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Fish Culture in the United States

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Summary. The culture of channel catfish, trout, and crayfish is a well-established, profitable enterprise, but aquaculture provides only a fraction of the protein consumed by Americans, who prefer red meat. This situation could change, since pond-raised fish require less energy for protein synthesis than land animals, the supply of ocean food fish no longer appears inexhaustible, and fish culture can utilize resources unsuitable for other agriculture.

Americans are traditionally not fish eaters, as evidenced by an annual per capita consumption of 6.1 kilograms of fish compared to 60.1 kilograms of red meat (*1*). Supply, price, and quality of marine fish fluctuate considerably because the ocean is an unmanaged source whose yield is unpredictable. Supply can be controlled more effectively when fish are cultured under managed conditions, like corn in a field. High quality can be maintained because farmed fish usually reach the processing plant alive. If fish were farmed on a major scale in the United States, red meat would face healthy competition for the protein dollar.

Fish culture is an ancient practice. A classic account of the culture of common carp was written by Fan Lei in 475 B.C. (*2*). Fish culture was common in Eastern Europe and Southeast Asia in the 13th and 14th centuries (*2*). Although fish culture has made significant contributions of protein in many countries for many years, the methods used were relatively crude. Fish culture as a science emerged only during the past 25 years in the developed countries. Japan has been one of the leaders, increasing its production of pond-cultured fish from 0.1 million ton in 1971 to 0.5 million ton in 1976 (*3*). In Israel in 1977, 58 percent of the total fish catch (marine and freshwater) came from culture ponds (*4*). In the United States, aquaculture provides only a fraction of the protein consumed, but could provide much more.

Benefits of Aquaculture

The percentage of edible lean tissue in fish is appreciably greater than that in beef, pork, or poultry (Table 1). For example, more than 80 percent of the dressed carcass of channel catfish (*Ictalurus punctatus*) is lean tissue; only 13.7 percent is bone, tendon, and waste fat. The caloric value of dressed fish is about one third that of the edible portion of beef or pork. The net protein utilization value of fish flesh, 83 (as compared to 100 for egg), is slightly higher than that of red meat, 80 (*5*), although the essential amino acid profiles of fish and red meat both reflect high protein quality.

Fish can convert food into body tissue more efficiently than farm animals. Table 2 gives sample comparisons. The reason for the superior food conversion efficiency of fish is that they are able to assimilate diets with higher percentages of protein, apparently because of their lower dietary energy requirement. However, the superiority of fish in this respect is not absolute, since poultry convert the protein in their food to protein in their bodies at nearly the same rate.

The dietary energy requirement for

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metabolism is less in fish (*6*), which evolved in a protein-rich, energy-poor environment, than in warm-blooded animals because fish do not have to maintain constant body temperature and exert relatively little energy to maintain position in the water (unless pursuing food). Also, since fish excrete nitrogenous waste as ammonia instead of urea, there is less energy expenditure in protein metabolism. Because of their lower energy requirement, fish can synthesize more protein per calorie of energy consumed than poultry or livestock (Table 2). Thus the primary advantage of fish over land animals is lower energy cost of protein gain rather than superior food conversion efficiency.

Unfortunately, an energy budget for production of protein from freshwater fish-culture systems has not been developed as precisely as budgets for terrestrial animal and plant proteins (*7*) and seafood protein (*8*). The fossil energy required to grow channel catfish in ponds (*9*) is comparable with that needed for broiler chicken production (*7*): chickens require heating and ventilation; catfish require pumped water and aeration. Processing methods for channel catfish and broiler chickens are also similar (both methods involve transport from the production site to a nearby processing site, slaughter, and packing the dressed carcass in ice). Assuming that the fossil energy requirement for producing and processing catfish and chickens is similar, the lower metabolic energy requirement for protein synthesis by catfish (Table 2) makes them a more energy-efficient source of protein. Other land animals require more fossil and dietary energy to produce body protein than chickens (*10*).

