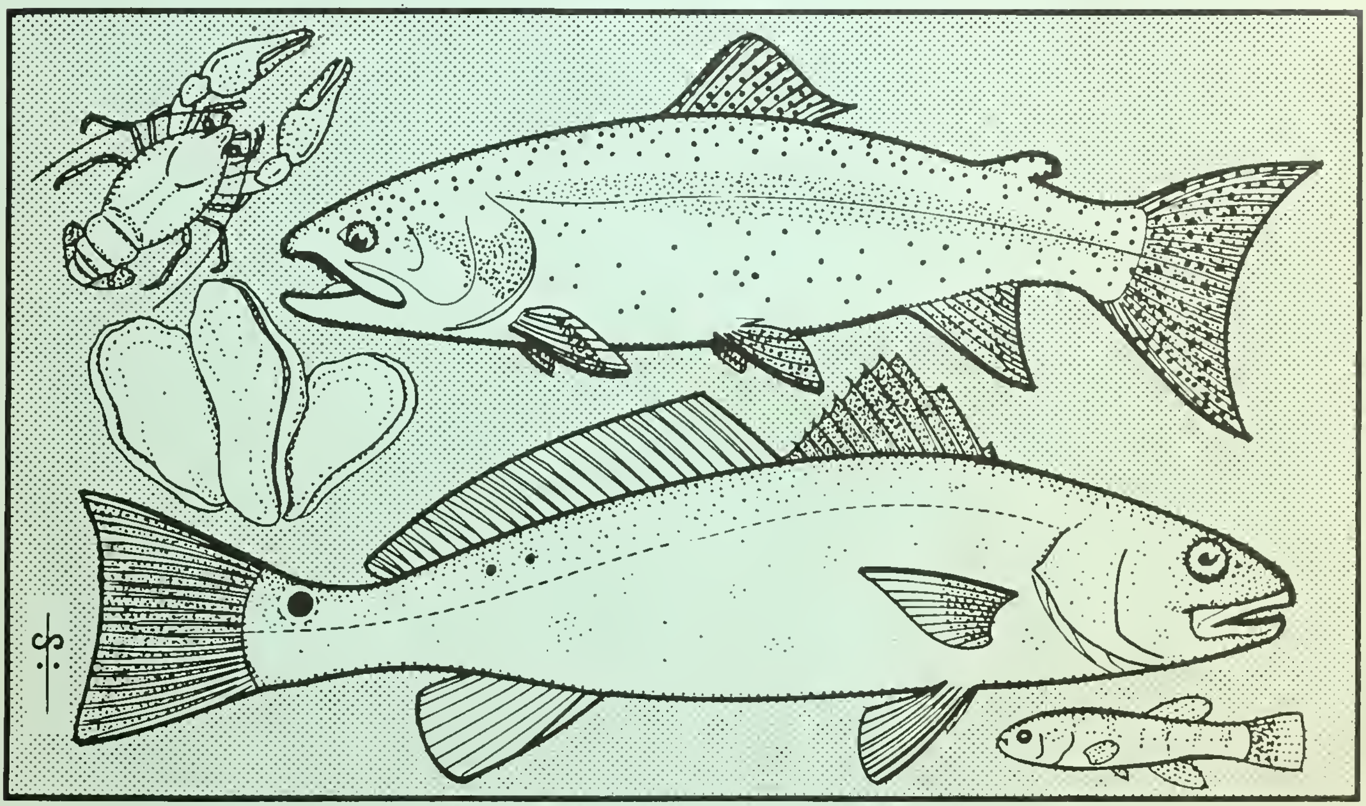
National Aquaculture Development Plan



Volume I

The Joint Subcommittee on Aquaculture
of the Federal Coordinating Council
on Science, Engineering and Technology

September 1983

United States Department of the Interior

OFFICE OF THE SECRETARY
WASHINGTON, D.C. 20240

Dear Sirs:

It is our pleasure to submit the National Aquaculture Development Plan as required by the National Aquaculture Act of 1980, Public Law 96-362.

Sincerely yours,

James G. Watt
Secretary of the Interior
Department of the Interior

Malcolm Baldrige
Secretary of Commerce
Department of Commerce

John R. Block
Secretary of Agriculture
U. S. Department of Agriculture

Enclosure

The President
The President of the Senate
The Speaker of the House

NATIONAL AQUACULTURE

DEVELOPMENT PLAN

VOLUME I

Prepared By:

The Joint Subcommittee on Aquaculture
of the
Federal Coordinating Council
on Science, Engineering, and Technology

Washington, D.C.

September, 1983

The Joint Subcommittee on Aquaculture (JSA) is established within the Office of Science and Technology Policy.

Members of the JSA include:

- The Secretary of the Department of Agriculture
- The Secretary of the Department of Commerce
- The Secretary of the Department of the Interior
- The Secretary of the Department of Health and Human Services
- The Administrator of the Agency for International Development
- The Chief of the Corps of Engineers
- The Secretary of the Department of Energy
- The Administrator of the Environmental Protection Agency
- The Governor of the Farm Credit Administration
- The Director of the National Science Foundation
- The Administrator of the Small Business Administration
- The Chairman of the Tennessee Valley Authority

AQUACULTURE IS DEFINED AS THE CONTROLLED CULTIVATION AND HARVEST OF AQUATIC PLANTS AND ANIMALS

Final Editing Was Done By:

United States Department of Agriculture
United States Department of Commerce
United States Department of the Interior

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PREFACE

The National Aquaculture Development Plan (NADP) is a two-volume document prepared by the Joint Subcommittee on Aquaculture (JSA) in response to P.L. 96-362, the National Aquaculture Act of 1980. The plan has been developed over an extended period of time with the assistance of numerous individuals. It's history, briefly, is as follows; on May 2, 1977, a Subcommittee on Aquaculture, under the auspices of the Interagency Committee on Marine Science and Engineering, developed an outline for a preliminary National Aquaculture Plan. On December 15, 1978, the JSA initiated work on that plan which was completed in May, 1980. It consisted of two parts: an overall plan and a collection of species plans. This particular plan was not published. The extensive list of Federal, State, academic, and private contributors to that plan is found in Volume II of the NADP.

On March 13, 1981, an ad hoc National Plan Task Force was established to develop from the unpublished plan the NADP to fully satisfy the requirements of the Act. Task force participants represented the U.S. Department of Agriculture, U.S. Department of Commerce, and U.S. Department of the Interior.

This volume (I) describes technologies, problems, and opportunities associated with aquaculture in the U.S. and its territories. It recommends actions to solve problems and analyzes the social, environmental, and economic impacts of growth in aquaculture. Volume II contains in-depth discussions of important, selected aquacultural species, an extensive bibliography and list of contributors.

The JSA is a subcommittee of the Federal Coordinating Council on Science, Engineering, and Technology. It was created to increase the overall effectiveness and productivity of Federal aquaculture programs by improving coordination and communication among Federal agencies involved in these programs. The Act assigns various activities to be conducted by the JSA, including preparation of this plan.

The JSA is made up of representatives of the following Federal agencies: Department of Agriculture (USDA), Department of Commerce (DOC), Department of the Interior (USDI), Department of Energy (DOE), Department of Health and Human Services (DHHS), Environmental Protection Agency (EPA), Corps of Engineers (COE), Small Business Administration (SBA), Agency for International Development (AID), Tennessee Valley Authority (TVA), National Science Foundation (NSF), and the Farm Credit Administration (FCA). The chairmanship and vice-chairmanship of the JSA rotates among representatives of the Department's of Agriculture, Commerce and

Interior every two years. On February 1, 1983, the USDI representative was appointed JSA chairman and the DOC representative became vice-chairman.

The National Aquaculture Act of 1980 states that it is National policy "to encourage the development of aquaculture in the United States", and it further states that "the principal responsibility for the development of aquaculture in the United States must rest with the private sector". It recognizes U.S. aquaculture as a viable approach to helping meet food needs and contributing to the solution of world resource problems and that aquaculture development will result from initiatives and actions taken within the private sector. The general role of government is to provide encouragement and support through programs and services that cannot reasonably be expected from private sources.

The government will act as a catalyst for private sector initiatives. Such action will help encourage the growth of a vigorous, self-sustaining industry that will benefit the economy and reduce or eventually reverse the trade deficit in fish and fishery products.

The members of the JSA respectfully and affectionately dedicate the NADP to the memory of David H. Wallace, late Director of the Office of International Fisheries Affairs, National Marine Fisheries Service. He was widely acknowledged as the principal advocate in the Federal Government of an expanded aquaculture program. His enthusiasm and skill were responsible for stimulating activity in this area, not only in the DOC but in other agencies as well. He was responsible for organizing the Joint Subcommittee on Aquaculture and served as its chairman until his death in January 1980.

Dave Wallace's encouragement and organizational skill contributed significantly in the early stages of the preparation of the NADP. It is particularly fitting that it be dedicated to him.

EXECUTIVE SUMMARY

World-wide aquaculture production is estimated to be as much as 21 billion pounds. Global production has increased significantly over the past 15 years. Total U.S. production is now estimated to be almost 400 million pounds, accounting for about 11 percent of the total edible production of fish and shellfish in the U.S. This figure represents a substantial increase in aquaculture production since 1975, when it was estimated at about 130 million pounds.

In September 1980, the National Aquaculture Act (P.L. 96-362) was signed into law. The Act states that National policy is "to encourage the development of aquaculture in the United States."

It is important to note that much of the increased production occurred prior to the passage of the National Aquaculture Act because sufficient incentive and motivation in the private sector existed for the aquaculture industry to expand. This expansion occurred in a period of: 1) increasing per capita consumption of fish and shellfish (10.3 pounds in 1960; 13.0 pounds in 1980); 2) a general concensus that a limit to commercial fishing of traditional species had been or shortly would be reached; and 3) increasing negative annual trade deficits ($2.2 billion) in fish and fish products.

But it is equally important to note that considerable support by various Federal and State agencies and academic institutions have directly and indirectly assisted this industry for many years. That support came from research and education programs in both Federal laboratories and State college and university laboratories; through extension education and technical assistance from Federal and State workers in areas of aquaculture expansion; and from a growing awareness and encouragement of industry activity by State and Federal administrators and decision-makers. It is this last point that was identified by the National Research Council (NRC, 1978, Aquaculture in the United States: Constraints and Opportunities) when it observed that "Constraints on orderly development of aquaculture tend to be political and administrative, rather than scientific and technological."

The JSA has noted that many impediments identified by the National Research Council still persist. These include continued use of wild animals that have not been genetically improved for culture, poor understanding of nutrition and diets of culturable species, continuing problems in preventing and controlling diseases, and poor knowledge of water quality criteria in culture systems. Coupled with a need for education, information, and technology assistance efforts, and a need to understand markets and marketing barriers for aquaculture, these constraints continue to present obstacles to rapid and orderly expansion of aquaculture.

Other barriers faced by some segments of industry include multiple-use conflicts, legal constraints, and difficulty in locating capital for entrepreneurial exploration. Finally, some observers argue that jurisdictional overlap and inadequate coordination at the Federal level has led to ineffective and inefficient Federal support of the emerging aquaculture industries. P.L. 96-362 formally recognized the JSA as the vehicle to provide the necessary coordination in order to bring about improved Federal support of aquaculture.

Although aquaculture is complex and diverse, certain common factors exist that offer opportunities for enhancement by Federal action on a National basis with the understanding that local and State constraints must be dealt with at a local or State level, and that industry must provide adequate support for aquaculture research and development.

The recommended activities of the JSA are included in the following summary. A more comprehensive discussion is presented in Chapter 5.

Joint Subcommittee on Aquaculture

The JSA will provide broad coordination and monitoring of Federal aquaculture programs including reviews, assessments, developing policy recommendations, and reports on aquaculture activities. Specific functions and responsibilities have been assigned to three panels:

Panel on Science, Technology, and Engineering: The Panel will annually update research needs, identify and report on ongoing research efforts, and coordinate Federal research programs.

Panel on Economics: The panel will periodically review and report on aspects that affect the economic feasibility of aquaculture; initiate, monitor, and report on Federal actions to reduce burdensome regulations, and publish and distribute a directory of financial assistance programs.

Panel on Education and Technical Assistance: The panel will provide for coordination and monitoring of education and information dissemination activities of Federal agencies, facilitate exchange of aquaculture information, and establish and monitor a National Aquaculture Information System (NAIS).

Issues and concerns that the JSA will address include:

National Aquaculture Information System (NAIS): Federal data banks containing information about aquaculture will be tied together under the leadership of the National Agricultural Library of USDA. Bibliographic files, translations of foreign articles, selected directories, statistics, survey results and research projects will be accessible at a single entry point.

International Activities: The JSA will coordinate the exchange of information with foreign nations and monitor bilateral programs to assure that the United States receives maximum benefit from information derived from these programs.

Capital Requirements: Although lack of financing is not a constraint to existing commercial aquaculture, it is for entrepreneurs working with innovative culture systems or untested species on a commercial basis. Therefore, while the JSA does not find adequate justification for creating new Federal financing programs, an effort will be made to educate the financial community about aquaculture and to inform prospective aquaculture borrowers about current funding sources.

Regulatory Impacts: Several Federal regulatory program areas have been identified by industry and the JSA as being of particular importance. These include dredge and fill permits, National pollutant discharge elimination system permits, drug and chemical registration procedures, fish and shellfish health programs, and restrictions on the movement of nonindigenous species. However, it is clear that the bulk of regulations, permits, and licenses occur at the State and local level.

Although it is unreasonable to expect aquaculture to receive special exemptions from environmental and health regulations, it is not unreasonable to expect that aquaculture be given equity with competing activities.

The JSA will actively work with appropriate Federal regulatory agencies to review problems associated with aquaculture, promote public forums to conduct periodic assessments of progress in achieving justifiable regulatory relief, and periodically make available directories of Federal regulations affecting the development and operation of commercial aquaculture.

Departmental Responsibilities: P.L. 96-362 assigns broad responsibilities in aquaculture to the USDA, DOC, and USDI, working with and through the JSA. The three Departments agreed to broad responsibilities in scientific and technical research, pilot testing and demonstration, economics, and information and technology assistance within existing programs. Expenditures in aquaculture by the three Departments (FY 1982) were: USDA--$9.5 million; DOC--$8.3 million; and USDI--$4.5 million.

Conclusions

Aquaculture is a dynamic and growing segment of the American economy. Tremendous strides in yields have been seen in the past 15 years. Giant corporations have joined the aquaculture field - Con Agra, Ralston Purina, British Petroleum, and Campbell Soup, to name a few. The JSA believes that aquaculture can and will become a significant source of aquatic products in this decade. For some regions of the country, and for some species, this is already the case.

Aquaculture also offers new jobs, increased farm income stability, wholesome products, and opportunities to improve our balance of trade. However, further progress will require a commitment to reduce burdensome regulations, enhanced support for research and education, and a well-coordinated partnership between Federal and State agencies, universities, and private industry. The JSA believes that the program input in this document will meet the National policy to encourage the development of aquaculture in the U.S.

CHAPTER 1
STATUS OF AQUACULTURE

The status of aquaculture in the world and in the U.S. is summarized in this chapter. For details on the status of individual species, see Volume II.

World Status

On a worldwide basis, at least 93 species of finfish (combining fresh, brackish and marine species), 7 species of shrimp or prawns, 6 species of crawfish, many species of oysters, clams and other shellfish, and a wide variety of freshwater and marine plants are cultivated. Comprehensive and reliable aquaculture production statistics are generally lacking. Ryther[1], combining various years from 1971 to 1978 for different species and countries, estimated world production at 5.6 million metric tons (12.3 billion pounds). (See Table 1). This figure is less than that commonly quoted because of a revised estimate of production from the People's Republic of China.[2] Of the total production, finfish account for 57 percent (12 percent from marine or brackish water culture and 45 percent from freshwater), molluscs 24 percent, seaweed 19 percent, and crustaceans less than 1 percent.

