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9. ABSTRACT

There commonly are three levels of fish farming: 1) fish produced exclusively from natural aquatic foods, 2) fish produced by supplementing natural foods with artificial feed, and 3) intensive fish farming under artificial conditions. Besides these, this report discusses also the benefits of fish farming as a source of animal protein and the desirable characteristics of fish for farming such as growth rates, efficient utilization of natural foods, tolerance to water conditions, and disease resistance. In examining present and potential yields through farming selected species of food fish, carp, channel catfish, trout, eels, tilapias, and the polyculture of several species are described. Finally, the technology of utilizing farm-raised fish is reviewed, including domestication of species with desirable consumer or cultural qualities, hybridization, polyculture, computer calculations of least cost rations, hypertensive raceway cultures, reuse of water, and development of new consumer fish products. It seems inevitable that fish farming will increase its contribution to discriminating consumers in both high and low income markets.

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Progress and Prospects of Fish Farming

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PROGRESS AND PROSPECTS OF FISH FARMING

R. T. Lovell, R. O. Smitherman and E. W. Shell

1974, 36 p

Fish farming has a long history in some areas of the world while in others it is still in its infancy. Three levels of fish farming are common. They,are production of fish exclusively from natural aquatic foods, fish production by supplementing natural foods with artificial feed,and intensive farming of fish under artificial conditions.

Benefits of fish farming as a source of animal protein are discussed. The desirable characteristics of fish for farming are described. Present and potential yields through farming of selected species of food fish are discussed. These species include carp, channel catfish, trout, eel and tilapia. Also the polyculture of several species is mentioned. The technology associated with the utilization of farm-raised fish is outlined.

TABLE OF CONTENTS

Progress and Prospects of Fish Farming

INTRODUCTION

Fish farming is believed to have begun in China. Artificial hatching of fish was known in China about 2000 B. C. (Villaluz, 1953), and a classic account of the culture of common carp was written by Fan Lei in 475 B. C. During the Han Dynasty (201 B. C. to 190 A. D.) fish were first reared in commercial quantities in ponds.

The Romans, considering fish among the most highly prized foods, built ponds during the first century A. D. and stocked them with fish. Reportedly, the Romans employed artificial foods to improve the flavor of the cultivated fishes.

During the Middle Ages, fish pond building was spread throughout Europe by religious men. A French monk, Dom Pinchon, first conceived the idea of artificially fertilizing the eggs of trout, and experiments in France and England during the sixteenth to nineteenth centuries laid the foundation for the trout and salmon hatchery technology in use today.

Fish farming in Poland and other East European countries involving the common carp was popular in the twelfth and thirteenth centuries.

In Indonesia, fish ponds (tambak) were believed to have naturally evolved along with salt-making, and the saltbeds were utilized to grow milkfish during the rainy season. This practice was originated by the Malay natives before 1400 A. D. (Schuster, 1952), and has been modified for extensive fish cultivation in other countries, notably the Philippines.

Early interest in fish culture ponds in the United States was carried over from England in the seventeenth century, and was concentrated on propagation and culture of trout and salmon. Significant developments during the twentieth century have been refinements of the intensive, large-scale culture of trout and salmon in flowing water and the emergence of bait minnow farming and catfish farming as new, multi-million dollar industries in the south-central United States.

Over the past 25 years, an awareness of the potential which aquaculture or fish farming holds for the supplementation of world food supplies has been developing with the United Nations and other international agencies taking leadership roles in disseminating information.

LEVELS OF FISH FARMING

Generally, fish with highest market value are cultured most intensively, using more artificial, or expensive, facilities and food; whereas, species with lower market value are produced under less modified culture conditions with greater dependence on natural foods, and lower subsequent yields per unit of culture space. For convenience, level or intensity of fish farming may be equated with food source, as presented in the following.

Production of fish exclusively from natural aquatic foods

Several important species of food fish are capable of obtaining their food from plankton. These fish are usually continuous grazers and have mechanisms for concentrating the suspended animal and plant organisms from the water. Some of them, such as the silver carp (Hypophthalmichthys molitrix), accept artificial (supplemental) food reluctantly. Others, such as tilapias, have the ability to feed on plankton but also feed on bottom materials (detritus) and readily accept artificial feeds. The common carp (Cyprinus carpio), which is cultured in many areas of the world, is an efficient bottom feeder. Some fish have herbivorous appetites and consume large quantities of higher aquatic plants. In this group are the white amur (Ctenopharyngodon idella) and some tilapia species.

All of these fishes have been cultured without the use of artificial feeds, mostly in areas outside of the United States. This level of production is most applicable in less-developed countries where supplemental feeds are expensive or unavailable. Usually, yields are low but production costs are less where supplemental feeding is not practiced.

Supplementing natural food with artificial feed

This level of fish farming essentially involves taking full advantage of natural aquatic productivity and using artificial feeds as a supplement to further increase yield. Most types of pond culture with artificial feeds are in this category. Usually with species that will accept supplemental feeds, the additional yield of fish resulting from the additional feeding is economically feasible. Production of common carp in fertilized ponds may be 390 kg per hectare (Yashouv, 1959); the addition of grain or grain by-products may increase yields to 1,530 kg per hectare, and where high quality supplemental fish feeds are used, yields of 3,300 kg per hectare may be obtained in culture ponds (Sarig, 1974). When channel catfish (Ictalurus punctatus) are not fed a supplemental feed, yields of 370 kg per hectare are obtained from the fertilized ponds (Swingle, 1968). With use of high-protein supplemental feed, yields of 3,000 kg per hectare are obtained in static ponds (Prather and Lovell, 1974).

Where natural aquatic food may make a relatively small contribution to the total protein and energy requirements of the fish grown in ponds, it can provide the small amounts of essential nutrients that will allow simple (nutritionally incomplete) supplemental feeds to be used. For example, common carp make appreciable gains in ponds in Europe when fed only grains (Ghettino, 1972); and channel catfish grown in ponds in the United States do not need expensive vitamin premixes and require less animal protein in their supplemental feeds than do catfish grown in artifical systems (Hastings and Dupree, 1969; Prather and Lovell, 1972).

Intensive farming of fish under artificial conditions

At this level of production the primary concern is maximum yield per unit of space and effort, with feed cost being secondary. This type of farming is feasible only where the market value of the fish is high. Examples of this type of production are rainbow trout (*Salmo gairdnerii*) cultured in spring-fed raceways and channel catfish produced in cages or flowing-water raceways. Production costs are high because water quality must be maintained, by oxygenation or continuous replacement, and nutritionally complete diets must be provided.