Aquaculture can make good use of land that is unusable for other agriculture. Many commercial catfish ponds have been built on hilly, poor land in the Southeast. Catfish ponds in the Mississippi River floodplain, where catfish farming is the most concentrated, are usually built on land less suitable to other agriculture. In Louisiana swampland, crayfish have been successfully farmed simply by building a circular levee and flooding the impoundment after a summer's growth of vegetation. Natural lakes in the prairies of the northern United States and Canada are stocked with trout fingerlings, which are given no further attention until 5 to 6 months later, when they are harvested.

Any body of water that can be confined or controlled is a potential fish farm. In the United States, commercial fish producers have leased public or private lakes for growing catfish during warm months and trout during cold months, in cages suspended in the lakes. Culture of salmon in pens or cages in coastal areas of the Northwest has recently become a commercial enterprise. Technology has been developed in the Southeast to grow and then trap fish in farm ponds not designed for fish culture. Production of catfish in effluent from hydroelectric generating plants shows potential (the warm temperature of the water extends the growing period for these fish).

Fish can be rotated with agricultural crops. For example, crayfish are rotated with rice in Louisiana. The large, shallow catfish ponds in the Mississippi River floodplain are often built with a gradual slope so that they can be planted periodically in soybeans or other crops to utilize the accumulated nutrients. In Southeast Asia (*11*), tilapias and other fish are cultured together with rice in paddies.

Fish that graze actively on plankton, macrophytes, and debris are desirable for farming because these are sources of nutrients. Phytoplankton, for example, are a good source of protein. *Microcystis* sp. (blue-green algae, which commonly grow in ponds) contains, on a dry basis, approximately 30 percent crude protein, which was shown to be 71 percent digestible by silver carp (*Hypophthalmichthys molitrix*) and 63 percent digestible by tilapias (*12*). Zooplankton and other small aquatic fauna are also excellent sources of protein. Fish that feed on detritus receive nutrients in significant amounts from bacteria and protozoans in the slime layer that covers the surface of fibrous particles in organically fertilized ponds (*13*). Fish with carnivorous feeding habits, such as channel catfish, obtain only a limited quantity of macronutrients from naturally occurring foods; however, the pond organisms they consume may provide important micronutrients (vitamins and trace minerals) that may therefore be economically omitted from the supplemental feed.

Fish that feed directly on pond organisms are the most energy-efficient to produce; however, fish production that is based exclusively on naturally occurring food sources is not always the most profitable. Natural aquatic foods provide nutrients at the lowest cost, but the yield of fish is usually increased when the diet is supplemented with artificial feeds. The tilapia hybrid *Tilapia hornorum* (male) × *T. nilotica* (female) gained more than 3000 kilograms per hectare in 180 days when manure was used as the only pond additive, but production increased economically when a supplemental feed was provided (*14*). Yields of 390 kg/ha of common carp were obtained with no

Table 1. Dressing percentage and carcass characteristics of channel catfish, beef, pork, and chicken.

Flesh	Reference	Dressing percentage*	Characteristics of dressed carcass			
			Refuse† (%)	Lean‡ (%)	Edible fat (%)	Food energy (kcal per 100 g)
Channel catfish	(*25*)	60	13.7	80.9	5.4	112
Beef, choice grade	(*26*)	58	15	51	34	323
Pork, medium fat	(*26*)	65	21	37	42	402
Chicken, broiler	(*26*)	72	32	64.7	3.3	84

*The marketable percentage of the animal after slaughter. †In fish, bones only; in beef and pork, bones, trim fat, and tendons; in poultry, bones only. ‡In fish, beef, and pork, muscle tissue only; in poultry, muscle and skin.

Table 2. Efficiency of utilization of feed by catfish, cattle, chicken, and swine.

