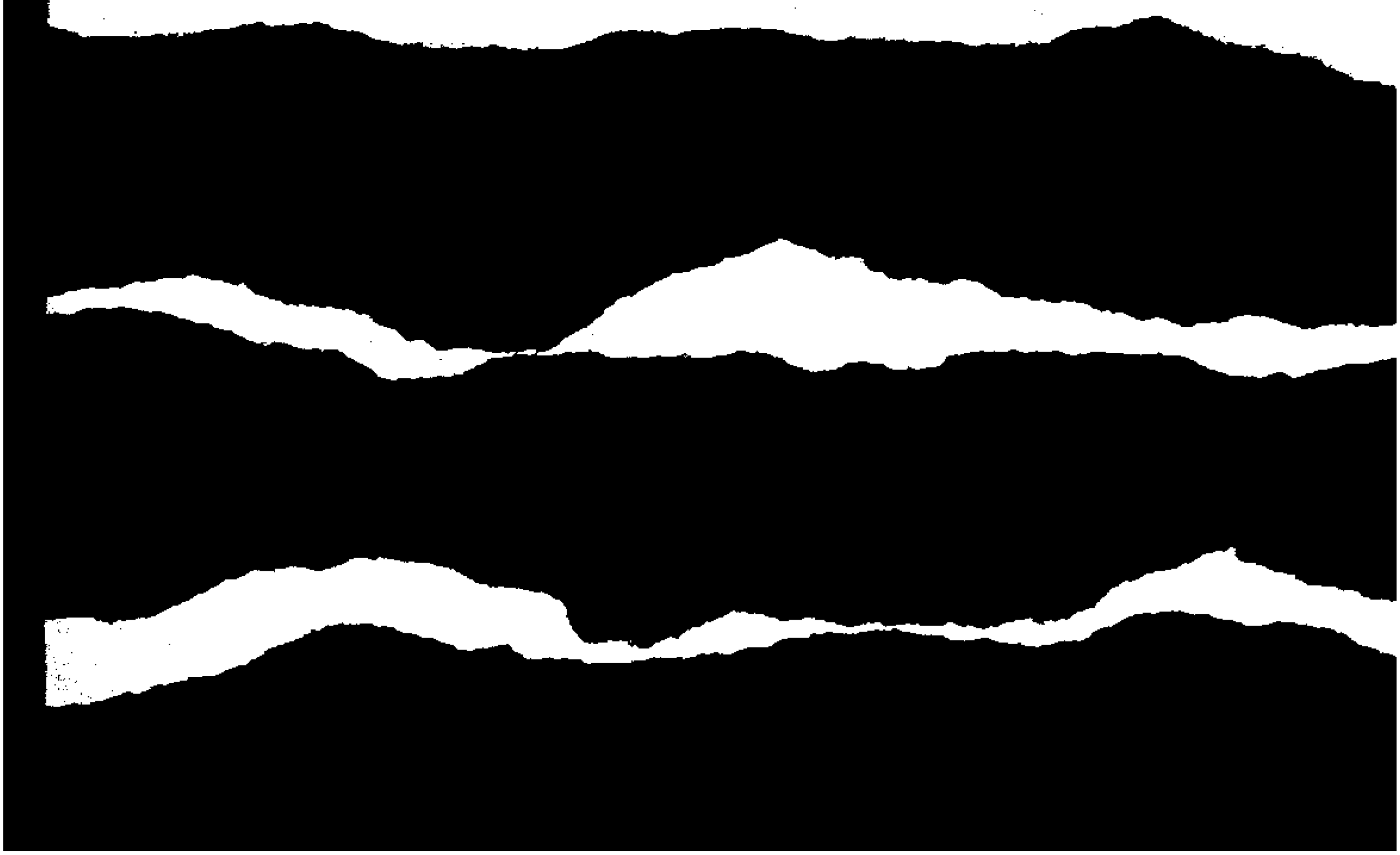
AQUACULTURE: A New England Perspective

Based on a conference conducted by *The Research Institute of the Gulf of Maine*

Thomas A. Gaucher, editor



The Research Insitute of the Gulf of Maine TRIGOM is a consortium of nine institutions of higher education in Maine primarily interested in the development of marine resources. Members are Bates, Bowdoin, Colby, Nasson, and St. Francis Colleges, The University of Maine at Orono, The University of Maine at Portland-Gorham, Maine Maritime Academy, and Southern Maine Vocational Technical Institute. Associate members are the Maine Department of Sea and Shore Fisheries and the Maine Medical Center.

The New England Regional Commission is a federal-state agency comprised of the governors of the six New England states and a federal cochairman appointed by the President. It was organized in 1967 under the provisions of Title V of the Public Works and Economic Development Act of 1965. As an equal partnership between the states and the federal government, the Commission's goal is to encourage and stimulate balanced economic development in the region. Research and regional action projects are undertaken by the Commission in ten functional areas which include commercial and industrial development, labor skills, education, health, housing, waste management, land management, resources management, transportation, and government services.

New England Marine Resources Information Program (NEMRIP) is part of the federal Sea Grant program and is based at the University of Rhode Island.

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Edited by THOMAS A. GAUCHER

Based on recommendations and several key documents from a conference to plan for aquaculture in northern New England, held October 21-23, 1970, in Durham, New Hampshire, conducted by The Research Institute of the Gulf of Maine, and sponsored by the New England Regional Commission.

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PREFACE

The Research Institute of the Gulf of Maine (TRIGOM) called a conference for October 21-23, 1970, in Durham, New Hamphsire, to consider the development of aquaculture in northern New England. Because the subject matter of the conference is applicable to all of New England, some of the key documents and the major recommendations have been collected and edited for this report offering a New England perspective on the subject.

Abundant freshwater resources, a long coastal marine interface, an existing fishing industry and fish processing infrastructure, relatively few competing land and water users, nearness to major population and market areas--all of these characteristics suggest that aquaculture should have a bright economic future in New England. Yet, in spite of these favorable endowments, presently little interest exists in investing in its development.

Although commercial aquaculture in the United States is in its infancy, there exist successful catfish farming enterprises in the South and Southwest, trout farming in Idaho, salmon and trout farming in Nova Scotia and the Northwest, and substantial pilot-scale culture of pompano and penaeid shrimp in Florida and Louisiana. A large oyster farming operation, in part utilizing heated water effluents from an electric power plant, has developed on Long Island, New York.

Since current aquaculture enterprises were initiated for profit and some are commercial successes, a basic assumption implicit in the conference objectives was that the major impetus for the growth of aquaculture would be private capital rather than public funds. In retrospect, this assumption is probably valid, although the most promising hope for initiating substantial aquaculture ventures in the region will be in various combinations of public and private capital and in response to economic and social needs.

An attractive possibility to reduce unemployment is the development of labor-intensive industries, such as shrimp and oyster aquaculture in Japan and mussel raft-culture in Spain. Although the development of aquaculture for the primary purpose of creating a maximum number of jobs is certainly a proper and important subject of study, these socio-economic issues fell outside the competence and interest of most of the conference planners and attendees and must be evaluated elsewhere.

There was a consensus at the conference that substantial commercial scale ventures would not be common for at least a decade. However, now is the time for planning in preparation for this development. The conference panels made specific recommendations for feasibility studies, aquaculture experiment station research, promotional activity, comprehensive planning, collection of needed environmental and biotechnical data, multiple use arrangements with existing industry, and legal accommodations for aquaculture.

Acknowledgments

The conference and this publication were made possible by a grant from the New England Regional Commission. The New England Marine Resources Information Program (NEMRIP) at the University of Rhode Island helped prepare pre-conference literature and this publication.

Many individuals worked conscientiously to make the conference a success. Dr. Donald B. Horton, TRIGOM director and conference chairman, provided the impetus and leadership which culminated in a most successful and fruitful conference. He was ably assisted by his dedicated and tireless staff, Mrs. I. Myra Siegel and Mrs. Carole Ferguson. Also especially helpful were Prof. Harlan C. Lampe, Prof. Orlando E. Delogu, and Mrs. Harriet P. Henry, attorney, who served with me as group session leaders. Special thanks are due the many colleagues who presented papers during the conference and to all participants.

Sincere appreciation is extended to the following individuals who also helped in conference planning: Mr. Spencer Apollonio, Dr. Robert W. Corell, Dr. Michael Mazurkiewicz, Dr. William D. Shipman, Mr. John B. Stewart, and Dr. Walter L. Schneider.

We also gratefully acknowledge our scribes, Mr. B. Paul Lindsay, Mr. William Rumage, and Mr. Henry A. Walker, who took notes at all conference sessions and gave their views on the proceedings and summary statements.

Thomas A. Gaucher, editor

CONFERENCE RECOMMENDATIONS

Donald B. Horton*

A NUMBER OF SPECIES HAVE HIGH POTENTIAL FOR DEVELOPMENT IN NEW ENGLAND

Two panels evaluated species for commercial aquaculture potential. The panel on the technological aspects of aquaculture concentrated attention on species in the high price range and used the following criteria: growth rate, conversion efficiency, the availability of feeds, hardiness, simplicity of larval development, and whether or not the species is indigenous to the Northeast. This analysis suggested that salmon, trout, bay scallops, oysters, mussels, hard clams, and the freshwater prawn have particularly high potential.

The criteria used by the panel that evaluated species from the viewpoint of economic potential were market volume, price, and price flexibility. The panel also concentrated attention on those species which would contribute most importantly to a potential increase in regional income. Although the minimum desirable increase in regional income was arbitrarily placed at one million dollars of gross sales at the producer level, the panel emphasized that individuals could profitably engage in the aquaculture of other species not satisfying this requirement and that, in the future, market conditions and new products could change the situation from a regional standpoint. The species selected by the economic panel were, with few exceptions, the same as those suggested by the technological panel and included salmon, trout, bay scallops, oysters, hard clams and northern lobster.

The point was emphasized that certain non-native species, either cultured elsewhere or having a high market price, can be excluded from serious consideration as candidates for aquaculture in New England at this time. These included sole, turbot, catfish, penaeid shrimp, pompano, spiny lobster, and abalone. It was deemed that further basic research is required before the commercial potential of the following native species can be realized: northern lobsters, marine worms, eels, northern shrimp, seaweeds, crabs, conch, sea urchins and tuna.

An important point made by the economic panel was that aquaculture production and marketing may develop in a manner similar to the development of the poultry industry, where, with new technology, mass-scale production became possible and led to specialization and integration of feed producers, marketing firms, hatcheries and production units. An industry of this kind can support a large infrastructure with corresponding economic stability and substantial employment.

*Director, The Research Institute of the Gulf of Maine.

PILOT-SCALE STUDIES, ENGINEERING STUDIES AND EXPERIMENT STATIONS ARE NEEDED TO IMPLEMENT RESEARCH IN AQUACULTURE

There are a number of species, notably salmon, trout and oysters, for which culture technology has already been developed and markets exist. For these species, engineering studies, detailed cost analyses and pilot-scale experiments must be initiated so that alternative technical approaches for both intensive and extensive cultivation can be evaluated.

Intensive cultivation generally utilizes small production units, intensive management, dense stocking, force feeding, and stock selection and manipulation. This approach involves a high capital cost, high operating costs, and produces a high yield per unit-area. Examples would include raceway culture, lentic ponds, power plant effluents, rivers, some intertidal sea locks, zones of upwelling, and coastal embayments with high tidal exchange.

Extensive cultivation normally involves large areas, low management, low capital cost, low operating costs, and low yield on a unit-area basis. Examples of such areas would include coastal embayments, sluggish ponds and open sea culture.

It is likely that early aquaculture progress in New England will yield the best results from an intensive approach since that method of cultivation can minimize the dependence on nature, thus reducing the uncertainties and risks and correspondingly increasing the system's reliability, output, and profit potential. Northern New England is typified by severe weather and sudden storms which could prove disastrous to an extensive farming operation in an exposed location. Moreover, in the early stages of a commercial operation, close control and inventory over stocks on hand may be necessary to secure financial backing. The investor may require that his investment be carefully protected rather than subject to the risks of an extensive operation. Although these risks may eventually prove modest in comparison to the economies realized by extensive culture operations, an intensive approach can be best justified initially. If this approach is economically and technically feasible, then larger production units and extensive ranging of the cultured stock can be considered as a means to reduce the costs of production.

Since market volume, seasonal market fluctuations and seasonal or cultural restrictions are limiting factors for some species, development of systems which permit simultaneous or joint production of several species could be advantageous in marketing. Whether such a system is feasible from technical and cost viewpoints must be evaluated in the context of a specific system. Multiple species culture does have certain inherent technical advantages. For example, the metabolic by-products of an intensive finfish culture operation could be utilized as nutrients to fertilize algal cultures for feeding to clams, oysters or bay scallops in a companion shellfish culture operation. Likewise the joint culture of salmon and trout, using almost identical technology, could help by providing an additional product for responding to market fluctuations and regional market preferences.

Aquaculture experiment stations should be established to help industry develop the required technologies for successful operations. Aquaculture is a high-risk industry which requires large capital investments. State and federal funds will be required to solve the biotechnical problems and to provide extension agent services. Particularly important in this regard is research needed on the development of basic biological information including selective breeding, disease diagnosis and control, nutrition, food conversion efficiency, and propagation requirements. In this connection, federal, state and private fish and shellfish hatcheries have a long and valuable experience which can be extracted from, evaluated, and used to augment the body of information concerning New England aquacultural prospects.

AQUACULTURE PROMOTION, DATA GATHERING AND PLANNING MUST BE INTEGRATED AND INCREASED

An investment promotion program should be initiated in the near future in order to induce the private sector to come to New England to investigate the commercial prospects for aquaculture of those species for which technology is developed, the environment is favorable, and markets exist. State agencies, citizens' groups, universities and conservation organizations should coordinate their efforts in this regard.