BENEFITS OF FISH FARMING AS A SOURCE OF ANIMAL PROTEIN

If fish is to make an important contribution to the nutritional status of people in developing countries, it must be available at a price most of the population can pay. Fish farming can play an important role in this regard; however, care must be shown in species selections, site locations, and the application of resources for fish farming.

Consumers in the United States are traditionally not fish eaters, primarily, because of the great inland concentration of the population where highly perishable seafoods have not always been accessable. However, as the supply of high quality fishery products has steadily improved throughout the country, consumption of these products has increased to 5.6 kg per year in 1974 (U.S.D.A., 1975), in spite of the fact that high quality fish is generally more expensive than red meat or poultry. No doubt fish will increase in consumer popularity as supply becomes more abundant, stable and economical. Fish farming is perhaps the major factor that will make fish not only more competitive with red meat, but will, under certain circumstances, make it preferable over other animal flesh.

Controlled quantity and quality in farm-raised fish versus sea-caught fish

Supply, price and product quality of marine fish fluctuate considerably. This is because marine fish are harvested from unmanaged sources and the yield is highly variable. Also, the distance that sea fish are transported is usually great, considering that 66 per cent of the seafoods consumed in the United States are imported (U.S.D.C., 1973). Supply can be controlled more effectively when fish are produced under managed conditions as are agricultural crops, than when fish are caught from their natural habitat. Quality of farmed fish can be maintained at a high level because the fish conventionally reach processing plants alive, in contrast to sea-caught fish which are usually transported long distances and are not alive when they reach the processor.

In temperate regions, fish growth is seasonal but most farmed fish are harvested the year round to comply with seasonal demand. In the United States channel catfish grow 6 to 8 months of the year but processing plants operate 9 to 12 months. In Europe and Japan, common carp gain most of their weight during the warm months but many are held over for marketing during other parts of the year. Trout raised in constant-temperature spring water are harvested in proportion to demand the year round. In tropical and subtropical areas fish have a year-round growing season.

High yield of muscle protein and favorable amino acid profile

Data in Table I show that the percentage of lean tissue in dressed fish is appreciably greater than that in beef, pork, or poultry carcasses. The percentage "refuse" (bone, trim fat, tendons), or uneaten portion, of the dressed fish carcass is less than that in the other animal carcasses. The amount of food energy obtained from dressed fish is only about one-third of that obtained from the carcasses of beef or pork.

Table II shows the essential amino acid composition of the protein in farm raised channel catfish, red meat (beef), a marine fish (haddock), and a cereal (rice), along with the FAO/WHO recommended amino acid pattern for human nutrition. Protein composition of the marine fish and red meat are quite similar, but freshwater catfish is lower in methionine and higher in lysine than the other two animal proteins.

High yields and efficient feed conversions by intensively farmed fish

Through intensive fish farming methods, i. e., by using high stocking densities, modified culture systems, and optimum performance diets, high yields of fish can be realized per unit of culture space. Channel catfish can be raised in cages to yield 275 kg per cubic meter of cage (Schmittou, 1970) and in raceway tanks to yield 92 kg per cubic meter (Allen, 1972). In efficiently managed commercial ponds, yields of 6,000 kg per hectare of channel catfish are produced (Smith, 1973). One efficiently operated channel catfish farm in the southeastern United States produces approximately 0.5 million kg of fish per man year of employment. Pond yields of carp of 24,000 kg per hectare are reported in Israel (Tal, 1974).

I. Dressing Percentage and Carcass Composition of Fish, Beef, Pork, and Chicken

Food Animal	Dressing Percentage	Refuse,[c] %	Composition of Dressed Carcass Lean,[d] %	 Fat, %	 Food energy, kcal/100g
Farm raised channel catfish[a]	60	13.7	80.9	5.4	112
Beef, choice grade[b]	58	15	51	34	323
Pork, medium fat[b]	65	21	37	42	402
Chicken, broiler[b]	72	32	64.7	3.3	84

[a] Lovell, R. T. and G. R. Ammerman. 1974. Processing Farm Raised Catfish. South. Coop. Ser., U.S.D.A., Bull. 193, 59 p.

[b] From "Composition of Foods", Agriculture Handbook No. 8, U.S.D.A. (Rev. 1963).

[c] "Refuse" in dressed carcass means: in fish, bone only; in beef and pork, bones, trim fat, and tendons; in poultry, bones only.

[d] "Lean" means only muscle tissue for all animals except chicken where skin is included in edible portion of carcass.

II. Essential Amino Acid Composition of Farm-Raised Channel Catfish, a Marine Fish (Haddock), Beef, and a Cereal (Rice)

Amino Acid	Grams per 16 grams of nitrogen				
	Channel Catfish[a]	Haddock[b]	Beef[b]	Rice[c]	FAO pattern[d]
Arginine	6.3	5.7	6.1	8.8	
Histidine	2.8	1.9	3.6	2.3	
Isoleucine	4.3	5.4	5.0	4.4	4.0
Leucine	9.5	7.5	7.8	8.6	7.0
Lysine	10.5	8.6	8.7	2.8	5.5
Methionine	1.4	2.8	2.7	1.4	3.5[e]
Phenylalanine	4.8	3.7	3.8	4.8	6.0[f]
Threonine	4.8	4.2	4.5	3.6	4.0
Valine	4.7	5.6	5.2	6.4	5.0
Tryptophan	0.8	0.9	1.0	0.1	1.0
Total essential	49.9	46.3	48.4	43.2	

[a] Lovell, R. T. and G. R. Ammerman. 1974. Processing Farm Raised Catfish. South. Coop. Ser., U.S.D.A., Bull. 193, 59 p.

[b] From Borgstrom, G., ed. "Fish as Food," Vol. 2. Academic Press, New York (1962).

[c] From Altschul, A. M., ed. "Processed Plant Protein Foodstuffs," Academic Press Inc., New York (1958).

[d] WHO Technical Series No. 301, FAO, United Nations, Rome (1965).

[e] Methionine + Cystine

[f] Phenylalanine + Tyrosine

The energy requirement for metabolism is less in fish than in warmblooded animals because fish do not have to maintain constant body temperature and exert relatively little energy to maintain position in the water. Consequently, the amount of protein synthesized per Mcal of available, or metabolizable, energy (ME) consumed in practical production rations is appreciably higher for fish than for poultry or livestock (Table III).

Data in Table III show that fish are able to convert ingested food into body tissue at a much higher rate of efficiency than can farm animals. This is because fish are able to assimilate rations of much higher protein content. When conversions of diet protein to body protein are compared, the efficiencies of fish, poultry and swine are about equal.