Food animal	Reference	Feed composition		Efficiency		
		Protein (%)	Metabolizable energy (Mcal/kg)	Weight gain per gram of food (g)	Protein gain per gram of food protein (g)	Protein gain per megacalorie of food energy (g)
Channel catfish	(*27*)	30	2.64	0.77	0.41	47.1
		40	2.86	0.91	0.36	50.8
Cattle	(*28*)	11	2.61	0.13	0.15	6.28
Chicken, broiler	(*29*)	18	2.60	0.48	0.33	23.0
Swine	(*30*)	16	3.30	0.31	0.20	9.65

supplemental feeding (15), 1530 kg/ha with grain only (16), and 3300 kg/ha with a protein-rich diet (17).

Even without a large increase in fish consumption in the United States, aquaculture must play a larger role in supplying food fish in view of declining ocean stocks and the fact that more dollars are spent importing fish than anything else except petroleum (18). In 1976, 66 percent of the fish and fish products consumed in the United States were imported (1). A productive aquaculture industry could improve the balance of payments by reducing our dependence on fish imports. Also, increased fish farming (with supplementary feeding) would increase the domestic use of grain.

Status of Fish Culture: The Species

Table 3 lists the major cultured fish and shellfish in the United States and their production levels. Pond-raised channel catfish and trout from raceways (channels through which water is circulated) are now the major cultured fish. The aquacultural characteristics of these and other important species are discussed below.

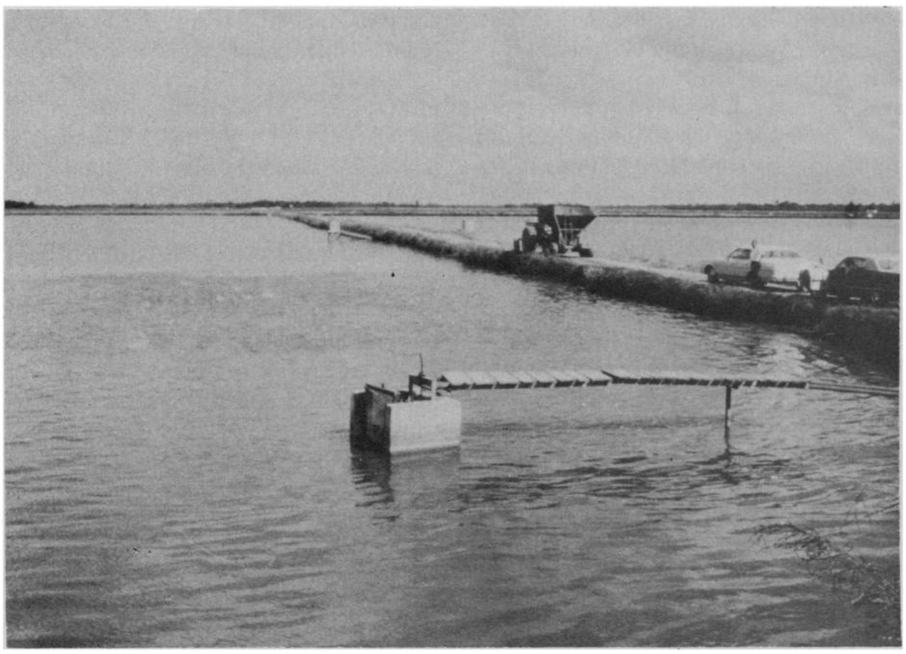


Fig. 1. Channel catfish ponds in the Mississippi River floodplain. The catfish are being fed from a feeder drawn by a tractor along the levee separating the two large (10-ha) ponds. Most catfish are fed an expanded floating pellet, enabling the farmer to gauge how much the fish consume.

Fig. 2. Emergency aeration by tractor-mounted paddlewheel of an oxygen-depleted catfish culture pond. The fish swim to the oxygenated water near the aerator and remain until the pond recovers.

Channel catfish. The channel catfish has many desirable characteristics. It can be spawned in captivity and can be cultured in ponds, densely stocked cages, or raceways. The 10-gram fingerling reaches a harvest size of 0.5 kg in 6 to 7 months if the water temperature remains above 23°C. It accepts a variety of supplemental feeds and is relatively disease-free when environmental stresses are minimized. It tolerates daily and seasonal variations in pond water quality and temperature (from near freezing to 34°C). Although it makes efficient weight gains from processed feeds, it does not make commercially economical gains in ponds without supplemental feeding. The flesh is mostly white muscle, is free of intermuscular bones, and has a mild flavor.