T.V.R. Pillay of the Food and Agriculture Organization of the United Nations (FAO), in a presentation at the World Mariculture Society meeting in Venice in September 1981, presented more recent total production figures. World aquaculture production for 1979 was estimated to be 9.4 million metric tons (20.7 billion pounds). His breakdown of total production was: finfish 37.1 percent, molluscs 36.7 percent, seaweed 25.4 percent, and crustaceans less than 1 percent.

Small operations produce most of the finfish and shrimp, while oysters, mussels, and seaweed come from larger farms. Aquaculture production constitutes roughly 10 percent of total world fish consumption, with some 65 percent being cultured in Asia.

Some countries have been aggressive and successful in promoting aquaculture development, and rely heavily on it for their supply of fish. Half of the fish consumed in Israel, over 25 percent of that consumed in China and India, and about 10 percent of that consumed in Japan comes from aquaculture.

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[1] Ryther, J.H. 1981. Mariculture, ocean ranching, and other culture-based fisheries. BioScience 31(3):223-230.

[2] Anon. 1980. China changes the figures. Fish Farming International 7(1):3.

Table 1.
World Aquaculture Production for 1971-1978[1]

Species groups	Production: Thousands of metric tons	Production: Millions of pounds	Percent of total
Finfish			
Marine			
Milkfish (Philippines, Indonesia, Taiwan; 1973-74)	207	456	3.7
Yellowtail (Japan; 1971)	52	115	0.9
Salmonid net cage culture (1975)	100	220	1.8
Salmon ocean ranching (USA, Japan, USSR; 1977-79)	200	441	3.6
Others (1978)	100	220	1.8
Subtotal	659	1452	11.8
Freshwater			
Carp, tilapia, others (1978)	2528	5573	44.9
Subtotal	2528	5573	44.9
Molluscs			
Oysters (1975)	652	1437	11.6
Mussels (1975)	591	1303	10.5
Clams, scallops, cockles, other molluscs (1975)	132	291	2.3
Subtotal	1375	3031	24.4
Crustaceans			
Shrimp and prawns (1975)	16	35	0.3
Subtotal	16	35	0.3
Seaweeds (1975)	1055	2326	18.7
Subtotal	1055	2326	18.7
Total	5633	12417	100.0

[1] Excluding sport, bait, ornamental fish, and pearls.
Source: Ryther, J. H. 1981. Mariculture, ocean ranching and other culture-based fisheries. BioScience 31(3):223-230.

More than one-third of the estimated production of cultured products consists of finfish raised by about a dozen countries in Southeast Asia and the Pacific. Most of this production consists of various species of carp and tilapia reared by low-technology methods in freshwater ponds and species such as mullet and milkfish raised in saltwater ponds along coastal areas.

In the U.S., aquatic plants are used primarily to produce extracts used as emulsifiers and stabilizers for industrial purposes. In Asia, aquatic plants are also of great importance as food. More than 1 million metric tons are produced annually through aquaculture in Japan, China, and Korea; seaweeds are also grown extensively in tropical waters around Singapore, the Philippines, and elsewhere.

There has been a world wide expansion of aquaculture over the past 15 years. In 1966,[1] a rough estimate of world aquaculture production was given as 1 million metric tons. A partial estimate based on 36 countries in 1972[2] showed a production of 2.6 million metric tons, and about 6 million metric tons in 1975. The latest estimate is over 9 million metric tons in 1979. These figures probably reflect both increased production and more complete reporting methods. Pillay[3] projected a fivefold increase by the year 2000, whereas Brown,[4] taking a more conservative approach, predicted that output would increase 3 to 3.5 times by the turn of the century.

U.S. Status

Except for a limited number of marine and freshwater species, rapid development of private aquaculture in the U.S. and its territories has not occurred as rapidly as some would like to see. Scientific and technological obstacles remain, but the primary constraints to the rapid expansion of aquaculture production are political,

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[1] U.S. President's Science Advisory Committee. Panel on the World Food Supply. 1967. The world food: a report. Vol. II. U.S. Government Printing Office, Washington, DC.

[2] Pillay, T. V. R. 1972. Problems and priorities in aquacultural development. Progress in Fishery and Food Science. University of Washington Publication Fisheries (New Series) 5:203-208.

3 Pillay, T. V. R. 1976. The state of aquaculture 1976. Paper presented at FAO Technical Conference on Aquaculture, Kyoto, Japan. 26 May-2 June 1976.

[4] Brown, E.E. 1977. World fish farming: cultivation and economics. The Avi Publishing Company, Inc., Westport, Connecticut. 397 p.

administrative, and economic.[1] The constraints include competition for land and water areas and markets, regulations on Federal, State, territorial, and local levels, inadequate transfer of information and technical assistance, and uncertainty about profitability. Coordinated and successful action to overcome these barriers has been lacking. Major impediments are detailed in Chapter 3 and the individual species plans presented in Volume II.

In spite of these barriers, private aquaculture accounts for a significant portion of the supply of some species in the U.S. (Table 2). Private aquaculture produces over 40 percent of our oysters, most of our catfish and crawfish, nearly all of our rainbow trout, and small quantities of several other species. Total harvest of edible fish and shellfish in 1982 was 1,500,000 metric tons (3.3 billion pounds), of which about 179,500 metric tons (395 million pounds), or about 11 percent of the total, was produced by aquaculture.

Emphasis in the U.S. private aquaculture sector has been on the culture of high-value species, with little commercial activity on the culture of low-cost fishes such as carp, buffalofish, tilapia, or mullet. However, these species are of considerable interest to the U.S. territories. Some experimental studies are being conducted by Federal, State, university, and private concerns on the culture of these and other species.

In addition to private aquaculture in the U.S., Federal and State governments have extensive hatchery programs for the production and stocking of fingerlings in lakes and streams. Benefits of these programs are enjoyed by both commercial and recreational fishermen. Species produced include Pacific salmon (pink, chum, sockeye, coho, and chinook), Atlantic salmon, steelhead trout, several species of sunfish, striped bass, channel catfish, largemouth and smallmouth bass, northern pike, muskellunge, walleye, and eight species of nonanadromous salmonids. Public releases involve massive numbers of fry, fingerlings, and catchable-size fish from Federal and State hatcheries. For example, 620 million small salmon and steelhead trout were released on the Pacific Coast in 1982, 6 million largemouth bass fingerlings were released in ponds and reservoirs in 1982, and 40 million striped bass fingerlings were released in reservoirs and coastal rivers in 1982. The current

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[1] National Research Council. Committee on Aquaculture. 1978. Aquaculture in the United States: constraints and opportunities: a report of the Committee on Aquaculture, Board on Agriculture and Renewable Resources, Commission on Natural Resources, National Research Council. National Academy of Sciences, Washington, DC. 123 p.

Table 2.

U. S. Private Aquaculture Production[1] for 1980 and Preliminary Data for 1982

Species groups	Value (1000 dollars)		Metric tons		Thousands of pounds		Percent of total	
	1980	1982	1980	1982	1980	1982	1980	1982
Baitfish	44,000	100,000	10,000	15,000	22,046	33,069[2]	10.7	8.4
Catfish	53,572	120,000	34,855	90,909	76,842	200,419[2]	37.2	50.7
Clams	10,398	12,000	1,777	2,045	3,917	4,508	1.9	1.1
Crawfish	12,951	27,000	10,849	25,000	23,917	55,115	11.6	13.9
Freshwater prawns	1,200	1,800	136	182	300	400[2]	0.1	0.1
Mussels	NA	1,600	NA	773	NA	1,700	-	0.4
Oysters	37,085	34,000	10,775	9,878	23,755	21,777	11.5	5.5
Pacific salmon	3,400[3]	4,000[3]	3,455	11,587	7,616[4]	25,544[4]	3.7	6.5
Tropical fish	NA	20,000	NA	NA	NA	NA	-	-
Trout	37,474	48,000	21,836	21,818	48,141	48,100	23.3	12.2
Other species[5]	NA	5,000	NA	2,273	NA	5,000	-	1.2
Total	200,080	373,400	93,683	179,465	206,533	395,632	100.0	100.0

[1] Data shown are live weight harvests for consumption, except for oysters, clams and mussels which are meat weight. Excluded are eggs, fingerlings, etc., which are an intermediate product level.

[2] Projected estimated production for 1983.

[3] Pen-rearing only; ocean ranching returns are currently used for broodstock.

[4] Includes pen-reared and ocean ranched salmon.

[5] Includes species such as sturgeon, paddlefish, carp, buffalo, tilapia, mullet, abalone, etc.

contribution of public hatcheries to commercial and sport salmon fisheries is estimated to be 40 percent for chinook, 45 percent for coho, and 5 percent for chum. An evaluation of the recoveries and returns for fall chinook salmon released from Columbia River hatcheries in the years 1963 through 1969 showed a return of $4.20 for each dollar spent.[1] A similar study on coho salmon releases for 1967 and 1968 resulted in a benefit-to-cost ratio of 7 to 1.[1] The following represents a best-guess estimate by species of commercial investment in aquaculture and production facilities:

Baitfish

In 1978 a Soil Conservation Service survey of the United States mainland found about 1,544 baitfish farms in operation on 17,576 hectares (43,940 acres). The average operation involved 17.6 hectares (44 acres) and produced 9,900 kilograms (21,780 pounds) of baitfish per year. Total production in 1980 was estimated to be 22 million pounds. Preliminary 1983 data indicates production will be 33 million pounds valued at $100 million. It is estimated that over $100 million is invested in baitfish enterprises.

Catfish

In a 1980 survey, farm-raised food size catfish production totalled 34,855 metric tons (76.8 million pounds). Fifteen leading States surveyed in 1981 had 1,069 commercial operations with a total production hectarage of 27,900 ha (68,941 acres). Total investment in the U.S. catfish industry is estimated to be more than $400 million. Preliminary data for 1983 indicates a crop value of $120 million and a total production of 200 million pounds.

Crawfish

Current estimates are that crawfish farmers operate on about 115,000 acres with an investment of over $100 million. In addition, there are approximately 40 licensed processing plants in the State of Louisiana. Crawfish farming is a rapidly expanding industry in Louisiana and in other nearby States, particularly Mississippi and Texas. In 1980 production was 23.9 million pounds. It is anticipated that production will increase to 55 million pounds in 1982, with a farm value of $27 million.

Freshwater prawns

A number of firms have locations and investments as follows: 20 in Hawaii average $50,000 to $100,000 each, or a total of about $1.8

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[1] Columbia River Fisheries Development Program. 1981. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Washington, DC. 34 pp.

million; 12 in Guam, $500,000 combined; one in California, $600,000 and one in Puerto Rico. Pilot projects are underway in several mainland States.

Hard Clams

Fifteen companies are engaged at present in hard clam culture. Seven to eight companies raise clams along with other species. Production of marketable-sized littleneck clams totals about 2 million, annually. Investment figures are unknown.

Largemouth bass

Most bass are produced by Federal and State hatcheries. For example, Federal hatcheries produced over 6 million fingerlings in 1982. Investment data for commercial production of largemouth bass are unavailable, but are estimated to be about $10 million.

Mussels

Less than 10 firms currently produce mussels in U.S. waters. Nearly all are located in New England. Production in 1982 was about 773 metric tons (1.7 million pounds) meat weight, and appears to be expanding.

Oysters

Although the production of oysters through aquaculture is significant (some 9,878 metric tons or 21.7 million pounds valued at $34 million in 1982), little information is available on the commercial investment by the industry. In a recent survey of the Northeastern United States, some 257 shellfish businesses were identified from Maine to Virginia. In the Gulf Coast area, some 1,424 individual lease tracts in Louisiana alone have been identified covering some 93,389 ha (230,760 acres). The west coast States also support a very significant oyster culture industry based on the Pacific oyster (Crassostrea gigas). To add to the complexity of the situation, there are approximately a dozen hatcheries which produce both clam and oyster seed; some are operational for self-sufficiency, others produce seed as a market product.

Penaeid Shrimp

There are successful shrimp farms in Latin America due to ease of obtaining year-round supplies of larvae, coastal land accessibility, and lack of stringent permitting and regulatory requirements. Many of these farms are utilizing U.S. financing. U.S. based companies, especially in Texas, appear to be on the verge of commercial success. It is estimated that some $44 million in U.S. funds has been spent on ponds and facilities both here and abroad.

Pacific Salmon

There are over 25 active projects in commercial salmon culture, including at least 7 in Oregon, 6 in Washington, 17 in Alaska, and 1 in California. One Oregon company has invested $15 million in capital assets; several others have invested at least $4 million combined. Projects operated by Native Americans in Washington and Alaska represent at least $15 million in Federal funds. A firm in the State of Washington has invested $5 million. Another company in California has invested $400,000. Two Alaskan projects represent $2.5 million, each. Interest in salmon culture in New England is growing as rapidly as it is in Alaska. An active pink and chum salmon ranching program exists in Maine. Preliminary data for 1982 suggests total production of food size salmon will approach 25.5 million pounds for pen reared and ocean ranched salmon.

Striped bass

Culture of striped bass by State and National fish hatcheries reached a production level of over 40 million in 1982. At least three or four private efforts exist with more in the planning stages. Current investment figures are not available.

Trout

Few substantive data exist to indicate private sector investment in trout culture. However, in 1981, about 250 private facilities in 14 surveyed States raised trout. These operations produced an estimated 48 million pounds of food-sized fish. Facility costs have been estimated at $3.30 to $22 per kilogram ($1.50 to $10 per pound) of trout produced annually. Capital investment in the production segment--public and private--is estimated to be between $64 and $430 million. Preliminary production and crop value figures for 1982 are reported to be 48 million pounds and $48 million, respectively.

Abalone

Three hatcheries in California and Hawaii have invested a total of $4 to $10 million. Current research and development activities for commercial production look promising.

Tropical aquarium fishes

A great demand exists for colorful fish and invertebrates for aquariums. This trade, centered in Florida and including both marine and freshwater fishes, grosses an estimated $200 million annually at the retail level. In Florida alone, 220 to 250 tropical fish farms are producing about 100 species of ornamental fish.

Unpredictable wild-stock supplies and future import restrictions may stimulate rapid development of culture techniques for aquarium fishes. Although detailed economic data on production are lacking, the profitable freshwater segment of this industry apparently deals effectively with its problems. Culture of marine ornamentals still faces difficulties, and as a result, 80 to 90 percent of the marine tropical fish sold in the U.S. are imported. Potential exists for further development of this type of culture.

CHAPTER 2
CURRENT TECHNOLOGIES

This chapter contains an overview of technologies employed by aquaculturists in the U.S. Subject areas include: production methods, genetics and reproduction, nutrition and diets, water and waste management, control of problem organisms, harvesting, transportation, and processing and marketing. For greater detail the reader should consult the individual species plans in Volume II.

Production Methods

Pond Culture of Freshwater Finfish

In the U.S., ponds are the most commonly used facilities for fish culture. The size, shape, and depth of ponds can vary considerably. Regardless of these factors, it is desirable to have ponds that are easy to harvest, drain, and refill rapidly and completely.

Many species of fish lend themselves well to pond culture. Some may be coldwater species such as trout, char, or salmon; they may be coolwater species such as walleye, perch, muskellunge, or northern pike, or they may be warmwater species such as carp, catfish, tilapia, and many others.

Most pond culture in the United States is monoculture in nature--one species of fish is reared in each pond. However, some polyculture is also practiced--two or more species being reared in the same pond simultaneously. An example of this type of culture is the rearing of tilapia or buffalofish with catfish. Catfish are fed pelleted diets while the other species eat the wasted feed, algae, and zooplankton.

Early pond culture was a form of extensive culture. Generally, broodstock were placed in a pond and allowed to spawn naturally. A minimum amount of supplemental feed was provided and a minimum amount of fertilizer was added to the ponds to generate food for the young. At the end of the growing season the pond was emptied and the remaining fish, usually a modest amount, were harvested.

