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Fish Culture: Problems and Prospects

With reorganized aims and methods, fish culture could make major contributions to world protein needs.

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Fish culture—the rearing of fish for food—is at least 2000 years old, but only a small fraction of the fish that man consumes is derived from this source. Nevertheless, it is important to certain communities for food and livelihood. Recently, interest in the potential of fish culture has increased, not only in such traditional strongholds as China and the Far East, but also in India, Africa, Europe, North America, and the Pacific rim countries. Fish culture is thus rapidly assuming the appearance of an idea whose time has come. It can certainly be expected to expand among those nations most affected by the recent introduction of the 200-mile fishing zone. The forms of such activity will range from hatchery-based restocking and sea-ranching programs to various types of intensive pond culture.

Some of the reasons for the new interest in fish culture are: (i) Fears that global overfishing and marine pollution will destroy fish harvests. (ii) Realization that coastal, estuarine, and inland waters constitute the only areas over which a country can be relatively certain of exercising control of fishing intensity, water quality, and labor deployment. (iii) Realization that, as in agriculture, man should view edible aquatic products as fruits of a system that not only can be exploited, but whose management can be planned and controlled at every level of the production pyramid.

Problems

Unfortunately, fish culturists lack an organized overview of their field of knowledge and of its operational scope. Reference works exist which contain prolific information on regional skills and practices but not many broad conceptualizations of the subject or penetrating interregional comparisons (*1–3*). There has been general failure to exploit such techniques as systems analysis and cost-benefit analysis, while, with a few notable exceptions (*4*), the influence of geography and sociocultural factors has been treated superficially or ignored. This is unfortunate in view of the ample evidence of the effectiveness of such techniques in exposing the essential organization and patterns of energy use in other complex human activities, such as the U.S. food system (*5*), or in examining modern marine commercial fisheries (*6*).

It is important to examine details of various fish-culture practices and also to derive some general principles to guide the progress of this activity and limit the further spread of needless and costly mistakes of a type that have become not uncommon. The various versions of fish culture in different parts of the world cannot now be viewed in a common frame for valid comparisons of origins and rates of use of food energy, efficiencies of fish energetics, and dynamics of fish growth in different pond systems. For example, the common assumption that the polyculture of fish species practiced in Chinese ponds is an effective way of exploiting the total food energy of the pond ecosystem has not been initially tested (*1*). There has been no investigation of whether the development of European fish culture from long-practiced methods of agricultural stock-rearing (*2*) has been appropriately adapted to the biology of fish growth, which is different in kind from that of terrestrial vertebrates (*7–9*). The famous milkfish (*Chanos chanos*) culture practiced in Indonesian brackish water ponds (a method recently adopted in the Philippines) is another system for the evaluation of which there are no adequate analytical techniques; yet, when the complex procedures of this fish culture are considered carefully, there emerges a distinct impression that they have evolved through unconscious application of optimality principles over an extended time (*1, 3, 4, 10, 11*). If this is correct, this method of fish culture may provide important lessons for the entire industry.

High Operating Costs

Numerous developing countries are showing interest in utilizing new forms of fish culture. It will be regrettable if such countries are encouraged to emulate certain costly, technically sophisticated, but otherwise not particularly satisfactory, systems of fish culture recently developed in the West. For example, the culture of salmonid fishes in the United States, the United Kingdom, Canada, Scandinavia, and Japan (*1*), of channel catfish in the United States (*1*), and of yellowtail in Japan (*1, 12*) are all distinguished by the use of remarkably expensive high-protein foods comprising so-called "trash" fish caught in the sea. Salmon, for example, are fed 60 to 70 percent of fish meal (from trash fish) by wet weight—a wasteful use of food energy from the ecological standpoint. If one adds to this the high operating costs, capital outlay for plant, depreciation,

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and loan repayment, then economic success can result only through a very high fish sale price—that is, such fish culture must tend to lead to a luxury food industry.

In Japanese yellowtail (*Seriola quinqueradiata*) culture, food (trash fish) accounts for half the production costs. In 1972, the production of 74,000 tons (metric) of yellowtail required 570,000 tons of trash fish, the approximate conversion ratio being 1:8. In the production of a 1-kilogram fish, food costs 320 yen [300 yen are equivalent to $1 (U.S.)]; the fish as a fingerling, 105 yen; depreciation, 70 yen; labor, 50 yen. Production costs totaled 652 yen. At the wholesale price of 951 yen, producers could make a considerable net profit, but such wholesale prices are naturally reflected in a very high consumer price. However, a preoccupation with profitability has not always led yellowtail producers to financial success. Early yellowtail culture was on too large a scale, and lack of research on site selection, design, and suitable materials for enclosures caused costly errors. This form of culture remains expensive. Nets in sea enclosures become fouled and must be replaced almost weekly. As the production of yellowtail expands, trash fish to feed them are becoming scarcer and dearer.