As a prerequisite to promotion there is a need to compile the available data and literature on what is known about the Gulf of Maine, (e.g.) species present, hydrography, climatology, water quality and soils, to assist interested parties in making site selections and systems approaches.

There are significant strides being made in compiling the needed data. For example, in Maine the Department of Inland Fisheries and Game in cooperation with the Department of Sea and Shore Fisheries is developing a computer-stored land and water inventory of the entire state, "A Comprehensive Fish, Wildlife and Marine Plan for Maine." This inventory will be used for rapid retrieval of all stored environmental information at any location. This and other similar efforts should be supported by all aquaculture interests.

In addition, comprehensive coastal planning efforts in Maine and Rhode Island should result in guides to specify locations for different kinds of aquaculture as well as allocate space for other uses. These planning efforts should be expanded throughout the region and should have wide support.

A number of research and management groups throughout the region are collecting data which will ultimately prove valuable to aquaculture interests. The various departments of marine fisheries, natural resources, conservation, and economic development; university marine laboratories; federal government laboratories, and many other agencies are all important sources of information. However, there is much evidence to indicate that the present activities are not nearly enough. There must be a determined, organized, well-funded effort to collect the data not available from other sources.

THERE ARE PROMISING COMPATIBLE RELATIONSHIPS BETWEEN AQUACULTURE AND OTHER WATER USES

Aquaculture is only one of many competing interests for coastal property and water use. The legal panel emphasized that comprehensive planning, allocation of water areas and police power regulation are necessary to facilitate the widest possible range of development alternatives in coastal and offshore areas, so that both the public and private welfare can be maximized. Since aquaculture does not necessarily require an exclusive use of the total environment, other uses can be accommodated. For example, vertical water column zoning for certain culture operations is feasible. Conceivably, oysters could be grown on estuarine bottoms while recreational boating and fishing occur on the surface.

Certain generalizations should be kept in mind now by planning authorities as they consider the allocation of space for aquaculture. First, in mariculture, most developments will probably be in protected coves and estuaries of coastal environments rather than on high energy beaches and rocky shore fronts. There are exceptions; Irish moss and other seaweeds of potential importance grow on the exposed rocky shore fronts. However, the growth and cultivation of Irish moss is probably compatible with most other uses of this zone. In the future, wide-ranging operations such as would be necessary in a tuna farming operation may use large areas of offshore coastal waters. However, in the more immediate future, intensive aquaculture is most promising and will be accomplished in protected environments.

A second generalization is that areas presently highly industrialized or irretrievably altered by pollution or engineering works are poor candidates for many kinds of aquaculture. Again, there are important exceptions. For example, oysters and other filter-feeding organisms are known to grow better in highly fertilized or eutrophic environments such as in estuaries in which there is domestic sewage pollution. However, shellfish can accumulate bacteria, pesticides and heavy metals on long-term exposure to small concentrations of these substances in the water column. Obviously, the use of domestic sewage in aquaculture is contingent on solutions to these problems. Partial solutions to these problems already exist. A post-harvest depuration cycle can be part of the production unit.

Intensive aquaculture itself can result in an organic pollution problem as a result of the accumulation of metabolic by-products of the cultured species and the high biological oxygen demand of unassimilated food, particularly in restricted environments where water exchange is slow and mixing processes limited. However, these are straightforward sanitary engineering problems which can be resolved. The pollution argument should not be used to discourage the development of these industries.

If we expand our concept of aquaculture to include the biodegradation of sewage and industrial pollutants, some interesting possibilities may exist. Conceivably, cost-sharing agreements could be established between units of government and the private sector for cultivation schemes which also minimize environmental degradation.

Various schemes have been considered and are now being implemented elsewhere in the country for the use of heated water effluents in intensive aquaculture operations. Biological and engineering feasibility studies should be undertaken at power plant sites to evaluate the potential for culture using heated water effluents. The Gulf of Maine is a cold body of water where temperatures are sub-optimal for growth of many indigenous species including salmon and trout. It may be that heated water effluents from electric generating stations can be harnessed for year-round production. However, the power plant and the aquafarm must be well integrated both early in conception and planning and later in the operational phases. If the aquafarmer is to have a guaranteed source of heated water, there must be provisions for alternative heat in the event of single-unit installations or unexpected plant shutdowns. Similarly, the present practice of using poisonous chemicals for condenser cleaning must be changed if use is to be made of the heated effluents.

THE LAW MUST ACCOMMODATE SUITABLE AND PROMISING AQUACULTURE VENTURES

In New England, the body of law affecting private and public ownership of coastal water and the management of natural resources is complicated and has probably discouraged commercial enterprise in aquaculture. However, the legal panel pointed out that the law is accommodating some promising experimental projects in aquaculture. They emphasized that the legal system will more readily respond if the economic potential and technical feasibility for specific ventures can be shown. It was emphasized by the panel that the system needs advance notice.

While it is recognized that a private investor needs to have his investment protected in the risky business of aquaculture by adequate laws (e.g. vested rights in leased coastal intertidal property), comprehensive aquaculture laws do not seem to be needed at the present time. There is considerable doubt that good and equitable comprehensive aquaculture laws could be drafted now, inasmuch as many of the basic requirements of future aquaculture ventures are not yet specified.

The panel recommended, therefore, as a first step that feasibility studies and pilot-scale experiments with the greatest likelihood of success be legally accommodated. Later, the legal system can allow (with appropriate safeguards and conditions) transition of proven aquacultural ventures from demonstration to development on a commercial scale, thereby assuring continuity and certainty with respect to initial investments.

Once the specific needs of commercial aquaculture are established, a variety of land and water use controls are possible. They include horizontal and vertical zoning, leasing, licensing, building and safety codes, easements, and the regulation of taxing power by variation in the rates of taxation.

While recognizing that in New England municipalities have traditional control over immediately offshore areas, eventually state, regional, or federal controls will be necessary to deal effectively with many aquaculture problems and opportunities. For example, an administrative authority must be established at the state level to accommodate private investment requirements in aquaculture effectively and fairly and to insure that these requirements are compatible with the public welfare. This authority for aquaculture would review proposals and evidence for specific ventures, would recommend enabling legislation, and would eventually be responsible for regulating multiple use arrangements with other agencies and industries. As a case in point, a means must be created through the state aquaculture authority to insure liaison between aquafarmers in need of heated water and power companies producing waste heat. Only by such foresight can a location be chosen which is optimum for power generation, aquaculture and environmental protection. Full consideration must be given by the authority to such factors as aquaculture plant design, species suitability, market needs, and regional employment very early in planning to insure the best possible arrangements for the public good.

A TECHNOLOGICAL PERSPECTIVE

Thomas A. Gaucher*

In recent decades, we have become accustomed to the world fishery catch increasing at a rate of six to eight percent annually. However, what is not widely appreciated is that most of the increase is due to the taking of small schooling species which are used for industrial purposes. In recent years, the world production of edible marine fish and shellfish has actually declined.

In the U. S., our domestic fishery has been unable to keep pace with demand for fisheries' products, so that today we import over 60 percent of our seafood. Those species most in demand and which command the highest prices are shrimp, lobsters, oysters, salmon, and trout. In fact, these alone account for over 80 percent of the value of all fisheries' products landed in the U. S.

Recognition of our inability to supply existing markets for quality seafood is particularly germane to the subject of this conference. Perhaps, more importantly, is the realization that an adequate technology does exist for culturing many of the species in the so-called luxury category. Outstanding examples include: (1) the advanced shrimp, yellowtail, eel and mollusc culture in Japan; (2) oyster culture in Long Island; (3) trout culture in Idaho; (4) salmon culture in Washington and Oregon; (5) mussel culture in Spain, and (6) a developing technology for lobster culture in New England and Canada.

The purpose of this paper is to evaluate selected species for commercial culture in New England and to review various alternative approaches to cultivation. We conclude that a variety of species should be assessed at this time, particularly the bay scallop, oyster, mussel, quahog, trout, salmon, and freshwater prawn. We believe that an intensive culture approach which minimizes dependence on nature offers decided advantages at the outset for New England development. Intensive culture systems developed in the salmonid industry are reviewed, since they provide examples which could be readily adapted to this region for a variety of species. Recent developments in Japanese bottom culture are also cited since such an approach offers a less costly alternative for intensive embayment culture in New England. Other technologies which are not reviewed because descriptions are readily available in the published literature include raceway, silo, rafted, cage, and thermal effluent cultures.

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Market Analysis

Table 1 estimates U. S. seafood comsumption to the year 2000 for all species and for the principal luxury generic groups: shrimp, shellfish, salmonids (salmon and trout), and catfish.

TABLE 1. United States fisheries potential based on population increase and on projected per capita fish and shellfish comsumption in (A) millions of pounds and (B) millions of 1967 dollars.*

	Year	Population (millions)	All Fish	Shrimp	Shellfish	Salmonids	Catfish
(A)	1967	197	2084	328	166	164	16
	1970	206	2264	356	179	177	17
	1975	219	2562	403	204	202	19
	1978	229	2771	435	220	218	21
	1980	235	2918	458	230	228	22
	2000	304	4620	724	365	362	35
(B)	1967	197	492	269	88	39	4.8
	1970	206	510	292	94	42	5.1
	1975	219	578	330	108	48	5.7
	1978	229	655	356	116	51	6.3
	1980	235	660	376	121	54	6.6
	2000	304	1042	594	192	85	10.5

*Explanation in appendix, page 19.

Shrimp alone accounted for over half of the total value of all fishery food products consumed in the U. S. in 1967. Of the total weight of heads-off shrimp consumed, 191 million pounds were caught domestically and the remaining 137 million pounds were imported. An average price of 82¢ per pound for shrimp was used in computing dollar value. Because the larger shrimp species (15 count or less per pound) sell for two to three times this price, perhaps a shrimp farming operation should focus on the larger, more valuable species.

The value of shellfishery products consumed is based on an average price of 52.8¢ per pound. Of the various species included in this determination, sea scallops were the most valuable, averaging 79¢ per pound. However, bay scallops, which were not harvested in sufficient quantities to be included statistically, sell at higher prices than sea scallops and warrant serious consideration for aquafarming. Although the average price for salmonid and catfish species is in the 20¢ to 40¢ per pound range, cultured stocks of these species sell for 60¢ to over $1.00 per pound.

Products other than luxury seafood items which may be profitable to the aquafarmer are certain seaweeds, ornamental fish, and worms. For example, the sand- and bloodworms used extensively by sport fishermen are in short supply. The bulk of the worms are taken from intertidal zones in Maine where there are indications that overexploitation has occurred. On the basis of weight, the worms are considered Maine's most valuable sea product, providing an average wholesale return of over $3.00 per pound. The current wholesale market is estimated to be over $3 million annually.

Table 2 shows the increase in value of fishery products due to processing and distribution. In the U. S. in 1967, domestic fishery products tripled in value from $438 million dockside to $1358 million retail.

TABLE 2. Value added to U. S. food fishery by processing and distribution (in million dollars).*

	Dockside	To Processor	To Wholesaler	To Retailer
Domestic Fishery	438	755	1042	1358
Domestic Catch plus Imports	1125	1193	2151	2578

*From 1967 Fisheries Statistics (11)

It should be noted that the U. S. imports over 60 percent of its fishery products, which are worth about one and one-half times more than the domestic dockside catch. Also, luxury products such as shrimp, oysters, and salmonids account for over 80 percent of the dollar value of the domestic catch. This information is particularly significant because these valuable groups lend themselves to large-scale, controlled cultivation employing known methodologies.

Traditionally, the U. S. fisherman has functioned as an independent operator and only in recent years have co-operatives, local fishermen's associations, and major privately-owned fishing fleets developed. However, due to rapid developments in aquafarming methodologies and erratic supplies of wild stocks, corporations are trying to enter the seafood culture business. Major U. S. companies known to be engaged in efforts to develop their commercial aquafarming status include Armour and Company, Corn Products Company, W. R. Grace and Company, Inmont Corporation, International Paper Company, Minnesota Mining and Manufacturing Company, Monsanto Company, Pennzoil Company, Potlatch Forests Incorporated, Ralston Purina Company, United Fruit Company, and United Gas Corporation.

Species Choices

Historically, culturists working with phylo-genetically different groups of aquatic forms have exchanged very little technical information. In the past few years, however, a general awareness has developed that methods and techniques used for one species may have value and utility when applied to completely different and biologically unrelated forms. In effect, a transference of methodologies is contributing in large measure to the current rate of progress in aquacultural accomplishments.

With this in mind, species from within several phyla have been selected for evaluation as candidates for cultivation in New England. The species selected for evaluation were restricted to those in the luxury high-priced category which have been shown to exhibit firm consumer demand. An extensive number of possible choices were screened and categorized in accordance with the technological state-of-the-art. The categories used include:

Advanced or adequate technological development for all life-history stages. Commercial operations exist. Representative types include catfish, oysters, and salmonids.

Advanced or adequate technological development, but the species are dependent on nature for some life-history stages. Some commercial activity exists, but requires some biological and engineering development for a completely integrated commercial system. This category includes scallop, mussel, prawn, and shrimp.

Require technical development, but at an advanced state. Basic biological developments are required in all cases. In this category are pompano, spiny lobster, the American lobster, abalone, plaice, sole, and turbot.

Require technical development but at a less advanced state. Require basic biological development before a decision can be reached on the suitability for commercial production. These include barnacle, sea urchin, bait worms, seaweed, crab, conch, and tuna.

Subsequently, ten species were selected for detailed evaluation. The candidate species, representing molluscs, crustacea, and finfish, were tested against selected criteria and rated on the basis of points obtained, using a binomial scoring system. (See Table 3.) The criteria were:

TABLE 3. Species selection.

