead catfish, Freshwater siluroids nei, Hong Kong catfish, Naked catfishes, North African catfish, Pangas catfish, Pangas catfishes nei, Philippine catfish, Sampa, South American catfish, Striped catfish, Torpedo-shaped catfishes nei, Upsidedown catfishes, Wels(=Som) catfish, and Yellow catfish.
Source: FAO, Fishstat Plus, 2007.

Hybrid Striped Bass

U.S. Production

Production of hybrid striped bass (HSB) began in the United States in response to restrictions placed in the 1980s on the commercial harvest of wild striped bass because of declines in the wild populations. Initial efforts to farm striped bass proved unsuccessful, but a hybrid of the striped bass and the white bass (*Morone chrysops*) proved more adaptable to culture techniques. In addition to striped bass and white bass, HSB are stocked in waterways in many states, although some states are concerned about HSB hybridizing with wild species.

HSB production in the United States relies on wild fish for broodstock, although a national domestication program is under way. Wild fish, mostly white bass females, are collected, with the Lake Erie commercial fishery being a prime source location. Approximately one dozen hatcheries in the United States produce fry and fingerlings; however, one operation in Arkansas supplies half of the fry and fingerlings used in U.S. HSB aquaculture operations. Remaining fry and fingerling production takes place in Delaware, Florida, North Carolina, and South Carolina. Fingerling production is seasonal, taking place largely during the spring and summer.

In 2004, 61 total operations were farming HSB in the United States. Production grew from 1.6 million pounds in 1990 to 11.5 million pounds in 2004 (see figure 3). The largest U.S. producer is located in California and produces approximately 30 percent of total U.S. production. Large producers located in Mississippi and Texas produce an additional 30 percent. Most of the remaining production takes place in Georgia, North Carolina, and South Carolina, although many other states account for some relatively small-scale HSB production. A census of producers taken in the late 1990s indicated production in 19 states.

U.S. HSB production has moved from mostly tanks to mostly pond culture, although a large California producer uses a semirecirculating tank system. Pond production surpassed tank production in 1998; in 2004, tanks accounted for 38 percent of production, compared with 61 percent from ponds. Cage production is practiced by a few producers in the upper Midwest, but it remains a minor component of production. Pond sizes range from 1 acre to more than 500 acres. Refinements continue to be made in production practices, allowing greater culture intensity. Water availability is the main limiting factor in HSB production, and several new technologies are on the horizon for HSB. Water reuse is one technology that is being explored, as are bacterial-based systems that will also decrease water use.

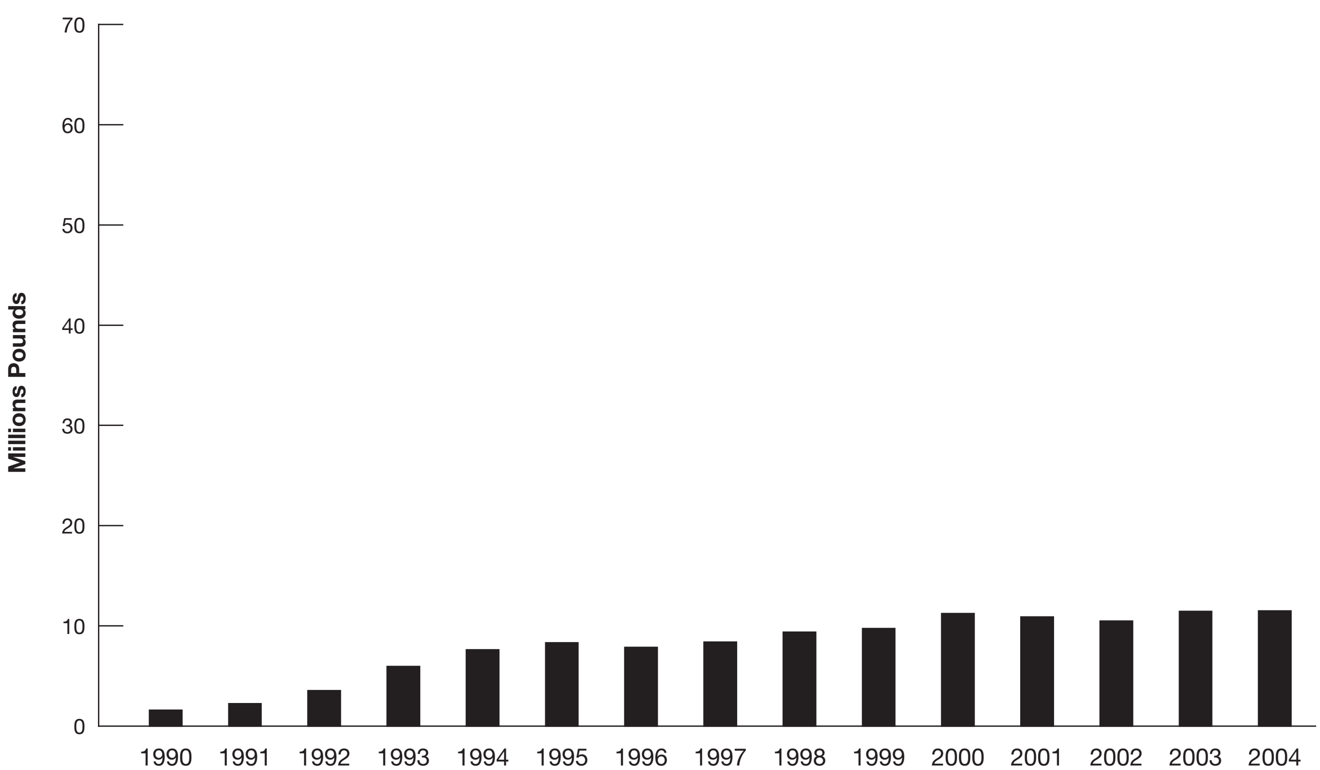
HSB are produced in three stages, with considerable numbers of fish lost at each stage. In the first stage, fry are stocked at 150,000 to 200,000 per acre with an expected survival rate of 20 percent. In the second stage, fingerlings weighing about 1 gram are stocked at 10,000 to 15,000 per acre, with an expected survival rate of 85 percent. After about six months, when the fingerlings weigh 0.25 pounds, the growout stage begins and fish are stocked at about 3,500 to 4,000 fish per acre. Survival rates in the growout stage are about 80 percent. The entire production cycle takes approximately 18 to 24 months for the fish to reach a harvest weight of 1.5 to 2.5 pounds. Because HSB are carnivores, production systems must be careful to maintain stock of similar size within each pond to avoid cannibalism. Additionally, at the end of each production cycle, producers must ensure that all fish have been removed either by draining or treating the pond. The optimum temperature for growth is 77 to 80 degrees Fahrenheit.

HSB diets are approximately 40 percent protein with 10 to 20 percent of the protein supplied by fishmeal (down from more than 33 percent fishmeal fed in the mid-1990s). Experiments using poultry by-product meal as a replacement for fishmeal in HSB diets are being conducted. There has been some experimenting with administering recombinant bovine somatotropin to enhance phosphorus digestion in HSB.

HSB are considered to be disease resistant. Contact with potential pathogens can happen through water inflow, introduced stock, and predation. Health certificates are required to move fish between some states. The two most important disease issues facing HSB in the United States are photobacteriosis and *Streptococcus iniae.* HSB are also affected by columnaris, mycobacteriosis, vibriosis, fungal diseases, and parasites.

Some HSB producers must comply with the new Environmental Protection Agency (EPA) Concentrated Aquatic Animal Production regulations for water and waste discharge. These regulations apply to producers using flow-through or recirculating systems that

Figure 3: U.S. Farmed Striped Bass Production



Source: NOAA, National Marine Fisheries Service 2004.

produce more than 100,000 pounds of fish per year. These regulations require that qualified producers obtain a National Pollutant Discharge Elimination System (NPDES) permit. The permit sets requirements on the discharged water to protect the quality of surface water. These regulations increase the need of the producers to manage pollution outputs and maintain records of this management. In August 2005, farmed HSB were ranked as a “Best Choice” by the Monterey Bay Aquarium Seafood Watch. The Seafood Watch program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the U.S. marketplace.

HSB breeding programs have focused on fast growth, disease resistance, and development of complete diets for each phase of production. Research on intensive larval rearing is being conducted. Additional research needs include optimizing triploidy, licensing additional antimicrobials, and establishing procedures to control grubs in ponds through the use of snails. USDA:CSREES facilities and the ARS Stuttgart and Auburn laboratories provide research support for HSB producers on issues such as domesticating broodstock, genetic selection, nutrition, efficacy of therapeutic agents, and new vaccines.

Marketing

Cultured HSB were initially marketed to fill the niche left behind when the wild striped bass harvest declined. Although farmed HSB have filled these relatively limited markets, HSB are not among the top 10 fish species consumed in the United States.

The majority of HSB (80 percent) is sold whole and fresh to wholesalers and retailers for the white tablecloth restaurant market. Most of the remaining 20 percent of the HSB produced in the United States are sold at live markets, but there were large regional differences in live market sales. The proportion of total U.S. live market HSB sales in 2004 ranged from 4 percent in the States of Alabama, Arkansas, Florida, Louisiana, Mississippi, and Tennessee to 59 percent in the States of Georgia, North Carolina, and South Carolina. These live markets cater mainly to Asian consumers. Demand for live HSB is growing in urban areas, including Baltimore, Boston, New York, and Philadelphia. A few producers market to recreational fish ponds. Prices for HSB are declining because of competition from other species, increasing commercial harvests of wild striped bass, and increased supply from farmed HSB production.

International Production and Trade

The United States is the world leader in HSB production, accounting for nearly 85 percent of worldwide production in 2002. HSB production is expanding in China, Israel, Italy, Spain, and Taiwan (China), often using fry purchased from the United States.

Approximately 20 percent of HSB fry raised in the United States are exported, as are 4 percent of the fingerlings. Import statistics for the United States do not separate HSB from other fish species, and therefore the quantity of HSB imports is unknown. It is believed that U.S. producers have been negatively affected by the rapid increases in imports of tilapia.