Catfish farming began in ponds in the Southeast for sport fishing. Because channel catfish have long been popular in that area, they were grown and processed for retail food markets. Earthen ponds were stocked with 2500 to 4000 fingerlings per hectare in early spring; the fish were fed pelletized, concentrated foods and were harvested the following fall. Yield was 1000 to 2000 kg/ha. By increasing stocking densities, improving nutrition, compensating for water quality problems, and using multiple harvesting techniques (harvesting the large fish several times per season and simultaneously restocking with small fish, without draining the pond), annual yields of 5000 kg/ha are now commonly harvested from ponds.

In the Mississippi River floodplain, where large ponds can easily be built, catfish farming has become a major enterprise. Many farms are 100 ha or more in size, with individual ponds of 5 to 10 ha (Fig. 1). A recent economic analysis indicated a yield of 109,000 kg of fish per man-year of labor in this region (9). In 1978, the average production cost was $0.86 per kilogram of live fish, and the farmer could sell at a price of $1.10 per kilogram (9). The average profit for catfish farming was $800 per hectare, the highest net return for any crop in Mississippi.

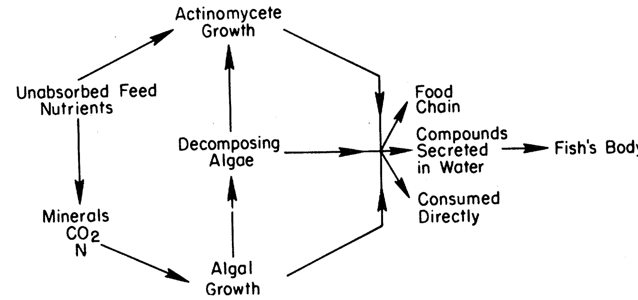
The major limiting factor in the culture of catfish in ponds is insufficient dissolved oxygen. Phytoplankton produce insufficient oxygen during prolonged cloudy periods to maintain a large catfish population. Fish farmers can prepare for oxygen depletion by predicting oxygen consumption rates in their ponds (*19*) and using emergency aeration equipment (Fig. 2).

Trout. The rainbow trout (*Salmo gairdnerii*) is the second-leading cultured food fish in the United States. In 1978, 13,600 metric tons were sold (*20*). Trout have been spawned and cultured to fingerling size in hatcheries for sport fishing for many years, so much is known about their husbandry, and strains that grow well under culture conditions have been developed. Trout grown for food are usually cultured in raceways where, because of the absence of natural foods, care must be taken that the diet is nutritionally complete. Trout are more carnivorous than the cultured warmwater fish and digest carbohydrates poorly; consequently, their feed must contain more animal products, which makes trout diets more expensive than those of warmwater fish. They grow to marketable size in 5 to 7 months and are easily marketed. A drawback is that production by the traditional raceway system requires large quantities of flowing, cold (10° to 15°C) water.

Crayfish. Most of the freshwater crayfish grown in the United States are produced and consumed in Louisiana (*3*). These crustaceans are raised in large, shallow impoundments that can be drained in the summer for growth of vegetation and then flooded in the fall. They can also be produced in harvested rice fields. They consume decaying plant material (such as rice stubble), organisms associated with its decomposition, and growing aquatic plants. They are usually not given supplemental feeds; however, the addition of agricultural by-products has increased yields, which range from 225 to 955 kg/ha (*3*)—seemingly low, but capital and operating costs are also low in comparison with other types of aquaculture. Only 12 to 16 percent of the crayfish carcass is edible flesh. Harvesting requires much labor and may cost up to one half of the value of the crop. Market prices of farmed crayfish are inversely related to the availability of crayfish from wild sources, which varies substantially from year to year.