Intensive culture requires that broodstock be held in separate ponds, be spawned artificially, and the young, in large numbers, be placed in special rearing ponds. They are fed to promote fast growth and then are periodically harvested. A comparison of yields is quite dramatic. Extensive pond culture production ranges from 1,684 to 2,245 kilograms per hectare (1500 to 2000 pounds per acre). Under intensive methods, annual yields may be 5,600 kilograms per hectare (5000 pounds per acre) or higher.

Raceways, Silos, and Circular Pools

Raceways, silos, and circular pools constructed of cement, fiberglass, or metal are examples of intensive cultural systems. They are easy to clean, do not require large tracts of land, and are not prone to heavy growth of aquatic vegetation.

Most trout and salmon in the U.S. are reared in raceways. Raceways are usually rectangular in shape and longer than they are wide. They are usually placed end-to-end in series with water flowing from one into another. Circular pools are typically shallow and have a center drain. Silos are very deep; circular pools are constructed above ground or are partially buried in the ground.

Closed Systems

Intensive cultural systems require large amounts of water and are usually open, flow-through systems. The water flows through each pool one time only. It may flow through one or more successive pools, but then it is discharged to a drainage ditch, creek, or river following settling of sediments in a settling basin.

In a closed system, the water is reused after it is treated. It must have all settleable solids and dissolved wastes removed, it must be re-aerated, and in some instances disinfected.

Closed systems are costly and difficult to construct, operate, and maintain. However, with water becoming a more valuable commodity and with pumping costs increasing, it is becoming more popular to investigate reuse of water. Refinements in reuse systems are expected and it is anticipated their use will increase with time.

Cage and Pen Culture

Cage and pen culture are essentially the same. The basic difference is in the size of the enclosure. Generally speaking, cage culture is practiced in freshwater, whereas pen culture is practiced in marine waters. Cages and pens lend themselves well to bodies of water which cannot be drained or otherwise manipulated to facilitate harvesting.

Cages are generally rafted two abreast and are worked from a boat. Pens can be rafted four or more abreast. There are generally walkways between rafts of pens and a serviceway the length of the pens. Both cages and pens must be anchored in locations that allow sufficient space between the bottom of the container and the bottom of the stream, lake, or bay to allow wastes to settle out of the enclosures.

Species reared using these techniques include catfish, trout, salmon, and many others. In some instances, cages have been double-cropped with catfish being reared during the warmer, summer months and trout during the cooler fall and winter months. The State of Arkansas has an arrangement with commercial producers who lease or rent space in public reservoirs for cage culture with the agreement that a certain percentage of the fish be released within the reservoirs. The pen culture of salmon on the Northwest Coast of the U. S. is growing rapidly. Cage and pen culture will play an increasingly large role in aquaculture.

Sea Ranching

Sea or ocean ranching involves the release of immature fish to the wild and the recapture of the fish when they return as adults. Currently, only anadromous species such as salmon and striped bass are being used for sea ranching. Private individuals and corporations culture salmon from the egg to the smoltification stage (smoltification is a physiological process that young fish undergo to prepare them for migration to the sea). At smoltification, the young are released and migrate to sea where they feed and grow to maturity. Maturation is the stimulus for the adult fish to return to their release point, where they are then harvested.

Usually less than 3 percent of all sea-ranched salmon are recaptured by those who released them. Commercial and sport fishermen catch many of them. One advantage to this method of culture, however, is that the expense of long-term feeding is avoided. Sea-ranching is legal in Oregon, California, Maine, and Alaska, but not in Washington, with the exception of some Native American activities.

Culture Systems for Shellfish

Most shellfish species have suffered dramatic population reductions in the past 15 to 30 years because of environmental degradation from toxic wastes, sedimentation, overharvesting, dredging, and channelization. Shellfish cultivation is beginning to reverse this trend. Long-term problems with hatchery production and artificial rearing of larval molluscs appear to have been solved. Techniques for the setting of oyster spat (young oysters) on suitable substrate have been greatly improved. Certain States require that shells from commercially harvested oysters be returned to the marine environment. The shells serve as substrates on which spat adhere and grow to a harvestable size.

Mussel culture in the U.S. on both the east and west coasts is centered on the blue mussel (Mytilus edulis). Most commercial producers are using suspended culture systems (long lines suspended from rafts).

In California, juvenile abalone (Haliotis sp.) are either stocked in natural habitats as part of an enhancement program or reared commercially in tanks. The time required to reach market size ranges from 2 to 7 or more years, depending upon species, water temperature, and feeding rates.

Hatchery techniques for clams are generally available for both commercial production and for planting (enhancement) programs to increase clam populations for recreational harvest. Grow out systems for bay scallops in natural bodies of water using various net and cage designs are approaching commercial stages. Off-bottom culture techniques which eliminate most predators and enhance growth, have only recently begun to be used in the U.S.

Crustaceans

Crawfish are reared commercially in extensive pond culture systems either in conjunction with rice farming or separately. Crawfish culture is rapidly expanding in Louisiana, Texas and Mississippi. The States are implementing their own crawfish industries.

Culture of the giant freshwater Malaysian prawn (*Macrobrachium rosenbergii*) is an emerging industry that is developing quite rapidly as well, especially in Hawaii. Most operations currently use extensive techniques in ponds, but some are experimenting with more intensive culture systems. The Malaysian prawn reproduces readily in capitivity. The larvae require brackish waters while the adults grow successfully in freshwater.

Commercial shrimp (*Penaeus* sp.) culture in the United States is basically at the pilot project level. However, successes in Japan and Latin America indicate that shrimp have good aquaculture potential. Most shrimp are cultured in large earthern ponds, but raceways are showing some promise. Major constraints for shrimp culture in the United States include inadequate control of reproduction and a short, growing season.

Culture Systems for Other Aquatic Organisms

There are many aquatic organisms that lend themselves to possible commercial production or cultivation. Certain seaweeds possess economic value as food items or as food additives. Many Asian countries have farmed kelp and other aquatic plants as food items for years. Large kelp beds grow naturally and are harvested off the coast of California. Studies have shown that kelp can be commercially produced by planting certain regenerative portions of the plant and harvesting it when mature. Other studies are exploring the potential of growing marine and freshwater plants for use as new material for biomass energy conversion.

Attempts are being made to culture some threatened or endangered aquatic species. For example, the state of the art has progressed to the point where artificially hatched and released sea turtles are now returning to beaches as adults to lay eggs. After alligators were placed on the endangered species list, methods of cultivating them were developed. Now, commercial alligator farms are supplying the market with meat and hides. As many as 13 alligator farms are producing about 1,000 animals per year.

Some progress has been made in bullfrog culture and a few small-scale frog farms do exist in the southeastern States. However, several cultural problems remain to be solved to make frog rearing a reliable and lucrative endeavor.

Rotation with Arable Crops

Several combinations of rotating arable crops with aquatic crops are now being practiced. As previously mentioned, crawfish in Louisiana are reared in rotation with rice crops. Rice is sown, grown, and harvested. Following harvest, the land is reflooded and seeded with crawfish. The crawfish feed on the rice straw and wastes and are harvested the following winter or early spring.

Catfish are sometimes combined with rice or soybeans on a rotation program. Nitrogenous waste products produced during catfish production serve as a source of fertilizer. Rotation can reduce the need for fertilizers, resulting in increased profits.

Use of Geothermal Springs, Waste Heat, and Waste Water

Geothermal (hot) springs have been used for fish farming for several years. A number of companies are experimenting with using warm cooling water from pulp and paper mills, steam plants, and atomic generating plants for aquaculture. The heated effluent can be used directly or mixed with cooler water sources to obtain optimum growth temperatures. Catfish, trout, salmon, carp, shellfish, tilapia, and other species have been successfully reared using water from these sources.

One of the largest salmon hatcheries in the world (a private hatchery located in Oregon), uses cooling water from a pulp and paper mill to double the growth rate of young salmon for release in a commercial ocean ranching program.

Using fish, shellfish, or aquatic plants to help remove organic or inorganic pollutants from wastewater and then harvesting the resulting crop is also practical in some areas. Effluent ponds of wastewater from municipal, industrial, agricultural, and even aquacultural sources can be high in nitrogen and phosphorous, two of the primary elements in the plankton food chain. This type of water develops excellent plankton blooms for filter feeding fish. In some areas, walleye, northern pike, or muskellunge fry have been stocked in effluent ponds for growth to a stockable size. Bait minnows also show good promise for this type of culture.

Other Production Methods

Recently there has been a great deal of interest in home fish farming for family consumption. The use of small ponds or plastic swimming pools as fish rearing facilities for personal use is becoming popular. With the development of effective and economical filters to remove organic wastes from the water, home fish farming may increase further in popularity. Small-scale mollusc culture under piers and in salt and brackish water ponds at the edge of the sea also has potential.

Genetics and Reproduction

Warmwater and Coolwater Finfish

Most warm and coolwater fish are produced by natural spawning in ponds. With some species, the broodfish are removed after spawning to keep them from eating the fry, to facilitate handling small fish, and to reduce competition. Channel catfish egg masses are usually collected from spawning containers in a pond and then moved to a hatchery incubation facility.

Hormone injection of broodfish to induce spawning is practical for some species. Striped bass broodfish are usually captured from rivers or lakes just prior to spawning, injected with hormones, and artificially spawned in a hatchery. This technique has also been successfully used to produce hybrid crosses of normally incompatible species. Sex steroids and hybrid crosses are also being evaluated for their potential to produce monosex or infertile fish populations. These methods promote more rapid growth rates and prevent animals that might escape to the wild from spawning and overpopulating to the detriment of indigenous species.

Coldwater Finfish (Salmonids)

Nonanadromous salmonids, such as trout, have been cultured in this country longer than has any other aquaculture species and their life histories are well understood. The rainbow trout is the most important species reared for sport fishing purposes. Strains and hybrids have been selectively developed for enhanced growth, disease resistance, age and season of sexual maturity, body color, and adaptation to hatchery conditions. Additional research will be required to understand and control sexual maturity, to produce monosex fish, and to develop methods for determining the sex of young trout.

Genetic research on anadromous salmonids has been directed at improving disease resistance, growth, and maximizing returns to freshwater. Additional research is needed to characterize strain differences, to assess the genetic composition of different spawning runs, to insure identification and protection of wild stocks, and to maintain a diverse genetic pool.

Marine Finfish

Spawning requirements have been determined in the U.S. for very few marine finfish. Anadromous and estuarine species are more adaptable to the aquaculture environment. Most marine finfish cultured today are captured from the wild and reared in coastal saltwater ponds.

A successful sturgeon fishery has been established in the Soviet Union by injecting hormones into broodfish that are captured during their spawning migrations. Hybrid sturgeon with improved growth rates have been produced. Research is now underway to culture sturgeon in the U.S.

Mullet, rabbitfish, and milkfish, three of the most important species for marine aquaculture in Asia, have only recently been spawned in captivity in the U.S. Genetic information is sparse and there are no established broodfish lines of marine finfish. Pompano, black and red drum, mahimahi (dolphin fish), and a few other species have been captured from the wild and spawned by using combinations of temperature and photoperiod control and hormone injections.

Molluscs

Oysters and clams are the only molluscs for which significant commercial hatchery techniques have been developed. Oysters can be spawned at any season of the year by manipulating temperature. Limited selective breeding has been conducted to produce strains with faster growth rates and increased disease resistance. Additional research will be required to quantify the genetic variation found in wild oyster populations and to assess their potential for aquaculture. Clams and mussels have been spawned using techniques similar to those used for oysters. A few hybrids have been produced but our knowledge of genetics on these species is very limited. Abalone and bay scallops are other molluscs which have aquaculture potential. Breeding and culture techniques for these species are being developed.

Crustaceans

Marine shrimp, freshwater prawns, and crawfish are currently of greatest importance in crustacean aquaculture. They can be spawned under hatchery conditions; however, there are few, if any, commercial aquaculture operations which rear and maintain genetically improved broodstock. Most broodstock consists of captured wild animals. In the case of crawfish, reproduction occurs naturally in ponds. Because of their relatively simple life cycles, crawfish are more easily cultured than shrimp or prawns.

Photoperiod and temperature control plus endocrinological manipulations have been used experimentally to induce sexual maturation and spawning in crustaceans. These and other culture techniques must be refined to produce seed stock reliably on demand. Genetic research is needed to define strain characteristics of cultured crustacean stocks, to improve growth rates, increase disease resistance, and reduce aggression and cannibalism. Lobsters and crabs are particularly aggressive and cannibalistic, making viable commercial culture difficult. These two valuable crustaceans are not yet cultured economically.

Other Organisms

Additional species which have interested aquaculturists include eels, frogs, alligators, marine baitworms, and aquatic plants. Eel culture is still dependent upon the capture of elvers (juvenile eels). Techniques to induce maturation and spawning have not yet been developed. Frogs, alligators, and turtles are not conventional aquaculture species, but are being cultured on a limited basis under controlled conditions. Not all breeding and rearing problems have been solved and essentially no work has been done to characterize genetic traits which would be valuable to aquaculturists. Culture techniques for marine baitworms have only recently been developed and further refinement would be expected only if commercial production were to begin.

Several species of freshwater and marine aquatic plants are cultured commercially in various parts of the world. Culture techniques range from simply fertilizing and seeding tanks or ponds with single cell algae or higher vascular plants, to the more complex culture of red and brown marine algae. Marine algae may be cultured on the seabed but more frequently are cultured on floating or hanging support structures. Most breeding and culture techniques in the U.S. are still rather primitive.

Nutrition and Diets

Natural Foods

Most aquatic animals require living organisms for food during some stage of their life cycle and a few species require living organisms throughout their entire life. Some species will feed only on moving organisms, which indicates that the requirement for living organisms in their diet is more behavioral than nutritional.

Natural foods include bacteria, algae, protozoans, zooplankton, other macroinvertebrates, and larger forage animals. Fertilizers are commonly used to stimulate the production of these natural organisms. However, the species composition of fish food organisms is difficult to control, and physical influences, such as temperature, dissolved oxygen, and light intensity may affect the standing crop. Particular care must be taken to limit the growth rate of some organisms since they may become too large to be consumed by the cultured animals, may become predators on the cultured animals, or may compete with them for other natural food organisms.

Other unprocessed fish foods include organ meats such as liver, kidney, and heart, cut fish, and various forms of organic detritus. The latter, resulting from the culture of other aquatic organisms, is the preferred feed for some fish species, molluscs, and crustaceans. Organ meats and cut fish are fed generally to large finfishes, but are expensive.

Formulated Feeds

Formulated feeds are widely used in intensive production systems and are of two general types: complete and supplemental. Complete feed formulations contain all the dietary nutrients needed for growth and reproduction. They are used in raceways, circular pools, silos, and high intensity production earthen ponds where natural foods are not available, or are present in insufficient amounts to meet the needs of the organisms.

Supplemental feeds are usually fed in low-intensity production systems. They contain the most important growth nutrients in the culture system--usually protein and energy. Natural foods are relied upon to balance the diet.

Fish feed formulations can be manufactured into meals, flakes, and sinking or floating pellets, or moist pellets. The type of formulation fed depends on the size and the feeding behavior of the aquatic animal being cultured. The efficiency of conversion of feed protein into fish flesh depends on how closely the feed formulation meets the nutritional requirement of the species being cultured, the quality of the ingredients, their resistance to leaching or disintegration in water, storage characteristics, and feeding practices.

Considerable information exists on the nutritional requirements of only a few aquatic animals. Research is needed on the individual requirements of most aquatic animals in order to determine the standard for a "healthy" animal and to increase profitability.

Effluent Control and Water Availability

Ponds

Ponds are normally built on level land by constructing earthen dikes from the excavated bottom area. They are usually filled by pumping water from wells or irrigation canals. Ponds in hilly areas are formed by constructing earthen dams to contain water in natural basins and are often filled by springs or rainfall run-off.

The source of inflow water greatly influences water quality. Surface waters may contain wild fish, pathogens, and toxic pollutants from agricultural run-off and industrial discharges. Well water is usually low in oxygen and may contain undesirable levels of nitrogen, ammonia, carbon dioxide, sulfur, sulfides, or dissolved metals. However, it appears that maintaining an adequate level of dissolved oxygen is usually the major water quality problem in ponds.