Salmon

U.S. Production

Salmon (principally Atlantic salmon, *Salmo salar*) are raised in the United States for food and for enhancing or restoring wild fisheries. Commercial salmon farming for food is limited to Maine and Washington. The U.S. industry is highly concentrated with one principal producer in Maine and one firm owning all operations in Washington. None of the companies owning U.S. salmon farms are American, and all of the parent companies have production facilities in other countries and export to the United States.

Atlantic salmon production in the United States peaked in 2000 at nearly 50 million pounds and dropped to less than 34 million pounds by 2004 (see figure 4). Production in Maine declined nearly 60 percent between 2000 and 2002 mainly because of ISA outbreaks; however, regulations restricting noise, site locations, and waste dispersal affected production capacity. Import price competition added further pressure on Maine production. The ISA outbreak in Maine in 2001 resulted in State regulations, industry best management practices (BMPs), and ISA program standards recommending lower stocking densities and mandated fallowing periods. During this same time, production in Washington remained steady. There have been no new leases approved for salmon farms in Washington since the early 1990s, and none for Maine farms since the late 1990s.

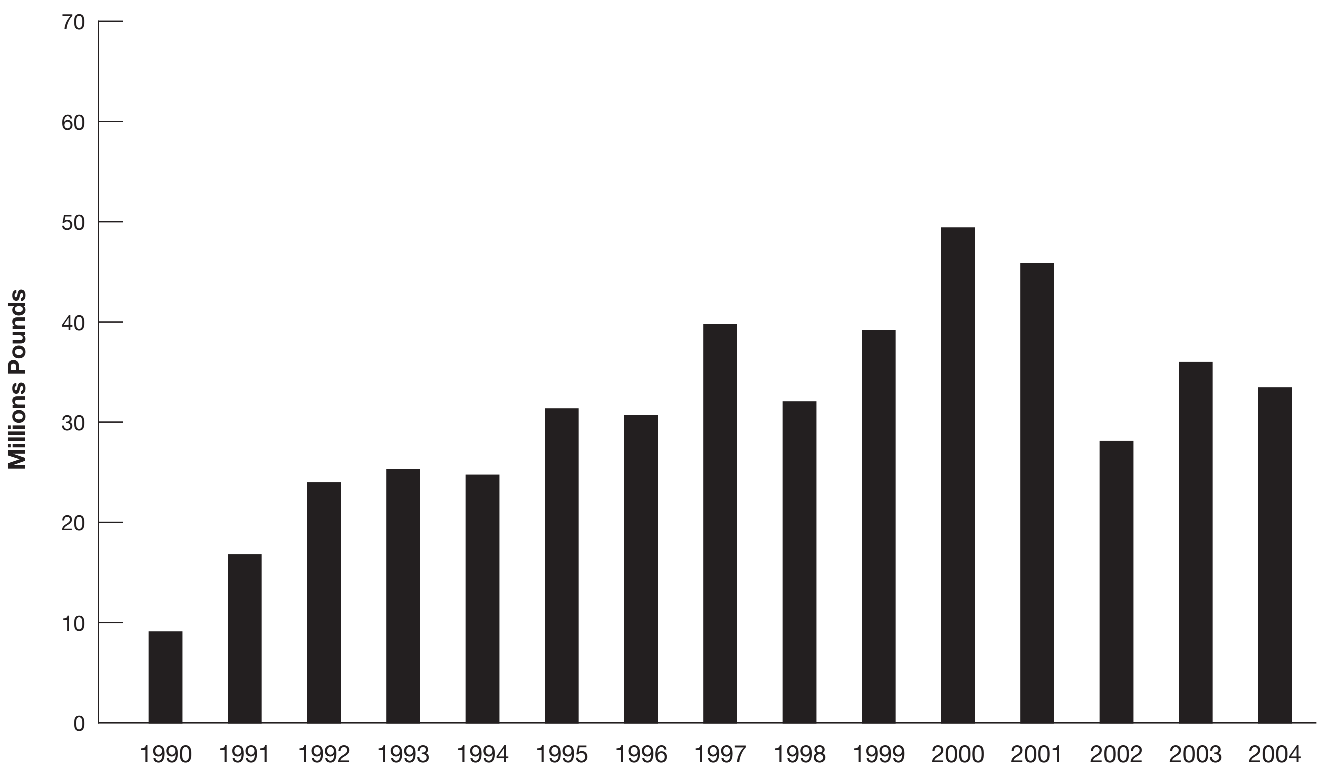
Salmon broodstock are generally selected from high-performing fish and kept separately in freshwater hatcheries as part of a breeding program. Eggs from each mated pair are incubated separately so that if a disease is found in the tissue samples or reproductive fluids of either parent, all of their eggs can be discarded. Fertilized eggs are incubated for seven to nine weeks in tanks at inland freshwater hatcheries, and the resulting fry remain in freshwater for up to 18 months

before reaching the smolt stage. Fry are typically vaccinated for several bacterial and viral pathogens before stocking in saltwater. Vaccination of fry has been found to be generally effective against various *Vibrio* species and, to a variable extent, against furunculosis, which is caused by *Aeromonas salmonicida.* Vaccination is also occasionally used against enteric redmouth (ERM), BKD, and ISA. When smolts are about 80 to 120 grams (about 7 inches long) they are moved to marine net pens for growout. The majority of these marine net pens are located in protected, inshore areas. Approximately 2.5 years after hatching, salmon are ready for market. Researchers in Canada have been experimentally manipulating salmon genetics to enhance growth and reduce time to market by 50 percent. These genetically modified salmon are awaiting approval by the FDA before they will be allowed to enter the U.S. market.

Concerns about genetic dilution and competition for nesting sites are associated with the escape of farmed Atlantic salmon into the environment. The escape of farmed fish into the wild has occurred, but such escapes are infrequent and generally caused by equipment failure during storms, predators such as seals damaging nets, and occasional vandalism by humans. Use of triploid salmon (sterile salmon) could reduce some of these concerns, but problems have been reported with commercial production of triploid salmon, including deformities, slower growth, and higher mortality rates.

In net pen operations, water flow is managed passively. Thus, salmon production is currently limited to areas with good water flow and optimal culture temperatures. However, there has been some experimental production of salmon in ocean waters 3 to 200 miles

Figure 4: U.S. Farmed Salmon Production



Source: NOAA, National Marine Fisheries Service 2004.

off the coasts of Washington, New Hampshire, and Virginia. The National Oceanic and Atmospheric Administration (NOAA) is currently developing an offshore aquaculture permit system that would oversee and regulate production in the EEZ (up to 200 miles offshore). New cage designs are being developed to allow production in these exposed waters. The advantage to moving salmon production further offshore is that it would be subject to less conflict with other users of inshore waterways and may help avoid harmful algal blooms.

Water for freshwater hatcheries is generally diverted from lakes, streams, springs, or wells. Salmon raised in marine net pens are in direct contact with the environment, including seawater, as well as fish (including wild salmon), mammals, and birds. Transport of fish-processing wastes from salmon farming in Eastern Canada into the Eastern United States for bait, composting, pet food, and rendering occurs regularly and currently is unregulated. Limited polyculture takes place with oysters, mussels, cod, and nori in Maine. Experiments in raising cod and halibut in a polyculture environment with salmon have been conducted in New Brunswick.

Biosecurity on salmon farms in Maine has improved greatly since the ISA outbreaks first occurred. Examples of new practices implemented that reduce contamination of the environment include piping all blood, water, and waste materials directly from the harvest ships into the processing plants. Another example is that carcasses from mortality surveillance are isolated, transported, and stored in leak-proof containers and disposed of through rendering or composting. In addition, bay management agreements are developed in which companies collectively agree on operating procedures for individual bodies of water constituting a unique tidal exchange. The purpose of these agreements is to break the disease cycle in the event of outbreaks. Health certificates are required to move fish between some states.

Farmed salmon consume a diet composed of 45 to 50 percent protein, fishmeal being the principal source. Worldwide, in 2000, it was estimated that more than 20 percent of fishmeal produced was used in salmon feeds. Salmon feeds are made using a cooking extrusion process that produces pellets. The current techniques allow the pellets to absorb and hold higher fat content; fat content has been found to be associated with feed palatability and protein utilization. With fishmeal supplies strained to meet growing demand worldwide, work is being done on using soybean meal to replace 50 percent or more of the protein in salmon diets. Additionally, mammalian blood meal is sometimes used as a protein source for salmon. Research has suggested that the inclusion of blood meal in salmon diets reduces the development of cataracts, which can lead to growth loss and secondary disease. Poultry meal, poultry fat, and feather meal are also used in some salmon feeds.

In addition to ISA, health concerns facing salmon production in the United States include BKD, sea lice, and a protozoan parasite (*Kudoa thyrsites*). Compared with other farmed food fish species, more health care and veterinary services are available for the salmon industry. Laboratory testing capacity appears adequate within the industry. As previously mentioned, a number of vaccines are available and used in salmon production. The U.S. Fish and Wildlife Service, in conjunction with the Aquatic Animal Drug Approval Partnership, has sponsored drug approvals for salmonids. Considerable research has been conducted on salmon production issues, including ISA vaccination and control, sea lice, basic and applied immunology, environmental factors, and genetics. CSREES funded $2.25 million of research in 2000 for salmonids.

The long-term viability of the farmed salmon industry in the United States is of concern. Import competition and negative press disseminated during the last few years regarding farmed salmon have hurt the industry. The regulatory and legal climate surrounding salmon-farming, including lawsuits based on the Endangered Species Act and Clean Water Act, is also of concern.