Tilapias. Tilapias have been cultured in tropical areas under primitive conditions for many years. They feed on plankton and benthic organisms, grow rapidly, and respond well to organic fertilization and simple supplemental feeds such as rice bran. However, tilapias are intolerant of cold and tend to overpopulate their culture ponds, which results in fish that are too small for the market. Their excessive reproduction can be controlled by sex-reversing chemicals, hybridization, manual separation of the sexes, or the introduction of predatory fish (*2*). Male tilapias stocked in experimental ponds at a density of 10,000 fingerlings per hectare grew to uniform size of about 0.3 kg in 4 to 5 months (*14*); their only supplement was chicken manure and rice bran. The tilapias *T. aurea* and *T. nilotica* are being produced commercially in several southeastern states, California, and Colorado, and are easily marketed since their flesh is light in appearance, mild in flavor, and free of intermuscular bones.

Fig. 3. Influence of unabsorbed feed nutrients on geosmin-synthesizing organisms and subsequent absorption of the off-flavor compound by fish.



Buffalofish. The bigmouth buffalo (*Ictiobus cyprinellus*) has feeding habits similar to those of the carp and grows well on pond foods and supplemental diets and in polyculture ponds with channel catfish. It was one of the first food fish commercially cultured in the South, so technology for its husbandry is well established. It has fewer intermuscular bones than carp and its flesh has a pleasing appearance and flavor. Although it is a warmwater fish, it is tolerant of cold temperatures. About 450 metric tons are produced in culture ponds annually (*2*).

Salmon. The salmon is a food fish of high value. Much research has been devoted to salmon rearing, primarily for the benefit of hatcheries. There has been recent commercial interest in the culture of Pacific salmon in pens or cages along the northwestern coast of the United States. Social and political problems concerning the use of coastal waters for fish culture are obstacles to the development of this culture system, although some salmon are being produced in commercial "feedlots" offshore.

Table 3. Major commercially cultured aquatic animals in the United States.

Species	Reference	Production (metric tons)	Year
Channel catfish	(*20*)	35,000	1978
Trout	(*20*)	13,600	1978
Bait fish	(*3*)	9,800	1975
Crayfish	(*3*)	6,800	1977
Oysters (in shell)	(*3*)	8,800	1973
Freshwater shrimp	(*3*)	140	1978
Ornamental fish	(*3*)	(97,000,000)*	1972

*The number of ornamental fish produced.

Salmon diets must be high in animal protein and in fish oil, should contain sources of pigment (to impart color to the flesh), and are usually fed in moistened form, which means an added storage expense. Although artificial spawning is easily accomplished, with a high rate of egg fertilization, salmon brood stock must grow to sexual maturity under stable natural conditions. Overfishing or water pollution can thus affect the availability of brood stock.

Shrimp, lobsters, oysters. The marine shrimp is one of the most popular seafoods in the United States, but efforts to culture it in estuarine areas along the coast and in ponds and tanks have not been very successful. Major reasons for failure are difficulty of managing its life cycle, dependence on wild spawners for eggs, unsuitable climate for year-round culture, high labor and energy costs, and legal and social constraints related to use of coastal areas. More success in this endeavor has been realized in Latin America, where growth of the industry is expected to continue.

Culture of freshwater shrimp (*Macrobrachium*) has begun to show profits in Hawaii [with yields of 1400 kg/ha (*3*)] and in several Latin American countries, where culture farms have been built by American investors. The freshwater shrimp has proved very marketable, although unlike the marine shrimp it is not an established food product worldwide. Freshwater shrimp are actually cultured in salt water until they reach the postlarval stage, at which time they can be grown in freshwater ponds until they are harvested. Technology has been developed for producing large quantities of seed stock in hatcheries and for managing production ponds where crude supplemental diets, such as poultry feed, have been used. Freshwater shrimp do not survive temperatures below 13°C, so the continental United

States is poorly suited for their culture.