Various other examples of high operating costs and hazards are encountered in the production of salmonids and channel catfish (*1*). "Failures" are not necessarily due merely to unsound application of economic principles, but also to haste and inexpertness on the part of entrepreneurs who expect too much without adequate knowledge of plant operation or of fish diseases, for example (*13*). For instance, since 1960 the area of channel catfish ponds in the United States has increased from zero to some 50,000 acres (1 acre = 0.4047 hectare), but the industry has had numerous problems related to production costs and product diversification, and for any secure future may have to aim at reduction of unit production cost, shifting the industry "from a luxury-food industry to a staple food source" (*1*).

The Energy Aspect

While we are not opposed to profits being made, we do think that more attention should be directed toward efficient energy use in the production of human food, including maximum efficiency of energy transfer between food and fish. When salmonids, channel catfish, and yellowtail are fed wholly or partly on trash fish, an energy pyramid is being tapped that is at least two trophic levels above that utilized by herbivorous fish (for example, mullet), or by sheep and cattle in terrestrial farming. Trash fish may be highly edible, even if they now happen to lack a market. If they are edible, their use as food for cultured fish must, in energy transfer terms, be regarded as absurd. If for reasons of present economic expediency, their use in a luxury-food industry can be tolerated, this should not lead to complacency, especially because fish culture based on this method cannot produce more than about 1 kg of cultured fish for every 5 to 10 kg of trash fish fed (*13*). Wherever possible, attempts should be made to use trash fish more directly for human nutrition. Much research is already being conducted on the preparation of optimal artificial diets, replete with correct quantities of vitamins, minerals, proteins, and fats (*1*). However, for application in fish culture, it is important that such studies should have as their major aim the more efficient use of food for growth.

Production costs that increase will cause corresponding increases in the market price of fish. Fish sales tend to relate inversely to price—although, admittedly, demand is involved, and this can sometimes be influenced by promotion. However, lower prices would bring luxury fish more within the reach of mass markets. Net profits could then be as great or greater than present ones even at reduced prices per kilogram. Much recent fish-culture research has, unfortunately, been subservient to the demands of entrepreneurs whose sole aim has been to make profit. To the eventual disadvantage of all concerned, such research has frequently failed to test the assumptions and practices of the industry, and may also have opposed long-term national or regional interests.

Improving the Outlook

A fish culture based on an integrated body of knowledge and well-formulated concepts would view regional aspects as particular instances of a problem set, to be investigated by the application of established principles and experience. This is how better-based applied sciences such as engineering and agriculture approach problem-solving. Prediction and management guidelines in new ventures would be simplified and improved, and major failures would be less likely. A multimillion-dollar salmonid culture operation begun in Nova Scotia in 1969 had failed by 1972. Full-scale research and planning of this operation might have led to its success—at least in commercial terms. In Puget Sound, salmon-rearing has been a relative commercial success because of better planning and closer cooperation of research and government agencies with commercial interests (*14*).

There should be congruence between type of fish cultured, the environment, and consumers' needs. Not only should the species be acceptable as food, but its life cycle should be readily manipulable (*13*). An ideal species might complete its life cycle within the pond system and be physiologically robust. Some of the most popular species reared, however, require hatcheries (salmonids, channel catfish) or the sea (milkfish, mullets) for completion of their life cycles, though such species may, of course, have compensations such as good growth and flavor. It has been said that hatcheries frequently constitute one of the more expensive aspects of fish culture and that their cost may be prohibitive in some underdeveloped countries. This leads us to suggest three areas in which research should be conducted.

1) The culture of potentially valuable fish species is frequently prevented through ignorance of their life histories, including breeding habits, their survival, food requirements, and the growth rate of the young stages. The carp, *Cyprinus carpio*, several tilapias (mainly *Tilapia mossambica*), a few salmonids, and several dozen other species constitute the basis of world fish culture. Since there is no general routine for testing the culture potential of new species, the prospects of discovering fish with superior characteristics of growth, productivity, robustness, and flavor remain largely a matter of chance. This situation should not be allowed to continue. In situations where many young fish are required to stock ponds, research could lead to the design of hatcheries capable of more economical and efficient operation, thereby helping to reduce the high costs of this aspect of fish culture.

