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Applying modern methods of mass production to fish culture forms . . .

The Technological Basis for Development of Aquaculture to Produce Low-Cost Food Fish

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ABSTRACT

The technological basis for development of large-scale production of inland water fish, such as carp, buffalo fish, tilapia, and white amur, is reviewed. It is proposed that modern methods of mass production and fish culture be evaluated and combined to make the production of low-cost food fish feasible and economically attractive. The fish would be processed for maximum recovery of edible flesh by mechanical methods of flesh separation. The minced flesh would be modified and stabilized as required to prepare high-quality frozen fish blocks. These blocks would be suitable for a wide variety of frozen fishery products and convenience foods and could be used as protein additives in other foods such as processed meats. A conservative yield estimate of 4,000 pounds of fish/acre/year on aquaculture developments totaling 500,000 acres in the delta land of the United States is projected. This could produce 2 billion pounds of landed fish per year in 25 years. Further, this production could supply the additional fish needed to maintain per capita fish consumption in an expanded U.S. population of 300 million.

The technological factors and limitations in this projection are discussed along with the need for research. These factors include: (1) competition for land use, (2) cost of suitable water, (3) increasing costs in a labor-intensive industry, (4) feed cost in relation to product value, (5) disease control, (6) efficient processing techniques, (7) pollution control requirements, and (8) development of markets and consumer acceptance.

INTRODUCTION

It seems clear to almost everybody that sooner or later the increasing population of the United States, together with the gradual rise in the living standard for many underprivileged groups, will greatly expand the demand for protein of all types. One can argue whether a protein shortage may develop in 10, 20, or 50 years, but most food technologists believe this is beside the point. The real question is the need to plan intelligently and do the studies to ensure that in the future the optimum harvest of protein may be obtained from every source—whether it is from plants, animals, or chemical synthesis. The future potential for developing aquaculture as a method to produce low-cost food fish as a major protein contributor is our concern in this report.

NEED FOR FISH AS A PROTEIN SOURCE

Certainly there are many protein sources other than fish that can be expanded; therefore, we first must consider the specific need for fish as a protein source. Its availability, high acceptability in the diet, and high food value are all important. Also important is that fishermen, processors, and buyers make a good living from it and add significantly to the nation's economy.

Traditionally, man has looked on the ocean as an almost endless marine pasture with a common-property fishery resource provided at no cost. All man needed to do was devise the fishing gear, take it to sea, and catch the fish, keeping in mind the seasons and areas of abundance. Certainly it is not that easy any longer. Today the intense competition for every usable food resource from the ocean is not only obvious but also is becoming a problem of international concern and regulation. It is in the knowledge of this problem that we propose a more serious study of the feasibility of large-scale aquaculture. Such a development, in our opinion, would provide in the future that amount of fish for the U.S. diet that will not be available from ocean resources, including that from domestic catches as well as from imports. The current fishery statistics (U.S. Department of Commerce, 1972) show U.S. landings in 1971 of 2.4 billion pounds of fishery products for human food and 1.8 billion pounds of imported edible fishery products. The civilian consumption of edible fishery products produced from this 4.2 billion pounds was 11.2 pounds per

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capita in the United States, a figure that has changed little over the last 25 years.

If we take the current estimate of population growth during the next 25 years, from 200 to 300 million, it's quite obvious that we're going to need over a billion pounds of edible fish products just to fill the gap created by the additional 100 million population, assuming we maintain the present sources of supply. This really means about 2 billion pounds of fish as landed in the United States or the equivalent in imported products will be needed.

Resource experts, of course, have estimated in recent years that the world fisheries harvest can be increased significantly by greater utilization of all available marine resources. Schaefer and Alverson (1968) thought a world fisheries production of 200 million metric tons was realistic. This compares with about 70 million tons at present. Better utilization of available fishery resources is very important. However, our problem as fishery technologists is that we note that U.S. catches have changed little for the past 25 years. Also, we see no indication of overwhelming change in the ability of our fishing fleet to double its production of ocean fish harvest in the next 25 years.