Lobsters (*Homarus americanus*) are in short supply and command high prices. Considerable research is being directed toward culturing the lobster, but its commercial culture is not yet feasible. It spawns and grows in captivity, but requires 2 to 3 years to reach marketable size.

More than 40 percent of the oyster catch in 1973 came from managed beds (*3*), but oysters are not generally considered to be a cultured food source since most of the management consists of little more than seeding the oyster beds. The technology of oyster culture has advanced to the point at which all phases of the life cycle can be controlled; however, the cost of growing oysters under controlled conditions is not economically attractive. The declining yield from natural sources should favor development of methods to produce oysters under managed conditions.

Research and limited pilot testing have been conducted for clams and scallops with respect to their suitability for culture.

Polyculture. Culturing several species of fish with different food habits in the same pond is called polyculture. The object is to increase yield through more efficient use of the natural pond foods. Carp species that have different food niches have been polycultured in China for many years, and Israeli fish farmers have mixed common carp, silver carp, tilapia, and sometimes mullet to increase yields by 30 percent over yields from culture of these species individually (*21*). At Auburn University, experiments have shown that by including tilapia and silver carp in catfish ponds and using the same amount of supplemental feed, annual yields can be increased by 50 percent, with no reduction in the catfish production.

Constraints and Opportunities

Development of aquaculture in coastal areas of the United States will be difficult because of increasing demands for alternative uses of these areas. Similarly, controversy may develop when fish are produced on land that is suitable for other farming. Aquaculture may have to be confined to marginal land.

Some cultured fish, such as tilapias and carp, lack consumer exposure and have a poor image in comparison with salmon, trout, and shrimp. The freshwater catfish carries a stigma in the eyes of many consumers, but energetic market development has increased the demand for this fish in many areas.

A serious constraint is the musty, muddy flavor that is sometimes absorbed by pond-cultured fish. The off-flavor is usually caused by geosmin [*trans*-1,10-dimethyl-*trans*-(9)-decanol], which is synthesized by some species of blue-green algae and some actinomycetes, both of which grow well in culture ponds (*22*). Fish absorb geosmin through the food chain and directly from the water (Fig. 3). In the average catfish pond there is a 10 percent chance of such contamination (*22*). Thus farmers are extremely careful to check for off-flavor before harvesting, as are processors before they buy. No consistent methods are available for eliminating geosmin production in fish ponds. Although the musty flavor usually disappears within several weeks, it is a serious inconvenience to the industry.

Another constraint on the development of aquaculture has been the lack of a national aquaculture program. To create such a program, public support and government assistance are needed. An important first step would be the establishment of a set of aquaculture policies. The recent assignment of the Department of Agriculture as the lead agency for aquaculture is an indication that progress toward the orderly development of this new field is being made.

Commercial and research interest in culturing marine species such as lobster, shrimp, salmon, and some finfish will continue because consumers are willing to pay high prices for them. However, according to Shell (*23*), the culture of marine species (mariculture) will probably develop less quickly than the culture of freshwater species because (i) production of seed stock of marine species under managed conditions is difficult; (ii) mariculture must compete with other uses of coastal land and water; (iii) maricultural products must compete with captured sea products and, at present, cannot do this economically; and (iv) the coast is made inhospitable by violent winds, unstable soil, tides, currents, pollution, corrosion, and erosion, presenting many engineering problems. Most American investments in warm-water mariculture will probably be made in Latin America because competition for coastal land and water resources is less severe there and temperature is relatively constant.

Fish farming will provide only a small part of the protein consumed in the United States in the next few years, but has potential for making a significant contribution in the future. The almost phenomenal growth of catfish farming, from 4000 to 35,000 tons per year in 9 years (*24*), is an indication of that potential. Aquaculture is a science in its infancy, and the direction of its growth is uncertain; however, the fact that fish farming can provide animal protein at a relatively energy-efficient rate, stabilize or increase the supply of fish while reducing our dependence on imports, and make unproductive land and water resources productive assures it of a strong and positive role in future food production in the United States.

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