Utilization of resources unused in other agriculture

1. Land: Swamp or poorly drained land, hilly terrain and other types of marginal or non-agricultural land may be used for fish farming. In southern areas of the United States swamp land has been farmed successfully with crayfish by simply constructing a levee around the area to be farmed and flooding the impoundment from bayous or drainage canals. The crayfish stock themselves naturally and obtain food from the decomposing vegetation that grows during summer months when the impoundment is drained. Many channel catfish ponds in the United States were constructed on land that was poorly suited for crop production. These "hill ponds" are relatively small but high yields may be achieved by circulating the water or mechanically oxygenating the water. In the Philippines extensive milkfish ponds have been developed on coastal land unsuitable for plant crop production (Blanco, 1973).

2. Water: Inexpensive and dependable sources of water are important assets

III. Efficiency of Utilization of Practical Productive Rations by Fish, Chickens, Swine, and Cattle

Food Animal	Ration Composition		Efficiency		
	Protein, %	Energy Mcal ME/kg	G weight gain per g of food	G protein gain per g food protein	G protein gain per Mcal food energy
Fish[a]	30	2.64	0.77	0.41	47.1
	40	2.86	0.91	0.36	50.8
Chicken[b]	18	2.60	0.48	0.33	23.0
Swine[b]	16	3.30	0.31	0.20	9.65
Cattle[b]	11	2.61	0.13	0.15	6.28

[a] Lovell, R. T. 1972. Protein requirements of cage-cultured channel catfish. Proc. Ann. Conf. S. E. Assoc. Game and Fish Comm. 26:357.

[b] Calculated from data presented in "Nutrient Requirements of Domestic Animals" series on poultry, swine and beef cattle. National Academy of Science-National Research Council, Washington, D. C. (1969-1974), and in "Composition of Foods", Agriculture Handbook No. 8, U.S.D.A. (Rev. 1963).

for fish farming. Any available aquatic environment such as streams, lakes, swamps, drainage or irrigation canals, or estuaries, where a portion can be confined or controlled, is a potential resource for fish culture. In the United States where govenment regulation restricts industrial or agricultural discharge into streams, there is less freedom to utilize natural water resources for fish production; however, in many countries these resources are effectively used for fish culture.

In Thailand, coastal impoundments are flooded by high tides, stocked with fish and cultured for several months, and drained by opening weirs at low tide. In Brazil, farmers construct commercial tilapia ponds adjacent to irrigation canals and pay a modest fee for water from the canals for the ponds. In Costa Rica "family size" ponds are constructed beside permanent streams for tilapia culture.

Suspended cages and pens allow a confined area of a large stream, a lake or the sea to be farmed. In Southeast Asian countries, cages for the purpose of growing fish are commonly suspended beneath or beside homes on water. Most of the carp cultured in Japan are grown in cages in a 5,000 hectare lake north of Tokyo. Pen culture, as practiced in Southeast Asia, involves building a fence or wall in the edge of a lake or an estuary and stocking the impoundment with fish. Unassimilated feed from the pens diffuses out into the main body of water and fresh water from outside maintains the quality of the water in the pen. In Europe, common carp have been cultured in sewage treatment ponds.

In the United States several commercial catfish production operations have leased the use of public or private lakes to grow channel catfish in cages. Production of channel catfish in cages or raceways using cooling water from hydroelectric generating plants has become a commercial venture. This process takes advantage of the availability of both water and heat.

3. Low cost food materials: The most economical production of fish flesh is through direct utilization of natural aquatic foods by the fish. This is not to imply that fish production exclusively from natural foods is always the most profitable. Natural aquatic foods may provide the lowest cost nutrients but when supplemented with artificial feeds the yield of fish may be economically increased. Various classes of foods that are consumed by cultured food fish are compared in Table IV.

An excellent example of fish converting crude materials into animal protein is tilapia hybrids (Tilapia hornorum (♂) X T. nilotica (♀) in Northeast Brazil yielding over 3,000 kg per hectare in 180 days when only chicken manure was placed into the pond (Lovshin, et al, 1974). In Thailand, Clarias catfish produced 25,000 kg per hectare, in two crops per year, in commercial ponds when fed a diet composed of ground trash fish mixed with rice byproducts in a 1:1 ratio (Shell and Lovell, 1973).

Polyculture is a system of fish farming practiced in many parts of the world in which different species of fish with divergent feeding characteristics are stocked in the same environment to effect maximum utilization of the various sources of food in the pond. This system may involve: (i) a fish that primarily consumes artificial feed; (ii) a fish that feeds predominantly on the plankton that grows abundantly in heavily fed ponds; and (iii) a fish that is an efficient bottom feeder that will effectively utilize wastes and detritus. In Israel, combinations of common carp (artificial feed and insects), silver carp (plankton), and tilapia (plankton, insects, organic debris) have shown impressive results. In the United States combinations of channel catfish with either tilapia or buffalo fish (Ictiobus cyrinellus) have been used commercially.

4. Labor: In the United States where most of the channel catfish are pro-

IV. Classes of Foods for Cultured Fish

Class	Examples	Protein Digestibility[a]
Natural aquatic foods:		
Micro	Phytoplankton, zooplankton	Good
Macro	Crustaceans, insects, larvae	Very good
Supplemental foods:		
Cereals	Corn, raw	Fair
	Corn, cooked	Good
Oilseed meals	Soybean meal	Very good
Animal protein	Fish meal	Very good
By-products	Rice bran	Good
	Trash fish	Very good
	Coffee pulp	Fair
Roughages	Alfalfa meal	Poor
	Grass, leaves	Poor

[a] Protein digestibility: above 75% = "very good"; 60-75% = "good"; 30-60% = "fair"; below 30% = "poor". Digestion coefficients were determined with channel catfish and Tilapia aurea and reported in Fisheries Annual Reports, Auburn University Agric. Expt. Sta., Auburn, AL. (1971-1974).

duced in large ponds, the greatest labor investment is during the time of stocking and harvesting the ponds. These operations are usually scheduled during the cool seasons (stocking in late winter-early spring and harvesting in late fall-winter) when other agricultural labor or warm season labor is less employed. In Asia and Southeast Asia fish have been grown in rice fields for centuries, and this combination permits conservation of labor resources.

DESIRABLE CHARACTERISTICS OF FISH FOR FARMING

Seedstock produced under managed conditions

Most of the farmed fish seedstock are spawned in captivity. This allows for control over supply and quality (genotype as well as phenotype) of the fry, which is difficult or impossible when the young fish to be stocked in production units must be taken from wild sources. Rainbow trout have been spawned under managed conditions for many years and, through selective breeding, highly productive strains have been developed which spawn at several different times during the year. Through selection among these strains and controlling the environment, spawns are obtained three times a year which permits trout farming to be more of a year-round operation than it would be if trout were spawned only once a year as in nature.