Options	Controlled Spawning	Simple Larval Development	Fast Growth Rate	High Conversion Efficiency	Satisfactory Feeds Known	Indigenous to Northeast U. S.	In Higher Price Range	Commercial Feeds Available	Hardy	Decision: Score
MOLLUSCS										
Bay Scallop - Aequipecten irradians	1	1	1	1	1	1	1	0	1	8**
Oyster - Crassostrea virginica	1	1	0	0	1	1	1	0	1	6*
Mussel - Mytilus edulis	1	1	1	1	1	1	0	0	1	7**
Quahog - Mercenaria mercenaria	1	1	0	0	1	1	1	0	1	6*
CRUSTACEA										
Lobster - Homarus americanus	0	0	0	0	0	1	1	0	0	2
Shrimp - Penaeid sp.	0	0	1	1	0	0	1	0	0	3
Freshwater Prawn - Macrobrachium rosenbergii	1	0	1	1	1	0	1	0	0	5*
FINFISH										
Trout - Salmo gairdnerii	1	1	0	1	1	1	0	1	1	7**
Salmon - Salmo salar	1	1	0	1	1	1	0	1	1	7**
Pompano - Trachinotus carolinus	0	0	1	1	0	0	0	0	0	2

1 - advantage; 0 - disadvantage

** highly favorable; * favorable

Spawning and gametogenes controllable under laboratory conditions.

Simple larval development.

Fast growth rate.

High food conversion efficiency.

Satisfactory feeds known and available.

Indigenous to the region.

Sold at retail in the higher price range.

Commercial feeds available in quantity at competitive prices.

Hardy organism resistant to stress induced by confinement.

A degree of subjectivity was unavoidable in scoring. With a maximum possible score of nine points, a rating of seven or greater was deemed highly favorable because it is within the top 25 percent of the point spread. In this range are the bay scallop, mussel, and salmonids. The next most favorable species for cultivation, those within the top 50 percent in total points, were the oyster, quahog, and freshwater prawns.

The recommendations are based on general considerations only. Certainly, given a specific situation and more definitive information, other choices might be more suitable. However, the selections made according to this point scale seem the best prospects for aquacultural development in New England at this time. Success in farming the species listed would provide a broad and sound basis for adding other species in the future.

Alternate Methods of Cultivation

Aquaframing can be classified as extensive and intensive. Extensive cultivation normally utilizes large areas, low management, low capital cost, low operating cost, and low yield on a unit-area basis. Examples include coastal embayments, sluggish ponds, and open-sea culture. Intensive cultivation generally utilizes small production units, intensive management, dense stocking, force feeding, and stock selection and minipulation. This approach requires a high capital cost, high operating cost, and produces a high yield per unit-area. Examples include raceway culture, lentic ponds, power plant effluents, rivers, some intertidal sea locks, zones of upwelling, and coastal embayments with high tidal exchange.

An intensive approach employing modern processing techniques can minimize dependence on nature and correspondingly increase a system's reliability, output, and profit potential. Very likely, early aquacultural development in New England would yield best results from an intensive approach.

The major subsystems involved in an intensive aquaculture operation consist of the hatchery to support spawning, hatching, and larval culture requirements; the nursery to support juvenile development; the ranging subsystem to support post-juvenile development to market size; the water subsystem including provisions for waste disposal and, in some cases, recycling of processed water; and a feed production and feeding subsystem.

The combination of subsystems employed is determined principally by the type of species under cultivation, the source of water, and the desired operating temperature. The major process parameters to be considered in a culture operation are water and food requirements, stocking density, and the length of the growing period needed to attain market size.

An intensive recycling cultivation system, which might be appropriate for New England has been developed for the salmonid industry. However, the hardware system described is suitable for cultivating various other aquatic species including molluscs and crustaceans.

STATE-OF-THE-ART OF SALMONID AQUACULTURE

The technology for intensive salmonid fish culture advanced rapidly during the 1960's from efforts centered notably in the United States, Japan, Denmark, and the United Kingdom.

In the U. S., the Oregon moist pellet diet, the Donaldson moist feed formulation, and the dry pellet rations developed by several major feed companies such as Agway, Ralston Purina, J. R. Clark, and National Food have been credited with much of the increased success in hatchery and aquacultural operations. These rations contain nutritional factors lacking in earlier diets, but essential for healthy and rapid growth of salmon and trout.

The new moist diet formulations have several desirable qualities. Because they are pasteurized, several serious diseases previously transmitted through the feed are now controlled. Other diseases, not controllable by pasteurization alone, can now be controlled by orally administered medication incorporated into the diet. Furthermore, certain soluble essential food elements of current feeds are not now lost into the water by leaching, because new methods of feed manufacture have been developed which bind these elements firmly into the pellets.

Sanitation control in the rearing ponds and raceways is also greatly improved with these new feeds. They do not break up or wash out, and little food which can harbor unwanted microorganisms is lost into the water. Diseases then are a less serious limitation on survival and consequent yields.

Means are well developed to stimulate gametogenesis and to induce spawning. The ability exists to produce large quantities of fertilized eggs on command. Among the salmonid fishes which respond favorably to these new endocrinological techniques are Atlantic salmon (Salmo salar), Chinook salmon (Oncorhynchus tschawytscha), chum salmon (O. keta), silver salmon (O. kisutch), sockeye salmon (O. nerka), rainbow trout (Salmo gairdnerii), cutthroat trout (S. clarkii), brown trout (S. trutta), and brook trout (Salvelinus fontinalis). Selectively bred and hybridized strains have been developed to provide a spectrum of desirable characteristics, including early maturity, fast growth, large egg yield, high survival rate of progeny, disease resistance, and efficient feed conversion. A developed aquaculture now exists for fish husbandry that offers appreciably higher certainty of adequate yields, while significantly reducing production costs and increasing return on investment.

Only rarely is a natural water supply entirely suitable for salmonid culture. The most common faults are insufficient supply, a temperature too low or too high for optimum fish growth, a high silt burden, deleterious organic pollution, poor gas exchange, toxic pesticides, industrial wastes, and waterborne diseases. Now the recent development of large-scale water recirculating, controlled environment systems has eliminated or greatly reduced the effects of these limiting factors.

The controlled environments which can be operated completely closed, partially closed, or as flow-through systems, allow expansion of rearing space on limited areas and permit full use of growing facilities throughout the year. These systems reduce the silt problem and the quantity of intake water demanded. Due to the smaller quantity of water required, control of temperature, salinity, pH, and sterilization are considerably simplified.

Higher yields from genetically improved strains of fish grown to maturity in controlled environments are now realizable. Under investigation and giving promise for more efficient and profitable salmon and trout production are new methods in disease control, new automatic feeding systems, physical conditioning of the animals, and the design and operation of raceway, pond, silo, cage, and embayment systems. The adaptation of freshwater salmonids to saline environments has been shown to result in faster growth, fewer diseases with a consequent reduction in mortality, and improved fish quality. Taste and appearance (flesh, color, and texture) of the processed product is considered greatly improved over the same species grown in fresh water.

PRECEDENTS FOR NEW ENGLAND SALMONID CULTIVATION

Controlled production of salmon and trout by both government and private operators is carried out on a large scale in the U. S. In 1963, some 334 state and national fish hatcheries produced about 250 million trout and 290 million salmon for release into natural environments to contribute to commercial and sport fishery needs.

Of the hundreds of private salmonid businesses, most are small operations, servicing regional needs for eggs, and/or fingerlings for stocking, and/or mature fish for luxury food and recreational fishing. Less typical are some of the large trout companies located in Idaho and in certain other Western states.

The Snake River Trout Company in Buhl, Idaho, is the largest commercial trout farm in the U. S. It maintains a stock of more than 10 million trout in various stages of growth. The farm includes a complete fish growing and processing operation. Trout are spawned in a hatchery, raised to maturity in raceways and then killed, processed, and packaged as commercial food products. Annual production is approaching 2 million pounds. The fish are sold fresh and frozen throughout the U. S. primarily to institutional markets. Intensive cultivation, which yields as much as 400,000 pounds per acre annually, is realized in large part because of the abundant, 58°F constant temperature, natural, spring water supply available. The spring water, routed through the 10-acre farm at a rate of 60,000 gallons per minute, ensures a constant optimum temperature, replenishes the dissolved oxygen supply, and removes the products of metabolism and unused food particles.

Another successful example, Trout Lodge Springs in Washington also is endowed with a mountain spring, supplying constant 52°F water at about 40,000 gallons per minute the year round. This farm sells over 50 million eggs to other trout growers and roughly 200,000 pounds of live and dressed fish annually.

The key to success in large-scale salmonid cultivation evidently is an abundant supply of water of high quality and temperature. When an appropriate water supply is located, steps must be taken to guard against pollution or depletion. The land surrounding the site must be controlled to protect the water supply, ordinarily imposing considerable additional cost on a trout culture enterprise. The average acreage for the 50 cold-water national fish hatcheries is about 150 acres, much of which is obtained solely to protect the water supply to the hatchery that may occupy less than five acres.

These examples of commercial trout farms have exceptionally abundant water supplies, but a successful venture can be based on an alternative approach when quality water is in limited supply. The culture water can be cleaned by mechanical and biological filtration, aeration, and temperature adjustments, and then can be recycled for reuse. Recent achievements in recycling controlled water systems have obviated in large part the former requirement for very large water supplies.

The adaptation of freshwater trout to full salinity waters is a further means of freeing commercial trout culture from a dependence on an abundant resource of clean, cold, fresh water. Although the sea is not limitless, it can provide a vast quantity of good water on certain unpolluted coasts.

A SPECIFIC EXAMPLE OF INTENSIVE SALMONID CULTURE

These new technologies have been imaginatively applied in an integrated commercial operation by Sea Pool Fisheries Limited at Lake Charlotte, Nova Scotia. Because this operation incorporates these new features in an approach which appears suited to the culture of salmon and other species in New England, its basic concepts and systems are presented here in some detail. The Company employs closed-cycle, temperature-controlled rearing systems for culture of all the life history stages of trout and salmon. These facilities include pools that can be filled with seawater, surface fresh water, spring water, or any combination of the three. Water is continuously aerated and recirculated through limestone filters by air-lift pumps. Heat is added to the water when necessary from the waste heat of an oil-fired power plant. The required amount of new make-up water, primarily to replace evaporative loss, is less than 1 percent of pool volume in all of these closed-cycle systems.

Such rearing pools allow for conservation of water, removal of organic wastes, particularly the nitrogenous ones, and lower heating costs; and they make possible more efficient general control of the environment.

The units are multi-pool systems with associated gravel and dolomite filters designed according to the principles developed by Dr. Roger E. Burrows at the Bureau of Sports Fisheries Salmon-cultural Laboratory, Longview, Washington. Each module is independently regulated for temperature, salinity, pH, and filtration rate.

Growth scheduling that produces a marketable trout in eight months, from fertilized egg to a half-pound processed product, requires increasing amounts of seawater as the fish grow and a high quality, high protein pellet diet. Seawater provides certain essential trace minerals, which are absorbed through fish skin and gills; lowers the disease probability because the majority of fish diseases encountered at hatcheries are freshwater borne, and results in excellent color that produces a more attractive product for the market.

The fish diet used, which was developed at the University of Washington, is prepared on the site from autolysed, ground fish obtained locally, imported fish meal, dairy additives, cereals, vitamins, and shellfish byproducts high in carotenoid pigments, such as shrimp offal. The end product, a moist pellet readily accepted by the fish, produces rapid growth and an excellent pink flesh color. The diet formulation requires a 5:1 fresh to dry ratio. It is now produced at a cost between 10 and 15¢ per pound and results in a conversion ratio of 1.5:1. Feed costs are expected to be reduced as the feed production facility approaches an economical scale.

OTHER ALTERNATIVES

In addition to recycling culture systems, other alternatives for New England include embayment culture, thermal aquafarming, raceway cultivation, and sea-bottom farming. Although these various approaches have been previously described in the literature (See "Useful References," page 67), suspended bottom culture techniques are not well documented in the literature and, therefore, are briefly cited here.

Sea-bottom farming could prove to be particularly suited to New England. Coastal bottom culture offers a means to circumvent problems caused by freshwater runoff during the spring thaws, by capriciousness of weather and temperature, and by storm currents and tides, which are often disastrous to those who farm the surface waters, shallows, and margins of coastal seas and embayments.

In Japan, experimentation in cultivating fish and shellfish on the seabed has been conducted cooperatively by the Ministry of Agriculture and Forestry, the Fisheries Agency and the fisheries laboratories of the Prefectures. This program involves some of the following studies:

MUTSU BAY - Sea-bottom culture of scallops and ark-shells. Culture of scallops and ark-shells 10 to 20 meters below the sea surface in buoyant baskets attached to bottom resting concrete pods. Shells are superior to natural ones in their weight and size.

AGO BAY - Sea-bottom culture of pearls. To circumvent a parasitic infestation in shoal waters resulting in pearls of poor quality, oysters in wire cages were placed on the sea bottom at the mouth of Ago Bay at a depth of 22 to 24 meters. The tests show that young shells grow better on the sea bottom than at the upper or middle depth, while adults grow poorest on the bottom.

KOTSUTO - Sea-bottom culture of ear-shells. Ear-shells are herded and raised in corrals made of steel fencing attached to the rock sea floor by stakes at depths of 6 to 8 meters. Feed, in the form of seaweed, is given once a week by divers. This type of sea-bottom facility has proven to be safe in stormy weather and the shells' survival rate to maturity is high.

YUSHO BAY - Sea-bottom culture of salmon and trout. In Hokkaido and

Tohoku, the summer surface temperature reaches 20-24°C, which is lethal to cold-water salmon and trout. However, the temperature is under 18° at a depth of 15 to 30 feet where the fish could survive the summer. Consequently, bottom-setting and suspended fish preserves are being evaluated as a solution to the temperature problem. Feed is supplied through a "chimney" extending to the surface, and occasionally the condition of the fish is observed by divers.