Marketing

In 2001, salmon became the third most consumed fish in the United States, behind shrimp and canned tuna, a status it continues to hold. Since 1990, per capita salmon consumption has tripled, increasing from approximately 0.75 pounds to 2.2 pounds per year. Fresh fillets and salmon steaks are more popular than whole fish at the retail level. Increasing salmon consumption in the United States is related to consumers' desire to obtain the health benefits associated with eating fish, increased availability of salmon, lower prices, and more processed products such as boneless fillets. Farmed salmon are not marketed live within the United States, although small quantities of wild salmon may be sold live. Salmon is not a preferred fish among Hispanic and Asian consumers. Retailers such as Costco and Sam's Club sell the most popular cuts, including salmon filets and steaks. The large buying power of these retailers has influenced the structure of the salmon industry. Organic and eco-friendly salmon are more widely available in other countries.

The processing industry has been consolidating. U.S. farmed salmon are generally processed by large processors located in Maine and Washington and in New Brunswick, Canada, in the case of Maine salmon production. As processing facilities move to more value-added products, the plants require consistent, year-round production.

Less than 50 percent of each salmon produced in the United States is used to produce fillets and steaks. Development of products that use salmon by-products is under way. Product development includes salmon patties, burgers, and kabobs for human consumption and fishmeals made from salmon by-products for use in fish feed. Smoked salmon is an important commodity, and both actual and potential salmon and fish oil markets exist. Salmon by-products can be included in high-end compost and fertilizers.

International Production and Trade

Salmon-farming began in the 1970s in Norway, Scotland, and the United States, with production volumes quickly increasing dramatically in Norway. This success in Norway encouraged production in North America, both in Canada and the United States. Global production is currently dominated by Norway and Chile. These two countries together accounted for 75 percent of production in 2005 (see table 3). The United Kingdom and Canada accounted for 9 percent and 7 percent, respectively, of production in 2005. Between 2003 and 2005, production in China increased by 42 percent, while production in Japan grew by 38 percent and production in Chile grew by 27 percent.

Internationally, the number of companies producing salmon is declining as mergers continue. The largest company is a Dutch conglomerate, and the next four largest companies are Norwegian-owned. Three-fourths of salmon in international trade are farmed.

U.S. imports of salmon more than quadrupled between 1990 and 2004 (see figure 5). Leading source countries for U.S. imports (in decreasing order by volume) in 2004 were as follows: Chile, Canada, China, the United Kingdom, and Norway. Chile and Canada

Table 3: Top 10 Farmed Salmon-Producing Countries, 2005

Salmon	
Country	**Production in 1,000 pounds**
Norway	1,164,786
Chile	959,944
United Kingdom	260,306
Canada	196,882
Faeroe Islands	37,924
Australia	32,066
China	29,014
Ireland	27,528
Japan	25,458
United States of America	18,802
World Total	**2,809,526**

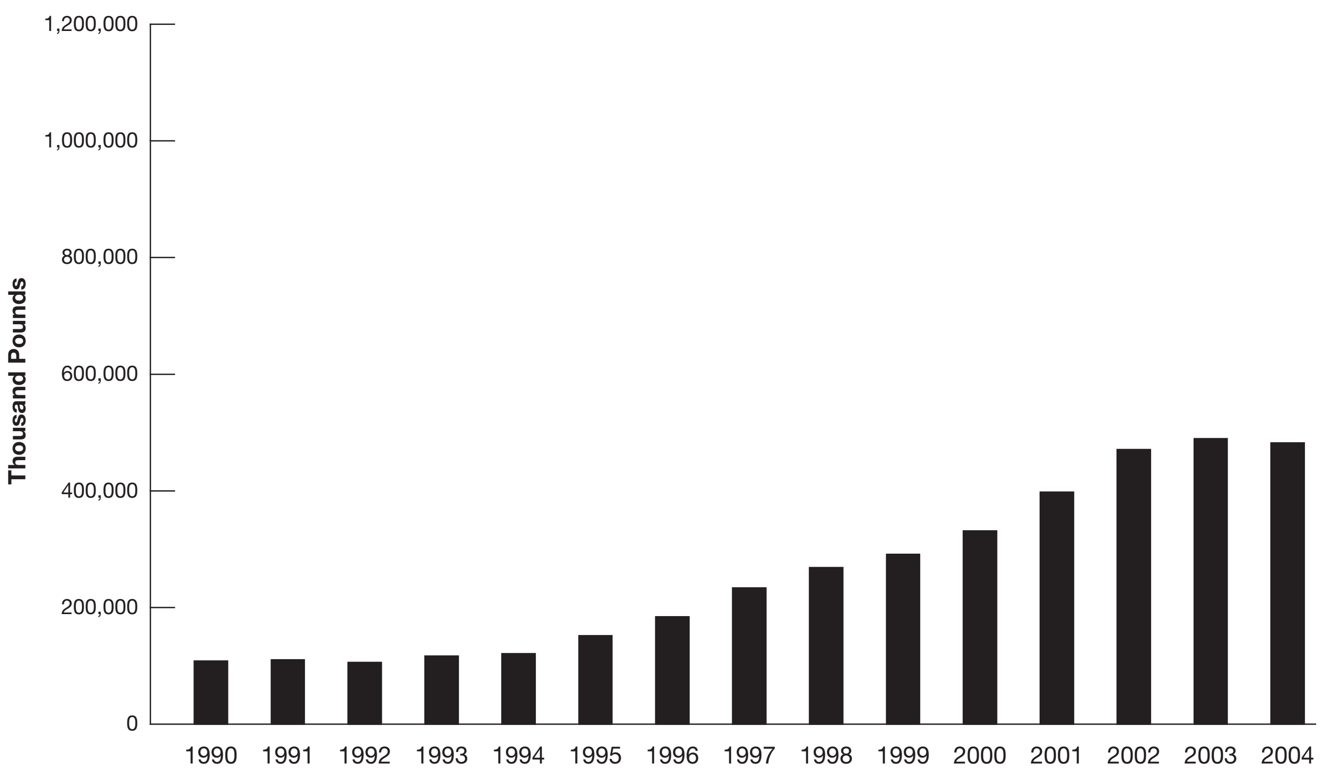
Note: Salmon include the following species: Arctic char, Atlantic salmon, Chars nei, Chinook(=Spring=King) salmon, Chum(=Keta=Dog) salmon, Coho(=Silver) salmon, European whitefish, Grayling, Huchen, Masou(=Cherry) salmon, Pacific salmons nei, Peled, Salmonids nei, Sea trout, and Sockeye(=Red) salmon.
Source: FAO, Fishstat Plus, 2007.

together accounted for more than 80 percent of total U.S. imports. Imports from China have grown rapidly, increasing more than sevenfold between 2000 and 2004. In 2004, the United States imported salmon from 39 countries. U.S. salmon imports consist of fillets and whole fish; live fish, other than fry or smolt, are not imported. Chile has been able to market fresh products to the United States; salmon imported from Europe are generally frozen. Most imports of whole fish are imported from Canada, but a substantial percentage of those are actually Maine-raised fish that were processed in Canada.

U.S. producers have filed antidumping cases against salmon imports in the past. U.S. producers won their case against Norway in the early 1990s and a duty was imposed that made it difficult for Norway to compete in the U.S. market. A case against Chile in the late 1990s was also won by U.S. producers and resulted in a duty; however, the duty has not slowed imports from Chile.

Major U.S. trading partners have suffered from disease outbreaks in salmon. IHN outbreaks have occurred in British Columbia. Farmers in British Columbia have also suffered from sea lice and *K. thyrsites.* Chile has suffered outbreaks of BKD, IPN, and piscirickettsiosis. Western European producers have suffered losses from BKD, gyrodactylosis, IPN, ISA, piscirickettsiosis, infectious viral retinopathy and encephalopathy, and viral hemorrhagic septicemia (VHS). Diseases believed to have occurred in China include IHN (1988), IPN (1988), and infectious viral encephalopathy and retinopathy.

Figure 5: U.S. Salmon Imports



Source: USDA, Foreign Agricultural Service, 2006.

Shrimp

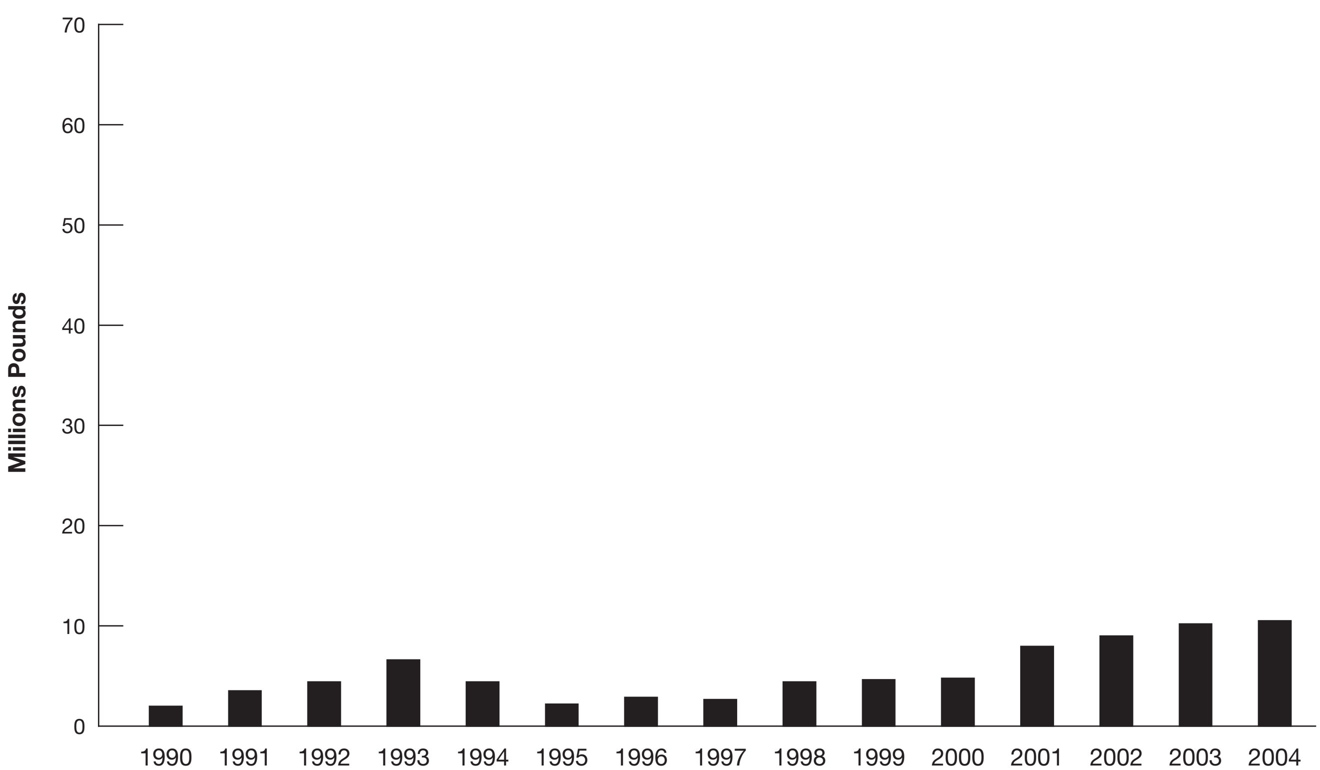
U.S. Production

Shrimp farming in the United States includes production of marine shrimp (*Litopenaeus vannamei*) and freshwater prawns (*Macrobrachium rosenbergii*). Annual freshwater prawn production was approximately 100,000 pounds between 2001 and 2003, while production of marine shrimp is estimated to have been 10.5 million pounds in 2004 (see figure 6). U.S. production of farmed shrimp grew rapidly between 1990 and 2004 from 2 million pounds to 10.5 million pounds, a fivefold increase.