An important reason that channel catfish in the United States and common carp in many areas of the world have become popular farmed food fish is the ease with which they reproduce in captivity. Several domestic strains of channel catfish in the United States have been maintained and upgraded for over 25 years and genetic studies are in progress to improve the productive traits of the fish. Fish culturists have improved desirable traits in the common carp in Israel through several years of selective breeding (Moav and Wohlfarth, 1968).

An example of the disadvantage of not having control over supply of seedstock may be seen in eel farming in Japan. Eel farming is an important industry in Japan and the market value of eels is high. However, the supply of elvers(eel fingerlings) for stocking production ponds is becoming increasingly scarce because of pollution of rivers where capture is ordinarily done.

Rapid growth

Rapid growth rate is a desirable feature under all fish farming conditions. Even under primitive cultural conditions, the farmer is eager to harvest the fish that he has been tending for weeks or months. Often a serious problem in developing countries is the harvesting of fish long before they have reached optimum size for maximum economic return. In intensive fish farming operations, where overhead costs are high, the length of time required for fish to reach marketable size is of economic importance. In pond culture in temperate regions the growing season is limited by temperature to 5 to 9 months. If the fish do not attain a favorable market size by the end of the growing season, the producer will receive a reduced price for his fish or must maintain the fish until the following growing season for additional growth, which also will reduce his profit.

Efficient utilization of natural foods

Fish species which make maximum use of natural food produced in the culture system have an advantage over species which can utilize only a limited amount of the material produced in the aquatic environment. *T. mossambica*, which are effective feeders on plankton as well as on materials from the pond bottom, made gains of 1,400 kg per hectare in ponds in 6 months without supplemental feed (Swingle, 1960).

In cages where they could only consume plankton filtered from the water, T. aurea gained 45 kg per cubic meter cage in five months (Armbrester, 1970). The common carp is not a plankton feeder but is an efficient forager of bottom animals. Yields of 390 kg of carp per hectare have been reported from nonfed fertilized ponds (Yashouv, 1959). Milkfish are continuous grazers and in fertilized commercial ponds have yielded 1,500 kg per hectare per year by consuming plankton and benthos (Anonymous, 1974).

Fish with such feeding habits are able to obtain a significant amount of protein and energy (macronutrients) from natural productivity, depending upon the mass of fish per unit of pond space and fertility of the pond. However, fish which derive only a limited amount of their macronutrients from natural foods may receive significant amounts of micronutrients (namely vitamins) from natural foods so that expensive nutrients, like ascorbic acid, may be omitted from the supplemental feed (Prather and Lovell, 1972).

Response to supplemental feeding

Supplemental feeding allows yield per unit of culture area to be increased appreciably. Fish species that will not accept artificial feeds are generally undesirable for intensive farming.

Some fish have feeding habits which require conditioning of the fish to accept supplemental feeds. For example, Clarias batrachus "walking" catfish in Thailand was thought to accept only soft, moist feeds, but recently have been trained to feed on dry, pelleted feeds at the early fry stage (Shell and Lovell, 1973). Largemouth bass are extremely difficult to train to accept artificial feeds after they pass the fingerling stage, but if trained when small they will subsequently make efficient gains on diets exclusively of artificial feeds (Snow, 1969). The most critical step in rearing striped bass (Morone saxatilis) under intensive culture conditions is getting the recently hatched fry to accept artificial feeds. After striped bass reach a size of 5 to 8 cm they accept supplemental feeds readily.

Yields of 1,530 kg per hectare have been obtained with common carp by feeding only grain as a supplement to the natural pond food (Ghittino, 1972). When protein-rich supplemental feeds were used, yields increased to 3,300 kg per hectare (Sarig and Marek, 1974). In channel catfish farming, the use of moderate to high protein supplemental feeds is usually the most economical. This is illustrated by the data in Table V which represent comparative economic returns from pond raised channel catfish fed low, medium and high percentages of protein in supplemental feeds containing 0, low and moderate proportions of animal (fish meal) protein. In this case, catfish fed the higher (36% or 43%) protein supplemental feeds in which some (1/6) of the protein came from fish meal, were the most profitable.

Tolerance to variable water conditions

Fish to be cultured in ponds should be tolerant of variable conditions of dissolved oxygen, temperature and metabolic waste materials in the water. In the early part of the feeding period dissolved oxygen levels are relatively high and consistent. But as feeding rate increases and water becomes more enriched with algal growths, the dissolved oxygen levels vary diurnally and may be quite low at night or on cloudy days when plant respiration exceeds photosynthesis, and supersaturated on warm, sunny days when the reverse occurs.

V. Growth Responses and Economic Returns from Pond-Raised Channel Catfish Fed Rations Varying in Quantity and Quality of Protein

Ration		Yield, kg/hectare	Return above feed costs,[c] $/hectare
Crude protein, %	Animal protein,[b] fraction of crude protein		
28	0	2,076	1,645
36	0	2,205	1,700
43	0	2,352	1,731
28	1/6	2,174	1,670
36	1/6	2,593	2,024
43	1/6	2,682	2,035
28	1/3	2,459	1,894
36	1/3	2,620	1,863
43	1/3	2,699	1,855

[a] Lovell, R. T., E. E. Prather, G. Tres-Dick, L. Chhorn. 1975. Interrelationships between quantity and quality of protein in rations for pond raised channel catfish. Trans. Am. Fish. Soc. (Accepted for publication).

[b] Source of animal protein was menhaden fish meal.

[c] Feed costs were calculated from market prices of feed ingredients, Memphis, Tenn., January, 1973, plus 25% for manufacturing. Value of fish was $.45 per lb ($.99 per kg), January, 1973.

In raceways where water only passes through the culture system one time, fluctuations in dissolved oxygen and accumulation of waste materials are not problems to the fish; however, in the United States the water must be "cleaned up" to comply with Environmental Protection Agency regulations concerning discharge pollutants into streams.

Tolerance to a range in temperatures is desirable. Several tropical species of fish have desirable cultural characteristics but aren't raised in temperate regions because of sensitivity to low temperature. Conversely, rainbow trout have excellent market value and their husbandry is highly developed, but they only grow in cold water (10-18°C). Most desirable for the temperate zones are fish that have an optimum growth temperature of 23-30°C, but the brood fish and seed stock will remain in good condition at low temperature (4-16°C).

Disease resistance

Immunizations against diseases have not been developed for fish although practically all farmed species are subject to infestations of pathogenic organisms or viruses. Most disease problems occur when the fish are under environmental stresses related to crowding, water quality, temperature, poor nutrition, and handling. Consequently, desirable species for farming are those that do not readily succumb to pathogen infestations when environmental conditions change and are not especially sensitive to specific pathogens.