Ponds require vastly different approaches to maintain water quality and successfully manage the resultant effluents, depending upon their size and the kind of aquatic animal being raised in them. In smaller ponds, water quality may be quickly improved by draining and re-filling with fresh water. In larger ponds it is sometimes necessary to use various aeration devices. These devices agitate the surface, spray water into the air, or otherwise increase the transfer of oxygen from air to water.

In some cases, pond effluents may be of higher quality than receiving waters since the majority of waste materials are retained on the pond bottom. Because of the relatively good quality of effluent from ponds, usually little or no treatment is required before discharge into receiving waters.

Raceways and Intensive Culture Systems

For many intensively cultured species, water quality, not physical space, limits the number of animals that can be reared in a raceway or similar system. Water must be continuously added to flush away wastes and to maintain a quality environment.

Water usually flows through raceways by gravity. However, in some raceways, effluents from downstream sections are pumped back upstream and reused. The effluent may first be improved by aeration, filtration, sedimentation, ozonation, or a combination of these and other processes before recycling. In single pass raceways, where water is used only once before being discharged, incoming water quality depends on the source.

Effluent quality from intensive systems is a function of the number and size of fish or other organisms, the feeding rate, and water flow rate.

Cages and Pens

Aquatic organisms may be confined at very high densities in cages or pens placed in ponds, lakes, rivers, and estuaries. Mollusc cages may be suspended from piers, long lines, or rafts. Water quality within cages and pens depends primarily upon both the quality of water in the surrounding area and the rate of exchange by circulation through these aquaculture units. Cages and other devices placed in estuarine areas with tidal flows are flushed by tidal action. In lakes and ponds the swimming and feeding activity of fish cultured in the cages, and of wild fish around the cages, can generate sufficient water movement to permit water exchange in cages. Wind-generated waves also help to circulate and exchange water around cages and pens placed in ponds and lakes with little or no natural current.

Cages placed in rivers or industrial effluents take advantage of the flowing water to remove wastes. It is usually not necessary for water quality to be further manipulated; however, cages, rafts, and other off-bottom systems may be moved from one site to another to take advantage of better environmental conditions. For example, caged fish cultured in the intake canal of a power plant during the spring and summer may be moved to the discharge canal to take advantage of the thermal effluent during the fall and winter.

Factors which may seasonally alter water quality--for example, nitrogen gas supersaturation in thermal effluents, agricultural run-off, industrial discharges, and reservoir drawdown for irrigation or flood control--must be understood by the aquaculturist prior to placing cages or pens in a body of water.

Other Systems

Silos or deep cylindrical tanks are similar in operation to horizontal raceways. Water is exchanged at a rapid rate to maintain adequate oxygen levels and to remove waste products. Water quality in silos is usually no better than that of the incoming water; however, dissolved oxygen may be increased by aeration and agitation, or in some units by the addition of gaseous or liquid oxygen. Silos may be constructed with sediment basins to remove solid waste before water is discharged.

In polyculture systems the waste produced from one cultured species may be used as a food source by another species. Aquaculture systems may be further integrated with both aquatic and terrestrial animals and plants. For example, wastes discharged from aquaculture production units or sediment basins may be applied to agricultural cropland, or used to support the hydroponic culture of high-value terrestrial plants. Wastes from agricultural operations may serve as food supplements in certain aquaculture systems.

Hatchery systems for the production of fry and larvae or other seedstock may use elaborate processes including aeration, filtration, treatments with ultraviolet light and ozone to maintain or adjust water quality. Discharges from these systems are frequently of higher quality than the receiving waters. Water quality can be more easily and economically manipulated in small systems used for fry production than in larger systems used for production of food fish. Equipment failure and system mismanagement are two of the greater risks encountered in intensive culture and water reuse systems.

Control of Problem Organisms

Infectious Diseases and Parasites

All animal populations are affected to some degree by infectious organisms and parasites. The incidence of infection is increased by high concentrations of fish in intensive production monoculture systems and the stresses resulting from water quality deterioration. High fish populations and high feeding levels bring about a decline in water quality which, in turn, result in animal stress and the incidence of diseases and parasites which would be only minimally or moderately troublesome in natural or semi-intensive production systems.

The preferred method of controlling disease is to prevent it by simple sanitation and disinfection of equipment and culture facilities and reduction of stress on the animals by maintenance of good water quality, provision of adequate feeds, and use of non-stressful handling, holding, and transportation techniques. Acceptable techniques are generally available but improvements are needed.

Occasionally, infectious diseases and parasites do become a problem and an appropriate chemical or drug treatment must be applied. Some disease organisms are easily and economically controlled or eliminated, but others are impossible to control with current techniques.

Aquatic Vegetation

Aquatic vegetation includes submerged, emergent, rooted, and free-floating forms, and constitutes many hundreds of species. Some forms of vegetation may be beneficial to aquatic animals for spawning media, protection, or food. However, the same species of plant can adversely affect the growth of aquatic animals through competition. Aquatic vegetation can be controlled by chemical, mechanical, or biological methods. The selection of the appropriate method is based on the characteristics of the production system, the characteristics of the undesirable plant, economic considerations, and environmental constraints.

In aquaculture, the preferred methods of controlling vegetation is to construct the facility to inhibit plant growth or to maintain plant-eating animals. Chemical control is the only practical method of vegetation control in some production systems. However, relatively few chemicals are registered for aquatic use. Mechanical control is employed only in exceptional cases, due to labor costs and limited benefit.

Competitors and Predators

Competitors are not uncommon in culture systems and include microorganisms and higher forms of plants and animals. However, a plant or animal that may be a competitor for one cultured species could be a beneficial source of food or protection for another. Predators, on the other hand, are generally more easily identified, and include some zooplankton, insects, crustaceans, fishes, reptiles, mammals, and birds. Some animals may be predatory on a cultured species for only a portion of the life cycle -- for example, during juvenile stages.

Effective and economical techniques exist for controlling some predators. However, for others it is difficult to control or eliminate the predator without harming the cultured organism.

Harvesting

Ponds

Harvesting techniques employed in ponds depend on the size range of the animals, the intensity of production, and species cultured. Technology exists for harvesting most cultured aquatic animals. Some harvest systems, such as those used in intensive catfish pond culture, are well developed and modern. For other species, harvesting equipment and techniques need to be improved. Animals reared for recreational fishing have special handling and transporting requirements which are not readily adaptable to mechanized harvesting methods and thus will remain labor-intensive and expensive.

Raceways

Harvesting techniques for raceways are generally well developed. Some of this technology is not being used by the commercial industry or governmental agencies because of the cost of redesigning the present facilities to install various equipment items. The high labor costs of nonmechanized harvesting will encourage the inclusion of mechanized methods in future facility construction.

Cages and Pens

Harvesting is a major problem in cage and pen culture. Cages or pens are usually located away from land and access is provided by boat or barge. Pond and raceway harvesting techniques are unworkable in this setting. At present, most cage- and pen-reared fish must be dipped by hand and placed in containers--a labor-intensive operation. Another disadvantage is that net pens or cages do not permit partial or selective harvest.

Transportation

Transportation of aquatic animals serves several purposes: distribution to production systems for further growth, movement to processing plants to be prepared into food and by-products, or for stocking public waters or private fee-fishing waters. The techniques and equipment used depend on the purpose of the transport, the number of animals, their size and species, and the distance and transport time involved. Support systems for transporting live aquatic animals may be either open or closed. The simplest open system is a water-filled tank in which dissolved oxygen is maintained by compressed air, pure oxygen, or by agitators. These systems are further modified by adding water chillers (or heaters) and filters. Various chemicals, salts, and drugs may be added to maintain water quality and reduce stress on the animals.

The closed system is simply a plastic bag or other container filled with water and pure oxygen. The proper ratio of water to oxygen to fish load has been studied and is used successfully in practice. Salts, drugs, and other chemicals are also used to improve fish handling in transport. This system is usually used to transport relatively high-value animals over long distances.

Some species such as molluscs and crustaceans do not need water during transport and may be shipped merely by keeping them in a refrigerated environment.

Processing and Marketing

The processing and marketing of aquaculture products varies widely depending on the species and, to a lesser extent, on the geographic area. The infrastructure for processing and marketing is not well established for most species. Producers of cultured aquatic species often use standard commercial fisheries facilities and distribution networks.

CHAPTER 3
IMPEDIMENTS TO AQUACULTURE DEVELOPMENT

The general constraints to aquaculture, detailed on the following pages, may significantly affect the development and culture of any species. Specific constraints and recommended actions for particular species are addressed in individual species plans (Volume II).

Inadequate Assessment of Current Status

Adequate data on the size and production levels of operations for various species would be helpful in improving production efficiency and in estimating the amount of funds necessary for initiation of a commercial venture. This information would also be useful for predicting how much the industry could expand, based on present and projected market demands.

Information on current aquaculture research efforts by various governmental, academic, and industry groups would make it easier to direct resources to areas where they are most needed.

Aquaculture is one of the few food-producing industries where cultured animals may be in direct market competition with wild animals of the same species. Insufficient production and marketing information may create seasonal overabundances or erratic prices in the market.

To date, with the exception of Hawaii, no wide-scale, detailed assessment exists of land or water resources potentially available for aquaculture.

Knowledge, Economic and Legal Barriers

Life History and General Biology

For some species, lack of knowledge in this area limits an accurate assessment of their aquacultural potential. This deficiency restricts the producer's ability to control or manipulate factors (breeding, environment, nutrition, maturation, and metamorphosis) crucial to the success of large-scale culture.

Genetics and Reproduction

Without development of strains adapted to intensive culture, the potential productivity of a species may never be realized. Knowledge of how altered genetics affect indigenous stock and the genetic diversity of a species also needs to be gained.

In the culture of some species (for example, crawfish), operators harvest faster-growing individuals first, holding over the slower-growing animals to serve as broodstock. If differential growth is hereditary, this practice will produce smaller animals and result in lower production levels.

Knowledge of the genetic characteristics associated with economic traits is essential. Without knowledge of how to control and manipulate reproductive activities, year-round production of seed stock or fingerlings is difficult. Gene pool maintenance is also essential, if further advances in breeding are to be made.

Growth and Behavior

Growth rates and behavior largely determine the potential for culture and the manner of rearing a particular species. Information is needed about factors such as metamorphosis, optimal growth conditions, feeding behavior, and feed conversion efficiency.

The aggressive and cannibalistic character of some species, such as the American lobster (*Homarus americanus*) necessitates use of individual grow-out containers. The extra cost associated with maintaining animals individually represents a major drawback to the economic culture of animals with these behavioral characteristics.

Nutrition and Diets

Clinical techniques used in various fields of animal science for determining nutritional status have not been developed for important fish. Although data on nutrient requirements for salmonids have been used to formulate diets for other species of fish with reasonable success, there is a need to develop complete and inexpensive diets that meet the specific nutritional requirements of each species and to determine proper feeding levels. To complicate matters, nutritional requirements and diets vary for specific species during different stages of their life and reproductive cycles. Lack of a suitable diet to maintain larvae until they can eat processed foods is a serious drawback to the culture of several species. Agricultural and fisheries by-products also need to be examined for their feed value in aquacultural production.

Environmental Requirements

Minimal information is available about the environmental requirements (for example, oxygen, salinity, space, and temperature) of certain species at different stages in their life history. Such information must be obtained before the species can be raised commercially.

Facility Engineering, Construction, and Operation

Insufficient knowledge of fish stress tolerance, water chemistry, water quality and temperature control, optimal harvesting and processing techniques, and control of aquatic vegetation hampers the engineering, construction, and operation of new facilities. Costs associated with all phases of construction and maintenance are high.

State, territorial, and Federal laws regulate the discharge from aquaculture facilities. The industry considers the costs involved in meeting the requirements of these laws prohibitive and has urged the Environmental Protection Agency and State agencies to re-examine standards for aquaculture operations.

Control of Disease and Parasites

Trained personnel are lacking and scientific and technical knowledge are insufficient to adequately address disease detection, prevention, and treatment needs. Private aquaculturists often must rely on handbooks or leaflets to diagnose and treat disease problems and no diagnosis or a faulty diagnosis can easily lead to loss of the entire crop. Specialists are particularly lacking for molluscan and crustacean culture.

Disease detection is especially important when health certification is required for transportation (required by law in some States). Another problem is often the lack of on-site record-keeping or documentation of circumstances surrounding a disease problem.

One of the greatest hindrances to disease control is the lack of registered therapeutic compounds. Some drugs have been banned because of potential harmful side effects to humans or because they have not gone through the lengthy and expensive process of registration for aquaculture use. Pharmaceutical companies are unwilling to spend the funds required to register therapeutics, because their generic nature precludes patent protection and the aquaculture industry is a comparatively small market for their products.

At present, no effective registered drug treatments exist for viral diseases, many bacterial diseases, several internal protozoans, and some fungi. Immunization is not available against most pathogens. Operators often must rely for control on stock eradication, isolation, and facility disinfection for control of parasites and diseases.

Production of Seed Stock

A common practice in laboratory studies and small-scale production is to obtain seed stock or fingerlings by spawning wild, gravid females. This is impractical for large-scale commercial ventures or for those located at a considerable distance from sources of wild broodstock.

Location and capture of suitable wild broodstock frequently is difficult and expensive. Legal restrictions in many cases prevent commercial fish farmers from capturing broodstock. In other cases, permits or licenses are required. The aquaculturist usually has little expertise in the use of hormones or manipulation of temperature and light for controlled reproduction. The techniques of seed production for some species are known, but a supply of seed or broodstock may be unavailable. Ideally, domesticated broodstock should be available for each cultured species. In addition, a major problem in some species is the lack of immunological and other procedures to prevent disease during the fry-to-fingerling rearing period. Another problem is the cost and availability of natural foods for those finfish that produce eggs and larvae for which no adequate formulated feed exists. Solutions to these problems are needed, since a dependable supply of seed and fingerlings is vital to the operation of the industry.

Predation and Mortality

Predation is an especially serious problem in the culture of various marine molluscs and some freshwater species. Lack of suitable techniques for the control of predators represents a major constraint to production.

Mortality is also directly related to other factors such as poor water quality, disease, and the lack of appropriate food, particularly in larval stages. Water contaminated by various chemicals and pesticides can also be a cause of death.

Harvesting, Processing, and Distribution

Technical knowledge in these areas is lacking for some species. Even for some successfully cultured species, mechanized harvesting methods have not been developed. Also, differential growth necessitates harvesting larger animals without injuring the smaller ones being kept for further growth.

Technological advances must be made to improve water quality, oxygen supply, water cooling, and waste removal in long-haul trucks, ships, and planes, for the live-market trade. Also, there is a need for improved flash-freezing and storage techniques to lengthen shelf life.

Product Quality Control

Growing organisms in wastewater effluents and using nonregistered drugs for disease control may contaminate the final product with chemicals or harmful pathogens.

Off-flavor is sometimes a problem with cultured products. This can be caused by poorly formulated feeds, substandard water quality, blue-green algae blooms, pollution, and poor product storage techniques. To ensure the public of a high-quality product, grading standards are needed.

Introduction of Nonindigenous Species

A number of successful imports of nonindigenous aquatic animals into the U.S has occured in connection with aquaculture. For example, culture of the imported Malaysian prawn has developed rapidly in Hawaii and Guam and shows promise for expansion in other warm areas of the U.S. and its territories.

Another example has been large-scale development of the Pacific oyster (*Crassostrea gigas*) in the estuarine waters of Washington, Oregon, California, and to a lesser extent, Alaska.

However, uncontrolled movement of nonindigenous species from one area to another can transmit exotic disease and parasites to indigenous populations or cultured organisms. Introduction of the new species for aquaculture could impact the environment.

Disease organisms carried by transplanted aquatic species have included viruses, bacteria, and protozoans. Examples of accidental introduction of adverse species include the walking catfish, oyster drills, and the water hyacinth. Nevertheless, the record shows that under controlled conditions, certain species can be introduced to expand and develop aquaculture. Rules for control should be based on sound biological and ecological considerations.