Farmed marine shrimp are produced in 11 states (up from three in 1993) and at more than 60 farms. Texas accounts for more than 60 percent of U.S. production. Florida, Hawaii, and South Carolina together account for an additional 25 percent. Production has been moving into new states, including Alabama, Arkansas, Kentucky, Michigan, and Florida. Freshwater prawn production takes place in 16 states in the South and Midwest. It is estimated that more than 500 small freshwater prawn farms are operating in the United States.

Modern shrimp farming began in the early 1970s. Farmed marine shrimp production in the United States was originally based in ponds located in coastal areas using brackish or inlet water. Since then, producers in Alabama, Arizona, and Texas have been able to take advantage of underground saltwater to establish ponds in inland locations; now, approximately 25 percent of marine shrimp production comes from inland farms. Although the majority of current marine shrimp production takes place in ponds, efforts are under way to move to more closed systems. Experiments

Figure 6: U.S. Farmed Shrimp Production



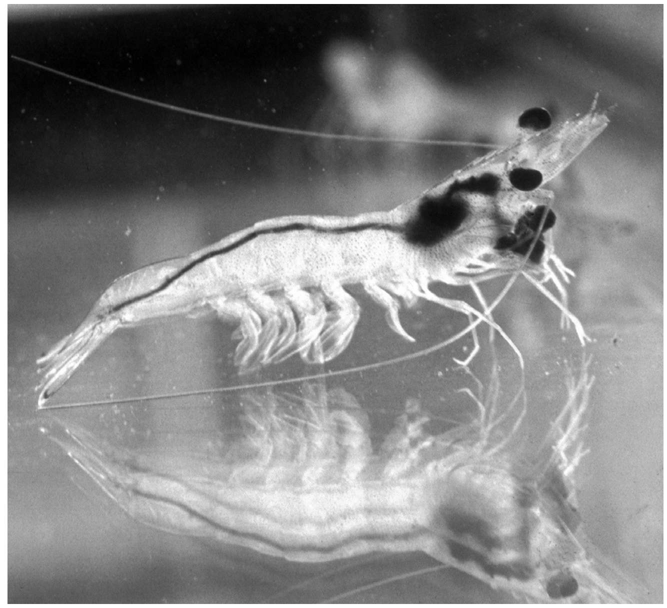
Source: NOAA, National Marine Fisheries Service 2004.

are taking place with biosecure raceway systems. Additionally, development of low-salinity production techniques are now allowing marine shrimp to be produced in indoor recirculating aquaculture systems (RAS). This is also allowing production in new areas, including states such as Kentucky, Michigan, and North Carolina.

Prawn farming techniques were developed in the 1950s in Malaysia. Until the mid-1990s, freshwater prawn production did not seem economically viable in the United States, but improved management techniques have altered that assessment. Freshwater prawn production takes place in ponds. Because catfish ponds are adequate for production, some catfish producers are converting ponds to freshwater prawns or alternating catfish production with prawn production.

Within the farmed marine shrimp industry, there are specialized broodstock and seedstock producers. In the last decade, there has been significant effort to produce specific pathogen-free postlarvae (SPF PLs). These SPF PLs are guaranteed to be free from known viruses that cause disease, including baculovirus, infectious hypodermal hematopoietic necrosis virus (IHHNV), Taura syndrome virus (TSV), and WSSV. In the United States, broodstock producers are large-scale operations that use stock developed from extensive breeding programs. One large broodstock facility is located in Texas; other large facilities are located in Hawaii. By maintaining broodstock in tanks, seed-stock can be produced year-round in these hatchery facilities. Fifty percent survival rates are common for seedstock. Between the hatchery and growout phases, postlarval shrimp undergo a nursery phase in ponds, raceway systems, or tanks lasting no more than 25 days. Postlarval shrimp are moved from nursery ponds to growout operations (ponds or tanks). The growout period takes approximately 120 to 180 days.

In freshwater prawn production systems, broodstock are selected from the harvested crop and moved into indoor facilities. Suppliers dedicated to producing postlarvae and juvenile prawns have developed in the



United States. Postlarval prawns undergo a nursery stage (45 to 60 days) before being placed in growout ponds. Within the United States, the nursery stage usually takes place in climate-controlled buildings. The growout period can last 110 to 140 days with 60 to 85 percent survival rate. Well water is the preferred water source for prawn ponds.

Shrimp are carnivorous and require a high-protein diet. Shrimp feeds can contain more than 30 percent fishmeal by volume. Globally, shrimp farming is a significant user of fishmeal, accounting for more than 17 percent of all fishmeal used in aquatic feeds in 2000. In addition to fishmeal, feeds produced for shrimp and prawn may contain blood meal, feather meal, krill meal, meat and bone meal, and shrimp meal. Broodstock and larvae are generally fed live feeds such as *Artemia,* bloodworms, krill, and squid. Ongoing research continues to look for plant protein products that could be used to replace animal and fish protein in farmed shrimp diets. Probiotics are increasingly being used in shrimp diets.

Many notable diseases have occurred globally and in the United States during the last decade in marine shrimp farms. Among these diseases are those caused by IHHNV, hepatopancreatic parvo-like virus, TSV, yellowhead virus, WSSV, and necrotizing hepatopancreatitis bacteria. Disease spread within the United States on shrimp farms has been associated with waste from processing, bird depredation, and infected postlarvae. TSV is believed to have been spread as birds feed on ponds with diseased shrimp and then move to other ponds; TSV and IHHNV can survive in a bird's digestive tract and be shed in its feces. An outbreak of TSV in Texas and South Carolina was caused by the use of infected postlarvae. Outbreaks of most of these diseases in the United States have been limited to localized areas. Disease has not been a problem to date in the freshwater prawn industry. Health certificates are required to move shrimp between some states.

In addition to the use of probiotics, shrimp producers globally are taking steps to reduce disease occurrences. These steps include fallowing ponds between shrimp crops; alternating shrimp production with crops of finfish, such as tilapia or milkfish (Philippines); and using disease-free, captive-bred postlarvae. U.S. marine shrimp producers have taken steps to improve biosecurity at their facilities to reduce contact with birds and other predators.

Veterinarians are not widely used by shrimp farmers. Two drugs are approved for use on shrimp: tricaine methanesulfonate (anesthetic) and formalin for treating protozoan parasites. No antibiotics are approved for shrimp. However, research on oxytetracycline (OTC) has been ongoing for many years, and the industry has submitted documentation to the FDA for approval of OTC to treat bacterial diseases in shrimp. Shrimp producers have access to laboratories for disease testing. The Aquaculture Pathology Laboratory at the University of Arizona is globally recognized for its shrimp disease diagnostic and certification services and is the Office International des Epizooties (OIE) reference laboratory for shrimp pathogens for North America.

In 2000, CSREES allotted more than $5 million to shrimp research. CSREES supports the U.S. Marine Shrimp Farming Program, which supports research on marine shrimp.

Marketing

In 2001, shrimp became the most consumed fish or shellfish in the United States, surpassing canned tuna. Since 1990, per capita shrimp consumption has almost doubled, increasing from 2.2 pounds to 4.0 pounds per capita. Shrimp is a preferred seafood in the growing Hispanic and Asian populations in the United States.

Shrimp are not sold live in the United States, but they are often sold as fresh/frozen with the shell on. Shrimp processing generally does not take place on the farm. The number of shrimp processing plants in the United States has declined because of competition with imports. Research has shown that freshwater prawns can be live-hauled. Several shrimp farms have obtained organic certification from the USDA and are marketing organic shrimp. U.S. farm-raised shrimp have been rated as a Best Eco-Choice by the Environmental Defense organization.

Shrimp by-products have a number of uses. Chitin and chitosan are used in a number of human dietary supplement products. Shrimp meal (made from the heads and hulls) is used in livestock and fish feed, including shrimp diets. In diets for salmon and trout, shrimp meal can provide the pink coloration of the flesh. Shrimp meal or silage is also used in poultry and swine diets. Shrimp head waste is especially suitable for silage production.

International Production and Trade

China is the leading producer of farmed shrimp globally, having overtaken Thailand in 2001 (see table 4). In 2005, Chinese production accounted for more than one-third of total global production. Thailand, Vietnam, and Indonesia are significant farmed shrimp producers; each produced approximately 14 percent, 12 percent and 10 percent of world production, respectively, in 2005. Between 2003 and 2005 shrimp production in Myanmar grew 154 percent, while production in Mexico grew 58 percent, and production in Indonesia grew 46 percent. The processing sector is well-developed in many of these major producing countries. Thai shrimp processors are focusing on marketing value-added shrimp products, including ready-to-eat and cooked products. Freshwater prawn production worldwide is estimated to be around 200,000 metric tons, with Bangladesh and China leading production.