Lack of reproduction

Fish cultured for food should not reproduce during the growing period required to reach acceptable harvest size. Reproduction in the culture system results in failure of the stocked fish to reach desired size, and small fish are discouraging to the farmer and have poor market value.

A serious problem in growing tilapia for food in tropical countries has been the tendency of these fish to reproduce at an early age in culture ponds, which results in an excess of small fish. Recently, reproduction of tilapia in culture ponds has been abated by producing near 100% male hybrid offspring with selected species crosses. Also, all-male offspring have been produced by oral administration of synthetic male hormones to recently hatched tilapia fry. Sex control in other farmed species may be beneficial if one sex grows faster than the other or if gonadal development causes a reduction in weight of marketable flesh.

PRESENT AND POTENTIAL YIELDS THROUGH FARMING SELECTED SPECIES OF FOOD FISH

The foregoing discussions have identified types of food fish production with regard to intensity, benefits of fish farming as a source of animal protein, usable resources in fish farming and desirable characteristics of fish for farming. Species of fish and culture practices that have been proven or have potential for practical production of food fish for markets or for subsistence are presented in the following. Conventional technology and husbandry aspects of fish farming will not be presented except for purposes of illustration.

Carp

The common carp is the most widely farmed fish in the world. Because of its boniness however, the carp is not a desirable food fish in the United States. This fish more nearly meets the prerequisites for farming than does any other species of warmwater fish: it is easy to spawn and manage under farm conditions; it is not seriously affected by disease problems when not stressed; it is a diligent feeder and efficiently utilizes foods from the pond bottom and eats a variety of supplemental foods; it grows rapidly; and it tolerates a wide range of temperatures and dissolved oxygen values.

Annual yields of 390 kg of carp per hectare have been obtained from ponds in Europe without supplemental feeding (Yashouv, 1959). Use of simple feeds, such as grains or grain byproducts, effected yields of 1530 kg per hectare (Ghittino, 1972). In Haiti, farmers fed carp only crude cottonseed byproduct in small ponds and harvested 1,000 kg per hectare (Lovell and Moss, 1971).

Formerly, it was thought that carp could utilize artificial food only in limited amounts and only in combination with natural foods from living organisms. Common practice was to feed small amounts of grain and rely on pond food for a significant part of the fish's nutrients. Subsequently, it was learned that with high stocking densities heavy feeding of high-protein (25%) supplemental feeds would result in yields of 3,300 kg of fish per hectare in 6 months in ponds (Sarig, 1974). Further improvements in fish technology, such as nutritionally balanced feeds, genetically improved strains and mechanical aeration of ponds, have resulted in production rates as high as 20,000 kg of carp per hectare in a 6-month period (Sarig and Marek, 1974).

In Japan, common carp are raised in suspended cages and fed high performance rations containing approximately 35% protein and all essential nutrients. The annual yield for a 50-cubic meter cage is approximately 5,000 kg (Lovell, 1974). The Japanese also produce carp in raceways where water flows from one raceway unit into another through a series. The water enters the system from a river or canal and returns to the stream from the last raceway unit. Yields of 187 kg per square meter of raceway are produced (Swingle and Moss, 1969).

Thus, carp are farmed in simple operations ranging from producing gains from primarily natural aquatic foods on one hand to complete artificial diets on the other. The feasibility of any system will depend upon the value of the fish versus the expense of producing the fish.

Although the carp is not a highly acceptable food fish in the United States, a similar fish, the buffalofish (Ictiobus sp.), has relatively good market value in some parts of the country and shows considerably more potential as a food fish than does the common carp. The buffalofish has several desirable characteristics for culture and may be increasingly used as a farmed fish.

With development and acceptance of products from minced flesh that has been mechanically separated from bones, fish such as carps and buffalofishes, that are conveniently managed and produce high yields, have potential as farmed food fish in the United States.

Channel catfish

The channel catfish is the leading farm-raised fish in the United States. It has many of the essential characteristics for fish farming. It can be spawned in captivity and can be managed under a variety of culture conditions ranging from ponds to intensively stocked cages or raceway tanks. It grows from a 10-gram fingerling to a desirable harvest size of 0.5 kg in 6 to 7 months. It accepts a variety of supplemental feeds and is relatively disease free when environmental stresses are minimized. It tolerates diurnal and seasonal variation in pond water conditions; however, when compared to carps, the channel catfish is somewhat more sensitive to low dissolved oxygen levels. Although it makes efficient weight gains from processed feeds it does not make economical gains in ponds without supplemental feeding (Swingle, 1968).

An important reason that the channel catfish is a food fish is that the flesh is essentially all white muscle in fish less than 1 kg in size, is free of intermuscular bones, and has a mild flavor. The high quality of channel catfish flesh was not formerly known outside southern United States, but its desirable qualities as a table fish has allowed its markets to grow rapidly to keep pace with increases in farm production.

An advantage for channel catfish as a cultured food fish is the broad base of research information that has become available on this fish. There are published reports and research programs in progress relating to such factors as: the nutrition, genetics, management, water quality, processing technology and marketing aspects of channel catfish as a food fish.

Catfish farming began in the southeastern United States in ponds for sport fishing. Because channel catfish was a popular food fish in this area, they were grown and processed for retail food markets. Initially, earthen ponds were stocked with 2,500 to 4,000 fingerlings per hectare, weighing from 10 to 40 g each, and the fish were fed pelleted concentrated feeds for 6 to 7 months for harvest at an average size of about 0.5 kg. Average yields were 1,000 to 2,000 kg per hectare. By increasing stocking densities and using more concentrated feeds, yields in excess of 3,000 kg per hectare are now commonly harvested from static ponds. With higher stocking densities and greater inputs of nutrients, risk concerning dissolved oxygen depletion in the ponds is increased, but farmers are becoming more experienced managers and can compensate for this hazard.

A number of modifications of conventional pond culture methods have allowed yields to increase. For example, with mechanical aeration of the pond, yield per hectare of 5,500 kg or more may be obtained (Loyacano, 1969). Another practice used to increase yields of catfish in ponds is multiple harvesting, two to four times per year. By using a harvest seine of a specific mesh size, only the larger fish are removed. Each time fish are removed from the pond they are replaced by an equal number of small fingerlings. The pond is not drained at the end of the growing season. Feeding ceases when temperature decreases below 16°C and begins in the spring when the water becomes warm again. This system makes more efficient use of pond space than does the conventional method of stocking small fish in the spring and harvesting all fish in the fall. By multiple harvesting, yields of 5,000 to 6,000 kg per hectare are obtained per year.