Inadequate Pilot-Scale Testing and Demonstration Facilities

A deterrent to successful development of some aquaculture species is the lack of pilot testing and demonstration facilities to accomplish an orderly transition from laboratory research to commercial production. Such facilities are one of the most effective ways to transfer technology.

Limited research projects and demonstration facilities particularly hinder the commercialization of many marine species. In addition, some segments of aquaculture will be hampered unless prototype production systems can be tested for technical and economic feasibility.

Legal Constraints and High Start-Up Costs

A significant amount of U.S. effort in aquaculture is still in the research and early development stage. However, financial data are sufficiently available on scaled-up systems to be helpful in pinpointing some economic problems.

Few laws or regulations are designed specifically to promote or protect aquaculture. Many existing land-use restrictions and environmental regulations reduce economic incentives to aquaculture by creating lengthy and uncertain permit processes, adding to costs and delaying operations. For example, a report on the regulatory process in California indicated that up to 42 Federal, State, and local agency permits and licenses would be involved in the activities of a single aquaculture venture. Although many of these restrictions may be necessary, they need to be examined critically to avoid economically unjustified costs being imposed on aquaculture enterprises.

Fluctuating resource costs for land, water, and energy are periodic barriers to the development of aquaculture. It is hard to generalize how these costs will affect this industry as compared with their impact on other protein sources.

Naturally, the early stages of any industry will have higher costs than later stages, when the industry begins to adopt more efficient processes. With regard to aquaculture, this indicates the importance of government investment in aquaculture research, with its potential high-value, long-term payoff.

Inadequate Transfer of Information and Technical Assistance

Much of the technical information on aquaculture is potentially available to established or potential fish farmers from National and international sources and State and university advisory and Cooperative Extension Services. However, many who need this information and assistance are not aware of its existence or how it may be obtained. Proven educational and technical assistance delivery systems are in place, but their effectiveness could be significantly expanded by employment of more trained aquaculturists.

Workshops, short courses, clinics, demonstrations, publications, and on-site technical assistance are proven ways to get technical information to those who need it. Improvement and expansion of existing education and technical assistance delivery systems are needed to insure the orderly establishment and growth of successful aquaculture enterprises.

Multiple-Use Conflicts

Many activities and uses have already established claims to areas where aquaculture might develop. The competing activities are particularly acute in coastal areas and include fisheries, coastline residential and industrial development, aquatic recreation, and water-borne commerce. These uses interfere with the development of aquaculture by creating pressures to prevent the introduction of structures such as dikes, nets, pens, rafts, lines, and buoys.

Jurisdictional Overlap and Inadequate Coordination

Many Federal agencies and numerous State and local agencies have direct or indirect responsibility for U.S. aquaculture. The JSA will continue to make progress in coordinating these multiple activities.

Marketing

Preferences and biases exist for aquatic foods as they do for all other foods. A fish species considered to be a delicacy in one area may be regarded as undesirable in another.

Market development efforts may help to overcome some of these preferences. Consumer research in domestic and internal markets may help to identify high demand locations for a variety of species.

Shortage of Trained Aquaculture Workers

A major factor limiting the expansion of the aquaculture industry for certain species is the shortage of trained workers at the technical level. Professionals in aquaculture are needed at both undergraduate and graduate levels to teach, provide technical assistance, to conduct extension educational programs, and to work in all phases of the management of aquacultural enterprises. Academic programs should be multidisciplinary to prepare aquaculture professionals to be knowledgeable in such diverse areas as marketing, bioengineering, economics, business, and food processing.

There is also a shortage of trained aquacultural technicians because few vocational schools currently offer a curriculum in aquaculture. Such programs need to be developed with a strong emphasis on hands-on field training.

CHAPTER 4
EXISTING PROGRAMS

This chapter discusses existing Federal, State, territory, and university programs related to aquaculture. The functions currently performed by the various agencies are described.

Department of Agriculture

The following are FY 1982 USDA expenditures in support of aquaculture:

Agricultural Marketing Service (AMS)	$173,000
Agricultural Research Service (ARS)	269,000
Animal and Plant Health Inspection Service (APHIS)	230,000
Cooperative State Research Service (CSRS)	2,150,000*
Economic Research Service (ERS)	35,000
Extension Service (ES)	976,000**
Farmers Home Administration (FHA)	1,500,000***
Federal Crop Insurance Corporation (FCIC)	55,000
Foreign Agriculture Service (FAS)	10,000
National Agriculture Library (NAL)	60,000
Soil Conservation Service (SCS)	1,325,000
Statistical Reporting Service (SRS)	150,000
Aquaculture nutrition program purchases(AMS amd FNS)	2,500,000
General Coordination	100,000
Total	$9,533,000

* Federal funds only (States contribute an additional $4.8 million)

** Federal funds only (States contribute an additional $1.5 million)

***Management costs only; does not include loans

Agricultural Marketing Service

The Agricultural Marketing Service (AMS) cooperates with State Departments of Agriculture by providing matching grants to States. Grants are generally used to conduct marketing assessments and to identify solutions to marketing barriers.

Agricultural Research Service

Studies on waste byproduct utilization and genetics in catfish are being carried out at the Southern Regional Research Center in New Orleans. A new treatment has been developed to convert catfish processing waste into a useful oil and the bone-free residue can be dried to produce a nutritious feed supplement for animals. A catfish breeding and genetics research project at Auburn University is also funded by the Agricultural Research Service.

Animal and Plant Health Inspection Service

APHIS performs veterinary, plant protection, and quarantine services. Veterinary activities in aquaculture include: (a) providing diagnoses of infections and toxicological conditions of fish; (b) providing consultation by field veterinary epidemiologists to local officials and individual fish producers; and (c) administering the Virus-Serum-Toxin Act of 1973 which pertains to biological products developed for fish.

Cooperative State Research Service

CSRS supports aquaculture research at State agricultural experiment stations at land-grant colleges through formula funding. CSRS also maintains a special grant program for aquaculture. Research is directed to solve problems of local, regional, and National importance.

Economic Research Service

The ERS conducted supply, demand, and price analysis of the aquaculture industry (with emphasis on freshwater species) and published a semi-annual Aquaculture Outlook and Situation report.

Extension Service

ES provides educational programs through the State Cooperative Extension offices nationwide. Extension interprets new aquaculture research, adapts the technology to local needs, and makes the information available to all users. It informs scientists of research needs as identified by aquaculturists at the local level. Ongoing extension educational programs in aquaculture include: economics; water management; stocking; feeding; disease identification, prevention, and control; weed control; predator control; hatchery, pond, and reservoir management; harvesting; transportation; marketing and processing; on-site pilot testing and demonstrations; workshops and in-service training of professional and technical aquaculturists; and consumer education on the nutritional value of aquaculture products.

Farmers Home Administration

FHA extends credit to aquaculture operators. Direct or guaranteed loans for aquacultural purposes may be used for production of aquatic organisms under controlled conditions. This involves feeding, tending, harvesting, and other activities necessary to raise and market the products. Economic emergency loans are also available.

Federal Crop Insurance Corporation

FCIC is developing an all-risk crop insurance program for fish farmers.

Foreign Agricultural Service

Cooperates with aquaculture associations to promote the export of farm-raised fish through sponsorship of trade development teams and trade shows.

National Agricultural Library

NAL programs include provision of referral bibliographic services to inquirers in the U.S.; photocopies of foreign and U.S. literature, including JSA-sponsored translations; compilation of a limited bibliographic database on aquaculture as a part of AGRICOLA. The Library initiated the National Aquaculture Information System on behalf of the JSA.

Directories are compiled when needed and published for wide use in the aquaculture community. Two major efforts were completed in 1983: a listing of primary contacts at Federal, State and county levels for assistance and information on programs for aquaculturists and a directory of major informational resources with inquiry, literature, and datafile holdings or capabilities within the U.S. Work is in progress on an aquaculture bibliography, as well as a comprehensive directory of major aquaculture associations, education, and research resources in the U.S.

Soil Conservation Service

Through local soil and water conservation districts SCS provides technical assistance to potential and established aquaculture producers. SCS assists would-be-aquaculturists in conducting resource assessments for aquaculture production. These assessments include detailed analyses of soils and site, water quantity and quality, and facility (ponds, reservoirs, raceways, waste disposal, water supply systems, and related facilities) design and layout. The assessments also include a general review of potential production levels and cost-return information within the context of soil and water resource potentials. Similar technical assistance plus basic biological information pertaining to stocking, feeding, water quality management, and waste disposal is provided to established producers.

SCS refers to other agencies and institutions requests for assistance in the following activities: parasite and disease control (treatment), detailed economic (cost-return) analyses, harvesting and processing techniques, and marketing studies and analyses.

SCS technical services are available to persons interested in commercial, recreational, or home-use aquaculture. About 60 percent of SCS's current aquaculture assistance goes to land users engaged in recreational or home-use aquaculture. The Fiscal Year 1982 funding figures are for commercial aquaculture, only.

Statistical Reporting Service

SRS conducted surveys on aquaculture production of catfish and trout. The agency publishes the monthly Catfish Processors report.

Aquaculture Nutrition Program Purchases (AMS and FNS)

The Agriculture Marketing Service and the Food and Nutrition Service may purchase aquaculture commodities for distribution to institutions during periods of temporary and unanticipated overproduction.

Department of the Interior

The bulk of USDI aquaculture-related programs are conducted by the Fish and Wildlife Service (FWS). The Bureau of Indian Affairs (BIA) does not have a line item budget for aquaculture, but frequently funds Indian aquaculture projects. The Office of Territorial and International Affairs (OTIA) does not directly fund aquaculture activities but does represent constituents who are involved in aquaculture in American Samoa, Guam, the Northern Marianas, and the Virgin Islands.

Fish and Wildlife Service

The Service has a comprehensive program of research, development, extension, and training in many areas of freshwater fish production. Most funding is appropriated by Congress with the ultimate objective being the enhancement of sport fishing. However, many of the activities and research results are applicable to commercial aquaculture. The Service has strong programs in fish health and nutrition and many other areas of importance to aquaculture.

FWS aquaculture and related research is conducted at the National Fisheries Center (Leetown, West Virginia), eight laboratories and field stations, and five fish cultural development centers. Major subjects under study include: fish disease control methods, production of fish biologics, nutrition and diet, registration of fishery drugs and chemicals, improvement of cultural methods, genetics and breeding, reuse and treatment of wastewater, and evaluation of nonindigenous species for aquaculture.

All of the 25 Cooperative Fishery Research Units have the capability to conduct aquaculture research in cooperation with their host universities and State agencies. Currently, 11 of the units are conducting 16 aquaculture research projects. Much of their other research produces information that can also be used by aquaculturists.

National Fish Hatcheries produce and distribute five species of freshwater trout, seven species of anadromous salmonids, and several species of warmwater and coolwater fishes. In FY 1982, 2,046,068 kg (4,501,350 lb.) of trout, 647,718 kg (1,424,980 lb.) of salmon, 4115 kg (9,054 lb.) of other anadromous fishes, and 128,523 kg (282,750 lb.) of pondfishes were distributed. Total distribution was 2,826,425 kg (6,218,135 lb). The Service has 16 hatchery biologists at 12 locations who provide fish disease diagnostic services, disease inspections, and certification inspections to Federal, State, Indian and private hatcheries.

The Service is currently expanding efforts to transfer applicable information from its large information base to the aquaculture community. Techniques include the use of Service facilities as demonstration sites and the use of Service personnel to provide technical assistance to local fish farmers and other interested parties. Many Service publications are distributed to users in cooperation with the Extension Service.

The FWS operates a Fisheries Academy at Leetown, West Virginia, that provides training in fish hatchery management, fish disease diagnosis and control, and a variety of other aquaculture topics tailored to user needs. To comply with the National Aquaculture Act of 1980, the academy increased its capabilities to train aquaculture workers and to serve as a clearinghouse for information concerning the availability of aquaculture training.

Rainbow trout seed stocks held by the Service at Leetown, and identified by industry as being of potential use to them, are presently available to commercial producers. Through cooperative agreements, selected strains of trout are being tested under industry conditions. If results are favorable, breeding stock will be provided to the industry.

Expenditures for Fiscal Year 1982 are shown in the following table.

Fish and Wildlife Service
Aquaculture Expenditures in FY 1982

Expenses that directly support public and private aquaculture.

	1982
R&D and Information Dissemination	$3,632,000
Aquaculture Research by Coop. Units	275,000
Fish Cultural Development Centers	570,000
Inter-and Intra- Agency Coordination	50,000
Total	$4,527,000

Hatchery-related expenses in support of recreational and commercial fisheries that have "spin-off" value to public and private aquaculture.

	1982
Hatchery Fish Production	$18,675,000
Hatchery Biologists	559,000
Training for Hatchery Personnel	368,000
Total	$19,602,000

Bureau of Indian Affairs

BIA provides funding for the construction of Indian tribal hatcheries and other aquaculture related projects. Tribal aquaculture activities include the operation of approximately 13 salmon hatcheries and commercial aquaculture pilot projects. Most of the Indian aquaculture projects are in the Pacific Northwest. The Lummi College of Fisheries in Washington has a 2-year program leading to an associate degree in aquaculture.

Office of Territorial and International Affairs

OTIA represents interests of the various territories. The Pacific Island Territories have aquaculture programs and their governors have expressed an interest in the development of aquaculture. American Samoa and Guam, for example, have aquaculture projects for tuna baitfish, food finfish, and prawns.

Department of Commerce

Aquaculture research and development activities have been supported by the DOC through the Economic Development Administration (EDA) and the National Oceanic and Atmospheric Administration (NOAA). EDA has provided funds for aquaculture primarily as a means toward job creation and to generate or preserve income. These programs have provided various Native American groups with almost $8.0 million for aquaculture development during the past 14 years.

NOAA conducts aquaculture research and development through the National Marine Fisheries Service (NMFS) and the Office of Sea Grant (OSG). Research supported by NMFS is conducted primarily by utilizing inhouse scientific expertise at NMFS centers, laboratories, and field stations. OSG supports research through grants to universities and other entities. The technology gained from this research is utilized by private industry for commercial purposes and by public agencies for augmenting natural stocks through enhancement programs.

In FY 1982, NMFS conducted research programs at 6 laboratories and field stations. These programs included research on development of salmon diets utilizing fish by-products as feed ingredients in diets and improved broodstock fecundity through dietary control (Seattle, Washington); monitoring smoltification enzyme activities for determination of best procedures for conditioning hatchery produced salmon for their migration into the sea, identifying diseases in salmon and developing control measures, developing biochemical and genetic techniques to identify stocks of hatchery and wild salmonids, and improved husbandry techniques for Atlantic salmon broodstock and subsequent egg production for stocking New England streams (Manchester, Washington); development of high-quality salmon fry and smolts for release into the ocean, and bio-environmental estuarine and marine studies to determine the causes of fluctuations in juvenile-to-adult stage survival of both hatchery and wild salmon stocks (Auke Bay, Alaska); maturation and spawning of marine shrimp indigenous to the Gulf of Mexico, and head-start techniques for marine turtles (Galveston, Texas); diagnosis of diseases of shellfish (Oxford, Maryland); and a variety of molluscan studies on natural diets, genetics, culture methods, disinfection techniques for contaminated hatchery water for oysters, and the development of methodology for the culture of bay scallops and surf clams (Milford, Connecticut).

Total program funding in FY 1982 for the marine aquaculture program was $5.3 million. NMFS also provided about $750,000 to the States on a cost sharing basis for marine aquaculture research and development activities under the Commercial Fisheries Research and Development Act of 1964 (Public Law 88-309) and the Anadromous Fish Conservation Act of 1965 (Public Law 89-304).

In addition, the NMFS Columbia River Fisheries Development Program provides funds for production of anadromous salmonids through the use of hatcheries. Program funds are provided to State agencies in the Pacific Northwest as well as to the FWS to rear and release salmon and steelhead trout.