Conclusions

A ready and growing market exists for quality seafood products. Because the commercial fisheries appear unable to fulfill the demand, it appears that cultured products can assume increasing significance in the marketplace in the years ahead. Recognition of this fact has encouraged large corporations to assess the business potential of commercial aquafarming.

Species considered particularly suited to cultivation in New England and for which the technology exists include trout, salmon, scallop, and mussel. Other suitable species include oyster, quahog, and also freshwater prawn in heated effluents.

An intensive culture technology employing recirculating, controlled culture systems is preferred for finfish, molluscs, and crustacea. Other alternatives which should be evaluated include sea-bottom embayment farming, thermal aquafarming, and raceway cultivation.

APPENDIX

TABLE 1 (A)

The projected population for each year (1) was multiplied by per capita consumption for each product for that year. The ratio of the consumption of each product to consumption of all fish was kept constant at the 1967 level for all years. Total per capita fish consumption of all fish was assumed to change linearly from 10.6 to 15.2 pounds per capita in the period 1967 to 2000 (2). Per capita consumption in 1967 for the other categories was obtained as follows:

SHRIMP: Bureau of Commercial Fishery data (3) for consumption on heads-off basis.

SHELLFISH: U. S. catch for clams, oysters, and scallops was 136,334,000 pounds (4). Adding imports of 29,570,000 pounds for oysters and scallops (5) gives a total consumption in pounds of 166 x 10^6. (There were no exports.) Dividing by population (166 x 10^6 lbs./ population) gives 0.84 pounds of shellfish per capita.

SALMONIDS: U. S. catch of salmon in pounds was 206.4 x 10^6 (6). Imports were 8.814 x 10^6 pounds (frozen) and 107 x 10^3 pounds (canned) (5). To find pounds of imports in round figures, multiply by 1.18 and 1.52, respectively (12), giving 10.4 x 10^6 pounds (frozen) and 0.16 and 10^6 pounds (canned) (7), which is equivalent to 22.3 x 10^6 and 31.2 x 10^6 pounds in round figures, respectively. Then consumption in pounds is:

206.4 x 10^6	catch
10.6 x 10^6	imports
217.0 x 10^6	
- 53.5 x 10^6	exports
163.5 x 10^6	= 0.83 pounds per capita

CATFISH: Per capita consumption of 0.08 pounds (2).

TABLE 1 (B)

Values were obtained in most cases from average 1967 ex-vessel (dockside) prices for each product. The all-fish price had to be adjusted for the difference between heads-off and heads-on shrimp prices. This report's figures are based on heads-off prices; however, the total U. S. ex-vessel catch value includes shrimp at the heads-on price. Details for each category are as follows:

ALL-FISH PRICE: Value of the total U. S. catch in 1967 was $\$438 \times 10^6$ (8), but this includes industrial fish. The latest value available for industrial fish is 1.7¢ per pound for 1965 (13). The 1967 industrial catch was 1.667×10^6 pounds and at 1.7¢ per pound its value is $\$28.3 \times 10^6$. Therefore, the value of all food fish in 1967 was $(\$438 - \$28) \times 10^6$ or $\$410 \times 10^6$. The 1967 food fish catch in pounds was 2385×10^6 (8), giving an average value of $410/2385 or 17¢ per pound. From this basic price, the difference in value between the heads-on and heads-off shrimp for each year is added, as explained above. For example, 1967 consumption of all fish = 2084×10^6 pounds. The 1967 shrimp heads-on price was 42¢ per pound (9), shrimp consumption was 328×10^6 pounds, thus:

$$2084 \times 10^6 \times 17¢ = \$354 \times 10^6 \text{ base value}$$
$$328 \times 10^6 \times 42¢ = \underline{\$138 \times 10^6} \text{ shrimp consumption}$$
$$\$492 \times 10^6 = \text{total value for all fish in 1967}$$

SHRIMP PRICE: 82¢ per pound, based on average 1967 heads-off prices for 15-20 count, 31-35 count, and 51-65 count brown, white, and pink shrimp (15).

SHELLFISH PRICE: 52.8¢ per pound, based on average price of 79¢ per pound for sea scallops (16), 55¢ for oysters, 44.3¢ for hard clams, and 9.7¢ for surf clams.

SALMONID PRICE: 23.5¢ per pound based on U. S. fisheries statistics (10)

CATFISH PRICE: Value of the catch of wild catfish and bullheads in the U. S. in 1965 was 21.6¢ per pound (14). Pond-raised catfish were selling from 45¢ to 70¢ per pound in some areas in 1967-1968 (6). A value of 40¢ per pound was chosen as a conservative estimate for cultured catfish.

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AN ECONOMIC PERSPECTIVE*

John M. Gates and George C. Matthiessen+

CRITERIA FOR SPECIES SELECTION

The objective of this paper is to develop and apply certain criteria as a means for the selection of species most suitable for commercial culture. By sequential application of the criteria, it is possible to eliminate, from a broad spectrum of species, those which currently have less potential for an industry of significant size. The elimination or "filtering process" makes it possible to concentrate in detail upon present and potential methods of culturing those species of greatest promise.

The reasons why certain species have been eliminated for serious consideration will be discussed in detail, from both a bio-technical and economic point of view. The net effect of the selection process has been to reduce to five the number of species (or groups of species) that appear to warrant serious consideration for commercial aquaculture in New England at this time.

The selection of criteria, and their application, has been based upon literature research, interview with members of industry and of the scientific community, and upon personal judgement and experience. It has been guided by the understanding that the interest of the New England Regional Commission is in projects where development could result in substantial increases in regional income and employment.

We wish to emphasize the following points:

(1) Rejection of a species on the grounds of limited impact on the regional economy does not necessarily mean that individuals should not engage in aquaculture of the rejected species.

(2) It is recognized that certain species currently judged unsuitable by these criteria may in future years become

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suitable. This change could occur as a result of technological development, shifts in consumer preferences, etc.

The criteria used fall into two distinct categories--biological and economic--and are discussed accordingly. The biological criteria include environmental adaptability and adaptability to intensive culture. The latter criterion includes a consideration of the present state of cultural knowledge. The economic criteria include market volume and price considerations, interregional competition and natural supplies.

Certain taxonomically related species are similar in their environmental requirements, mode of reproduction, etc., and may satisfy most criteria; in this case, the species whose prospects appear most likely is selected from the group for intensive examination in our continuing study. For example, several salmonids--rainbow trout, Atlantic Chinook and silver salmon--are highly similar in their requirements under culture and satisfy most or all of the criteria outlined. The implicit assumption is that, while an aquaculturist may culture more than one member species of an accepted group of species, initial efforts might be most successful if concentrated on the selected species. We obtain, through this sequential process, two major categories, viz., rejected species and accepted species.

Bio-technical Criteria

ENVIRONMENTAL ADAPTABILITY

There are many species of aquatic organisms throughout the world that have been found suitable for aquaculture and that form the bases for local or regional industries. Even though many of these operations may be economically viable or technically feasible in the particular region in which they are pursued, they will not be so in the New England states if they are physiologically unsuited to this area. Thus, the initial screening of aquatic species as a means of evaluating their potential for culture in the New England region should eliminate those that are physiologically incapable of tolerating the environmental conditions of this area.

The fact that water temperature can, for purposes of culture, be regulated is appreciated. In many aquacultural operations in temperate and semi-tropical latitudes, temperature regulation is in fact a vital part of the culture system. However, because of economic considerations, every effort is made to minimize the amount of heated water required, and the species under culture is usually, at some stage of its life cycle, exposed to ambient temperatures. Temperature manipulation is usually used to hasten reproductive processes, to insure the survival of larvae at times of the year when reproduction does not normally occur, or to accelerate the growth rate of juveniles. As a result of cost considerations, temperature manipulation is rarely, if ever, relied upon throughout the complete maturation process.

Practical use has been made of the cooling water discharge from steam electric systems--both nuclear and fossil fuel--as an inexpensive source of heated water for culture purposes, and there is little question that these effluents may be a highly useful aquacultural tool. However, for species that could not otherwise survive in the event of plant shutdown and consequent temperature decrease, total reliance upon steam electric system effluents for survival of the species cultured would seem to involve an unjustified risk.

If it is accepted that species incapable of surviving the climatic extremes of New England do not warrant efforts directed toward their large-scale culture, many species otherwise potentially worthy of consideration are eliminated. Included in this group would be such species as common pompano (Trachinotus carolinus), which succumbs to temperatures below 10°C; the pink shrimp (Pennaeus duroarum), which occur for the most part in tropical or semi-tropical waters; and many others that are suitable for culture in more tropical latitudes.

It is felt, then, that as an initial basis for selection of species for culture in New England, the species should be able to tolerate, at least through a significant portion of its life cycle, the temperature extremes characteristic of New England.

The rationale for this criterion is as follows. Aquaculture is, from a technical standpoint, in its infancy. Within the past ten years, many aquacultural projects have been initiated in the United States, and many have failed. Particularly with respect to marine species, relatively few projects are operating on a profitable basis. Certainly, as in any new endeavor, this picture should brighten as the technology improves. However, it would seem essential that species selected for culture should provide the culturist with minimum disadvantages and offer the maximum chance of success.

This view is reflected in the following statements by Iverson (1968):

"The species best for farming are those that are indigenous to an area. Through scientific farming of these species, the fish farmer will get the greatest production. He should not delude himself that transplanting species into a new environment will result in very rapid growth and high production. Such results are rare. Much has been written about the relatively successful transplants, but little about the unsuccessful ones.

"Clearly animals are most successful in the geographic areas where their best living conditions can be found. Trying to farm a species at the ends of its range is foolhardy because these animals live on a marginal basis. With a change in environment and conditions for the better, the species occasionally becomes abundant, but if the conditions become less favorable mortality will be high."

ADAPTABILITY TO INTENSIVE CULTURE

Bardach and Ryther (1968) have listed the following characteristics of organisms that lend themselves to commercial culture:

(a) ability to reproduce in captivity,

(b) hardiness of eggs and larvae,

(c) food requirements that are readily satisfied, and

(d) relatively fast rate of growth.

Although few species satisfy all these requirements, certain species fall so far short as to virtually preclude, at this stage, large-scale attempts at culture. In the case of other species, so little is known about their reproductive habits and larval and juvenile requirements in captivity that recommendations in favor of their commercial culture would seem unjustified.

The blue crab (Callinectes sapidus) is a species of commercial importance that has been cultured through various stages of its life cycle, although largely experiementally and not in New England. The difficulties in rearing this species through its rather prolonged larval period and in satisfying its rather extensive food requirements, when weighed against its ultimate market value of 10¢ per pound, tend to argue against efforts directed towards its commercial culture (Idyll, 1969).

Similarly, the northern shrimp (Pandalus borealis) is an oceanic species that to date has not been reared successfully in captivity. In cases where this has been attempted, the larvae generally have failed to survive (R. E. Knowlton, personal communications).

Most offshore groundfish and pelagic finfish species do not appear to be logical candidates for intensive culture at this time. From the point of view of the culturist, little practical information regarding reproduction is available. Their adaptability to intensive culture is questionable, and their nutritional requirements during their larval stages are uncertain. It is difficult at this state to conceive, for example, of culturing tuna on a practical basis. Therefore, even though certain species of flatfish, i.e. plaice and sole, have been cultured in Europe, the technical (and economic) difficulties encountered tend to discourage similar efforts here.

As a second basis for selection, therefore, sufficient technical information should be available regarding environmental requirements in captivity of the species in question. In short, the species has been cultured already through most, if not all, stages in its life cycle, at least on a pilot scale.

In summarizing selection criteria to this point, those species that appear most qualified for further consideration are those that (a) are physiologically adaptable to a New England environment, and (b) have been cultured, even to a limited extent, under conditions corresponding to the New England environment.

Economic Criteria

In addition to biological considerations, economic factors must be analyzed in the selection of species that possess high potential for commercial culture in the New England region. Economic factors include market price and volume, potential competition from other regions and natural supplies. Selection of species is based on judgements stemming from biotechnical and economic factors extant at the time of selection. This sequential approach permits elimination of many species from more detailed analysis at this time. Changes in technology, biological knowledge, consumer preferences and natural supplies could alter the selection of appropriate species. The selection results should, therefore, be reviewed periodically.

MARKET PRICE AND VOLUME

Selected species with a high price, the so-called luxury species, are analyzed further in this report. However, although high unit price is probably necessary, it is not a sufficient condition to recommend a species on economic grounds. Additionally, there must exist a significant sales volume for the species. Products with a high unit price but relatively low volume may be exemplified by the bloodworm which yields over $1.00 per pound to the digger. Products with high price and high volume may be exemplified by the American lobster. In this analysis the bloodworm has been rejected but the lobster has been retained. Other species with high price and volume include the salmonids, oysters, and hard and soft clams. Examples of species with a low unit price, but a high market volume would include certain groundfish (flounders, haddock, cod) which have been rejected by the analysis.

Many species exhibit substantial seasonal price fluctuations. If aquacultural production permits control of time of harvest, then prices higher than annual averages may be obtained. For example, trout supplies and prices are quite stable over the year, reflecting the control exercised by culturists. The opposite is true of salmon species. Supplies and prices fluctuate with salmon runs. At this time the only significant control which exists is using cold storage.

Market volume has been suggested as an important factor influencing the likelihood of success of a substantial aquaculture industry. It may be argued that new products can expand current market volume, and it is true that under some conditions development of new product forms can increase total demand for a primary product. The conditions under which such increases are likely can be determined by detailed analysis of markets. Certain high priced species have low market volumes as discussed earlier. It is tempting to gloss over the market volume criterion for these species by resort to the "new product" argument. This approach, however, would reverse the logical sequence, which would be to utilize existing supplies to first demonstrate that (1) a new product form potentially exists, (2) the new product is accepted by consumers, and (3) existing supplies are inadequate at prevailing prices to meet the demand for the new product. Demonstration of these conditions is normally executed by private industry. In the absence of a demonstration of these three conditions, market volume considerations should be based on current per capita market volume.