Giant tiger shrimp (*Penaeus monodon*) have been the most common species farmed in Asia. They are native to the Indian Ocean and southwestern Pacific Ocean and are the largest and fastest growing of the farmed shrimp, but captive breeding can be difficult and they are susceptible to yellowhead disease and WSSV. Asian producers are switching to western white shrimp (*L. vannamei*), which is native to the Pacific coast of Central and South America.

International trade in shrimp accounted for 20 percent of the value of all seafood imports worldwide in 2000. U.S. imports of shrimp have risen steadily since the mid-1990s (see figure 7). Shrimp imports globally are increasingly from aquaculture compared with wild-caught (estimated at two-thirds). In 2004, the top five source countries for U.S. imports were (in decreasing order of import quantity): Thailand, China, Indonesia, India and Ecuador (see figure 8). Imports from these five countries accounted for approximately 60 percent of total U.S. shrimp imports. In 2002, the United States imported shrimp from more than 60 countries. Recent new source countries for shrimp include the Islamic Republic of Iran and Saudi Arabia. Shrimp imported into the United States are mostly whole, fresh/frozen. As a result of an antidumping ruling in 2004 by the International Trade Commission regarding Asian shrimp imports, U.S. processing plants may be negatively affected; however, U.S. producers could benefit from the new tariff structures.

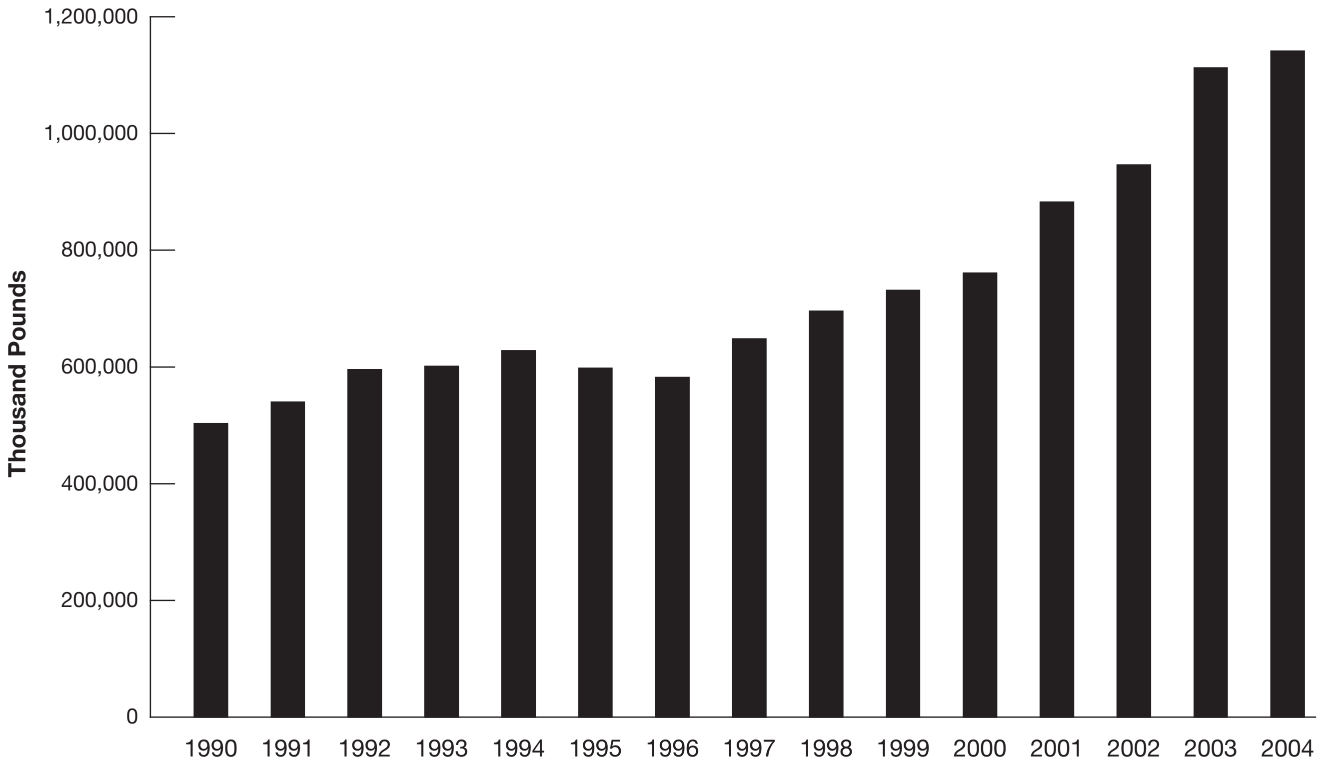
The United States is an important exporter of SPF *L. vannaemei* seedstock.

Table 4: Top 10 Farmed Shrimp/Prawn-Producing Countries, 2005

Shrimp/Prawn	
Country	**Production in 1,000 pounds**
China	2,049,898
Thailand	750,640
Vietnam	654,400
Indonesia	559,078
India	286,340
Mexico	144,558
Brazil	126,268
Bangladesh	126,104
Ecuador	112,600
Myanmar	97,280
World Total	**5,350,476**

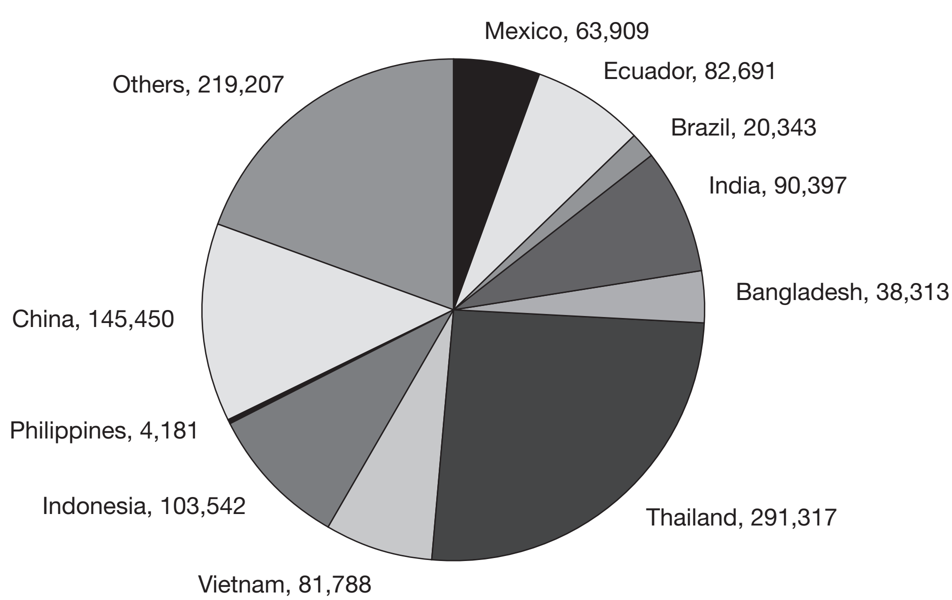
Note: Shrimp/Prawn include the following species: Akiami paste shrimp, Baltic prawn, Banana prawn, Blue shrimp, Brown tiger prawn, Caramote prawn, Eastern king prawn, Eastern school shrimp, Fleshy prawn, Giant tiger prawn, Greasyback shrimp, Green tiger prawn, Indian white prawn, Kuruma prawn, Metapenaeus shrimps nei, Natantian decapods nei, Northern white shrimp, Palaemonid shrimps nei, Penaeus shrimps nei, Redtail prawn, Southern white shrimp, and Whiteleg shrimp.
Source: FAO, Fishstat Plus, 2007.

Figure 7: U.S. Shrimp Imports



Source: USDA, Foreign Agricultural Service, 2006.

Figure 8: U.S. Shrimp Imports by Country, 2004 (1,000 pounds)



Source: USDA, Economic Research Service 2005.

Tilapia

U.S. Production

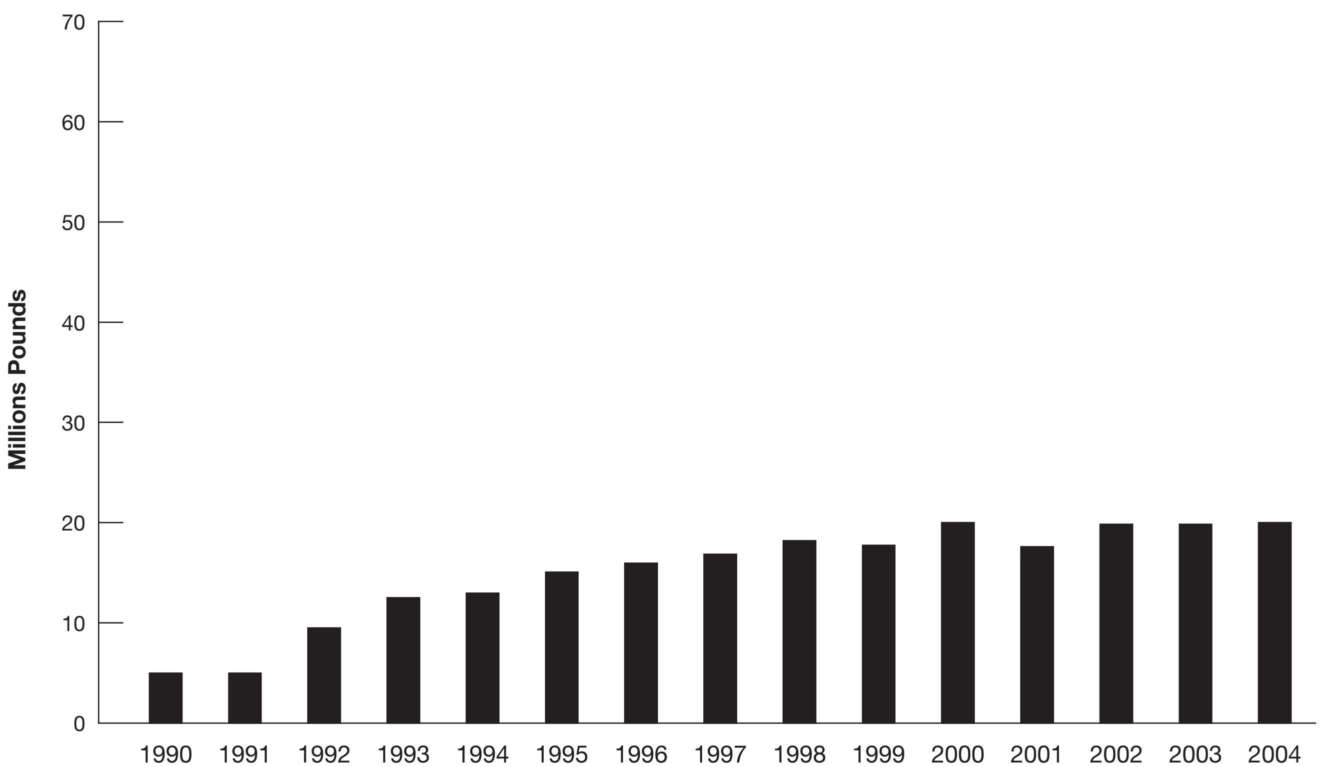
Tilapia were introduced into the United States in the 1950s. The first uses of tilapia were for display in aquariums and for weed control. Commercial aquaculture production of tilapia for food began in the 1980s. In the United States, tilapia are no longer used for weed control, having been replaced by grass carp.