We wonder how many experts would objectively consider the current resource developments and still predict confidently that this increased supply is going to be available to the United States in 2000 from the known ocean resources. There are some who say that world competition for protein sources, the problems of international fisheries management, and the economics of world fisheries make it unlikely that we will be able to maintain our present sources of fish supply, including domestic catches and imports, during the next 25 years.

This perspective suggests that either fish consumption will decrease substantially or else additional resources must be developed. Our belief is that one feasible development to meet this future need for domestic fishery products is the large-scale production of low-cost fish in warm-water pond culture.

CONSIDERATIONS FAVORING INLAND FISH CULTURE

We have referred to inland fish culture, and you are likely wondering "What's the matter with marine species culture for filling this future gap?" One must be impressed by the achievements in marine fish and shellfish culture in the past decade, yet it appears that the developments are primarily in high-value species such as salmon, shrimp, pompano, plaice, tuna, and lobster. For this discussion we will exclude oysters, mussels, and other mollusk culture. Salmon culture has been highly developed in recent years for the purpose of restoring and maintaining the fish stocks. This important aspect of fish culture is also applicable in a lesser degree to other species.

Our objective, however, is further development of aquaculture to increase production of fish for direct consumption. In recent years such a development has occurred in Pacific salmon in Puget Sound. Salmon mariculture techniques are being applied commercially in which coho salmon are raised in salt-water pens to a market size of 8 to 10 oz in less than a year. The dressed fresh and frozen salmon will sell wholesale for over a dollar a pound. There are many problems, of course, of feeding, predation, disease, and maintenance of the marine pens, including pollution and water-quality aspects. However, no one presently expects this to be a means of mass-producing low-cost fish. The outlook is somewhat similar to that developed by the large-scale trout farms in the United States, which concentrate on a highly desirable species to be marketed fresh or frozen with a gourmet image.

Japanese contributions and developments in aquaculture have been substantial for many years, and their culture technology for yellowtail, seabream, shrimp, and other high-value species has been well documented.

Ryther (1968) commented that the Japanese shrimp culture has been perfected to the degree where mass hatchery rearing is carried out routinely. The species was reared to market size and sold for the first net profit in 1967. The quoted market price at that time of $4.00 per pound in Japan for live cultivated shrimp in relation to the relatively low cost of Japanese labor and materials appears out of proportion. However, Ryther indicates that this reflects the effect of the high costs for facilities and feed in shrimp culture.

Let's take another example, yellowtail, from the well-developed aquaculture industry of Japan. Furukawa (1970) showed that the cost of yellowtail culture depends on the methods of culture management, e.g., floating net cage as compared to embanked pond. Feed costs were the biggest single item, however, and varied from 46 to 60 percent of production costs in the three methods of yellowtail culture. Other costs, such as maintenance, wages, and seed varied relatively far more in the various methods. Furukawa concluded that cheap feed of good quality is necessary for successful yellowtail culture in Japan and that the preparation of an artificial diet is desirable to expand the industry.

Other species developments may be cited, but these examples of aquaculture for high-value species illustrate that problems in marketing, technology, and management limit the industrial development after the biological success of seeding and reproduction techniques is assured. Second, it appears that selection of a high-value species with the gourmet image does not assure instant industry success and profits.

Third, it appears that feed costs and feeding technology are high-cost factors that must be studied comprehensively and solved within the economic limits of a particular species. With these points in mind we can turn to a closer examination of the technological basis for production of low-cost food fish by aquaculture.

Production of Low-Cost Food Fish

The feasibility and economics of freshwater aquaculture to provide fish on a substantial national level must be demonstrated on its potential for large-scale production of suitable food species at low cost. Otherwise, aquaculture will provide no more than an additional source of high-priced fish to provide variety for the American gourmet. This is desirable but will not help provide much of the 2 billion pounds of additional fish needed in 2000. To accomplish this with aquaculture we suggest the technological development of warm-water inland fish culture utilizing species that will produce the maximum protein return per acre per year.

The fish species proposed for expanded production study are those for which we already have from fish culturists some firm indication of a high production potential. Species will be selected for maximum productivity and desirable growth characteristics under warm-water conditions and might include carp, buffalo fish, tilapia, white amur or grass carp, mullet, milkfish, and catfish. Selective breeding of adaptable species for maximum growth return in large-scale inland water impoundments is an essential part of the development, just as it has been for poultry and livestock.