Recirculation of water through earthen raceways is a culture method developed for intensive catfish farming in hilly areas where pond construction and water supply are expensive. This system includes a series of earthen raceway units, 35 meters long by 6 meters wide, constructed one below the other from top to bottom of a hill, and 1- to 2-hectare reservoirs from which water is recirculated. Water is pumped from a lower reservoir to one at the top, then flows by gravity through the raceways. Residues from feed and feces are removed by scraping the raceways when empty or collected in a settling basin at the foot of the raceway series. Practical yields of catfish from raceways are 900 to 1,200 kg per raceway unit for a 6-month period (Brown et al., 1971). A twenty-raceway system requires approximately 2 surface hectares of water. This represents a production rate of 9,000 to 12,000 kg of catfish per hectare per 6 months. Production of rainbow trout during the cold weather season after the catfish have been harvested is being practiced (Hill et al., 1973). Yields of trout equivalent to those for catfish would represent an annual harvest of 18,000 to 24,000 kg of fish per hectare of water surface from the raceway system.

Circular tanks, 1.5 to 4 meters in diameter and approximately 1 meter in depth, with fresh water continuously flowing through each have yielded 92 kg of channel catfish per cubic meter of capacity in 6 months (Allen, 1972). Slightly lower yields are obtained when the water is recirculated through the tanks subsequent to passing through a biological filter to remove wastes. Advantages of raceway culture are high volume production per unit of space and labor, accessibility of fish for harvesting, elimination of pond-related off-favors, and continuous year-round production when suitable water temperature is maintained.

Growing catfish in cages suspended in lakes is being practiced in several places in the United States. Yields of 275 kg of fish per cubic meter of cage space are obtained in 6 months (Schmittou, 1970).

Trout

Rainbow trout have high market value in the United States and the technology for their production is well developed. However, their production is limited to areas with large amounts of cold, running water. Since they are grown in raceways with no natural foods, they require nutritionally complete diets. This makes the cost of producing trout generally more expensive than that of carp or catfish. The high consumer appeal of rainbow trout has stimulated a search for other areas to culture this fish. Rotating trout with channel catfish in raceways during cold and warm seasons of the year is feasible in some areas of the United States. Other countries with favorable resources are producing rainbow trout for United States markets. Peru has large quantities of fish meal for making trout feeds, and plentiful cold water streams for economical trout culture. In Japan several large rainbow trout operations are producing fish for American markets.

Rainbow trout was the first major cultured species in the United States. Excellent strains of fish that make gains under cultural conditions have been developed through many years of selective breeding. Practical, nutritionally complete feeds are available that produce a kg of gain for each 1.29 kg of feed consumed (Hill _et al._, 1973), and trout are raised from 45 g to 318 g in 3 months. Rainbow trout are not so seasonal as are pond raised fish; consequently, year-round production from the raceways is possible.

Eels

Eels do not meet many of the prerequisites for desirable fish for farming. However, in Japan where they are extremely popular, technology for intensive culture of eels is well developed. Yields of 10,000 kg per hectare per year are harvested from earthen production ponds (Schmittou, 1973). Eels require expensive feeds which contain large quantities of fish meal and all essential vitamins and minerals. They do not obtain a significant amount of food from the aquatic environment. They are cultured under crowded pond conditions which requires mechanical aeration. Seed stock for the culture ponds cannot be provided from managed sources. The elvers (young eels) are expensive because they must be caught in rivers as they migrate from the sea where they are spawned.

Although relatively high production rates are obtained, eel culture is profitable only because of the premium value the consumers place on eel flesh.

Tilapias

Tilapias have been cultured in tropical areas, usually under relatively primitive conditions, for many years. They are the most suitable fishes for farming for food under conditions of most developing countries. There are many species with varying food habits, and several have been selected which fulfill most requirements for fish culture. They are of excellent flesh and do not have intermuscular bones. They grow rapidly while feeding low on the food chain, utilizing large amounts of plankton and debris. They respond to organic fertilization, as they consume decaying plant materials, and have made excellent gains on agricultural byproducts as supplemental feeds. The principal difficulties in culture of tilapias are lack of cold tolerance and their tendency to over-populate. Over-population results in fishes too small for the market in certain areas, although even the smallest are acceptable as food in some countries. The problem of excessive reproduction may be solved with predatory fishes (Swingle, 1968), chemical sex-reversal (Guerrero, 1975), hybridization (Lovshin *et al.*, 1974), and culturing in cages (Pagan, 1969).

The most widely cultured fish of this African family is *T. mossambica*. This animal, which feeds mainly on plankton, insects and detritus, has yielded up to 1,480 kg/ha in fertilized ponds and 4,389 kg/ha with supplemental pelleted feed (45 per cent protein) in 191 days in the southeastern United States (Swingle, 1968). *Tilapia aurea* yielded 4,004 kg/ha with supplemental feeding in 208 days and about one-half the fish were of harvestable size.

Hybridization of tilapias results in heterosis, and in certain crosses, all male populations (Lovshin *et al.*, 1974). In Northeast Brazil, such a cross used is *T. hornorum* (♂) X *T. nilotica* (♀). This hybrid, stocked at 10,000 fingerlings per hectare, grew to a uniform average size of approximately 0.3 kg in 4 to 5 months. The only supplement to the commercial ponds was chicken manure. This culture system represents an annual yield of 6,000 to 8,000 kg/ha of fish. This type of fish farming holds great potential for increasing food protein for families in developing countries. As the recently developed technology of reproduction control is more widely applied in combination with low cost fertilizers and feeds from agricultural byproducts, there is little doubt that the several species of tilapia will make an increasingly important impact on animal protein supplies.

Polyculture of species

The goal of rational pond management is the utilization of all existing feeding niches in the pond to produce the maximum aquacultural crops (carrying capacity). Multispecies association of fishes of different food habits to optimize yield is also called polyculture. Polyculture, first practiced by the Chinese with a combination of carps of different food habits, notably common carp (bottom insects), silver carp (phytoplankton), bighead carp *Aristichthys nobilis* (zooplankton), and grass carp (higher plants), has been adapted by Israeli fish culturists to include a mix of common carp and silver carp with mullet (*Mugil cephalus*) and *T. aurea* (Yashouv and Halevy, 1972). Yields have thus been increased approximately 30 per cent over mono-species culture. Experiments in progress at Auburn University indicate that annual yields may be elevated from 2800 kg/ha with channel catfish alone to 4200 kg/ha with channel catfish, T. aurea, and hybrid buffalofish (Ictiobus cyprinellus x I. niger) in polyculture with the same amount of supplemental feeding. This represents an increase of 50 per cent. Further refinements are needed to take full advantage of this added efficiency in fish protein production.