The only census of tilapia producers in the United States was conducted in 1998 as part of the U.S. Department of Agriculture's Census of Aquaculture. That census identified more than 100 tilapia producers in the United States. Production was reported in many states, with California accounting for more than 25 percent. Tilapia production is restricted or prohibited in many states because of concerns about tilapia becoming established in natural waterways.

In 2004, 20 million pounds of tilapia were produced in the United States with a value of approximately $40 million (see figure 9). Leading producing states in 2005 include California, Idaho, Florida, Delaware, Maryland, West Virginia, and North Carolina; one large producer is located in New York. About a dozen farms account for more than 90 percent of U.S. production. Tilapia production is clustered in areas such as the Coachella Valley and Snake River Valley in California and Idaho, respectively, around the Houston and San Antonio areas in Texas, and the Orlando area in Florida.

Tilapia are tropical fish and require warm water with optimal growth occurring in water between 77 and 86 degrees Fahrenheit (25 and 30 degrees Celsius). The number of tilapia species being farmed is declining globally and in the United States. Nile tilapia (*Oreochromis niloticus*) and red tilapia (a hybrid) are

Figure 9: U.S. Farmed Tilapia Production

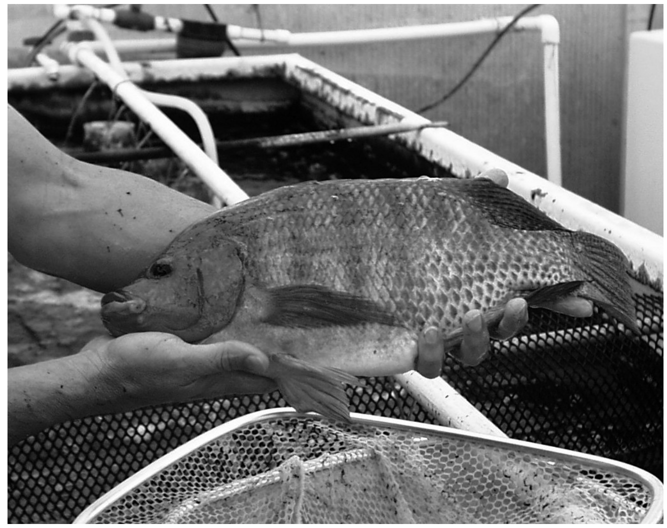


Source: NOAA, National Marine Fisheries Service 2004.

the predominant species farmed because of their larger size and lighter flesh color. Tilapia reach market size in approximately 12 months. Tilapia require 25 to 30 percent protein in their diets. Their diets contain fishmeal and fish oil. Experiments are under way using pelleted poultry meal to meet the protein requirements.

It is estimated that up to 90 percent of U.S. tilapia production takes place in RAS tanks; however, only about 60 percent of these facilities are enclosed. Tilapia production in Idaho takes place in a raceway system, and some pond production of tilapia takes place in southern Florida. Geothermal water is often used as the water source. Industrial waste heat and greenhouses are used in the United States to heat the water. Geothermal water use is common in the West, compared with the industrial waste heat sources used in the North and the greenhouses used in the South. Stocking rates for younger fish are high. Recirculating tank systems use specialized equipment for water filtration and oxygen infusion. Production is becoming more intensive as improvements are made in diets, aeration, water reuse, and disease control. The largest one-third of producers must comply with the new EPA Concentrated Aquatic Animal Production regulations, which established requirements for discharge of water and waste from the facility.

The opportunity for contact with pathogens occurs primarily from the introduction of new stock or inputs, such as feed, and water inflow. Research on biosecurity practices at recirculation facilities suggests that many of the facility managers are college educated with 10 years of related work experience. More than 90 percent of the surveyed operations kept records. Eighty percent of producers have on-site hatcheries, but specialization is increasing within the industry, so the percentage of producers purchasing stock from hatcheries is also increasing. Some broodstock arrives internationally from Africa and Southeast Asia via the ornamental fish trade. Health certificates are required to move fish between some states. Studies indicate that when new fish are introduced they are quarantined in isolated areas of the tank sharing the water supply rather than sequestered in isolated water supplies. Most operations use all-in/



all-out production and routinely collect mortalities. In the United States, polyculture with catfish, shrimp, and striped bass is limited (less than 10 percent of tilapia producers). In shrimp production systems, tilapia are thought to reduce disease. Other polyculture trials have taken place with perch and freshwater prawns.

Tilapia are a hardy species and can withstand poor water quality. Tilapia are not considered to be susceptible to any OIE-listed fish diseases. Most species of tilapia are susceptible to *Streptococcosis iniae* for which a vaccine is available, but this vaccine is not yet approved for use in the United States. Parasites have been a problem within the industry in the past, and *S. iniae* is currently a problem for the U.S. industry. Tilapia are susceptible to diseases affecting cichlids, which make up a large portion of the ornamental fish industry and many of which originate in the wild. Veterinarians are not widely used by the industry; studies indicate that 75 percent of producers used nonveterinary fish health specialists.

CSREES funded $1.25 million of research projects for tilapia in 2000. Research needs identified for tilapia include the following: drugs, genetics, hormone use, infectious diseases, and nutrition.

Marketing

Tilapia consumption is increasing steadily in the United States. Tilapia was the tenth most popular seafood consumed in the United States in 2001 and climbed to eighth in 2003. The American Tilapia Association reports that tilapia is currently in sixth place. Tilapia is gaining wider placement in supermarkets and food service establishments within the United States and competes with catfish and other fillets. Some experts have speculated that tilapia will eventually become one of the top three most consumed fish in the United States.

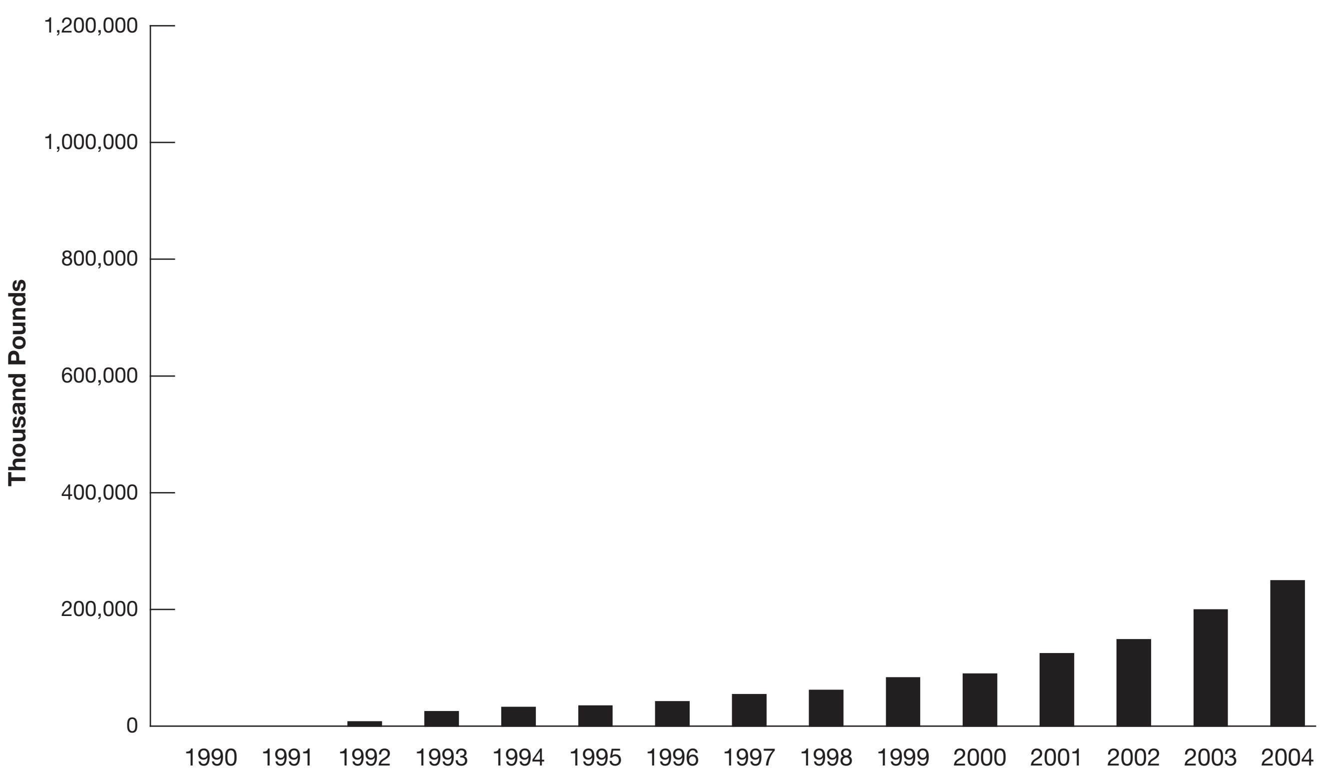
In the United States, tilapia are generally marketed live to restaurants and seafood markets in large urban areas that sell to ethnic populations, especially Asian and Hispanic. Surveys of U.S. tilapia producers in the late 1990s indicated that only 5 percent of U.S. tilapia production was sold to distributors and processors; sales generally are from individual farms to retailers. Major markets for U.S. production are in Chicago, Dallas, Houston, New York, San Diego, San Francisco, Toronto, and Vancouver. Past attempts in the United States to run a processing plant with contract growers failed.