It is well established in fish culture that the highest production may be obtained by use of species having the shortest food chain; therefore, plankton-feeders like tilapia and herbivorous species such as white amur will win the production race against insectivorous fish like channel catfish. Swingle (1968) of the Auburn University Experiment Station, Auburn, Alabama, reported in 1966 to the FAO Symposium on Warm-Water Pond Fish Culture that species combinations are highly useful and productive in pond-fish culture. This polyculture means, for example, combining plankton feeders like tilapia with insectivorous fish like catfish and piscivorous fish such as large-mouth bass. Dr. E. W. Shell, also of the Auburn University Station, has provided information (personal communication, August 1972) that carp and buffalo fish may be raised to commercial size in either one or two years, depending on the market size required. The yield per year is about the same, 2,000 pounds per acre. An increase of this yield to 3,000 to 4,000 pounds per acre per year is forecast with improvements in culture methods.

Even more promising from a production viewpoint is the white amur or grass carp. This herbivorous species may be started in the pond as fry and will produce more than 4,000 pounds per acre per year. If culture facilities permit the introduction of 3-inch fingerlings, two-pound white amur may be harvested in three months and three crops a year could be harvested for a total of 8,000 to 12,000 pounds of yield per acre per year. As an indication of production cost, the fish culturists at Auburn University (Dr. E. W. Shell) and the Bureau of Sport Fisheries and Wildlife Station at Stuttgart, Arkansas, state that buffalo fish can be raised for 12 to 14 cents a pound with the present knowledge in fish culture. Faster-growing species, such as the white amur, can probably be raised even more cheaply, given the technological production facilities. Use of polyculture and control of water temperature for optimum growth the year around are other likely methods for decreasing production cost. More examples of production potential might be cited; however, we think these illustrate the real possibilities ahead for inland fish culture.

Space is another factor for aquaculture but offers no real problem. In the Pacific Northwest, especially in the Columbia Basin, there is substantial acreage of undeveloped land which is either not suitable for irrigated crop development or is not attractive economically for agricultural development. Greenwood (1971) stated in a review of inland fisheries that over 2 million acres of delta land in the United States are apparently available and acceptable for aquaculture development. If one assumes development in the next 25 years on only one-fourth of this delta land with a production of 4,000 pounds of fish per acre per year, we would have 2 billion pounds of landed fish produced just from the southeastern part of the United States.

Utilizing Pond-Fish For Food

The U.S. consumer has shown generally a preference for marine species and for cold-water, freshwater fish like trout and whitefish. With the exception of cultured catfish in recent years, these preferences have inhibited the development of inland fisheries and pond-fish culture. The question then is how does the technologist propose to use these large volumes of cultured pond fish for food in view of the fact that they are not well accepted. Briefly, the answer is to use them for processed products in which species is not important but convenience, food value, and acceptability of the finished products are important.

Recent developments in the field of fish-processing technology make it practicable to use a wide variety of species not accepted as prime food fish. Methods are now available for the production of high-quality fish blocks (Figure 1) from the mechanically separated minced flesh (Figure 2) of either single species or of combinations of species. During the 1950's the development and wide acceptance by the consumer of fishsticks, breaded fish portions, and other heat-and-eat convenience foods created a substantial national market for frozen cod and haddock fillet blocks. As the demand increased during the 1960's, the processors became increasingly dependent on imported cod blocks (Figure 3).

Figure 1.—A National Marine Fisheries Service scientist in Seattle examines a flavor- and texture-modified plate-frozen fish block produced from hake, one of our underutilized species. The minced flesh for this block was obtained by passing headed and gutted hake through a flesh-separator machine, at about half the cost of conventional fillets.

Predictably, the average price rose sharply (Figure 4). As supplies of domestic and imported cod and haddock became too limited to meet the demand, processors turned to less-desirable species still suitable for blocks, such as Pacific pollock, Greenland turbot, ocean perch, and wolffish. In December 1971 frozen blocks of these and other miscellaneous species accounted for 43 percent of the available supply.