Similar comments can be applied to the concept of new market development. The marketing process is also subject to some economies of size which reinforce the case for minimum market volume criterion. Advertising costs per unit of product tend to vary inversely with market volume. The same is true of distribution costs.

Application of the market volume criterion requires specification of a minimum annual sales level to be used. We use a level of a million dollar increase in annual sales. The associated percentage increase in supplies at current ex-vessel prices is computed. If the supply increase exceeds 50 percent the species is rejected. If the supply increase is less than 50 percent its effect on prices is estimated by multiplying the present increase in supplies by the estimated price flexibility coefficient of the product in question. If the anticipated price decline is less than ten percent the species is not rejected. If the anticipated price decline exceeds ten percent, the supply increase is compared to the projected rate of growth in demand. If projected growth in demand cannot absorb the associated supply increase within ten years, the species is rejected. The rate of growth of demand is projected by assuming a 1.5 percent growth in real per capita income and multiplying this rate of growth of income by estimated income elasticity.

It is necessary to reiterate the following points: (1) Rejection of a species by the minimum sales criterion does not mean that individuals should not engage in production should they so desire. It is simply a recognition that the potential aggregate payoff is quite small. To an individual producer this payoff may appear quite large. (2) The minimum sales criterion implies nothing about the optimum size of production units. It refers to potential scale of the "industry" which may be comprised of numerous small firms, a single large firm, or any industry structure between these two extremes.

INTERREGIONAL COMPETITION

The significance of interregional competition lies in the fact that a species which does not have consumer acceptance in the region in which it is produced must be exported for sale in regions in which it is accepted. Interregional shipments would require that New England producers compete favorably with other areas. The importance of interregional competition is exemplified by channel catfish (*Ictalurus punctatus*). If one were to ignore unfavorable bio-technical considerations, production in New England might appear feasible. However, production is expanding rapidly in southern states where natural conditions are favorable. Furthermore, these states are closer than New England to feed supplies (a major item in production costs) and to product markets. Consequently, New England does not appear to have a strong competitive position vis-a-vis the South in catfish production. Not only is local demand limited, but exports to southern demand centers would incur a transportation cost higher than that faced by southern producers who have production cost factors in their favor.

Another example in this connection is the Pacific oyster. This species is of limited value for the half-shell trade in domestic markets due to aesthetic factors--taste and appearance. Export opportunities appear limited.

NATURAL SUPPLIES

Natural supplies are of obvious importance to successful aquaculture. Discovery of new supplies or fluctuations in availability of native stocks can influence the potential market value of the same species grown under controlled culture. The flow of production yielded by a given fishery depends partially upon the size of the population stock. The population stock at any point in time is influenced by past catch rates. The interaction of fishing effort (and hence catches) and population stocks is frequently summarized in the abstract by a yield-effort curve. An idealized example of such a curve is presented in Figure 1.

The level of effort indicated by E_{max} and its associated level of catch, L_{max}, are of particular relevance. The point L_{max} is termed the maximum sustainable yield (MSY) of the fishery. Increases in effort beyond this point may result in temporary increases in catch through stock depletion. Eventually, however, landings will be decreased below L_{max} although greater fishing costs are incurred by the associated increase in

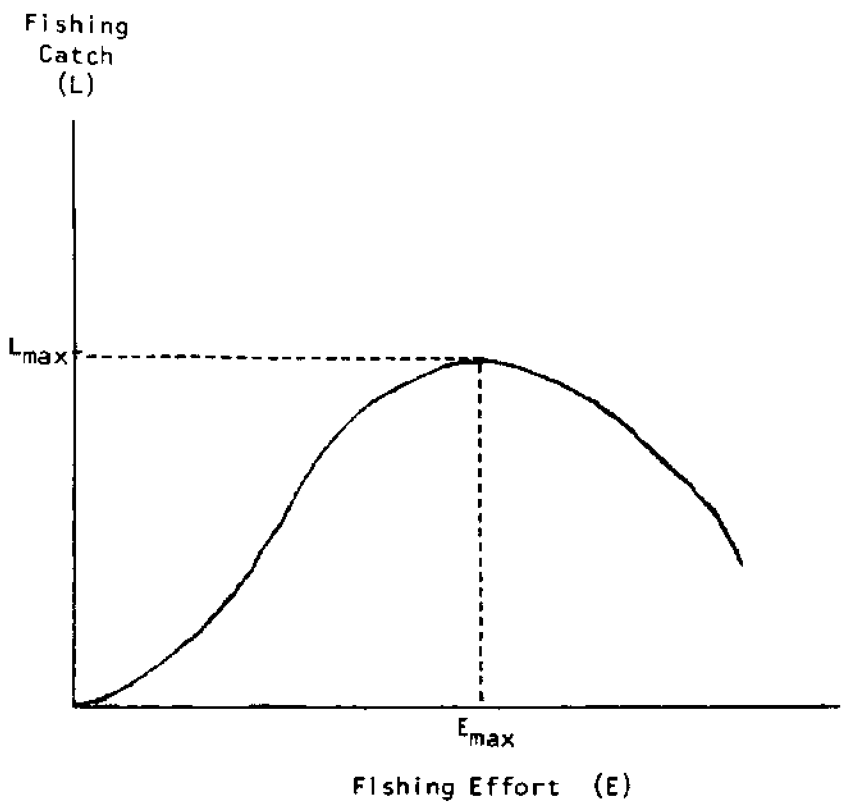

Figure 1. Hypothetical yield-effort curve for a fishery.

effort. A fishery whose annual landings are in the neighborhood of MSY will not have sustainable supply increases in the future. Demand increases will be absorbed by discovery of new supplies and/or aquaculture and/or price increases. Conversely, if current landings are considerably less than MSY, increases in landings may occur in the future.

The relevance of natural supplies could be stated in terms of future price trends. If current landings are in the neighborhood of MSY, market prices may be expected to rise in the future. The rate of price rise will depend on the rate of growth of demand even if fishing effort is stabilized at E_{max}*. If fishing effort is permitted to increase beyond E_{max} the physical yield of the fishery will be diminished and prices will rise more rapidly than the rate of growth of demand. Conversely, if current landings are considerably less than MSY, future price rises will tend to be less than the rate of growth of demand. The difference in growth rates of price

*The rate of growth of demand is discussed in connection with income elasticity of demand.

and demand in this case will reflect the dampening effect of increased supplies on price.

For example, the inshore lobster fisheries of the New England states are near their MSY point and future prices will rise quite rapidly unless new stocks are exploited.

Conversely, landings of clams by the New England, Middle Atlantic states and the Atlantic Coast provinces of Canada were less than 8.0×10^4 pounds in 1966. This total includes surf clams. By contrast, the estimated MSY of hard and soft clams in the Northwest and West Central Atlantic is 3.36×10^8 pounds which is many times greater than current landings by the coastal states of the area.* Future price rises will probably occur but will be limited by increased exploitation of abundant natural stocks.

Rejected Species

The preceding criteria are applied to several species in this section. The purpose of this section is to act as a filter to narrow the detailed discussion. The New England species sometimes considered for culture but rejected in this section include Atlantic sea mussel, bloodworm, winter flounder, rock crab, sea scallop, soft shell clam and several miscellaneous species. Discussion of each of these follows.

ATLANTIC SEA MUSSEL (MYTILUS EDULIS)

The Atlantic sea mussel is an extremely common species that occurs in abundance in the intertidal and sub-tidal zones throughout New England. Although considered a delicacy in many parts of Europe where, as in the Bay of Viga in Spain, it may be cultured intensively, this species has been of only limited commercial value in this country, where it is more frequently regarded as a pest rather than a potentially valuable food product.

In the 1960 thru 1967 period, mussel landings in the United States ranged from 3.20 x 10.5 pounds meat-weight valued ex-vessel at $\$3.4 \times 10^4$ in 1964 to 8.03×10^5 pounds valued $\$1.01 \times 10^5$ in 1967. Ex-vessel prices were approximately 8-10¢ per pound.

In recent years most of the U. S. production has been centered in

*Sources: U. S. Department of the Interior, Bureau of Commercial Fisheries Division of Economic Research Working Paper No. 55: Basic Economic Indicators - Clams (April 1970); Canada Department of Fisheries and Forestry, Fisheries Service, Economic Intelligence and Statistics Division Annual Review of Canadian Fisheries Volume 1, 1958-68.

New England, primarily in Massachusetts and secondarily in Maine.

A production target of $\$10^6$ would increase U. S. production by 1000 percent, at current ex-vessel prices. It appears that a European export potential may exist for mussel production. It does not appear that exploitation of this potential requires aquaculture. Natural supplies could be harvested for this purpose, if a profit potential exists.

Characteristics favorable for commercial culture:

1. The sea mussel is a hardy species, capable of withstanding prolonged exposure to warm or freezing temperatures when established between the tide lines. By means of its byssal threads, it can establish dense colonies on virtually any type of substratum other than soft mud.

2. Like most other bivalve mulluscs, the mussel is highly fecund. A mature female may release up to 10 million eggs at a single spawning.

3. Growth rate is relatively rapid, particularly if the mussels are established below the low tide mark (Scattergood et al, 1949). It has been estimated that mussels may attain the desired market size of three inches within a three-year period, (Matthiessen and Toner, 1962), and possibly sooner. According to Dow (1970), off-bottom culture techniques may produce marketable mussels in 12 to 18 months. Since the mussel is a filter-feeder, subsisting upon phytoplankton and particulate organic detritus, its nutritional requirements are immediately available in the water column.

4. Due to its habits of attachment, mussels are readily cultured by suspension techniques, and intensive yields from relatively small areas may be obtained in this manner. Bardach and Ryther (1968) report an annual yield of 240 metric tons of mussels per acre per year in parts of Spain where raft culture techniques are employed.

5. The mussel has been induced to spawn in captivity, and the larvae have been reared successfully through metamorphosis (Loosanoff and Davis, 1963). However, because of the general abundance of parent stock and because annual reproduction appears to occur rather consistently wherever adult beds are established, artificial techniques for supplying juveniles on a regular basis would in all probability not be required.

Characteristics unfavorable for commercial culture:

1. In the Northeast sector of its range, i.e. Eastern Maine and the Maritime provinces of Canada, mussels occasionally become toxic and unfit for consumption (Medcof, 1947). Incidents of mussel poisoning have been attributed to seasonal blooms of the phytoplanktonic dinoflagellate, Gonyaulax tamerensis, which, when ingested by the mussel, make the flesh

poisonous (Walford, 1958). Periods of mussel toxicity appear to be restricted to the late summer and early fall.

2. In certain areas, mussels may develop pearls, which, because of the resulting annoyance when chewed, may limit the mussel's market value.

3. In order to be attractive and presentable for market, the mussel must be washed and its byssal threads removed. Although this procedure may be time-consuming, it is perhaps no more so than cleaning oysters for the half-shell market.

Summary:

The major limitations upon mussel culture at present appear to be economic rather than technical. Present demand for this species does not yet warrent the expense involved in culture and natural supplies are abundant. Should this marketing picture change, this species would appear to be well suited for commercial culture efforts in New England.

BLOODWORM (<u>GLYCERA</u> <u>DIBRANCHIATA</u>)

The marine bloodworm is a common resident of muddy intertidal flats along the New England coast. Dow (1969) has indicated that this species has perhaps the highest unit value of any marine organism, since as much as $5.25 per pound may occasionally be paid to the fisherman. The bloodworm is marketed almost exclusively as bait for sport and commercial fishermen. Since, as pointed out by Iversen, (1968), the number of sport fishermen in the United States is increasing more than two and a half times as fast as the population and, by the year 2000, there will be over 62 million such fishermen in this country, methods for culturing this species in commercial quantities are being seriously considered.

In recent years U. S. bloodworm landings have been rather steady at approximately 8.0×10^5 pounds valued ex-vessel at approximately $\$10^6$.

Most of the U. S. production is centered in Maine which landed 8.32×10^5 pounds in 1968 and 7.82×10^5 pounds in 1969, valued at $\$10^6$.

A production target of $\$10^6$ would be a 100 percent increase in supplies at current prices.

Characteristics favorable for commercial culture:

1. The bloodworm is extremely fecund, with large females bearing anywhere from two to nine million eggs (Creaser et al, 1967).

2. This species is primarily a detritus feeder rather than a carnivore (Klawe and Dickie, 1957). As such, its nutritional requirements might

be satisfied relatively inexpensively under culture.

3. According to Klawe and Dickie (1957), the bloodworm is far less active in its wanderings than the sandworm (Neanthes virens). Therefore, the problem of maintaining large numbers of worms in a particular area until they reach marketable size might be minimal.

4. The bloodworm is tolerant of a wide range in salinity and occurs in both estuarine and oceanic environments.

5. This species reaches most favored market size in about three years. However, as a result of high demand, it may be of commercial value after its first year (Creaser et al, 1967).

Characteristics unfavorable for commercial culture:

1. According to Klawe and Dickie (1957), intensity of natural reproduction of the bloodworm in any given area may, for various reasons, be variable from year to year. However, these investigators experienced considerable difficulty in rearing the larvae of this species under artificial conditions and reported that little is known of the environmental requirements of the larval and post-larval stages.

2. Bloodworms are customarily harvested from the intertidal flats by hoe. Consequently, a minimum of equipment and hence capital investment is required. Although this fact is highly advantageous to the individual fisherman, it is also true that any species so easily accessible and readily harvested at minimum expense poses certain economic problems to the culturist who intends to invest in the acquisition and maintenance of private beds, and possibly in the controlled rearing of the species. Specifically, entrance and egress in the natural fisheries may lead to unstable prices. Without adequate property rights in the form of a lease, the culturist may face losses due to his inability to deny public access to growing beds.