In 1982, expenditures totalled $6.4 million for the operation of 24 hatcheries and rearing facilities operated by the cooperating fisheries agencies, resulting in the release of approximately 115 million migrant anadromous salmonids. Other activities of this program include studies on the quality of hatchery produced fish, habitat improvement, and fish passage devices, totalling another $2.5 million.

During FY 1982, 100 aquaculture projects were conducted involving $3.0 million in Federal Sea Grant funds by scientists in 30 academic institutions. Major centers of Sea Grant-sponsored work on aquaculture exist in all coastal and Great Lakes regions of the United States with the research generally focused on one or two species. These centers are: University of Hawaii (Malaysian prawn, Macrobrachium, and seaweeds), University of Alaska (salmon), University of Washington (salmon, bivalve molluscs, and seaweeds), Oregon State University (salmon and oysters), University of California (abalone, shrimp, lobster, and seaweeds), Texas A&M University (shrimp), South Carolina Marine Science Consortium (*Macrobrachium*), North Carolina (finfish), Virginia Graduate Marine Science Consortium (oysters), University of Delaware (oysters), State University of New York (finfish and bivalve molluscs), Woods Hole Oceanographic Institution (bivalve molluscs), University of New Hampshire (seaweeds), and University of Wisconsin (finfish). In addition, OSG expends major funding for aquaculture education, training, advisory/extension services, and planning activities.

Agency for International Development

AID serves as the principal foreign assistance arm of the U.S. Government. Technical assistance with agriculture and food production includes fishery development. The Fisheries staff of AID's Science and Technology Bureau handles development of both commercial fisheries and aquaculture activities.

AID's objectives are to increase food production, employment, income, and nutrition of the rural poor; and to promote resource management and environmental protection in developing countries. AID's aquaculture activities involve small-scale enterprises raising low-priced species and species for local consumption. Emphasis is placed on relatively simple production units that can be operated by small landholders with limited resources.

The regional bureaus of AID support a variety of aquaculture development projects. Most of these involve pond culture of freshwater fishes, such as carp and tilapia, in areas where human protein supplies are inadequate. The Agency's usual inputs include technical assistance, education and training, capital for public facilities such as hatcheries, and specialized equipment.

The Fisheries staff provides technical assistance to the regional bureaus. It also manages a few centrally funded aquaculture projects, including ongoing support for the International Center for Aquaculture at Auburn University and a collaborative research support program in aquaculture pond dynamics. Present funding for centrally funded aquaculture development projects is about $900,000 per year.

Corps of Engineers

The Corps' involvement in aquaculture includes meeting its regulatory responsibilities, which are to protect the navigability and quality of the Nation's waters. With passage during the last 10 years of considerable environmental legislation and the rendering of many associated judicial decisions, this task has grown in both size and complexity.

Department of Energy

DOE does not conduct any major activities in aquaculture. DOE's few aquaculture studies have been done from points of view other than food production. For example, research has identified aquaculture as an activity that could use waste heat from power stations. The DOE biomass program also includes aquaculture as it relates to the production of matter that could be used for energy conversion.

Department of Health and Human Services

The Public Health Service (PHS) has responsibilities and activities concerning the safety of food for human consumption and environmentally related diseases and disorders. The Food and Drug Administration (FDA) of the PHS performs research and provides technical assistance in aquaculture. Research areas include determination of bioavailability of cadmium and lead in oysters. FDA regional offices and the National Shellfish Sanitation Program give technical assistance to the States. The National Institute of Environmental Health Sciences of the National Institute of Health has research interests in absorption and metabolism of toxic chemicals by marine organisms.

Environmental Protection Agency

Some aquaculture systems may create waste products that are subject to regulation and control under the National Pollutant Discharge Elimination System (NPDES). Effluent guidelines for the aquaculture industry have not been fully promulgated.

The Water Management Branch of EPA (Ada, Oklahoma) studies the use of aquatic plants, wetlands, invertebrates, and finfish to produce clean water. Municipal waste treatment systems incorporating aquaculture processes can potentially qualify to receive 85 percent design and construction grants and 100 percent replacement or modification grants. The Municipal Construction Grants Program is developing design criteria for systems eligible for these grants. Past research funding has promoted the use of thermal effluents for aquaculture.

The Federal Insecticide, Fungicide, and Rodenticide Act administered by EPA requires registration of pesticides used in aquaculture to protect the environment, the product, the applicator, and the consumer.

Farm Credit Administration

FCA supervises and examines the banks and associations that make up the Farm Credit System. These FCA institutions make loans on commercial terms to farmers, ranchers, producers, and harvesters of aquatic products, and to their cooperatives.

Aquatic loans are defined as those supporting the production or harvesting of species under controlled conditions, primarily the fisheries industry. FCA considers aquaculture under controlled conditions to be a form of agriculture. Since banks and associations do not segregate loans for aquaculture from agricultural loans in their financial reports, it is currently difficult to determine what proportion of the loans are made to those engaged in aquaculture. However, it is known that loans have been made to catfish farmers in Arkansas, Mississippi, and other Southern States. Several small oyster and clam operations have also been financed in the Northwest and the Middle Atlantic coastal areas.

Based on observations made from the system's exposure to aquatic lending, increased demand and a potentially small supply of capture fishery products are causing increased prices at the consumer level. The Farm Credit System will make funds available to deserving aquacultural production applicants on the same basis as agricultural and marine fishery (vessel) loans.

National Science Foundation

NSF supports a limited number of projects directly related to aquaculture through its basic science programs and its Small Business Innovation Research Program. Total funds for these projects were estimated to be about $250,000 in FY 1982. In addition to the activities directly related to aquaculture, NSF also supports a number of basic research projects on marine and freshwater species which provide an important contribution for aquaculture research and development.

Small Business Administration

SBA makes guaranteed, immediate participation, and direct loans to aquaculture operators. SBA loans may be used for purchase and improvement of land or buildings, construction, machinery and equipment, operating expenses, and refinancing of debts. SBA also provides disaster loans in authorized areas. Since SBA does not separate its loan funds according to enterprise, there are no means to assess current levels of aquaculture loans.

Tennessee Valley Authority

In 1979, TVA initiated a 5-year aquaculture plan involving the use of waste heat from the Gallatin Steam Plant in Gallatin, Tennessee. The Fisheries and Aquatic Ecology Branch, Office of Natural Resources, has responsibility for this project, but coordination with other TVA divisions provides the expertise necessary to solve problems that arise as work progresses.

The Fisheries and Aquatic Ecology Branch also handles TVA's aquaculture technical assistance program. This program involves disease diagnosis and recommended treatment, advice on developing water resources for aquaculture production, improvement of present facilities, and techniques to achieve maximum production. Channel catfish, bait minnows, and rainbow trout are the species most commonly cultured for profit, but information is provided for other species as well.

TVA's Office of Agricultural and Chemical Development (OACD) has responsibility for developing aquaculture methods which are compatible with organic fertilization practices. Several systems are being developed to treat organic wastes from confined livestock facilities, fuel alcohol plants, and heavily fed fish culture ponds. OACD is conducting basic and applied research related to propagating fish and plant species which perform well in organically fertilized systems. Fishery stocks being evaluated include tilapia (five species), Asiatic carps (three species), and the giant Malaysian prawn. A tilapia overwintering facility (100,000 fingerling capacity) is in operation at TVA's waste heat research station located in northern Alabama. Warm condenser cooling water from the Browns Ferry Nuclear Power Plant is used to maintain fingerlings and broodstock tilapia during winter months. In the spring, this facility doubles as a hatchery and nursery for producing straight-line and hybrid tilapia stocks which are sent to cooperating universities for yield trial evaluations. OACD also maintains several stocks of the Chinese water chestnut, an emergent aquatic plant, which is under evaluation as an aquatic crop for reclaiming nutrients from municipal and agricultural wastes.

Long-range objectives are to increase aquaculture production within the Tennessee Valley by encouraging individuals to use available water resources. TVA funding for aquaculture programs was approximately $275,000 in FY 1982.

State and Territorial Governments

Many States and territories are involved in support of aquaculture either directly or indirectly through one or more of their agencies or through the college and university system. Activities include basic and applied research, extension and advisory services, assessment of markets and potential economic benefits, issuance of permits and leases, demonstration facilities, stocking for enhancement purposes, and cultured product inspection.

Realizing the potential of aquaculture, a number of States and territories have developed or are in the process of developing aquaculture plans (e.g.; California, Guam, Hawaii, Louisiana, Maine, Missouri, Rhode Island, and Texas). Some States are drafting legislation and establishing policy to expedite development, ease regulatory constraints, and reduce and simplify the mass of red tape involved in the permit process. Hawaii has increased the availability of loan capital which is contributing significantly to the establishment of a successful prawn farming industry.

State efforts in aquaculture are usually coordinated with Federal efforts. The land-grant and sea-grant programs interact very closely with the State college and university system. Legislation such as the Intergovernmental Cooperation Act of 1968 (P.L. 90-577), and the Coastal Zone Management Act of 1972 (P.L. 92-583) are additional means for coordination of activities.

Universities and Other Organizations

Universities and nonprofit laboratories represent a significant part of the continuing effort to expand aquaculture in the U.S., the territories, and in developing nations. These institutions conduct research and development, education and training, and extension education and advisory services. In many instances, they possess or have access to relatively large-scale culture facilities such as ponds, tanks, and hatcheries. Near production-scale research programs take place in these facilities. Some of the best equipped and staffed laboratories in the world perform the research. More than 50 academic institutions and nonprofit laboratories are involved in aquaculture activities.

CHAPTER 5
RECOMMENDED PROGRAMS AND ACTIONS

The National Aquaculture Act of 1980 requires that the development plan include actions for both the public and private sectors to take in implementing the plan. Industry, State, and university roles are discussed. Federal actions discussed in this chapter are based on existing programs and activities.

Industry, State, And University Roles

The National Aquaculture Act of 1980 states that the principal responsibility for the development of commercial aquaculture in the United States must rest with the private sector. The United States aquaculture industry is represented by 1,100 catfish farms; 250 trout farms; 400 crawfish farms; 25 commercial salmon farms; over 500 oyster culture firms; 30 firms culturing clams, mussels, and abalone; 15 U.S.-owned shrimp farming firms operating in Latin America and the United States; 20 freshwater prawn firms concentrated in Hawaii; and a number of individuals and firms who have developed or are developing the culture of many new species. Their role as commercial entrepreneurs is to apply available aquaculture science and technology to the real-world problems of operating commercially viable aquaculture ventures. Through their practical orientation and business acumen they carry research and prototype aquaculture concepts through optimization and cost-reduction processes in order to maximize their margin of profit.

Motivated by the needs and activities of the developing aquaculture industry over the past decade, many States and universities have established extensive research, extension, and teaching programs in aquaculture. The total effort has resulted in significant improvement in our understanding of all aspects of aquaculture.

Some States, territories and Indian tribes, have active programs in aquaculture development. Aquaculture extension programs are provided as part of an existing agricultural Cooperative Extension network. Research and development groups exist in a number of States. In addition, aquaculture plans are included in the overall water and land use policy planning of several States. In some cases, a diversity of State agencies address issues of public health, disease and pest control, aquatic animal imports and exports, and the ecological aspects of aquaculture.

The role of the academic community in the development of aquaculture is to conduct programs in aquaculture science, technology, and education in concert with State and Federal laboratories. The academic community should be involved in innovative approaches to aquaculture development through the creation and dissemination of knowledge. Academia's role is to solve problems of a generic nature that further the improved commercial status of aquaculture.

States, territories, and universities should be encouraged to develop aquaculture programs of their own. Some have already developed adequate laws and regulations concerning aquaculture, others have not. Consequently, all States and territories should be encouraged to reexamine legislation and enforcement mechanisms now in effect. Where necessary and appropriate, these laws, regulations, and enforcement procedures should be modified or new ones developed. Aquaculture extension and advisory services provided by States, territories and universities should continue. National aquaculture programs should continue to make use of expertise existing in nonfederal groups to conduct the needed research and development, planning, and related activities.

Federal Programs and Actions

Coordination of National activities regarding aquaculture will be conducted by the JSA of the Federal Coordinating Council on Science, Engineering and Technology. The Joint Subcommittee is composed of (1) the Secretaries of Agriculture, Commerce, Interior, Energy, and Health and Human Services; (2) the Administrators of the Environmental Protection Agency, the Small Business Administration, and the Agency for International Development; (3) the Chief of Engineers of the U.S. Army Corps of Engineers; (4) the Chairman of the Tennessee Valley Authority; (5) the Director of the National Science Foundation; (6) the Governor of the Farm Credit Administration; and (7) other Federal agencies as appropriate.

The Subcommittee will:

- Provide leadership within the Executive branch for the encouragement of aquaculture
- Review National aquaculture research, information transfer, and assistance needs
- Assess, with the help of the private sector, the effectiveness and adequacy of Federal efforts to meet those needs
- Undertake planning, coordination, and communication among Federal agencies engaged in the science, engineering, and technology of aquaculture
- Collect, compile, and disseminate information
- Encourage joint programs among Federal agencies in areas of mutual interest

- o Relate specific policy recommendations to appropriate agency policy officials for implementation, and

- o Recommend to sponsoring committees and the Federal Council specific action on issues, problems, plans, and programs in aquaculture, including seeking relief from burdensome regulations when appropriate.

Panel Functions

In 1981, three panels were established by the JSA. They include: the Panel on Science, Technology, and Engineering; the Panel on Economics; and the Panel on Education and Technical Assistance. The panels are important operating, coordinating, and monitoring units of the JSA. New panels or subpanels may be established, as appropriate or necessary, to carry out certain functions as assigned by the JSA or the Secretaries. Panels will present formal annual reports to the JSA chairman.

The following material describes the primary areas of responsibilities for the panels.

Panel on Science, Technology, and Engineering

The panel will periodically seek advice from industry, State, university and government professionals to identify research needs and to establish research priorities.

The panel will formulate and annually update a roster of current aquaculture research activities. Each agency represented on the JSA will be asked to complete a current research questionnaire on an annual basis.

Drawing upon information collected, the panel, assisted by liaison groups representing States, territories, universities, and the private sector, will be able to advise Federal agencies of areas of research needs and areas where additional coordination is needed.

The panel will present reports of its activities to the JSA consisting of the following parts:

- o A listing and brief description of research needs and priorities as well as a description of the methods and sources used to obtain the information

- o A roster of current research activities, which will include the name and location of the research organization, principal investigator(s), title of the project, funding level, beginning date and target completion date, and publications to date if any. A description of the methods and sources used to obtain the information will be provided

- A description of coordination activities by the panel as well as other known efforts of coordination by Federal, State, territorial, or private entities

- An evaluation of the effectiveness and adequacy of Federally sponsored or conducted research

- A list of foreign aquaculture articles recommended for translation

Panel on Economics

The Panel on Economics of the JSA has the responsibility for providing oversight, coordination, review, and planning for Federal activities related to the development of commercially successful aquaculture in the U.S.

This panel will:

- Conduct periodic reviews and make recommendation on laws, regulations, insurance, financial and marketing assistance, and other aspects that affect the economic feasibility of aquaculture operations

- Monitor and report on the effectiveness of Federal actions to reduce unduly burdensome regulations

- Publish and distribute a directory of financial assistance programs

- Coordinate U.S. activities relating to international exchange programs in aquaculture

Panel on Education and Technical Assistance

This panel will be responsible for providing overall coordination and for monitoring information dissemination activities of the Federal agencies. The panel will:

- Coordinate agency activities in aquaculture technology transfer to user groups

- Facilitate the exchange of aquaculture information materials between agencies and the distribution of appropriate materials produced by agencies lacking strong information delivery systems

- Provide translation services based on recommendations of the Panel on Science, Technology, and Engineering

- Establish operating procedures and monitor activities of the National Aquaculture Information System

- Publish and update biannually, a directory of aquaculture assistance. This publication will list major libraries and sources of information and technical assistance. It will include Federal, State, university and other sources by subject matter and species

Liaison Groups

On a continuing basis, the JSA will seek to obtain input from a wide variety of aquaculture interests. This will include private aquaculturists and their trade organizations, States, territories, Indian tribes, universities, private and nonprofit institutions, and others.