In the past four years our laboratory has made large gains in developing the technology of separating edible flesh from skin and bones in high yield by mechanical methods. Yields can now be increased from present hand- or machine-filleting 30-33 percent to machine separation of 45-65 percent. This can be directly applied to economical preparation of frozen blocks of the minced flesh from cultured species of warm-water pond fish. Most important for application to many less-desirable species, the method lends itself to flavor and texture control and to improved stabilization of product during frozen storage (Teeny and Miyauchi, 1972).

We have demonstrated that blocks made from the comminuted flesh of buffalo fish and of carp are of high acceptability and have good processing characteristics. Considerable enthusiasm has been shown on the part of processors in inland areas, where wild buffalo fish, carp, and other warm-water species are relatively abundant. It is obvious, however, to even the most optimistic processor of

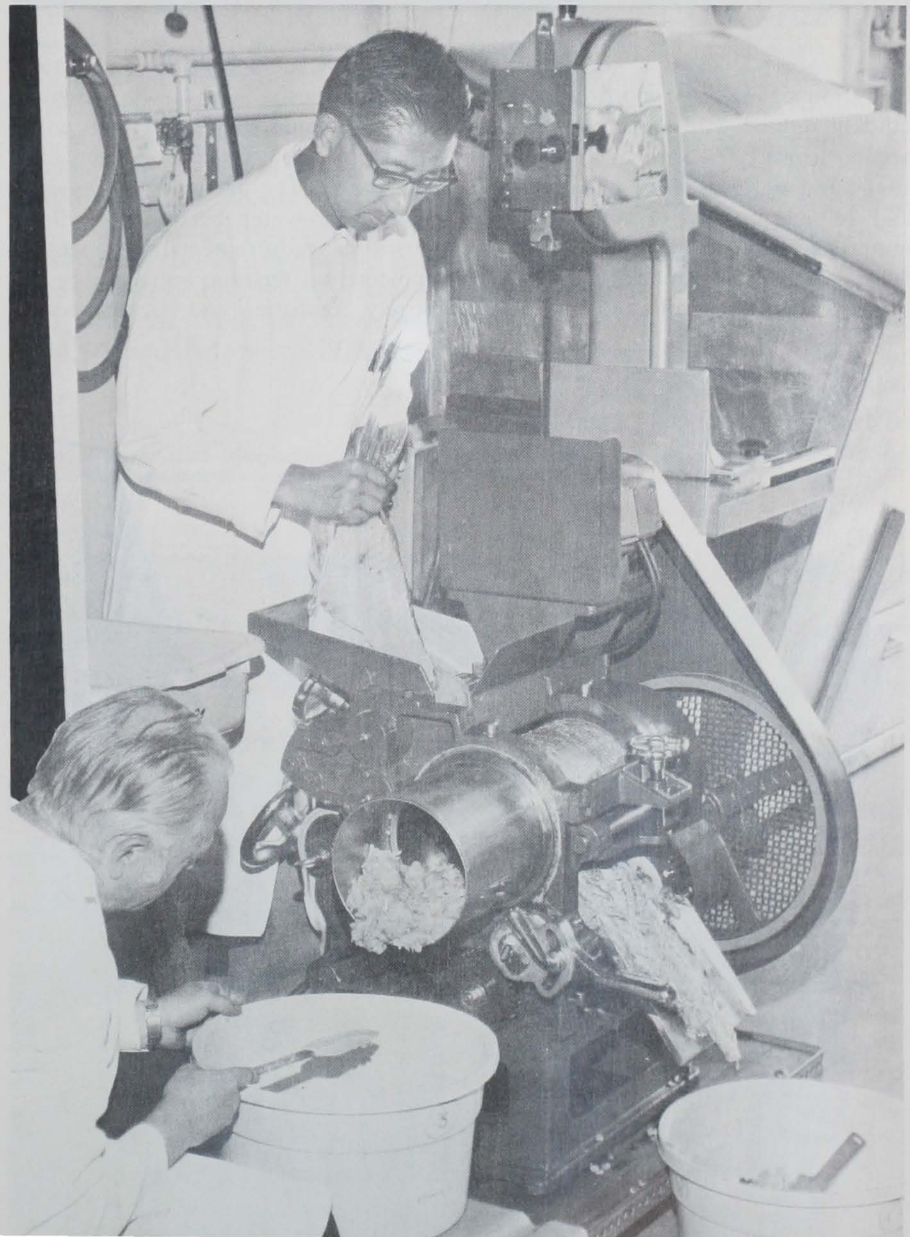

Figure 2.—Technologists at the National Marine Fisheries Service Fishery Products Technology Center in Seattle are preparing minced flesh from dressed fish by use of a Japanese flesh-separator machine. The work is part of research in developing new ways of recovering and using all the edible portion from underutilized fish species.

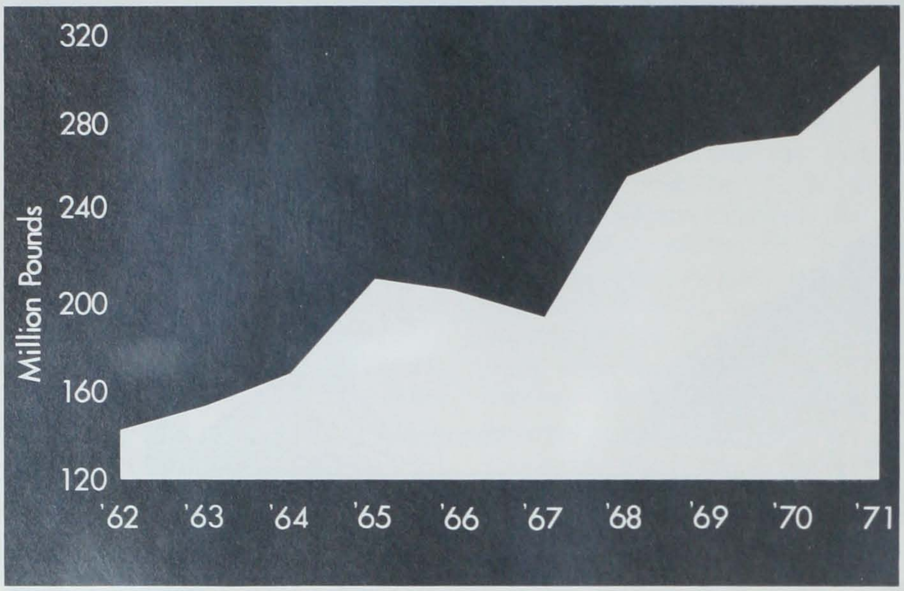

Figure 3.—U.S. imports of fish blocks (1962-71).