2) Figure 1 shows a scheme of possible food sources for cultured fish. The simplest trophic route to fish flesh is from the carbohydrate and protein of plants growing in the fish pond (for example, *Tilapia* spp., *Chanos*, and mullet). Many fish can eat terrestrial plant material (for example, *Ctenopharyngodon*, the Chinese grass carp), which is bioenergetically advantageous in pond culture, since fish may be held at high densities in very small ponds while their food is con-

veniently produced on agricultural land. Far more tropical fish are herbivorous than their temperate counterparts, which is why, aside from the more favorable temperature conditions, the tropics offer greater potential for fish culture. However, genetic research might lead to fish being bred with changed food habits. If salmonids could be bred as even partly herbivorous, actually digesting plant carbohydrate as well as protein, major increases in their productivity could be effected.

3) The role of genetics in growth remains an enigma. Fish somatic growth is more flexibly responsive to environmental factors (such as temperature) and biotic factors (competition for food) than growth in higher vertebrates (*8*), but there has been little obvious understanding of this in attempts to breed faster-growing fish. Most present claims that stocks with superior growth have been produced by genetic selection are suspect (*15*), though some recent work seems much more soundly based (*16*), and the basic genetic principles involved in the selection of individuals of superior somatic growth rate can be simply stated (*9*). If geneticists became more aware of the peculiar properties of fish growth, they would almost certainly be able to select for physiologically superior growth. Certain physiological factors are particularly involved in influencing growth. For example, levels of such hormones as somatotropin and thyroxine have been shown to be significant (*17*). There are numerous data on the importance of temperature (*8*). The pattern of partitioning of the net energy, derived from the food, among the "competing" demands of the standard metabolic rate, specific dynamic action, nitrogen excretion, and spontaneous activity, must affect growth, that is, the elaboration of new tissue, especially muscle, liver, gonad, and fat (*9, 18*). Maximum growth should be sought in terms of the most useful edible product, protein. Also, the dynamics of protein and fat are linked in growing fish, but in ways that are not well understood (*8, 9, 19, 20*). Fish given plentiful food may show increases in both components, but in migratory fish, fat may be stored periodically in muscles and liver to be utilized in preference to protein. In *Oncorhynchus keta*, the ratios of glycine to alanine change from 1.3 in immature to 0.5 in mature fish (*8, 19, 20*). By studying the genetics and physiology of growth, methods for increasing the relative growth rate of muscle over that of liver, gonad, or adipose tissue might be found.

Future Possibilities

The scope of fish culture is enormous. Any unpolluted area of water, fresh, brackish, or salt, is a potential space for fish-rearing. Countries of the most diverse climate and geography might turn to fish culture because it offers an economical, attractive use of "waste" water. Water simultaneously employed for other primary purposes such as irrigation, stock watering, or even for drinking can be used for fish culture. Wetlands, including swamps and mangroves which are of little value for agriculture, could be used for fish-rearing with little damage to their recreational value or appearance.

Fish-culture research in developed countries may eventually make major contributions to the management of exploited wild fish stocks. For example, the present exploitation of salmon is based partly on captures at sea and partly on captures during spawning runs in various parts of the Northern Hemisphere. It has been suggested that the strategic location of salmon hatcheries in the vicinities of the Aleutians, the Magallanes region of Chile, and Iceland could lead to the establishment of new major salmon runs and sea fisheries in suitable feeding areas (*21, 22*). In some instances, hatchery-rearing of young salmon might be followed by subsequent pen-rearing in streams where, it is claimed, rapid growth could be obtained economically by means of supplementary feeding (*22*). Eventual release of subadult salmon in the ocean would follow. However, the