Workshops may be held to assist the JSA in deliberations of interest to special groups, such as in determining research needs and priorities, selecting drugs for FDA clearance, identifying nonindigenous species for evaluation, planning educational and technology transfer activities, and other efforts. The continuity of effective communication with the private sector is essential for the successful execution of this plan.

National Aquaculture Information System

A National Aquaculture Information System (NAIS) will be established under the auspices of the JSA. The National Agricultural Library (NAL) of USDA will have the lead responsibility for the system. The Departments of Agriculture, Commerce, Interior, and others will inform NAL of the aquaculture research information and related literature in their data banks. NAL will be responsible for providing access by all user groups to aquaculture information maintained in these agency data systems. It is anticipated that aquaculturists seeking information will first contact local or regional information sources. However, if the information is not available at these sources, then they may contact the NAL for further assistance.

It is envisioned that, initially, NAIS will provide three basic services. It will: (1) keep bibliographic files; (2) translate important foreign scientific papers and store them in the system; (3) make available the results of surveys and statistics and selected aquaculture directories. Materials to be translated and stored in the system will be cleared by the JSA Panel on Science, Technology, and Engineering. Dissemination of information will be conducted through existing delivery systems and commercial trade magazines. Coordination of the overall effort will be the responsibility of the Panel on Education and Technical Assistance.

It will be the continuing responsibility of NAL and the Panel on Education and Technical Assistance to consult with and coordinate its efforts with ongoing information services available in many States, especially those in Cooperative Extension, sea-grant and land-grant institutions.

International Activities

The National Aquaculture Act of 1980 calls for arrangements with foreign nations for the exchange of information on aquaculture and the support of a translation service. The latter function has been provided since 1979 by the JSA. The former responsibility has been met in the past through bilateral aquaculture programs between one or more Federal agencies and their foreign government counterparts. The JSA will obtain and provide more complete dissemination of information on such bilateral programs, and coordinate the activities to assure that the United States receives maximum benefit from information derived from these programs. The Panel on Education and Technical Assistance will be responsible for coordinating these activities.

Capital Requirements

A key element in recent public and private debates concerning the need for government support of the aquaculture industry is the question of whether sufficient financing is available in the private sector to develop the industry or, if not, whether additional government financial support is necessary. Of particular importance is the question of whether or not aquaculture is treated equitably by private and public financial institutions.

In order to determine if new or specialized financial support for aquaculture would be appropriate at the Federal level, the JSA initiated a comprehensive and indepth examination of the capital requirements of the U.S. aquaculture industry. This study involved contacts with private banks, Federal Land Banks, insurance companies, production credit associations, investment bankers, private investors, investment banks, corporations involved in aquaculture, and venture capitalists. In addition, aquaculture experts, producers, university and government researchers and consultants were contacted.

The conclusion of this examination was:

> "Financing new ventures is always a difficult proposition and one that raises a good deal of controversy. The promise of aquaculture is so vast that it would be unfortunate indeed if the capital markets proved to be a true constraint on its development. The research conducted by the Wharton Applied Research Center has indicated that the major obstacles to growth in the culture of the four species which have reached a stage where financing can be a significant issue are not financial in nature. This should not be taken to imply that all worthy aquaculture projects are funded, that all loans are closed, or that at a time when the credit markets are in great flux, financing hurdles are not severe problems for some enterprises. Rather, this conclusion indicates that the aquaculture industries, taken in general, face other constraints to growth than the lack of financing. Policy

analysis therefore should probably turn its attention to these other types of programs and, at least for the present, not attempt to alter the financing systems for aquaculture."

In general, if the technology to produce a species exists and markets are available to return a reasonable profit, it appears that financing is not currently a constraint. Consequently, the JSA does not find adequate justification for recommending the creation of new Federal financing programs. Aquaculturists (and potential aquaculturists) can and do compete in the financial markets for capital. It should be pointed out also, that Federal tax and other policy changes that stimulate the formation and nurturing of high-technology, high-risk businesses can be expected to similarly effect the establishment and growth of new aquaculture ventures pioneering new species.

However, entrepreneurs who cannot raise enough capital and must borrow funds may find that lenders have little experience with aquacultural enterprises. Although the usual financial channels are open to aquaculturists, they may not be open to the extent that they are to, for example, producers of soybeans, beef cattle, or swine. This is especially true of entrepreneurs who are culturing species that have not become established in the marketplace. At the same time, many potential aquaculturists may not be aware of private and public sources of financing.

The JSA and the Panel on Economics will seek to develop the public's awareness of financing opportunities by:

- Developing and disseminating a directory of funding sources to assist would-be aquaculturists

- Providing educational materials about aquaculture that may be useful to financing institutions not now familiar with aquaculture

- Encouraging research on the relationship between potential aquaculture products and the land, labor, capital and operating inputs required to produce the species

Regulatory Impacts

The JSA authorized a comprehensive investigation of the impacts of Federal and State regulations on the development of aquaculture in the U.S. The objectives of the study were to identify Federal and selected State laws and regulations which could potentially affect the initiation and operation of aquaculture enterprises and to define the practical effects of these laws and regulations.

The issue of regulatory impacts is complex. A regulation may be viewed by one individual as a constraint and by another as a benefit. Regulations are presumably developed to meet a public need. Aquaculturists have cited certain regulations, such as health and sanitation, which are essential to their enterprises and should be kept stringent. Conversely, regulatory inconsistencies, overlaps, unnecessarily restrictive applications, and the sheer magnitude and complexity of regulations all combine to create real or perceived barriers to commercial aquaculture ventures.

Often, it is not the regulations themselves which constitute a major hindrance to aquaculture development but rather the time required for the permit or certification process, the undefined or indistinct jurisdictional roles of regulatory agencies, and inadequate information on what regulations apply in specific situations.

After case studies were completed on 12 aquaculture operations, the following Federal regulatory program areas were identified as being most commonly encountered:

- o Federal environmental regulations
  - -Permits for dredging, filling, and using offshore structures
  - -NPDES permits
- o Drug and chemical registration procedures
- o Fish and shellfish health programs
- o Regulations concerning the importation and interstate shipment of plants and animals

The JSA will undertake the following activities to help solve these problems:

- o Make available the following documents:
  - A literature review of the regulatory constraints on aquaculture
  - A directory of Federal regulations affecting the development and operation of commercial aquaculture
  - A directory of State regulations affecting the development and operation of commercial aquaculture (32 States)
  - Case studies of 12 commercial aquaculture operations
- o Work with industry and appropriate regulatory agencies to identify and review problems associated with particular regulations and to eliminate the hindrance or to streamline the regulatory process
- o Publish and disseminate Federal permit compliance guides specifically tailored to the needs of aquaculturists
- o Promote multiagency workshops and discussions to devise new strategies for more efficient drug registration efforts

- Encourage professional certification and training programs with States to increase the availability of fish and shellfish disease diagnostic services in areas of need

- Assist States in identifying promising nonindigenous aquaculture species and encourage studies relative to any potential impacts of accidental release into the environment

- Monitor the effectiveness of the above actions on reducing burdensome regulations, continue to assess and to define regulatory constraints, and make public the results of this continuing effort through periodic reports

Planned Program Activities

In view of the numerous and complex impediments to commercial and recreational aquaculture identified in Chapter 3, the JSA recognizes the following areas where actions are needed. These actions are, in general, continuations or extensions of on-going activities.

Assessment of Current Status

Statistical surveys describing the status of aquaculture in the United States, including such factors as production, value, employment and acreage, should be conducted frequently enough to be of value to aquaculturists.

Scientific and Technical Knowledge

Research and development efforts would be directed toward solution of problems inhibiting the full development of those species or strains now produced for commercial and recreational use or with the greatest potential for future utilization. However, some exploratory and developmental research would be included to assure that other species-types are evaluated to determine their potential.

Life history

Research would be conducted to improve understanding of important species for aquaculture application. An understanding of basic biological aspects of organisms is necessary to make their culture feasible, including such factors as life cycle, behavior, smoltification, and the causes of variability in growth rate.

Genetics and reproduction

It is important to understand the production of quality gametes and the basic genetic characteristics of species of interest to determine which may be improved for culture systems and how specialized techniques needed for such improvement programs may be developed. Research would be initiated on the genetics of cultured species so that strains possessing desired characteristics may be developed; emphasis would be on increased survival rate, rate of gain, efficiency of gain and disease resistance. Research would include development of special procedures to maintain genetic integrity of intermixed wild and hatchery-produced stocks. Work is required to:

- o Establish registers describing the characteristics of important strains of major aquaculture species
- o Establish broodstock selection programs to develop improved strains
- o Prepare manuals and courses on genetic management of broodstocks
- o Develop the capacity to test strains through centralized evaluation of broodstock
- o Investigate the application of hybridization to the development of improved broodstock
- o Investigate gamete preservation methods and other techniques to provide a continuous source of fertilized eggs throughout the year
- o Develop improved technology for assessment of resistance to specific fish diseases

Nutrition and diets

The nutritional requirements of cultured species throughout their life cycles would be determined. Improved nutrition and diet formulation for cultured species, including increased feed utilization and the development of least cost diets is needed. Specifically, research is needed to:

- o Define the basic nutritional requirements of cultured species
- o Develop least-cost feeds based on commonly available ingredients for various sizes and ages of cultured species
- o Define feeding techniques for efficient and effective production of various sizes and ages of cultured species
- o Identify man-made and natural toxins, growth inhibitors, and contaminants in feed ingredients, and develop techniques for their prevention, removal, or detoxification
- o Define the relationship between fish health and nutrition

Environmental requirements

Studies are needed on interactions between cultured organisms and their environment. Knowledge about the effects of chronic exposure to metabolic wastes, intensive culture stress caused by intraspecies interactions, carrying capacity of natural and artificial environments, and comparisons of various configurations of culture facilities such as ponds, raceways, and suspended culture is needed. Research would help to:

- o Develop methods for predicting and correcting water quality deterioration in fish production systems

- o Develop methods and techniques (management, mechanical, chemical, biological) to control the production of undesirable aquatic plants and animal in culture systems

- o Design equipment and evaluate techniques such as aeration, filtration, recirculation, water exchange, and chemicals to improve water quality and fish production

- o Improve culture systems and equipment with particular reference to hatching technology and bioengineering

Facility engineering, construction, and operation

Culture systems and equipment would be improved with particular reference to hatchery technology and bioengineering and to mechanization and automation of closed and semi-closed, and other culture systems. Emphasis would be placed on research to:

- o Analyze hydraulic, aeration, energy use, filtration, and water quality factors in raceways, silos, water-reuse systems, and ponds for culture

- o Develop reliable automatic and demand feeders for small-particle and moist feeds

- o Develop practical and reliable degassers and oxygenation devices for large-scale aquaculture systems

- o Test the performance and operational reliability of ozone and ultraviolet filters for pathogen and parasite control in large-scale aquaculture systems

Effluent controls

Develop innovative and economic techniques to reduce or prevent pollution by recycling organic wastes, preventing water runoff, and studying alternative wastewater utilization practices for grow-out systems for species in all stages of development. Work is needed to:

- o Develop biological, mechanical, and chemical methods to remove natural and man-made contaminants from water supplies for culture systems

- o Compare aquaculture production systems having self-contained filtraton systems, which do not require an effluent discharge, for use in aquaculture production

Control of disease and parasites

Basic research would be expanded on characteristics and modes of infection of diseases, and their prevention and control. Improve knowledge of disease organisms and develop appropriate control techniques.

Research programs would be expanded to determine methods needed to control disease and parasites responsible for mortalities or conditions detrimental to growth of cultured organisms. The research would include understanding the life histories of disease organisms, development of curative and prophylactic treatments, and providing assistance to States for the development of seed stock certification programs. Action would be taken to:

- o Identify and describe life cycles of important parasites and diseases

- o Improve diagnostic methodology for pathogens

- o Develop specific pathogen free stocks to provide to the commercial freshwater finfish industry

- o Define the relationship between fish health and nutrition

- o Conduct a literature survey to identify pathogens associated with nonindigenous species which have potential use in domestic production

- o Establish a central data storage and retrieval capability for monitoring regional and National health problems in aquatic species

- o Intensify research on immunology and development of vaccines and vaccine delivery systems in order to control pathogens

Production of seed

Research would be conducted to improve understanding of mass culture in order to increase control of behavioral and reproductive processes so that the necessary stocks of seed and juvenile organisms can be developed. Efforts would include initiatives to:

- Identify, with public and industry assistance, currently unavailable species that have aquaculture potential

- Acquire and maintain broodstocks of candidate species and develop methods and equipment for breeding and rearing

- Provide the mechanism to distribute these new stocks to appropriate user groups

Predation

Research would be enhanced to improve knowledge of predation and to develop appropriate prevention or control techniques. Research is needed to identify and develop approaches for controlling predators, competitors, and other nondisease causes of mortality in culture systems including chemical, biological, and management techniques to eliminate or control serious predators.

Harvesting and transportation

Harvesting, fish handling, and transportation technology for commercially cultured species would be improved. New techniques are needed for harvesting and grading of selected culture species associated with experimental or new concepts in grow-out systems. Research would help to:

- Develop methods for selective harvesting from ponds and raceways

- Develop improved methods and equipment for transferring animals from capture devices to transportation units

- Develop practical methods to eliminate or neutralize those limiting factors that restrict transportation

Production quality control

Research would be initiated to improve processing and marketing practices, including processing technology and new product development. Research is needed to develop methods for identifying, preventing, or controlling deterioration of products, including improvements in processing and packaging techniques, and in depuration systems.

Introduction of nonindigenous species

The use of nonindigenous organisms showing culture potential should be evaluated, as should the identification of the ecological impact of these introduced species to indigenous populations. In addition, control procedures would be developed for nonindigenous diseases, predators and parasites to indigenous stocks. Work would include efforts to:

- Develop and evaluate techniques for production of monosex and sterile species

- Conduct literature surveys to identify pathogens associated with nonindigenous fishes which have potential use in domestic production

- Establish a quarantine procedure for monitoring the health of newly imported species

- Develop improved methods to breed and rear beneficial nonindigenous species

Drug and chemical registration

Data on efficacy of drugs and other chemicals for aquaculture would be developed. Activities would include efforts to:

- Intensify negotiation with the FDA on clarifying and streamlining registration requirements for needed drugs and chemicals

- Register antibacterial compounds to combat strains of bacteria

- Identify new antiprotozoan compounds for parasites

- Identify new antifungal compounds for fungus control

- Conduct mammalian safety studies for registration of high-priority drugs and chemicals

Pilot Testing and Demonstration Facilities

The development and demonstration of techniques and systems on a pilot scale would be supported in order to:

- Demonstrate all major aspects of aquaculture technology

- Present special demonstrations of new technology

- Distribute a directory describing what technologies, equipment, and species culture can be observed at various locations

- Support a pilot-testing program for species, equipment and methodologies

Economics

Economic data

Research and reporting would be accelerated on the relationship between aquacultural products and the land, labor, capital, and operating inputs required for production, including the relationship between scale of operation and input requirements. The ability to determine economic feasibility of culture operations and to identify major cost factors in those operations would be improved. The awareness of the industry concerning sources and availability of investment capital through extension and technical assistance efforts should be increased.

Market development

Markets for aquaculture products, including identification of market barriers and opportunities would be examined and studies expanded on marketing economics and new products development where lack of markets and market barriers are restricting the industry.

Information and Technical Assistance

Extension education and information

Improved information exchange would be enhanced by providing increased extension activities. Other special emphasis would be directed towards efforts to:

- Gather, synthesize, and index all aquaculture materials of research and education agencies on a continuing basis into an on-line data base

- Rewrite highly scientific and technical publications, as applicable into publications that are readable by and useful to aquaculturists at all levels

- Produce bibliographies on various aspects of species involved in aquaculture

Technical assistance

Rapid expansion of commercial aquaculture has resulted in large demands for technical services. Appropriate staff will be provided specialized training to keep pace with advances in technology.