TECHNOLOGY OF UTILIZATION OF FARM-RAISED FISH

Harvesting

Farm-raised fish have the advantage over sea fish or wild fish in that the fish can be harvested at the discretion of the farmer. When the fish farmer constructs his pond or raceway or whatever type of culture system, he designs it for convenient harvesting of the fish.

Ponds are harvested by removing the water, trapping, seining, or by a combination of these. Properly constructed ponds have catch basins where fish are concentrated when water is drained, and subsequently they are transported to the processing plant or markets. Fish farmers using a multiple cropping system, where several sizes of fish are in the culture system and only the largest ones are removed, employ either a seine of a specific mesh size which will allow the small fish to escape or collect all of the fish and allow the small ones to return to the pond by means of a size-grader.

Another advantage of farm-raised fish over wild-caught fish is that farm harvested fish usually reach the consumer in better condition than fish that have been held for long periods post mortem and transported long distances prior to processing or marketing. Farm raised fish can be harvested to comply with market demand or processing schedule, thus avoiding overstocks of unprocessed fish. In the United States farm raised fish are usually processed and sold to consumers either packed in ice or frozen; however, in countries where carp are raised such as Japan, China and Israel, the fish are largely marketed alive. The fish are held in tanks of water in the retail markets.

Live-hauling of fish to be processed has several advantages. The fish may be held alive in circulating-water holding tanks for several days before being processed and not deteriorate in quality. This method of holding also may allow purging of off-flavors which the fish may have acquired from the culture ponds.

Processing farm raised fish

In the U. S., channel catfish are processed by removing the head, skin and viscera, and either ice-packing the dressed fish for immediate shipment to the consumer or freezing in packages ranging from approximately 0.5 to 4.5 kg. Optimum market size of the dressed fish, which are usually marketed whole, is 0.17 to 0.34 kg. Dressed fish larger than approximately 0.4 kg are cut into pieces or filleted. Presently 50 to 75 per cent of processed channel catfish are ice-packed for short term storage and the remainder frozen. As the industry grows, a larger percentage obviously must be frozen or otherwise preserved for longer storage. Canned and smoked channel catfish have received favorable acceptance in test markets but are not yet commercial products.

Catfish processing plants are semi-automated, relatively small-scale (9,000 kg per day maximum capacity) operations which are generally located within 100 miles of most of their sources of fish. A flow scheme of plant operation is as follows: live fish from holding tanks outside enter the processing building where they are beheaded, eviscerated, skinned on semiautomated machines, and trimmed of bits of skin and fins and washed; the dressed fish are sized by machine either before or after chilling in an ice bath; smaller fish are hand packaged whole, while large fish are cut up or filleted before packaging; and within 10 to 30 minutes after the fish are beheaded, they are packed in ice or frozen. Approximately 60 per cent of the live weight of channel catfish is marketed as dressed fish; the remaining 40 per cent (head, skin, fins and viscera) represents processing waste and may be reduced to fish meal and oil.

Trout are marketed primarily as frozen whole fish less head and viscera. The percentage of the live fish marketed as food is approximately 70 per cent. Trout processing plants are larger in size but fewer in number than catfish processing plants. Since trout processing is an older industry than catfish processing, more equipment is available for heading, conveying and packaging trout.

In some countries such as in Japan and Israel, a large proportion of farm raised fish are sold alive from holding tanks. This insures high quality and consumer appeal in the fish but limits the distribution area.

In developing countries, farm-raised fish are seldom processed or preserved more than perhaps holding the fish on ice, and the whole fish are sold fresh on a daily basis. Processing and preservation of farm-raised fish are necessary to extend the markets of farm raised fish farther from the production sources. The absence of preservation methods is also a handicap to the farmer because his harvest operation is limited to only the amount of fish that can be removed daily to supply the fresh markets. Although fish farmers can usually remove their fish on a daily or piecemeal schedule, it is more economical to harvest the fish in larger quantities. In the Philippines, milkfish production in large ponds has developed rapidly and with improved technology the cost of the fish is within the means of many people to purchase them; however, preservation and marketing methods are major obstacles preventing widespread consumption of milkfish in the country. Development of preserved milkfish products would not only increase distribution but would reduce the cost of the fish by reducing the great losses from spoilage of non-preserved fish.

In developing countries where purchasing power is extremely low and the size of the fish production operations is small, daily marketing of unprocessed fish may be the most practicable. Tilapia raised in tropical countries are usually sold as whole fish and usually without ice. Although this method of marketing limits the distribution of the fish to areas near the production sites, the farm-raised fish are a highly acceptable and economical source of animal flesh for those who have access to the fish.

Minced fish flesh

With the development of equipment for separating fish bones from the flesh, fish species that have many bones but are economical to grow may find a great demand in the U. S. Species such as carp, buffalo or tilapia that can tolerate heavy stocking densities and use natural pond foods well, could be produced specifically for minced flesh products or could be produced in polyculture combinations with a fish that has high market value such as channel catfish. Several such species have been processed on bone separation equipment and the quality of the minced flesh and products made from it is good. By extruding the flesh through relatively large diameter holes, 5 to 8 mm, the texture of the fish flesh maintains much of its original flakey structure while bones and scales are rejected. Many tropical fish, like tilapia, have a black peritoneal membrane that must be removed prior to processing through bone separators;

also, the dark pigment on the skin of catfish must be removed. Dark particles are highly objectionable in minced fish products.

Yields of minced fish flesh from various freshwater species are shown in Table VI. These fish were produced in polyculture with channel catfish as the primary species. These secondary species will yield several hundred kg of fish flesh per hectare at relatively little additional cost of production or sacrifice in yield of catfish. One of the major problems in polyculture in the United States has been markets for the secondary species. The development of minced flesh products should open up new markets for these generally unacceptable bony species produced in catfish ponds and could stimulate production of these species as the primary fish since they may produce higher yields in ponds than do channel catfish.

Utilization of waste from farm-raised fish

The most valuable source of animal protein for feeds is fish meal. It is a valuable ingredient in balancing swine and poultry rations containing largely plant proteins. It is considerably more important in fish feeds. Processing waste from farm-raised fish can be recycled into fish feed. Channel catfish processing waste, which amounts to 40 per cent of the weight of the fish, was fed back to channel catfish as an ingredient in both moist and dry, pelleted feeds (Lovell, 1972). Diets containing 15 per cent fish waste (dry basis) produced excellent gains. When all catfish processing waste is continuously recycled back into the fish, the waste will contribute 3.2 to 3.6 kg of protein per 100 kg of diet. This quantity of animal protein will significantly improve the nutritional quality of an otherwise all-plant fish feed (Lovell, 1972). Nutrient composition of catfish processing waste is shown in Table VII.