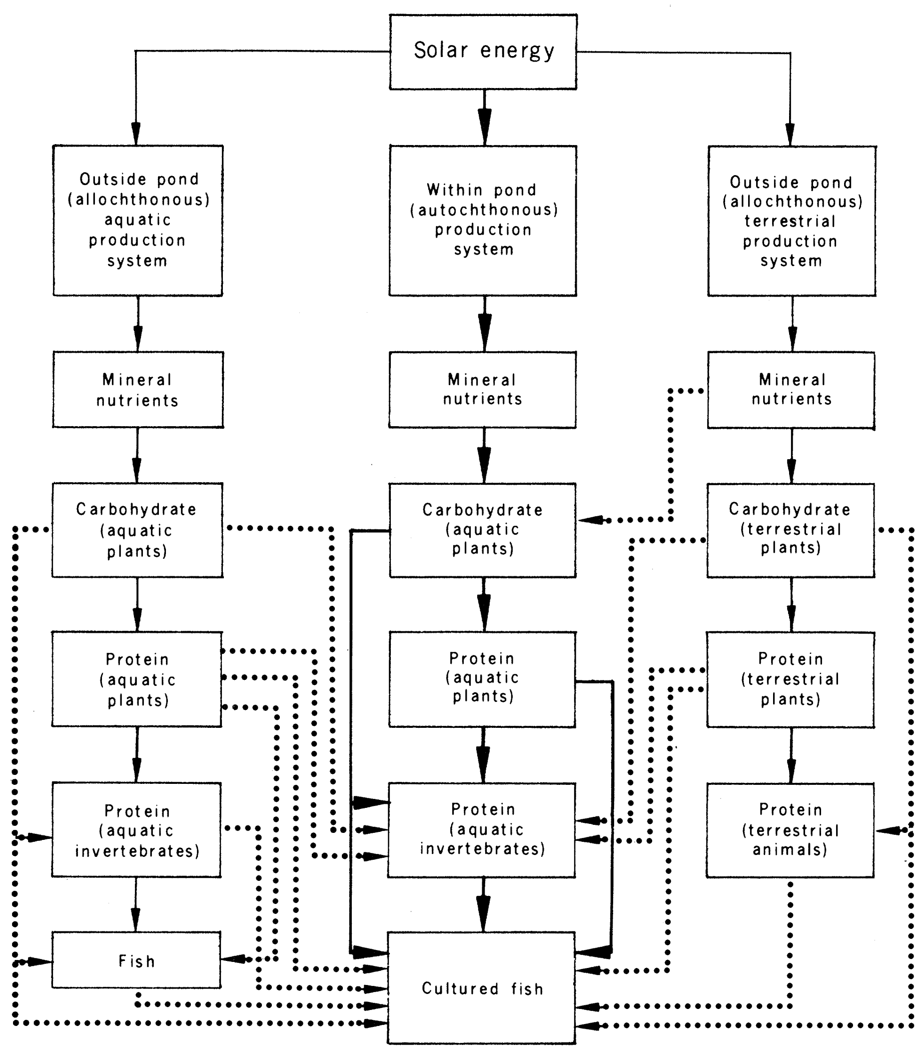

Fig. 1. The possible sources of food for cultured fish. The heavy solid arrows indicate a direct line of food production wholly within the pond system (autochthonous); light arrows indicate direct lines of food production leading to fish (aquatic allochthonous) and terrestrial (allochthonous) animals, respectively, both of which could also be the food support systems of cultured fish. The broken arrows indicate the various whole or partial contributions to the food production of cultured fish which may be made by various components of the allochthonous systems. The range of options is great and the trophic potentialities indicated in the scheme have not been realized by fish culturists.

advantages of establishing new salmon stocks should be weighed against possible damage to already existing fisheries which may occupy the same areas in the oceans (*22*).

The role of fish culture in "enhancing" exploited fish stocks by permitting "massive planting programs [which] can produce spectacular results" has recently been noted (*23*). By means of such programs the yields of salmon in the U.S. Pacific Northwest and in Lake Michigan have already been improved.

With more attention being given to basic aims and production strategies (*24*), to improving the technology, and to developing fish with superior growth rate and superior food-conversion efficiency, fish culture could make a major contribution to world food needs. Much basic research will have to be done in developed countries because of inadequate facilities for research and development in many of the developing countries. People who are truly aware of the needs and problems of developing countries will have to participate in the planning of these studies, and there will have to be massive exchanges of scientists, technical experts and, in some instances, practicing fish culturists.

Money and scientific expertise from the West could power such programs. However, Western countries have made various mistakes about fish culture, and a misplaced positivism is even now underlying various false objectives. To develop sound policies and practices for its own fish culture, the West must put the subject into perspective with such questions as the intensifying pressures on marine fisheries, especially in view of the new opportunities introduced by the establishment of the 200-mile zone. If the West wants to increase production of cultured fish of high food value and palatability to satisfy mass domestic (and possibly export) markets, it must greatly reduce its production costs. Such reduction could be brought about by improving the food-conversion efficiency and the growth rate of fish and by finding more plentiful sources of food energy, or by selecting species of fish capable of feeding closer to the base of the trophic pyramid.

Perhaps the West should not involve itself at all in fish culture, given its already high production of foods of every kind. This option should at least be given careful consideration. However, there may be some opportunities for effective fish culture that have not been considered seriously enough. For example, an interesting form of fish culture is being practiced in Canada in the many small prairie ponds which can be readily stocked with small trout. It is reported that the fish grow from fry size to 200 g or more in a single 6-month growth season (*1, 25*). The main costs are those of distributing the fry and of catching the fish again, while the cash return is two and a half times that of wheat farming on an areal basis (*1*). Recoveries as high as 86 percent of the number of fingerlings stocked are reported, and the major mortality is a "summerkill" produced by occasional severe oxygen depletions induced by decomposing algae (*25*). Winterkill removes all stock not fished out at the end of the growing season.

There are various forms of aid the West can provide to developing countries to help solve their food needs. Better than offers of food surpluses at low cost would be long-term investments of time, money, and scientific expertise in attempting to revamp food production enterprises, including fish culture.

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