Summary:

The bloodworm has certain characteristics that highly suit it for commercial culture. If cultured under natural conditions, without efforts towards intensive management, it would appear that a suitable area of roughly 300 acres might yield as much as 225,000 pounds of bloodworms each year. It is possible that such yield might be significantly increased if intensive management practices were applied. Whether or not reproduction might be guaranteed through hatchery techniques is unknown at this time. Although bloodworm prices are quite high, the species is rejected by the market volume criterion.

SOFT-SHELL CLAM (*MYA ARENARIA*)

The soft-shell clam is a common inshore species ranging in its Atlantic Coast distribution from Labrador to the Carolinas. Although it occurs most commonly in intertidal areas, it may also be fished intensively below the low water mark, as in the Chesapeake Bay and in various salt-water ponds in the New England area.

The soft-shell clam has had an ex-vessel price of \$0.30 - \$0.40 per pound since 1960. At 1967 prices, the increased production required to generate gross sales of $\$10^6$ would be 2.5×10^6 pounds. This would represent a 25 percent increase in supplies. Using an estimated price flexibility coefficient of -1.6, (National Marine Fisheries Service Working Paper No. 55, p. 14) this supply increase would depress prices by 40 percent. Since this percentage exceeds the ten percent level discussed in connection with the market volume criterion, we consider the rate of growth of demand in the following paragraph.

Assuming a 1.5 percent annual growth in real income, and an estimated income elasticity of 0.25 (NMFS Working Paper No. 55, p. 14), a 0.38 percent annual growth in demand is projected. This would result in approximately four percent growth in demand in ten years. This is not sufficiently rapid to absorb the above 25 percent supply increase.

Characteristics favorable for commercial culture:

1. This species is extremely hardy. It reportedly ceases to grow only when water temperatures drop to 3°C (Turner, 1948) and thrives at temperatures in excess of 26°C (Matthiessen, 1960). With respect to salinity, it has been planted successfully in waters ranging from 5 o/oo to over 31 o/oo (Belding, 1930). It may successfully populate a variety of sediment types, ranging from soft mud to coarse gravel. Intertidal populations can endure prolonged exposure between tides, accompanied by significant seasonal variations in air temperature.

2. In the southern portion of its range in New England, this species may grow extremely rapidly. According to Turner (1948) clams in Rhode Island waters may reach a legal marketable size of two inches in length in one year. North of Cape Cod, the rate of growth is somewhat slower, but even in northern Massachusetts and the western part of Maine, marketable size may be attained within three years.

3. As is true of most other bivalve molluscs, this species is sedentary rather than fugitive, and, because of its normal occurrence in intertidal or shallow water areas, it is readily accessible for harvest.

4. This species acquires its food directly from the water column or water-sediment interface--in the form of phytoplankton or particles of

organic detritus--and, therefore, its nutritional requirements are satisfied readily and inexpensively.

5. At least in the natural environment, soft-shell clams may thrive in extremely high densities. Populations of 50 legal size clams per square foot have been reported (Turner, 1948), although such densities are rarely attained. A well-managed flat, however, may yield over 100 bushels per acre on an annual basis (Wallace, 1967).

6. Clams may be harvested rapidly and efficiently with little breakage by the use of hydraulic dredging gear.

Characteristics unfavorable for commercial culture:

1. A commercial operation, in order to be viable, must be assured a reliable source of supply of juvenile stock. For this reason, certain of the larger oyster growers in New England have been forced to invest in oyster "hatcheries," since natural reproduction was not reliable. In the case of the soft-shell clam, consistent reproduction year after year in any given area can seldom if ever be guaranteed, and artificial methods of rearing the young might be required for sustained production. However, efforts to produce clams by conventional hatchery techniques have, for the most part, failed (Zuraw et al, 1967). Loosanoff and Davis (1963) and Stickney (1964) have succeeded in inducing this species to spawn in captivity and in rearing the larvae through metamorphosis, but only on a limited scale. In short, it has proven to date to be a difficult species to propagate under controlled conditions.

2. Soft-shell clams are extremely vulnerable to natural predators, which include the green crab (Carcinides maenas), horseshoe crab (Limulus polyphemus), and boring snails (Polynices heros and P. duplicata). Experimental plantings by Spear and Glude (1957) resulted in mortalities as high as 95 percent during a single growing season. Turner (1953b) has also reported cases of extremely high mortalities among populations whose histories have been traced through consecutive years. Even in areas surrounded by fencing as a means of excluding predators, heavy mortalities, for reasons not clearly understood, have been reported (Turner, 1950), in one instance as high as 85 percent. Virtually nothing is known about diseases and their cause among clam populations, but widespread mortalities may occur that cannot be attributed to predation.

Summary:

Despite certain characteristics of the soft-shell clam that make it a highly desirable species for commercial culture, it has, for the reasons given, failed to be cultured consistently on a commercial scale. Clam flats populated as a result of natural reproduction have been managed relatively successfully through predator control and regulated harvesting, but these efforts have followed the natural occurrence of the clams, which has not been subject to control. As of now, profitable clam culture, on a private, commercial basis, awaits further developments in methods for rearing the larval and juvenile stages to a point where they might be successfully managed in nature. Market conditions as discussed earlier are also unfavorable, and significant additions to the regional economy appear unlikely. For these reasons, this species is rejected.

WINTER FLOUNDER (PSEUDOPLEURONECTES AMERICANUS)

The winter, or blackback, flounder is a species common to all of the coastal New England states, where it is highly valued for food. This species commonly spawns in bays and estuaries, where the young may remain for the first few years of their existence. Because of its food value and apparent tolerance to a reasonably wide range of environmental conditions, and because closely related species have been cultured intensively in captivity (Shelbourne, 1965), some consideration has been given to the commercial culture of winter flounder in New England. However, the ex-vessel price of this species (about 10¢ per pound) is rather low to justify the costs of capital facilities and acquisition of suitable food.

Characteristics favorable for commercial culture:

1. By means of stripping ripe adults, the eggs of this species have been fertilized in captivity, and viable larvae are readily obtained.

2. The winter flounder is relatively fecund; large females may produce over 1 million eggs annually (Bigelow and Schroeder, 1953).

3. This appears to be a hardy species, capable of tolerating a wide range in both temperature and salinity. It may be found in abundance in areas heavily polluted by industrial and domestic wastes, and on bottom varying in sedimentary characteristics from soft mud to firm sand.

4. The winter flounder becomes of marketable size when only 3/4 of a pound in weight, or roughly 10 inches in length, at which time it may be three years in age.

5. Although the adult of this species is capable of extensive migrations (Coates et al, 1970), the juveniles may remain within the area in which they were spawned for two years or more (Perlmutter, 1947).

6. The adult flounder does not appear to be particularly selective in its feeding habits, reportedly being onmivorous to a degree and feeding upon algae as well as small marine animals, e.g. worms, clams, crustaceans, etc.

7. A related species--the plaice, *Pleuronectes platessa*--with

presumably rather similar environmental requirements--has been reared from fertilized egg to maturity under controlled conditions and in significant quantities (Bardach, 1968).

Characteristics unfavorable for commercial culture:

1. The food requirements of the larval and post-larval stages of this species are not well understood. On the basis of experiences with related species, it is presumed that these require animal protein to a degree and must, therefore, be provided small animals maintained in culture for this purpose, e.g. brine shrimp, marine worms, etc., or finely ground meat. Therefore, satisfaction of nutritional requirements may be costly in terms of both time and expense. According to Shelbourne (1969), pelletized food is not satisfactory for the larval or juvenile stages of the plaice.

2. Because of spatial requirements, it does not appear feasible to culture flatfish to maturity in commercial quantities under totally artificial conditions. Transfer of the hatchery-reared young to enclosed lochs or lagoons, where they may mature to marketable size, appears to be the most promising approach. However, according to Bardach (1968), considerably more must be learned of methods for preventing oxygen depletion, predation and disease before even this approach can become economically feasible. Furthermore, some form of enclosure would be necessary, since the winter flounder is inclined to wander considerable distances from its spawning and nursery areas when two years old or more.

Summary:

The winter flounder has certain characteristics favorable for commercial culture. However, although it is an important commercial species, its present market price (approximately 10¢ per pound, ex-vessel) is too low to justify the cost of hatchery operation and maintenance, the feeding of the larval and post-larval stages, and the construction and maintenance of impoundments required for rearing the juveniles to maturity.

SEA SCALLOP (PLACOPECTEN MAGELLANICUS)

The sea scallop, as a result of declining stocks on Georges Banks since 1966, has become an increasingly high-priced food item. In January of 1970, ex-vessel prices of domestic scallops reached a record high of \$1.46 per pound. Over 24×10^6 pounds of sea scallops were consumed in 1969. In view of the fact that imports are now roughly twice the volume of domestic landings (Surdi and Whitaker, 1970), and since it should be possible, theoretically, to culture this species by the same techniques developed for other species of bivalve molluscs, the sea scallop has been considered for aquaculture in New England.

Characteristics favorable for commercial culture:

1. The sea scallop is tolerant of low temperatures and, in fact, appears to grow most rapidly at temperatures approximating 10° C. In this respect, it would have a distinct advantage over most bivalve molluscs with respect to culture in northern New England.

2. As far as is known of this species, it subsists upon phytoplankton and particulate organic matter occurring in the water column (Posgay, 1950). Therefore, its nutritional requirements are readily satisfied without need of supplementary foods.

Characteristics unfavorable for commercial culture:

1. This species has proven difficult to rear under culture. Posgay (1953) had little difficulty in inducing adults to spawn under controlled conditions, but the larvae failed to survive to metamorphosis. Posgay (personal communication) reports that other investigators in Canadian laboratories have experienced similar negative results. Although the reasons for the failure of the larvae to survive are not understood with certainly, it is suspected that the nutritional requirements of the larvae of this species may be complicated and not readily satisfied by the algal foods conventionally employed in shellfish hatcheries. Quite recently, larvae have been raised successfully through metamorphosis by biologists in Maine (Dow, 1971).

2. As compared with the bay scallop (Aequipecten irradians), the growth rate of the sea scallop is relatively slow. It is estimated that a minimum of two years is required for this species to attain 40 millimeters in shell height, a size that may be attained by the bay scallop during its initial growing season. (Merrill and Posgay, 1967).

3. With many species of bivalve mulluscs, growth rate may be accelerated by elevating water temperature above normal. In the case of the sea scallop, however, maximum growth rate occurs at around 10° C; growth rate declines at higher temperatures, and mortality is generally complete at temperatures approximating 23° C (Posgay, 1953).

4. This species is a relatively active swimmer, and juvenile scallops reportedly have been observed swimming near the surface on Georges Bank where the depth exceeded 25 fathoms. Regardless of the reliability of these observations, it is evident that some mechanism for containing the scallops would be required for private culture operations.

5. The meat yields of sea scallops are low in comparison with bay scallops of similar size. According to Baird (1954), the weight of the muscle of a 50 millimeter sea scallop approximates 2.6 grams. Belding (1931), on the other hand, determined the meat weight of bay scallops in this size range as approximately 7 grams.

Summary:

Despite its current high market value and its physiological adaptability to the low temperatures characteristic of northern New England, the sea scallop does not appear to be a logical candidate for culture at the present time. Certainly the initial and most serious obstacle to culture is the inability to obtain juvenile stocks on a reliable and annual basis, whether by natural or controlled methods of reproduction.

ROCK CRAB (CANCER IRRORATUS)

The rock crab is the only crab species that presently supports a commercial fishery in New England. Although this species is reasonably abundant and ranges from Nova Scotia to Florida, relatively little was known of its ecology and life history until recent work by Sastry (1970). Nevertheless, in view of rising consumer demand for various edible crustaceans, including lobsters, shrimp and certain crab species, the possibilities of culturing this species on a commercial scale have been considered. Several economic criteria are not favorable however. Ex-vessel prices in 1967 were about 5-12¢ per pound. The market volume criterion is unfavorable unless a culturist were able to compete with king crab, which seems unlikely. Natural supplies appear abundant, and no evidence of general resource depletion is reported.

Characteristics favorable for commercial culture:

1. This species is tolerant of a wide range in temperature, other than during its larval period (Sastry, 1970), and is available in inshore waters during all seasons of the year.

2. The meat yield from the rock crab is equivalent to that from the blue crab (*Callinectes sapidus*), which supports a sizeable industry in the mid-Atlantic and Southern states, and its flavor is reportedly equal to that of the latter (Rees, 1969).

3. This species is readily trapped or harvested by trawl and is available closer to shore than its commercially valuable relative of the Pacific Coast, the Dungeness crab (*Cancer magister*).

4. Larvae may be reared at densities approximating two per ML of culture water (A. N. Sastry, personal communication).

Characteristics unfavorable for commercial culture:

1. This species is carnivorous and cannibalistic. The cost of feeding large numbers of crabs, held under artificial or confined conditions, might approximate the market value of the animals themselves, and

appreciable loss as a result of cannibalism might be expected.

2. There is large seasonal variation in the meat yield of rock crabs. Even under most favorable conditions, however, 20 crabs are required to produce one pound of meat (Turner, 1953a).

3. Even if the taking of female crabs were permitted by law--which it is not in Massachusetts--the female of this species is generally too small to be processed, i.e. the meat removed efficiently. Therefore, even if it were technically possible to culture large numbers of this species through the larval period, only the males would be worth retaining.

4. The growth rate of this species is unknown or, at least, has not been reported in literature. If it approximates that of the closely related C. magister, it can be assumed that, under natural conditions, three years would be required for this species to attain a size suitable for processing.

5. Although Turner (1954) found that the adult crab population of Boston Harbor was essentially non-migratory, it is nonetheless a motile species that would require some means of confinement if cultured in nature.

Summary:

The potential for culturing rock crabs on a commercial basis does not appear to be significant at this time, in part due to its carnivorous habits its small size, and our incomplete knowledge concerning cultural techniques. Certainly more should be learned of the life history and environmental requirements of this species before any effort is made to culture it on a commercial basis. Moreover, the market price and volume are not favorable for its culture.