The fat in farm-raised freshwater fish fed grain-type supplemental feeds is

VI. Yield of Mechanically Separated Flesh From Buffalofish, Tilapia and Channel Catfish[a]

Fish	Average size, kg	Average yield, % of whole fish
Buffalofish	2	50.5
Tilapia	0.23	39.7
Channel catfish	0.68	43.7

[a] Source: Auburn University Agricultural Experiment Station, Auburn, AL., "Fisheries Annual Report," 1974.

VII. Nutrient Composition of Catfish Processing Waste[a]

Component	Product	Per Cent Range	Per Cent Average
Water	Wet waste	60-70	67
Protein	Dry waste	27-49	42
Fat	Dry waste	30-60	35
Phosphorus	Dry waste	2.4-3.3	2.8
Calcium	Dry waste	5.0-7.0	5.4

[a] Source: Lovell, R. T. and R. G. Ammerman. 1974. Processing Farm Raised Catfish. South. Coop. Ser., U.S.D.A., Bull 193, 59 p.

relatively saturated (Worthington and Lovell, 1973) and does not impart off-flavor in food animals consuming the fat as does marine fish fat which produces a "fishy" flavor and poor acceptability (Lovell and Leary, 1972).

Processing waste from farm-raised fish may be used as ingredients in dried or moist forms. The dried meal and separated oil are more convenient to work with; however, the wet waste can be mixed with grain or grain byproduct and preserved by lactic acid fermentation in a sealed container. A mixture of 50 per cent wet catfish processing waste, 30 per cent ground corn and 20 per cent soybean meal, kept well for several months at ambient temperature and produced excellent weight gains when subsequently fed to channel catfish. In countries where drying of the waste into meal is prohibitive, fermentation preservation is possible by adding 25 per cent or more of a carbohydrate, such as rice bran, and sealing in an air-tight container where the pH will decrease to 4.5 within 24 to 48 hours.

Pond-related off-flavors in farm-raised fish

A serious problem in fish farming is absorption by the fish of off-flavor compounds from the pond environment. Most characteristic of this type of flavor is an "earthy-musty" flavor caused by compounds synthesized by certain blue-green algae and by some species of actinomycetes (Lovell, 1973). This type of off-flavor has been found in all types of food fish cultured in heavily fed ponds in all parts of the world. In most all cases it is considered highly repulsive by consumers and the fish farmer cannot market the fish until the flavor is removed from the fish.

In the fall of 1972 catfish processors in southeastern U. S. estimated that 50 per cent of the pond-raised channel catfish had off-flavor at the time they were tested prior to harvest, and could not be processed until the flavor improved. This is an inconvenience to both farmer and processor, although the flavor will always improve as soon as the source of the flavor compounds is removed. By leaving the fish in the ponds, as catfish farmers in the U. S. do, the flavor may improve in one week, or several months may be necessary. Under experimental conditions, off-flavor was removed beyond sensory detectable levels by holding channel catfish in clean, flowing water for one to two weeks, depending upon water temperature; however, there was a concomitant loss of 10 to 15 per cent of weight by the fish (Table VIII). This weight loss and the inconvenience of holding off-flavor fish in running water for one to two weeks has prevented catfish farmers from holding fish in flowing water tanks to clear up bad flavor. However, they usually try to exchange the water in the ponds by running fresh water into it, or in some cases the fish are removed from the off-flavor pond and placed into a "clean" pond.

This problem has been experienced in carp for many years in China, Japan and Europe; however, in those countries most of the fish are marketed alive and the solution is to simply hold the fish off the market, allowing water to run through the holding container, until the flavor is acceptable. Where fish must be moved rapidly from the production sites to a processing plant or to markets where they are not sold alive, these pond-related off-flavors are a serious inconvenience. The only solution at present is to either leave the fish in the ponds until the off-flavor has disappeared or to place the fish in clean water for a few days. Research is in progress at several stations to determine methods of preventing the condition from developing or to remove it soon after development in fish culture ponds.

VIII. Flavor Scores and Weight Changes for Off-Flavored Channel Catfish Held in Clean, Flowing Water for Various Times[a]

Water Temp., °C	Criteria	Time (days) 0	3	6	10	15
15	Flavor score[b]	4.7	6.1	7.1	7.6	9.2
	Weight loss, %	0	5	7	8	9
22	Flavor score[b]	4.7	7.0	8.7	9.3	9.6
	Weight loss%	0	9	10	12	15

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[a] Lovell, R. T. 1973. Environment-related off-flavors in intensively cultured fish. Proc. Tech. Conf. on Fish. Prod., Tokyo, Dec. 4-11, 1973, FAO (United Nations), FII: FP/73/E46.

[b] Scoring System:
10 = no off-flavor
8 = slight
6 = distinct
4 = intense
2 = extreme

CONCLUSION

The objective of this chapter was to answer the question, "why farm fish for food?" Fish farming has distinct disadvantages by comparison with other types of food animal production. For example: fish need water, the quality of the water must be maintained, expensive feeds are necessary for hyperintensive culture, presently no vaccines are available to protect fish from diseases, and fish are extremely perishable when removed from the water. Yet there are many places in the world where fish farming has a substantial foothold. The reason is that the available technology in fish culture has been skillfully applied to the proper resources. Evidence of this is in the fact that slightly over one-half of the total marine and freshwater fish catch by Israel in 1974 came from farm sources.

Fish farming, or aquaculture, is still in its infancy. Its scientists are rapidly developing a backlog of research data in areas of genetics, engineering, aquatic ecology, nutrition, pathology, processing technology and management. Research and training programs in aquaculture and mariculture have been instituted at many of the land-grant universities and federal experimental stations and through Sea Grant Programs in the United States. Trade and scientific organizations have been established internationally to promote fish culture.

Worldwide activity by the private sector in fish farming is evident from such developments as marketing cooperatives, trade organizations, investment by large firms in fish farming industries, demand by industry for technically trained fish culturists, and specially designed products and equipment for fish farming.

International funding agencies such as FAO, World Bank, and United States Agency for International Development are providing strong technical assistance programs in fish culture in developing countries.

New technologies are finding application, such as domestication of species with desirable consumer or cultural qualities, hybridization, polyculture, computer calculations of least cost rations, hyperintensive raceway cultures, reuse of water, and development of new consumer fish products.

With this bank of support and confidence, it is logical to assume that fish farming will inevitably increase its contribution of animal flesh to discriminating consumers in high and low income markets. The key to practical progress in this field is proper evaluation of the resources available for fish farming, use of the best available pertinent technology, and selection of appropriate species. An expanding worldwide need and demand for protein in a nutritious and palatable form gives impetus to a continuing effort to achieve this worthwhile goal.

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