these species, that a commercial operation of major proportions would quickly reduce wild stocks to uneconomic levels. The processor of fish sticks and portions must have a large and reliable supply of low-cost raw materials. This could be provided by large, industrial aquaculture operations. The concept of culturing relatively low-value species is a departure from previously held views in which only high-value carnivores were considered to be suitable subjects for aquaculture. The production of warm-water, fresh-water herbivores, whose nutritional requirements are met by supplemental feeding, seems to be an entirely realistic and economically feasible operation, provided it is geared to the needs of the processor and the institutional market. It has the potential for freeing the U.S. processor from dependence on the increasingly expensive and continually decreasing supply of imported groundfish.

TECHNOLOGICAL FACTORS IN PRODUCTION OF LOW-COST POND FISH

At this point we would like to summarize our position with a quotation from the chapter "Fish for 300 Million" by Philip M. Roedel (1971) in the book "Our Changing Fisheries."

"The potential for artificial cultivation is many, many times the present production from aquaculture, and scientific research and application of modern engineering techniques could result in many practical advances. Commercial firms are showing considerable interest in certain aspects of aquaculture because of the resource ownership aspects and the ability to employ advanced production systems that will provide a uniform supply to meet market demand. Today, artificial cultivation in fisheries can be likened to the poultry industry of 25 years ago, when production of broiler chickens was about 9 percent of what it was in 1968. Aquaculture has the potential to match the tremendous growth exhibited in the poultry industry."