MISCELLANEOUS SPECIES

A number of additional species have been suggested for commercial culture. We have found that these species either are of relatively low price or have certain other unfavorable characteristics. Therefore, profitable culture in New England appears highly unlikely. Included in this category are the alewife (Alosa pseudoharengus), shad (Alosa sapidissima), Pacific oyster (Crassostrea gigas), clam worm (Neanthes virens), and Irish sea moss (Chondrus crispus).

Virtually nothing is known of the requirements of the alewife and shad under culture, and their low price would not justify efforts in this direction. As indicated earlier, the Pacific oyster is unacceptable for the half-shell trade due to its unpleasing flavor when consumed raw and its comparatively coarse and unattractive appearance in the shell. The clam worm enjoys a rather high price, but, as was found to be true of the bloodworm, it would be rejected by the market volume criterion. Finally, Irish sea moss is not a species that is readily cutured--it is harvested where or when it occurs, and it, too, would be rejected by the market volume criterion.

These and other rejected species may warrant further research toward the eventual objective of establishing a commercial industry in New England. However, an important objective of this tudy has been to identify these species that appear to have the greatest potential for commercial culture at the present time, taking into consideration the degree to which additional research regarding their biology, environmental requirements in captivity, etc., would be required.

Accepted Species

Several species or groups of species satisfy most or all of the criteria, but are not selected for further analysis. These include several salmonid species and the European oyster. The salmonid species of interest include brook and rainbow trout, Atlantic salmon, red king (Chinook) and silver (Coho) salmon. A commercial trout industry has existed in New England and elsewhere for many years. The Atlantic salmon is somewhat unique in that it is indigenous to New England and has an extensive history of culture. We present a brief review of Atlantic salmon in this section. Of the Pacific salmon, the silver, or Coho, is the only one which has a significant history of culture in New England. We recognize that a culturist may choose to culture more than one of the salmonid species depending on circumstances of environment, prices and relative success in their culture.

ATLANTIC SALMON (SALMO SALAR)

The Atlantic salmon, once so abundant as to have been used for fertilizer in this country, presently occurs in only trace quantities in New England's river systems, and these systems are confined to the state of Maine. Currently, annual production from these rivers seldom exceeds 500 fish (Netboy, 1968). The Atlantic salmon is a valuable food species, when available, and commands a high market price. Since it would fall in the "luxury food" category and is obviously adapted to the New England environment, its potential for commercial culture would appear to be significant.

Characteristics favorable for commercial culture:

1. Techniques for obtaining the eggs and rearing the larvae and fry of this species under hatchery conditions are established.

2. The Atlantic salmon has been found to be highly responsive to

temperature and salinity manipulations. By maintaining water temperatures within a range of 9^o - 19^o C, Markus (1962) was able to rear newly hatched fry to the smolt stage in a period of ten months. Saunders (R. L. Saunders, personal communication), by manipulating both temperature and salinity, succeeded in rearing 35-gm fish to a weight of 456 gm in seven months and to 2,243 gm (roughly five pounds) in 19 months.

3. This species has a high food conversion efficiency. On a wet-weight to wet-weight basis, Saunders (personal communication) has estimated an efficiency of 25 - 30 percent. Using dry foods, a conversion of 1.5 - 2 appears typical for salmon in Canadian hatcheries (R. Macdonald, personal communication).

4. Atlantic salmon have been raised in captivity to a weight of five pounds at densities approximating one pound of fish per cubic foot of water.

5. This species lends itself to selective breeding, and strains that grew significantly faster than wild stock have been developed (Dalziel and Shillington, 1961).

6. Efforts to rear this species in commercial quantities, from fertilized egg to marketable size, under totally captive conditions have already been initiated, with indications of eventual economic success (Gunstrom, 1970). In other words, the technology for producing commercial quantities for Atlantic salmon, under conditions subject to a high degree of environmental control, presently exist.

Characteristics unfavorable for commercial culture:

1. Synthetic dry foods employed at most salmon hatcheries are expensive, ranging from 10 - 40¢ per pound depending upon the variety used. Lindroth (1963) has indicated that over one-third of the total operating cost of a hatchery in Sweden results from purchase of food.

2. Although population densities in excess of one pound of fish per cubic foot of water may be maintained, the water--in the absence of natural raceways--must be renewed at frequent intervals, i.e. every 1 to 2 hours (R. Hawkins, personal communications; Leitritz, 1960). The cost of pumping sufficient water in a large-scale facility may be considerable. (Obviously, pumping costs would not be realized in natural raceways, but, in these circumstances, the ability to exercise control over such environmental factors as temperature may be sacrificed.)

3. Control of disease has always been a serious problem in the rearing of finfish under crowded conditions. In an artificial environment, infectious diseases may flourish due to ease of transmission, higher water temperatures designed to accelerate growth rate, and dietary deficiencies

(Sindermann, 1969). Fish are also sensitive to such chemical factors as excessive nitrogen and low or super-saturated oxygen concentrations.

4. The Atlantic salmon is regarded by many biologists as the most difficult of the salmon to rear in captivity (J. Eagleton, personal communication).

Summary:

The Atlantic salmon has considerable potential for commercial culture in New England, largely because it is a species of high market value--in excess of 70¢ per pound--that has proven adaptable to intensive culture. We have chosen to regard Atlantic salmon as an alternate to the silver salmon in view of its similar environmental requirements and markets. We recognize that a culturist may choose to culture either or both depending on market conditions and relative success in culturing the two. Scientists who have cultured Atlantic salmon have indicated that it is one of the most difficult of the salmon to rear.

EUROPEAN OYSTER (*OSTREA EDULIS*)

The European oyster (*Ostrea edulis*) was imported into this country from Holland in 1949 for the purpose of establishing an oyster industry in Maine (Loosanoff, 1962). (This species spawns at lower temperatures than does the American oyster, *Crassostrea virginica*, and therefore would be more likely to self-propagate in northern New England.) Since its introduction, it has succeeded in reproducing naturally both in New England waters and on the Pacific Coast, to which it was later introduced (Loosanoff et al, 1966). Since this species is prized for the half-shell trade and may command an even higher price than *C. virginica* in certain markets--as on the Pacific Coast (Matthiessen, 1970)--it would appear to offer an economic incentive for commercial culture.

Characteristics favorable for commercial culture:

1. As mentioned above, this species will normally reproduce at temperatures considerably lower than those required for reproduction of *C. virginica*. Imai (1967) reports that spawning may occur at temperatures as low as 15° C, whereas *C. virginica* rarely spawns at temperatures below 20° C. This species would therefore provide greater flexibility in its culture in various regions of New England.

2. Conventional hatchery techniques have been employed successfully in the rearing of this species under controlled conditions. (Breese, 1969; Imai, 1967; Loosanoff and Davis, 1963; Walne, 1956).

3. The larvae of this species tolerate a wide range in temperature,

being capable of growing satsifactorily and metamorphosing at temperatures ranging from 17.5° to 30° C (Davis and Calabrese, 1969). These authors report that satisfactory growth of the larvae of C. virginica is possible only at temperatures above 22.5° C.

4. This species is a filter-feeder whose nutritional requirements are readily satisfied in the natural environment.

5. This species is adaptable to intensive culture. When grown in floating trays, it may be cultured to maturity at densities approximating 100 oysters per square yard (Belknap, personal communications). Moreover, growth rate is rapid, and marketable size may be attained in a period of two years.

Characteristics unfavorable for culture:

1. Despite the fact that this species has reproduced naturally in northern New England, successful "sets" reportedly have been sporadic from year to year. It appears probable that a viable commercial operation would have to depend at least in part upon supplementary reproduction through hatchery methods, if its supply is to be assured.

2. Controlled reproduction of this species has met with inconsistent results (Walne, 1956), and inducement of spawning in the laboratory reportedly may be difficult (Loosanoff and Davis, 1963).

3. As is true of other bivalve molluscs, this species may be subject to heavy predation by enemies in the natural environment, most particularly starfish and oyster drills. Adequate methods of predator control would be a necessity in any culture operation.

Summary:

The European oyster has certain characteristics favorable for commercial culture in New England. Certainly its ability to reproduce naturally and thrive in waters of relatively low temperature offers an important advantage over many species. However, the costs and technical difficulties inherent in hatchery operations, which might well prove necessary for sustained production, must be recognized. We have chosen to regard the European oyster as an alternate to the Eastern oyster in view of its similar environmental requirements and markets. We recognize that a culturist may choose to culture either or both oysters depending on market conditions and relative success in culturing the two.

Summary of Species Selected

By the process of elimination described above, involving application of technical and economic criteria, the following species emerge as the most suitable for commercial culture in New England at this time:

Eastern oyster (*Crassostrea virginica*)

hard clam (*Mercenaria mercenaria*)

bay scallop (*Aequipecten irradians*)

silver salmon (*Oncorhynchus kisutch*)

American lobster (*Homarus americanus*)

We have not included application of criteria to these species in this section. However, this will be done as part of our continuing study. It is emphasized that technological as well as economic developments could alter this list. At the present time, however, it is felt that these five are among the better species and warrant greater consideration than others for public research and private investment.

In addition, an aquaculturalist might wish to experiment with certain other species whose cultural requirements are similar. For example, Pacific and European oysters might be considered in conjunction with Eastern oysters; the former because of its rapid growth rate, the latter because of its high price and tolerance of low temperatures. Similarly, while silver salmon is selected for further analysis, a culturist might chose to experiment with Chinook and/or Atlantic salmon.

Multiple Species Systems

It may prove desirable to culture more than one species in an aquacultural system. If two or more species have symbiotic relationships under culture, then culture of the two may result in lower cost than if either were produced separately. Similarly, if species are noncompetitive in their spatial, environmental, labor or food requirements, greater efficiency in use of labor and/or plant capacity may be possible by joint culture. Many pathogenic organisms in nature are host specific and occur in epidemics whose frequency increases with spatial density of the host species. Should such organisms be a problem in aquaculture, joint production of species might reduce disease incidence without reducing the physical productivity of a given aquacultural system. Oysters produce a considerable volume of organic wastes which might prove a suitable cultural medium for sandworms. Although rejected as a species on which to base significant aquacultural industry, the sandworm might well be considered as a complementary product in the production of oysters. Similarly, the waste effluents from salmonid rearing are high in nitrogenous compounds which might stimulate algal growth for oyster culture. In sales, an aquaculturist may well find customers more receptive if more than one species can be supplied. Such complementary possibilities in sales re-enforce the case for multiple species systems or horizontal integration with other suppliers of food fish to obtain supplies of several species.

These considerations are hypothetical, however, and we can find no germane literature to support the hypothesis that mixed systems may prove more profitable than single species systems. Consequently, we have, somewhat reluctantly, abandoned the concept of mixed systems at the present time. Future research may yield results which warrant further consideration of the concept. Alternately, an aquaculturist may choose to explore the concept in experimental efforts ancillary to production in a single species system.

A related, but distinct, topic concerns the possibility of complementary relationship between domestic waste effluents and the culture of filter feeders, such as oysters. The extra-market costs of discharging these effluents have been largely ignored by the public agencies in order that monetary costs incident on taxpayers be minimized. This attitude is increasingly criticized by a concerned public. It may prove possible to use aquaculture in this context to help solve an environmental problem. It may prove necessary to develop public-private cost-sharing mechanisms to do so, however. Moreover, it should be recognized that most systems for disposal of domestic wastes have little or no control over fluctuations in the components of their effluents. Such fluctuations could be incompatible with successful aquaculture.

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A GENERAL LEGAL PERSPECTIVE

Harriet P. Henry*

To help evaluate the suitability of the present legal structure for aquaculture, I should like to briefly identify some aspects of the legal-institutional arrangements which should be considered.

STATE LAWS VARY

To begin, one should note that laws in each state vary according to the state's historical, economic, and social heritage; the special interests and peculiarities of a particular state or locality are reflected in its laws. Thus, it is not surprising to find that traditional oyster producing areas such as Virginia have extensive statutory provisions for the aquaculture of oysters or that oil interests have statutory priority over fishery resources in Louisiana statutes.

But what is more important than the differences in each state are the underlying basic similarities in the common law and statutes pertaining to aquaculture. One caveat, however, is that similar aquaculture statutes might not result in a similar pattern of rights in each state due to the complexities of land ownership in the intertidal zone as well as the geographic and special interest exceptions that plague substantive fishery laws in all states.

LOCATION IS IMPORTANT

The physical location of the aquaculture effort is a prime factor in determining what law will govern. Thus, beyond the 12-mile limit, water areas are subject to international control, although the bottom area of the continental shelf and fishery resources contained therein are under the jurisdiction of the nation state. Between three to 12 miles from shore, the federal government has jurisdiction which has been exercised in the granting of mineral leases. Except for regulations prescribed by international treaty, however, there has been no federal management of fishery resources in this area other than the preclusion of foreign flag fishing.

Within the three-mile limit, the sovereign coastal states of the United States have ownership and jurisdiction subject to federal supremacy in fields of navigation, commerce, defense, etc. How far municipal boundaries extend into tidal waters depends on the corporate charters of each locality, at least, in Maine. Thus, areas suitable for aquaculture may or may not be within the jurisdiction of a municipality.

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As a general rule, land under the low water mark in tidal waters is not capable of private ownership, except for areas which have been subject to a special grant or historical ownership. States can and have sold such lands, but the trend is otherwise. The pattern of public or private ownership in the intertidal area between the ordinary low tide and ordinary high tide varies from state to state. Most commonly, private ownership stops at the high water mark and the state owns beyond it; this corresponds to the concept of private ownership under English common law. Notable exceptions include Maine, New Hampshire, Massachusetts, Pennsylvania, Delaware, and Virginia.