National Aquaculture Information System (NAIS)

The NAL will provide leadership in establishing the NAIS in cooperation with other Federal data systems. Initial efforts will focus on the development of bibliographic files, translation services, and selected directories.

Resolution of multiple-use conflicts and legal constraints

Multiple-use conflicts and legal constraints would be identified. Strategies for addressing these barriers through JSA and other governmental entities would be developed and implemented.

Coordination

Coordinate activities within the government and with nonfederal entities.

Aquaculture training

Education and training programs to serve identified needs of public and private aquaculture industry and its supporting services sector would be enhanced.

CHAPTER 6
ANTICIPATED IMPACTS

The JSA recognizes the difficulty in accurately forecasting and quantifying changes which would be brought about by the activities and actions set forth in the NADP if it were implemented. Variables related to the expansion of aquaculture are many and highly complex. However, it is possible to explore potential economic, environmencal, and sociocultural changes based on past trends and knowledge about developments that may affect the future.

Economic Impacts

Primary Impacts

Basic supply, demand, and price data needed to assess and quantify the impacts of the aquaculture plan are limited. The problem of determining economic impacts is exacerbated by the diversity of operations, cultural practices, and nature of final demand for aquaculture products. A final obstacle is the current environment of uncertainty that surrounds economic activity. However, this holds true for many industries in the U.S.

The primary effects of this plan on the aquaculture industry would be to improve production technology and to disseminate technological advances to existing and potential commercial producers. The plan's programs, by contributing to the commercial viability of technology and by providing trained aquacultural personnel for management, research, and extension activities would decrease the risks of entering this relatively young and developing industry. This, in turn, might encourage the establishment of new operations. These effects would make it possible for aquaculturists to produce a given quantity at a lower cost per unit, thus increasing the supply of fish and shellfish products and lowering the cost for consumers.

This outward shift in the industry's supply curve would presumably bring about a net gain in U.S. economic welfare. The exact magnitude of the welfare change is difficult to estimate. In general, though, the rate of return to investment in agricultural research in the United States[1] has been estimated to range between 35 percent and 171 percent.

More readily apparent effects of this supply shift would include additional stability and diversification of American agriculture and agribusiness in some areas by providing employment on fish

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[1] Griliches, Z. 1964. Research expenditures, education, and the aggregate agricultural function. American Economic Review 54(6):961-974.

farms, feed mills, processing plants, and other supporting industries. Moreover, aquacultural development would be an attractive supplementary enterprise for many farmers, enabling them to maximize the income potential of land, labor, and other resources.

In the longer term, aquaculture could improve the net fish trade deficit of the U.S. for edible fishery products (at least $2.2 billion in 1982), both through decreased imports and larger exports. During 1982, shrimp imports valued at $980 million represented 31 percent of the total edible fish import bill. Meanwhile, salmon exports generally accounted for 48 percent of the value of edible fishery products exported in 1982.

However, a supply shift through technological advances or innovations does not create its own demand. A net economic welfare gain to society because of programs under this plan, will result only if consumers are able and willing to purchase aquaculture products. To that end, some of the production technologies resulting from the plan's research programs would make aquaculture products more attractive to consumers by meeting size, quality, and seasonal demands. Advances in post-harvest technology relating to product quality control, help ensure customer satisfaction, while others introduce cost-efficiencies in processing and distribution, providing a more competitively priced product.

The following are other factors that will influence the demand for aquaculture products in the coming years, which in turn will affect the economic impacts of this plan:

- Increases in per capita consumption of fish and seafood in the U.S. Per capita consumption has climbed upward since 1960 to a little over 12 pounds in 1982. However, even if per capita consumption should remain the same, the expanding population will increase overall demand. This trend should make it more viable for private industry to continue to expand and develop aquaculture in the U.S.

- Economic growth, and hence, larger per capita disposable income have been the primary forces causing a 25 percent increase in per capita consumption of red meats, poultry, and fish since 1960 (the share of fish and seafood consumed relative to the total has been steady, at or near 6 percent.) Also, economic conditions affect consumption of food away from home, where about two-thirds of fish and seafood sales occur

- The ability of the U.S. commercial fishing industry and/or imports to meet future demand for fish and seafood

- The price of aquaculture products relative to competing protein sources--red meats, poultry, and noncultured fish

The more cost efficient production of aquaculture products likely to result from implementation of the NADP would enhance the competitiveness of cultured fish in the market.

Secondary Impacts

Programs of this plan would have spillover effects. Some effects would benefit society, while others might impose social costs.

For example, since aquaculture generates additional economic activity by augmenting fish stocks for commercial and sport fisheries, the programs of this plan would tend to increase the positive economic benefit to society. On the other hand, impacts on land and water use could either enhance or detract from such things as habitat and environmental esthetics or groundwater and surface water quality and quantity. Likewise, the introduction of nonindigenous organisms, genetic changes, and possible human nutritional factors could have positive or negative economic effects. An important secondary impact of this plan would be on the commercial fisheries. For some species like catfish or trout, there would likely be few economic effects. Almost all trout sold commercially in the U.S. is farm-raised with the remainder imported. The farm-raised catfish industry now dwarfs the wild catfish fishery. Farm-raised catfish production sold to processors totaled 200 million pounds in 1982, while 8.2 million pounds of wild catfish was processed in 1981.

Culture of oysters and hard clams would also likely have little impact on their respective fisheries. U.S. production has declined over the past two decades, primarily because of pollution, loss of habitat, and disease. Also, like farm-raised catfish, cultured oysters and hard clams are considered superior products.

On the other hand, cultured shrimp and ocean-ranched salmon will compete directly with shrimp and salmon from the commercial fisheries. Cultured shrimp will also compete with imports. Shrimp and salmon are the United States' most valuable fisheries, which emphasizes potential benefits to be gained from shrimp and salmon aquaculture. In short, the source that can meet consumer's quantity and quality demands at the lowest price would likely gain market share at the expense of the other sources.

Salmon cultured by net-pen rearing are only 1 pound when harvested and are sold as fresh or frozen pan-sized fish, competing directly with rainbow trout.

Pond-raised and wild-harvested crawfish also compete with each other. Since most crawfish are marketed fresh, because they cannot be stored, available supply will dictate prices. Thus, if production of pond-raised crawfish increases, the major affect will be to dampen price swings, both from year-to-year and within the November-June harvest season.

Environmental Impacts

This section discusses general impacts of an expanding aquaculture industry.

Changes in Land Use

One of the strongest impacts of an expanding aquaculture industry will be the changes in land use and resultant changes in habitat for various terrestrial, wetland dependent, or aquatic organisms. Generally, the net value to wildlife would increase at upland sites, but decrease at wetland sites. The various forms of aquaculture also have different impacts on land use. Intensive culture systems use less space than extensive systems to produce equal numbers of fish.

Upland areas

The conversion of upland areas into aquaculture facilities could result in some wildlife and esthetic losses. The most detrimental losses would be of forests or old fields and their attendant fauna and flora. Few forested areas are converted to aquaculture because of high costs and physical problems associated with making the conversion. Old fields are more likely to be converted. However, the conversion of monoculture croplands to earthen ponds would create habitat for a variety of water dependent wildlife.

Wetland areas

Aquaculture facilities sited in the highly productive coastal wetlands could be destructive to natural ecosystems. Many species of fish and crustaceans use the estuarine nursery zone during juvenile stages of their life cycles. Fish and wildlife agencies generally oppose aquaculture programs for the coastal wetlands because of this loss of valuable habitat. Inland swamps and marshes also furnish valuable habitat for wildlife. Present local, State, and Federal regulations make it difficult to convert wetlands to other uses.

Open-water areas

The nature of the aquaculture facility determines to a great extent whether or not it displaces natural aquatic habitat. The exclusive use of an area for cultured species would eliminate its value as a nursery for wild species. On the other hand, the use of a portion of the bottom or water column for oysters or other shellfish may enhance the natural fisheries.

Net enclosures for salmon have been observed to degrade the bottom immediately underneath the nets but not to adversely affect adjacent bottom areas.

If State and Federal permit requirements are met, serious problems are not foreseen with displacement of habitat by open-water aquaculture operations.

Changes in Water Use

Aquaculture, particularly in more arid areas, may compete with other uses for groundwater and surface water. Except for closed systems, aquaculture uses large quantities of water. A dramatic increase in inland aquaculture facilities in concentrated areas could reduce the initial availability of groundwater for various other uses. However, in many regions of the country, water captured in ponds provides opportunities to conserve water and extend the availability of water for other purposes.

Effluent Discharge

Generally, effluent from aquaculture facilities poses only a limited threat to the aquatic environment. Potential impacts include high biological oxygen demands and eutrophication resulting from the discharge of organic materials, algae or other secondary growths, and nutrients such as nitrogen or phosphorus.

In most instances, the use of available treatment techniques and subsequent dilution in the receiving waters renders hatchery and grow out facility discharges harmless. However, in the absence of good management practices, an aquaculture facility could overload a small stream, lake, or lagoon.

Although concerns have been expressed about raceway facilities, because of the large volume of water utilized, the effluent is actually very dilute when compared with municipal effluent. Fish hatcheries have been responsible for water quality degradation in some instances, but the overall impact created by these discharges has generally been limited. In several studies it was demonstrated that hatchery effluent treatment, beyond simple settling of solids resulting from cleaning operations, should not be required. In closed systems concerns over discharges are practically eliminated, as these facilities discharge little or no effluent.

Physical and Biological Barriers

Certain types of aquaculture facilities situated in coastal waters may form barriers which hamper the migration of aquatic organisms, such as fish or shellfish, retard the movement of water (currents and tides), or hinder navigation. Nets or other structures placed across water courses may block or alter the movements of animals or people. Careful siting and attention to Federal, State, and local permit requirements should prevent significant problems.

Sport Fisheries

Aquaculture benefits sport fisheries by producing fish and shellfish to be taken from small impoundments and public waters. In fact, in many urban areas, much of the available fishery is supplied by cultured fish stocked in "fee fishing" lakes. In coastal waters, sea-ranching holds the potential to replenish stocks of depleted sport and commercial fish such as salmon, sturgeon, and striped bass (see Chapter 2).

Esthetics and Recreation

Impacts on esthetics and recreational use of waters is an important consideration for facility siting in the U.S.. Overall, inland aquaculture facilities are considered an asset, but facilities constructed in coastal environments may blend in poorly with the landscape and may thus be visually unacceptable to some segments of the public unless carefully planned. Large-scale development of coastal areas should proceed with caution, as such development creates conflicts with environmental groups, recreational groups, and adjacent landowners.

Recreation

There is a long tradition in the U.S. of using hatcheries to enhance fisheries and provide commercial and recreational fish stocks.

Public trout and salmon hatcheries are found in many States. Private aquaculture operations are akin to these public hatchery systems and may provide additional opportunities for stock enhancement in nearby waters or provide onsite recreation. Recreational enhancement may provide a useful mitigating point in cases where adverse sociocultural impacts have been predicted or observed.

Impacts on Wildlife

Because of the uniqueness of most aquaculture facilities, it is not possible to list specific positive or negative impacts on wildlife that would be representative of all operations.

Technologies concerned with facility siting and effluent management are such that the impacts of an aquaculture operation can be reduced to a minimum. Positive benefits can be gained through the development of additional aquatic environments which provide habitat for a variety of animals.

Impacts of Escaped or Released Nonindigenous Organisms

Nonindigenous organisms introduced for culture or other purposes may pose a threat to the environment. Adverse experiences with some species such as the common carp and water hyacinth have engendered caution. Approximately 40 species of nonindigenous finfish have become established in the U.S. The long term ecological implication of most of these species is not known. An example of a beneficial introduction is the striped bass which was introduced to the Pacific coast in the late 1800's and has since produced a valuable fishery. Aquaculture, like agriculture, stands to be improved by culturing productive nonindigenous species and by breeding with improved strains.

Oysters have been widely transplanted with both beneficial and detrimental effects on cultured and wild oysters. The most widely introduced oyster is the Pacific oyster, Crassostrea gigas. This species now furnishes much of the world's oyster supply, but may have adversely affected or replaced indigenous species.

There are numerous instances in which the nonindigenous organism has been a host to invertebrates that have become severe pests on wild indigenous and locally cultured species. Examples include the Japanese oyster drill, Ocenebra japonica, the flatworm, Pseudostylochus ostreophagus and possibly the copepod parasite, Mytilicola orientalis. All were introduced to North America with the Pacific oyster.

Parasites and Diseases

Imported organisms are often accompanied by diseases and parasites, sometimes with catastrophic impacts on cultured organisms and occasionally on wild populations. Scientists estimate that 48 species of freshwater fish parasites have become established on other continents through the transfer of infected live and frozen fish. Almost all of the spread of freshwater fish parasites have been as a result of man's activities. At least five of these parasites have caused severe problems. The best example is whirling disease of trout, caused by the organism, Myxosoma cerebralis. This parasite has caused large economic losses in rainbow trout culture on three continents.

Careful screening, certification, and quarantine could prevent the establishment of most parasites and diseases.

Genetics

The release of large numbers of cultured species to coastal waters, "sea ranching," has raised questions about the potential impact on the genetic integrity of wild stocks. Interbreeding between domestic and wild stocks could result in genetic degradation of wild stocks. Each wild stock has a harmonious gene combination suited to its particular environment.

Changes in the genetic makeup may affect the stock's ability to survive. Potential problems of mixing domestic and wild stocks could be prevented through proper research and management.

Treatment of Wastewater

Aquaculture has the potential of becoming a useful tool in removing pollutants from wastewater. The greatest potential is probably in the removal of organic wastes from municipal sewage effluent or food processing effluents. A potential byproduct of the treatment process is food or fiber for plant, animal, or human use. Aquaculture provides a viable alternative to the traditional expensive mechanical and chemical waste treatment systems.

Planktonic algae, water hyacinths, duckweed, and other aquatic plants have been shown to remove solids, nutrients, and metal salts from water. The effluent from a facility containing aquatic plants can be of much better quality than the effluent from conventional stabilization ponds. In some instances the plants may be harvested or processed for soil conditioners, paper, cattle feed, or for production of methane or alcohol for energy. Fish have not proven to be as efficient as plants in the removal of pollutants but have shown some potential advantages over traditional secondary and tertiary treatment methods. Detritus-feeding molluscs show some promise in this area. However, public health concerns and the difficulty of meeting modern effluent standards, while stimultaneously maximizing aquaculture yields, do not favor immediate widespread use of fish for wastewater treatment.

Social Impacts of Aquaculture Development and Implementation

Supply of Protein

The latest per capita consumption figures for fishery products for the U.S. is a little over 12 pounds. Aquaculture can provide a stable supply. In local areas, it can provide a significant contribution in the protein budget by making fresh fish more readily available.

Employment

Some aquaculture systems are vertically integrated organizations; the fish are grown, harvested, processed, and marketed by the same concern. This pattern is not normally found in other commercial fishing operations in the U.S. Aquaculture operations will increase the number of available jobs, especially in rural and insular areas, and will provide for a stability of employment and increased revenues.

Sociocultural Issues

Social and cultural impacts occur whenever there are changes in established practices. Managers and officials concerned with aquaculture will have an opportunity to solve possible social and cultural conflicts before they arise by using sociological data in the planning process.

Many land and water areas have a social value and an existing use and changes would affect the social and cultural values of the local population. Local inhabitants may find they must share their clam flats with a commercial operation, or recreational fishermen might lose a popular length of river. Although the economic benefits of using the space for aquaculture may be clear, the social benefits may not be as obvious.

Cultural values placed on fish and their processing and harvesting are reflected in consumer attitudes towards fish; in the U.S., less than a dozen marine species command a high degree of popular acceptance and demand. Operations involving other species may encounter situations in which cultural values impair acceptance of the product.

Research has shown that aquaculture development is ultimately dependent upon acceptance by local communities as being socially and culturally appropriate. The development may be economically and technically feasible, but may not flourish without the support of local and regional populations.