International Production and Trade

Growing consumption of tilapia in the United States is being met largely through imports. In 2003, U.S. consumers accounted for approximately 11 percent of world tilapia production. U.S. imports of tilapia have increased rapidly, growing more than sevenfold between 1995 and 2004 (see figure 10). Imports dwarf U.S. domestic production of tilapia; in 2002, tilapia imports outpaced domestic production by a 7-to-1 ratio.

In 2004, the United States imported tilapia from 29 countries. In the mid to late 1990s, Taiwan (China) was the dominant supplier of tilapia to the United States, supplying approximately 80 percent each year from

Figure 10: U.S. Tilapia Imports



Source: USDA, Economic Research Service 2005; USDA, Foreign Agricultural Service, 2006.

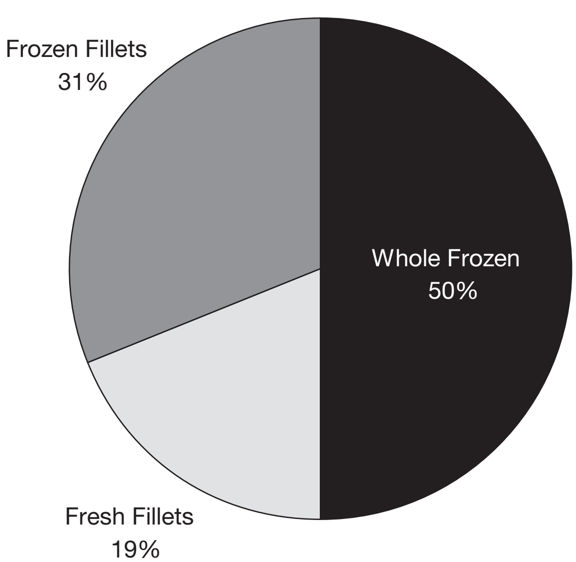
1995 to 1998. China surpassed Taiwan (China) as the largest exporter to the United States in 2002. In 2004, China supplied more than half of the tilapia imported. Other important suppliers in 2004 included Costa Rica, Ecuador, Honduras, and Indonesia.

Frozen whole fish are the predominant form of tilapia imported (see figure 11), but imports of fresh and frozen fillets have been growing rapidly. Live fish are not imported. China and Taiwan (China) provide most of the whole frozen fish (99 percent in 2004). Fresh fillets are provided by Central and South American countries with Ecuador, Costa Rica, and Honduras leading (47, 19, and 19 percent in 2004, respectively). Fresh fillets are being imported from China (9 percent in 2004). China is currently the largest supplier of frozen tilapia fillets (77 percent in 2004). Approximately one-third of each whole tilapia is processed into fillets. Formed fish products are made from the meat recovered after the fillets are removed. Tilapia by-products have been used in some poultry feeds.

Tilapia are farmed in more than 100 countries; however, China accounts for nearly 50 percent of worldwide production (see table 5). Other leading producing countries include Egypt, Indonesia, the Philippines, and Thailand (in decreasing order of production, 2005). Between 2003 and 2005, tilapia production increased by more than 20 percent in Honduras, Indonesia, the Philippines, Taiwan (China), and Malaysia. Brazilian tilapia production is currently used to stock fee-based fishing operations in Brazil.

Production in China, Taiwan (China), and Thailand is generally carried out in polyculture often with carp and sometimes shrimp. In Taiwan (China) and Thailand, production is often integrated with livestock production such as fish-chicken, fish-duck, and fish-pig systems. Reports indicate that human waste has been used to fertilize water in Asia, but details on the extent of this practice are not available.

Figure 11: Tilapia Import Breakdown 2004



Source: USDA, Economic Research Service 2005.

Table 5: Top 10 Farmed Tilapia-Producing Countries, 2005

Tilapia	
Country	**Production in 1,000 pounds**
China	1,956,270
Egypt	434,038
Indonesia	379,140
Philippines	326,008
Thailand	219,484
Taiwan Province of China	166,870
Brazil	135,702
Malaysia	57,270
Honduras	56,752
Colombia	55,906
World Total	**4,051,118**

Note: Tilapia include the following species: Blackchin tilapia, Blue tilapia, Longfin tilapia, Mango tilapia, Mozambique tilapia, Nile tilapia, Redbelly tilapia, Redbreast tilapia, Sabaki tilapia, Three-spotted tilapia, and Tilapias nei.
Source: FAO, Fishstat Plus, 2007.

Trout

U.S. Production

Farmed trout in the United States are produced for three primary markets: food, conservation and restoration, and recreational fishing. Because of these multiple market segments, trout are marketed or distributed in a variety of sizes. In 2004, 73 percent of food-size trout were sold to processors and 17 percent to fee-based fishing operations (see table 6), while the remaining 10 percent went nearly equally to live-haulers, direct to consumers, other producers, retail, and government. For stocker-size fish, 49 percent were sold to fee-based fishing operations, 15 percent to government, and 12 percent to other producers. Trout farming is carried out by the private sector and the government (State and Federal). Many government hatcheries distribute fish for conservation and restoration or recreational purposes.

U.S. farmed trout production is characterized by a few very large facilities and many small operations. The largest 20 percent of private farms account for more than 85 percent of total sales. Many of the largest private facilities are in Idaho. Idaho produced nearly half of the trout (by value) in 2004. Other states with significant numbers of production facilities include Pennsylvania (202 facilities), North Carolina (72 facilities), California (52 facilities), New York (52 facilities), and Oregon (51 facilities). Rainbow trout are the predominant species farmed; however, eastern brook

Table 6: Trout Food-Size Fish Sales, Percentage Sold by Point of First Sale for Selected States, 2004

	Live Haulers	Fee/Rec Fishing	Other Producers	Government	Direct to Consumer	Processors	Restaurant & Retail	Other
CA	*	91	*	*	*	*	*	*
CO	*	59	-	*	-	-	*	-
CT	-	*	-	-	*	-	-	-
GA	*	*	-	-	*	*	*	-
ID	*	*	*	*	*	98	*	*
ME	*	*	-	-	*	-	*	-
MA	*	72	*	*	*	-	*	-
MI	21	45	*	*	6	7	*	*
MO	*	*	*	*	*	*	*	
NC	*	*	*	*	7	83	3	*
NY	*	48	-	-	16	*	3	8
OR	8	12	*	*	8	-	*	*
PA	2	71	17	1	2	*	*	-
TN	-	*	*	-	*	*	*	-
UT	14	47	-	-	18	*	*	-
VA	-	61	*	-	19	*	*	-
WA	*	4	*	4	-	89	-	*
WV	*	47	*	*	6	*	*	*
WI	*	14	*	-	8	*	9	-
Other States	15	27	7	10	5	27	8	1
U.S. Total	**2.3**	**17.4**	**1.8**	**1.5**	**2.1**	**73.4**	**1.4**	**0.1**

* = Included in "Other States" to avoid disclosure of individual operations
\- = Not available or zero
Source: USDA:NASS Trout Production, February 2005

trout and European brown trout are produced in limited numbers on some farms. Different species of trout can be cultured together.

The amount of trout produced for food in the United States has remained largely unchanged for more than a decade (see figure 12). Trout production peaked at 60 million pounds in 1999. Trout compete with salmon and, to some extent, with newer species such as tilapia in the marketplace. Trout prices have been in a long-term price decline because of this competition.

Cultured trout production has existed in the United States since the late 1800s when Federal hatcheries were established to stock waterways. The trout industry expanded significantly in the 1970s and 1980s with the development of pelleted feeds. Today, more than 90 percent of the trout produced in the United States are produced in raceway systems. In these systems, water from lakes, springs, streams, or wells is diverted through concrete or earthen pens. Production in earthen ponds continues on a number of small farms, but additional trout production in freshwater and saltwater net pen systems is limited. Increases in production are limited by the availability of cold, clean water and waste management issues. Waste from raceway production is often returned to the surface water source. Trout produced in flow-through systems must comply with the EPA Concentrated Aquatic Animal Production regulation if more than 100,000 pounds of fish are produced at the facility annually and the facility discharges waste directly into U.S. waters. The EPA regulation establishes substantial requirements for the treatment of waste and water discharged from the facility.