The comparison with the development of the mass production poultry industry is most appropriate to us. We believe that the technological factors and limitations that are important to large-scale production of food fish by pond culture have much similarity to the problems faced by the poultry industry 25 years ago. Foremost among these limitations are: (1) competition for land use, (2) cost of suit-

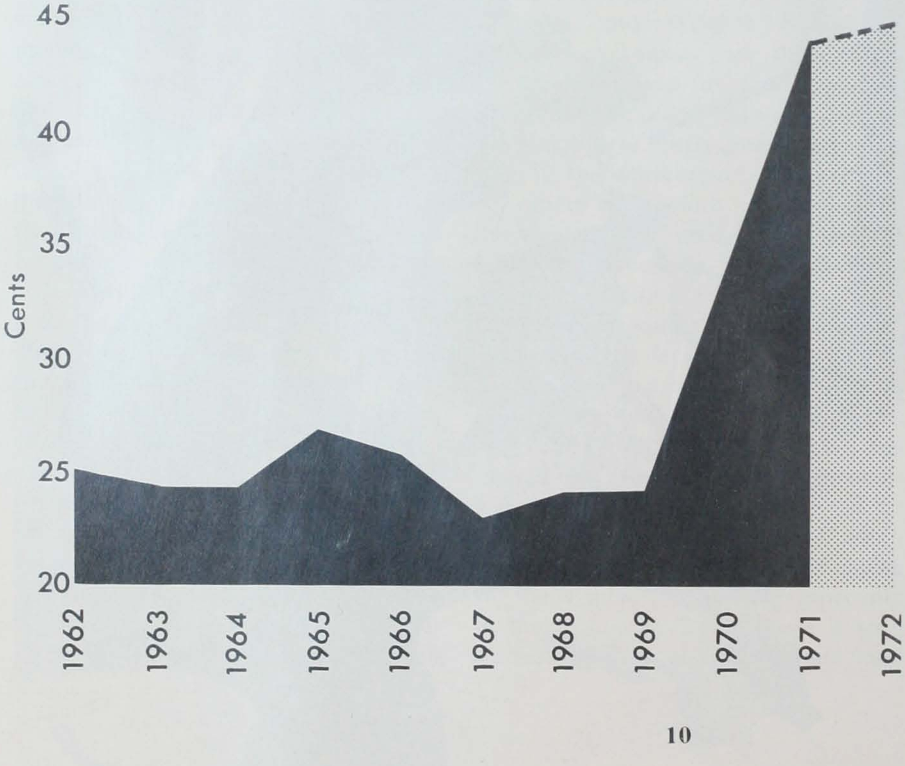

Figure 4.—Average price of cod blocks to U.S. fish processors (1962-72).

able water, (3) increasing costs in a labor-intensive industry, (4) feed cost in relation to product value, (5) disease control, (6) efficient processing techniques, (7) pollution-control requirements, and (8) development of markets and consumer acceptance.

In our comparison with the poultry industry of 25 years ago, however, the last two items, pollution control and marketing, were probably the least of the problems faced by the poultry producers in the 1940's and 1950's. Both of these items will assume major roles in the development of large-scale aquaculture. We have not mentioned the problem of securing risk capital for development of aquaculture simply because, if we can solve the technological limitations, the desirability of aquaculture as an investment will be established. In discussing these limitations, as follows, only the extent of the problem and the contribution toward solution that can be made by technological research are indicated.

Competition for Land Use

The pertinent question that must be answered is whether the value of the crop produced exceeds the value of competing uses. In 1971 U.S. processors spent about 137 million dollars for imported fish blocks. This cost will increase as the ocean resource declines and international competition increases for the available resource. Costs will also increase with the general trend of things. Of course, this last point applies to the culture of pond fish, but we suggest that production costs will decrease as knowledge is gained on methods for increasing efficiency through culture techniques, selective breeding, nutrition, improved feeds, and technological improvements. An aquaculture operation such as we are concerned with can absorb increasing land and water costs better than the marine fishery can absorb the costs of lowered yield per unit of effort. As for competing uses, we suspect that mariculture operations in sheltered coastal waters would experience more competition from recreational and commercial users than would fresh-water aquaculture operations in rural areas. Most agricultural operations would not be competitive because the land used for aquaculture will be of marginal value for agriculture and, in any case, the production and value of fish per acre will be justified as is any other return on the land.

Cost of Suitable Water

The water quality requirements for warm-water-pond fish must be defined on the basis of species requirements, although generally the water must meet accepted chemical and biological criteria now defined by the states in their water-quality standards. In future developments, the use of waste-cooling water or thermal effluents from steam-electric and nuclear-power plants has already been forecast by the work of National Marine Fisheries Service and other agencies (Yee, 1972; McNeil, 1970). This heated water will be used to maintain the optimum temperature for fish culture year around. Use of warm water from geothermal sources and developments is also likely. In the future but arriving very fast is the development of practicable water-treatment methodology to enable a fish hatchery or culture facility to treat and recycle the water. Such recirculation would appear to be particularly desirable for the raceway culture of food fish predicted for the future. With these developments, it is believed that water costs will be reasonable for large-scale fish culture. Some problems for research include the effect on the fish of buildup of trace elements and organic contaminants, if not removed in the treatment process. Use of chlorination and ozonation to purify natural or waste waters has definite limitations for later use in trout and minnow culture (Basch et al., 1971). Additional research on disinfection methodology is needed, including these and other treatments such as ultraviolet disinfection. However, there appear to be no severe limiting factors in the present technology and the known effects on the fish species studied to date.

Figure 5.—Large-scale trout production ponds near Buhl, Idaho. The tall metal silos are for dry feed storage and supply the feed lines to the automatic feed dispensers in each raceway.

Increasing Costs In A Labor-Intensive Industry

Anyone who has worked in or been around a fish-cultural facility knows the meaning of labor intensive. It seems as if everything to be fed, moved, or transferred involves a great amount of manual labor. Obviously, there is an answer through production design and mechanization but, in our judgment, only if the fish-culture production facility is large and planned for efficiency and mechanization. Such a facility will be as different from a conventional fish hatchery or trout farm as a modern battery-cage broiler-production plant is different from the poultry farm of 1940. Automated feeding methods are entirely feasible for many fish species (Figure 5). In at least one species, *Tilapia aurea*, the use of cage culture has been demonstrated for controlling reproduction in ponds used for intensive production of marketable fish (Pagan, 1969). Mechanized harvesting of fish of a desired size would be most practicable in a cage or raceway-type culture. Selection and adaptation of species and, indeed, the breeding and genetic development of adaptable species are forecast. This will require many years because, as pointed out by Simon (1970) in his research at Oregon State University, it is more effective to select a single population for changing one characteristic than to attempt simultaneous selection for several desirable characteristics. The selection and breeding of fish for inland waters having the necessary characteristics for production in a mechanized facility are essential to the solution of this problem of high labor costs in aquaculture.

Feed Cost

Feed is the highest single cost factor in raising fish to marketable size. The biologist is concerned primarily with feed conversion, the weight of feed needed to produce one pound of marketable fish. As indicated earlier, the feasibility of salmon mariculture in Puget Sound has been demonstrated by National Marine Fisheries Service researchers. In December 1970 the researchers reported that with a conversion of 1.5 and feed at 16.5 cents per pound (Oregon Moist Pellets), it would cost about 25 cents for the feed to produce 1 pound of coho salmon (Mahnken et al., 1970). The salmon would be harvested at the optimum size, about 10 to 12 ounces, for maximum conversion. Fish can be held longer to produce larger sizes, but this results in a significantly greater conversion figure of feed per pound of fish harvested. Costs per pound of product would be naturally higher. All this, of course, is similar to what went on years ago in the broiler chicken industry. The same approach is being applied in catfish farming currently and must be applied to make commercial culture of any species successful.