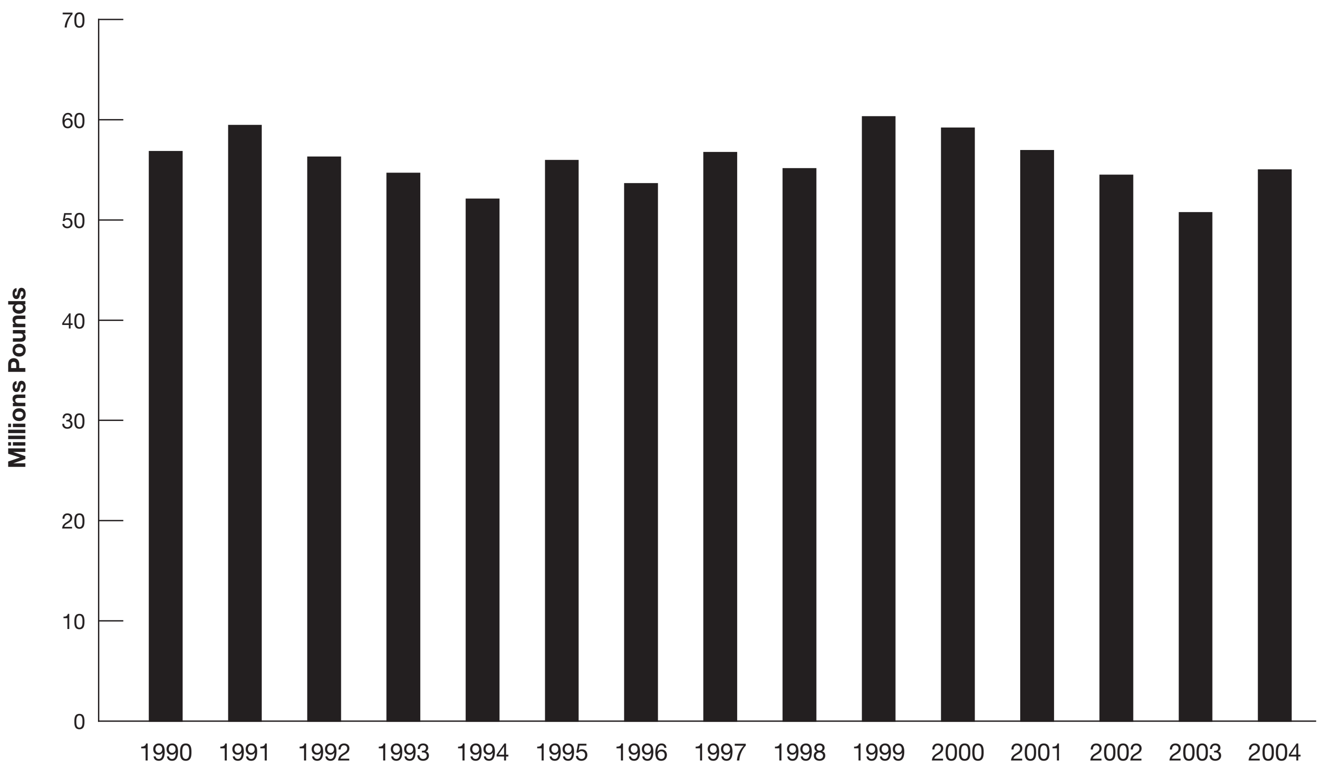
Some trout producers specialize in certain segments of the industry. Trout eggs are generally produced at dedicated broodstock operations and then are shipped to trout producers in the United States and internationally. In 2004, the State of Washington accounted for 96 percent of the trout eggs sold. Once shipped to producers, the resulting fry are generally kept in indoor ponds or tanks before being transferred to raceways when they reach fingerling size. In the Southern United States, producers often purchase fingerlings from dedicated producers. In 2004, more than 50 percent of the fingerlings sold were from North Carolina. An additional 13 percent were sold from California and Washington (combined total). New trends in production include the use of triploids (reproductively sterile fish). Triploids are preferred for aquaculture species in situations in which the potential exists for escape into wild waterways.

Trout require diets that are 45 to 50 percent protein. Fishmeal currently provides approximately half of this protein; soybean meal is sometimes used to meet these protein needs. Ongoing research is examining ways to replace fishmeal in trout diets with plant-based products.

Potential contact with pathogens occurs through feed, introductions of new stock, predators, and untreated water diverted into the facility. Water used in trout raceways is most often from aquifers and therefore does not need treatment. In spite of high-quality water, IHN virus, coldwater disease, and enteric red mouth disease have been important sources of loss. Health certificates are required to move fish between some states.

The use of veterinarians within the trout industry is higher than in some other fish industries. Laboratory testing is available. In raceway production, mortalities are removed on a daily basis and production records are kept. Despite the use of health professionals and management practices, production losses can be substantial. According to an Animal and Plant Health Inspection Service Agricultural Research Service Risk Management Agency study, producers report that two to three and a half eggs are required to get one fish to market. NASS data indicate that, in 2004, total losses

Figure 12: U.S. Farmed Trout Production



Source: NOAA, National Marine Fisheries Service 2004.

of all trout intended for sale numbered 22 million. Of these 22 million, 73 percent were reported lost to disease, 12 percent to flooding, and 10 percent to predators.

Trout production in the United States has been affected by the following: (1) viral pathogens, including IHHNV, and IPN virus; (2) bacterial pathogens, including *Flavobacterium psychrophilum,* enteric *Yersinia ruckeri, Flavobacterium columnare, Aeromonas salmonicida,* and *Flavobacterium branchiophilum;* and (3) trematode and protozoan parasites such as *Myxobolus cerebralis.* Hatcheries often suffer severe losses from fungal diseases. The FDA has approved two antibiotics for use in salmonids: OTC and a potentiated sulfonamide (Romet). Treatment options for some diseases are limited, however, which makes vaccine development a critical need for trout producers. Several important pathogens of salmonids are not currently present in the United States, including the epizootic hematopoietic necrosis (EHN) virus, *Oncorhynchus masou* virus, and the freshwater ectoparasite *Gyrodactylus salaris.* Disease outbreaks such as furunculosis, IPN, and trematode infestations have occurred in trout hatcheries because of avian and mammalian predators serving as mechanical and biological vectors.

USDA:CSREES invests significant funding in research for cultured aquatics. In 2000, research on trout represented 7 percent of total research funds. Research is generally focused on genetic selection and disease vectors ($2.25 million for all salmonids).

Marketing

Collectively, trout are not among the top 10 fish consumed in the United States. Trout compete with salmon in the restaurant market. Domestic trout (farmed and wild-caught) supply most of the U.S. market; imports represent only a small share of U.S. supplies. The wild-caught trout's share of the domestic supply is unknown because numbers caught are not reported.

Idaho's trout production supplies the retail trout market in the United States. In 2004, virtually all of the farmed trout sold in Idaho (98 percent) was sold to processors, while in California and Colorado, farmers sold most of their fish to fee-based fishing operations (see table 6). In the Eastern United States, some producers also rely on direct sales and fee-based fishing operations; producers in North Carolina sell most of their trout to processors. Some large trout farms have on-farm processing facilities. Live transport of trout to restaurants and direct sales to consumers are limited.

The U.S. Trout Farmers Association established a Trout Producers Quality Assurance Program. Some organic trout is produced in the United States. The USDA is working to develop organic standards for farmed fish. Given the lack of such a program, only third-party certifications are available in the United States. Organic production is more prevalent in other countries.

By-product utilization is an important issue for all fish species. Research is under way to create value-added products for human food use from trout by-products, such as surimi and fish oil. To date, however, these products have not been cost-effective to produce.

International Production and Trade

The United States imports live trout. Until 2000, these trout were almost exclusively imported from Canada. In 2002, live trout began arriving from Australia and, as of 2004, imports from Australia and Canada were equivalent on a value basis. The United States imports whole trout both fresh/chilled and frozen as well as frozen trout fillets. In 2004, imports of whole fish were slightly above imports of fillets (2,173 metric tons versus 1,719 metric tons). Canada is the principal supplier of fresh/chilled and frozen whole trout, supplying approximately 40 percent of each in 2004. Other major suppliers of fresh/chilled whole fish in 2004 include Colombia, Iceland, and Argentina (a combined 42 percent of total imports, in descending order). Major suppliers of frozen whole trout (in addition to Canada) include Argentina, Chile, Denmark, and Norway (a combined 46 percent of total imports, in descending order). The United States also imports frozen trout fillets. Until 2001, Argentina was the leading supplier of frozen trout fillets. From 2002 to 2003, U.S. imports from Chile were more than double the quantities from Argentina. Imports from Chile in 2004 were reduced. Other important suppliers of frozen trout fillets include Guyana and Uruguay. In 2004, the United States imported trout fillets from China for the first time.

Recently, Chile has become the leading global producer of farmed trout, followed by Norway (22 and 11 percent of global production in 2005, respectively) (see table 7). In 2005, the United States was the eighth largest farmed trout producer worldwide. Production in Iran grew 50 percent between 2003 and 2005, while production in Turkey increased 21 percent.

Table 7: Top 10 Farmed Trout-Producing Countries, 2005

Trout	
Country	**Production in 1,000 pounds**
Chile	236,558
Norway	117,562
Turkey	98,564
Denmark	73,586
Iran (Islamic Rep. of)	69,520
France	64,824
Italy	61,116
United States of America	55,008
Spain	51,918
Germany	38,686
World Total	**1,092,542**

Note: Trout include the following species: Brook trout, Rainbow trout, and Trouts nei.
Source: FAO, Fishstat Plus, 2007.

Appendix A: List of Acronyms for Phase I

Agriculture Research Service (USDA)	ARS
bacterial kidney disease	BKD
Cooperative State Research, Education, and Extension Service (USDA)	CSREES
Exclusive Economic Zone	EEZ
epizootic hematopoietic necrosis	EHN
Environmental Protection Agency	EPA
enteric redmouth (disease)	ERM
enteric septicemia of catfish	ESC
Food and Drug Administration	FDA
hybrid striped bass	HSB
infectious hypodermal hematopoietic necrosis virus	IHHNV
infectious hematopoietic necrosis	IHN
infectious pancreatic necrosis	IPN
infectious salmon anemia	ISA
Joint Subcommittee on Aquaculture (United States)	JSA
koi herpesvirus	KHV
National Agriculture Statistics Service (USDA)	NASS
National Animal Health Monitoring System (USDA)	NAHMS
National Aquatic Animal Health Plan (United States)	NAAHP
National Pollutant Discharge Elimination Program (EPA)	NPDES
oxytetracycline	OTC
proliferative gill disease	PGD
recirculating aquaculture systems	RAS
specific pathogen-free postlarvae	SPF PLs
Taura syndrome virus	TSV
United States Department of Agriculture	USDA
white spot shrimp virus	WSSV
World Organisation for Animal Health	OIE

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