The important thing to emphasize is that the development of the most efficient and lowest cost feed (as in the Oregon moist pellet for salmon) is a research job for the nutritionist and the food technologist in cooperation with the fish culturist. Recent cooperative tests by our laboratory with Dr. Lauren R. Donaldson at the University of Washington College of Fisheries demonstrated the value and possible use of pelagic red crab (*Pleuroncodes planipes*) in feeds for trout and salmon. This red crab is a small crustacean occurring in huge quantities in the southeastern Pacific and off both coasts of Baja California. The crab provides a good protein source and is exceptionally rich in carotenoids that are a desirable component for improving the color and acceptability of the fish. A study (Steel, 1971) at Oregon State University demonstrated that a trout diet rich in carotenoids also produces fish with a better flavor. More collaborative studies between the food technologist and the fish culturist are needed to make the best use of low-cost feed materials and to formulate the most efficient diet. Just as in other animals, it is essential to study each species' requirements in the culture environment. In this way technology can contribute to better utilization of our little-used fishery resources for foods and to production of lower-cost feeds for large-scale aquaculture.

Disease Control

The problem of disease control is not just up to the fish culturist or the pathologist in this greater perspective of modern aquaculture. Development and formulation of feeds, effects of trace elements and growth factors, control of water quality and temperature, and influence of other environmental factors such as tank, pond, or cage design are all important. The NMFS biologists working with salmon culture in Puget Sound found, e.g., that the infection of the salmon with *Vibrio* was related in part to design of the pens, the web used, and problems of fouling, and the need for rapid flushing by tidal currents.

Efficient Processing Techniques

The inefficient and unsanitary methods of harvesting and processing trout, buffalo fish, and catfish from simple farm ponds are not acceptable for modern aquaculture. Industry leaders in trout farming and most recently in salmon mariculture are interested in better methods of harvesting, killing, bleeding, butchering, processing, and packaging the fish. The use of cold-brine immersion for stunning and immobilizing the fish just out of the water has been an important step forward. Studies in our laboratory show that killing and bleeding techniques affect the color, quality, and even the cold storage life of dressed trout or salmon. We expect that these factors will be important in harvesting and processing mass-produced, inland-water species for both the marketed fresh fish and those processed to frozen blocks and a variety of fishery products.

The species selected for high yield and growth potential in inland waters will probably include fish such as carp, tilapia, buffalo fish, amur, mullet, and others that are not highly desirable as dressed pan fish. The processing of these species will consist of heading and gutting, separation of all edible flesh by machine, and the processing of the edible flesh to frozen blocks. The blocks form the intermediate material for processing at the wholesale level to fish portions, sticks, sandwich portions, fish cakes, spreads, specialty products, and as a wet-protein ingredient in processed meats and foods of many types. Much of the basic technological study has been done for this development by the NMFS technological centers in Seattle and Gloucester, Massachusetts. This proposal for the future use of cultured inland fish simply brings together the potential yield from large-scale production with a process technology capable of utilizing it in the most efficient manner for a wide variety of convenience foods.

Pollution Control Requirements

Little need be said on the importance of planning and research on pollution control in any large-scale aquaculture enterprise. If the concept of a large-scale culture facility is integrated with the processing facility, it is desirable to plan pollution control on a unified basis. For example, waste materials and protein from the food-processing plant become part of the raw materials for feed formulation, thereby closing the cycle for solid waste utilization. Plant effluents could be treated for recovery of dissolved proteins for feed materials, thereby lightening the pollution load. If plans call for secondary and tertiary treatment of all effluents, the complete technology of water treatment and reuse may be applied for both culture and process facilities.

Development of Markets And Consumer Acceptance

We do not underestimate the problem of marketing fish and fishery products with unfamiliar names, or worse, with names linked to strong prejudices. Those who have worked with marketing of buffalo fish and carp are familiar with this problem. A good product image and consumer acceptance will be difficult or impossible to achieve in our opinion within inland fish products unless the food industry approaches the problem of selling these new species and products to the American consumer in the same spirit used with every other new food concept. You will note that we said food industry, *not* fishery industry, for the obvious reason that the first element of success in this projection of an industry for large-scale production of inland fish will be to recognize that the producer is in the food business first and the fish business second. The government market specialists and technologists will be needed to assist industry in the developing years; however, the main solution to the marketing problem will lie with American food industry know-how.

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