Determining private or public ownership in the intertidal zone, however, by no means assures legal certainty. Even in states in which the riparian upland owner cannot own below the high water mark, such owners have been accorded privileges and prerogatives in the intertidal zone and even below the low water mark. Conversely, in states in which the upland owner can own to the low water mark, the area between the high and low water mark is impressed with a servitude for fishing and navigation. This results in similar operating rules in both types of states. Legislatures of states in which private ownership stops at the high water mark have a distinct advantage in allocating areas for aquaculture, but they still have problems.

For the inland waters of a state, legal ramifications are less complex. In some states the bottoms of non-tidal rivers are owned by riparian owners. In these states, as well as in those in which the bottoms are owned by the state, statutory provisions exist for aquaculture and for the authorization to divert water, take fish, etc.

Legal aspects of aquaculture in private ponds or artificially created ponds are progressively simplified. For aquaculture in artificial habitats of excavated areas in which tidal water is circulated, statutory provisions may be found in Rhode Island and Massachusetts.

DIRECTION UNCERTAIN

From a perusal of material on the subject, I conclude there is apparently no unanimity as to what direction the bulk of aquaculture activity will take. For instance, you may read, on page 219, Volume 2, of the recently published "National Estuary Study" issued by the United States Department of Interior Fish and Wildlife Service:

> Properly, aquaculture developments should be located in areas where the operations would not foreclose natural production or seriously limit public enjoyment of renewable or scenic natural resources. Such location would usually not be in marsh areas or intertidal areas. Rather they would be in relatively barren areas above high tide, with water supplied by pumping.

Those who progress to page 24, Volume 5, will find the following:

> Given that most near future aquaculture will either take place in "open" or "partially open" systems, they will be subject to waterborne pollutants, just as their untended counterparts.

GOVERNMENT LEVEL OF CONTROL VARIES WITH SPECIES

The location of an aquaculture enterprise, of course, depends on the species to be cultivated. But control of fisheries is a part of the sovereign power of each state, be they on inland or tidal waters. This is so whether the actual water or land areas are owned privately, by a municipality, or by the state.

The states have seldom delegated control of their fin fisheries except at times allowing local provisions for alewife fisheries. But in many instances responsibility for shellfish in the intertidal zone has been delegated to municipalities. Even in states where land in the intertidal zone is "privately owned," areas can be leased by the state or municipality for cultivation of clams, quahogs and mussels. Another troublesome factor, however, is that areas suitable for cultivation may extend beyond municipal boundaries. Connecticut, by the way, has statutory provision allowing municipalities to jointly regulate shell fisheries and, thus, permits allocation of cultivation areas on a regional, rather than a merely local basis.

If a species, such as oysters, is to be grown below the low water mark, responsibility for allocating culture areas in most jurisdictions is completely state controlled. (An obvious exception is Connecticut in which control of the near shore areas has, in most cases, been given to municipalities.)

RIPARIAN OWNER IS FACTOR

Owners of the upland, whether in a high or low water state, have been given certain prerogatives beyond the low water mark, an area usually not capable of private ownership. For example, in Maine, a riparian owner must give his consent for oyster cultivation in front of flats or shore or an upland owner in Virginia whose shore frontage measures at least 105 feet has the statutory right to a half acre of oyster growing territory in front of his property, if he cares to exercise the option. He may exert this right even if the property has already been allocated by the state, although a provision exists for phasing out a previous leasee. This is in accord with statements of the Virginia Supreme Court and is reflected in the laws of most states, which hold that a riparian owner has certain rights beyond the low water mark which accrue to him as natural advantages of adjacency to the water.

OTHER LEGAL PROBLEMS REMAIN

Once the riparian owner has been appeased or dispensed with, other legal problems remain: How large an area can be obtained? What type of area can be leased? How is a particular parcel to be allocated--first applicant or competitive bid? How much total acreage may one individual hold? For how long? Is the lease renewable? How often? What has the leasee bought--all fishery resources in the area or just shellfish or just a particular species? What exclusiveness does the aquaculture leasee enjoy from the competition of other marine activity such as swimming, boating, fishing, transportation, etc? What state agency grants the lease? How does aquaculture fit into that state's coastal plan?

Provisions covering these points vary greatly from state to state and from species to species within a state. For example, in Maine, no limit is placed on the area or the time for oyster cultivation, but in the statute providing for experimentation with Irish moss or other marine species, the area is limited to one square mile per parcel, no more than three parcels to an individual, and no more than ten square miles in the territorial waters of the state. In Rhode Island an oyster leasee may obtain only one acre at a time, although his total acreage is not limited by statute. In states like Virginia, areas up to 5,000 acres in Chesapeake Bay may be leased, 3,000 acres in other waters. Maryland, on the other hand, will allow a maximum of 500 acres to be leased for cultivation of oysters in Chesapeake Bay and a maximum of 30 acres in most other areas.

States like Virginia and Maryland allow the first applicant to obtain a lease, providing other conditions are met. Connecticut and New York laws provide for allocation of leased areas by competitive bid; whereas, the Director of Natural Resources in Rhode Island has discretionary power to require a public auction for submerged land. The time an area may be leased varies from five to 30 years, but some provisions for renewability in certain jurisdictions make a lease equivalent to an inheritable right "during good behavior."

It is not surprising that most present aquaculture laws deal with oysters, which were even cultivated by the ancient Egyptians. Other species will undoubtedly require different legal provisions for area, time, type of water and land, and degree of exclusiveness. And some revisions undoubtedly are necessary in state statutes to provide for the raft culture of oysters.

Once factors like time, place, duration, and species requirements are sorted out, a legal structure is still needed not only to integrate all law relating to aquaculture, but also to integrate the relationship of aquaculture and other competing marine activities.

STILL OTHER BARRIERS EXIST

Another aquacultural barrier to consider is the prohibition against allocating for cultivation natural growing areas of shellfish. This prohibition stems from historical dependence on this common property resource for subsistence. Almost all states prohibit exclusive private exploitation of natural beds (with some geographic exceptions) but, as far as I know, Virginia is the only state having a constitutional prohibition against such an allocation. The fact that the natural growing areas may be the best suited for biological growth and for maximum yield seems too obvious to belabor.

Another formidable obstacle may be the requirement that aquaculture leases may only be granted to state residents. Municipally controlled shellfish areas circumscribe such eligibility even further by requiring an applicant be a resident of the municipality. (Maine relaxes this requirement if the applicant is a taxpayer, but a strict interpretation of fishery laws make questionable whether a non-resident taxpayer could harvest the crop of shellfish.) The importance of this residency requirement should not be underestimated. Most states limit their shellfish resources to residents, and such restrictions have been upheld by the U. S. Supreme Court, although laws which would impose such restrictions on free-swimming fish have been successfully challenged.

With the exception of Connecticut, where statutes provide that residents or non-residents are equally eligible for leases for oyster cultivation, prohibition is the rule. New Jersey even demands an applicant swear under oath he is a resident. Virginia spells out residency requirements quite clearly, and an applicant for a lease must be a resident. If the applicant is a corporation, such a corporation must be chartered under the laws of Virginia and 60 percent of the stock must be owned by residents of the state. In addition, such a firm or corporation may employ only resident labor in planting, cultivating, selling, and marketing of the oysters, and its principal place for selling or marketing must be maintained within the state.

Another legal aspect pertinent to aquaculture success is the degree to which the general fishery laws of the state apply to artificially cultivated fish. Wide variance is seen in different states from absolute exemption (except for residency requirements and health restriction) to statutory insistence on complete adherence to all the state's fishery laws. This barrier could be eliminated easily by treating it as a legal drafting problem if the idea could be endorsed by state legislatures.

Another problem is the effect of pollution and deleterious substances introduced into water areas. The statutes of most states provide very little protection from pollution, and the available compensation or restitution is clearly inadequate. The legislature of one state has provided that rental on the leased area shall be abated if the land becomes unusable or inoperative due to pollution or other interference, but this is a rather inadequate approach. The "proceed at your own risk" attitude toward aquaculture is reflected in a Virginia case in which the Supreme Court of that state denied relief to a leasee whose oyster bed had been made inoperative due to pollution from a municipal sewer authorized by the state. The court's rationale was that the state had merely leased the submerged areas; it has not guaranteed the quality of the waters over the land.

I will close with a quote from an article found in an 1893 Yale Law School Journal dealing with the legal status of the oyster. It may indicate who reaps the economic benefit from aquaculture. The author, after a scholarly discussion of conflicting claims to oyster beds, problems of considering oyster leases as real or personal property, etc., suggested that to solve some problems "one precedent of acknowledged weight and ancient lineage," which had not as of that time been cited in court, might provide the best solution to the difficulty.

It was reported:

> Once (says an author; where I need not say)
> Two Travellers found a oyster in their way.
> Both fierce, both hungry, the dispute grew strong,
> While, scale in hand, Dame Justice passed along.
> Before her each with clamor pleads the laws,
> Explains the matter and would win the cause.
> Dame Justice, weighing long the doubtful right,
> Takes, opens, swallows it before their sight.
> The cause of strife removed so rarely well,
> "There! take (says Justice) take ye each a shell.
> We thrive at Westminister on fools like you.
> "It was a fat oyster--live in peace--Adieu."

A SPECIFIC LEGAL PERSPECTIVE: FLORIDA

Dorian Cowan*

As most students of aquaculture are aware, there exists a romantic tendency on the part of many well-intentioned persons to regard offshore coastal waters as a cornucopia of resources, from which American know-how will be able successfully to extract a large portion of the nation's food supply. Even if there is basis for such expectation--a notion that is rejected by some fish biologists as illusory if not inexpedient--it is unrealistic to ignore the totality of legal consequences emerging from such enterprises.

In the case of Florida, which was the first coastal state to adopt legislation to authorize aquaculture in the water column, it is apparent that insufficient attention was given to these legal considerations. Although the state cabinet prescribed a number of guidelines under the 1969 statute, some fundamental weaknesses still remain. The most significant of these are the following.

THE EFFECT OF AQUACULTURE ON NAVIGATION

For the most part the statute and supplementary regulations fail to deal adequately with the exercise of federal control over navigable waters and the possible interference of fenced or staked-out areas with the international right of innocent passage. Depending on the size and extent of coastal waters reserved for aquaculture purposes, it seems imperative that these navigational considerations be given specific attention.

Even though prospective leasing areas lie entirely within the jurisdictional limits of the state, there exists little doubt that under the commerce clause of the Constitution their use by the state is subject to the powers of federal control and regulation of navigation. A simple means of complying with such jurisdiction is an amendment to the law requiring a permit from the U. S. Army Corps of Engineers and the U. S. Coast Guard for all aquaculture sites. Concurrent jurisdiction of the Corps of Engineers exists for channel construction and other coastal projects in state waters, and parallel procedures for aquaculture can scarcely be regarded as innovative.

ADEQUACY OF PUBLIC ACCESS AND NAVIGATIONAL SAFETY

In some respects, the administrative guidelines, the evident purpose of which is to make the statute more effective, tend to obfuscate rather than clarify, particularly when they attempt to provide accommodation for

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conflicting uses.

Guideline 13, for example, requires that at least one opening, appropriately marked, be designated as a means of ingress and egress in the leased area for boating, fishing, and other public activities. Aside from the adequacy of the provision, which might be considered by some as a "facesaving" concession to such usage, it might also post a navigational hazard.

Posting of signs around the fenced area would suffice for daylight hours only. As safety and other matters directly related to navigation come within the province of the U. S. Coast Guard, whose authority is recognized in Guideline 12, the problems of ingress and egress as well as the adoption of specific safeguards would be better served if left entirely to the discretion of this federal agency rather than to arbitrary administrative rules.

Guideline 13 also appears faulty for requiring each posted sign read "Restricted--Aquaculture Area Under Lease by Trustees of the Internal Improvement Fund." The question is whether or not this language is consistent with the concept of public use. Although only of minor significance in itself, this question serves to raise another fundamental one, the nature of property rights vested in the lessee. By allowing common fishing privileges in the leased area, might this not be deemed a denial of his contractual and property rights under the lease and, hence, a "taking" without due process?

EFFECT OF AQUACULTURE LAW ON UPLAND OWNERSHIP

The law and guidelines now fail to consider the possible effect of aquaculture projects on riparian rights. It is difficult to envision a sizeable aquaculture area which would not have some adverse effect on ingress and egress or otherwise curtail rights of the upland owner. Under Florida law, impairment of such rights by acts of the state is considered a form of "taking," entitled to compensation in damages.

One solution is for the state to acquire adjacent riparian lands by eminent domain and include them in a leasing package. An alternative would require lessees to hold title to upland property or a purchase option. Whether such added financial burden on the state or prospective lessee is economically feasible is open to question. The alternative, however, is protracted litigation for damages.

NEED FOR STRONGER ANTI-POLLUTION PROTECTION

The act appears to provide only minimal attention to the subject of pollution not only with the protection of the interest of lessees, but with the possible harmful side effects of their aquaculture ventures. While a reasonable leeway should be accorded lessees in protecting their stocks from predatory species, such measures obviously should not be permitted to pollute adjacent areas. The harmful use of rotonone by Marifarms, Inc., Florida's first aquaculturist, for instance, is one of the allegations in a pending lawsuit.

Although Sec. 253.74 of the statute states that the lease is subject to cancellation for violation of the Florida Air and Water Pollution Control Act (Sec. 403 F.S.) it is difficult to envision the employment of such a drastic measure. (A similar provision appears in Guideline 10.) Whether the threat of cancellation provides an effective deterrent to the introduction of injurious substances in and around aquaculture sites is open to question.

It should be mentioned that the state anti-pollution law includes a number of specific penalties, but, like the provision in the Aquaculture Act, they must be viewed as "after the fact" measures that merely punish the violator. Apparently a more constructive approach to pollution prevention is needed. Two safeguards should be added to the statute including provision specifically banning the use by the lessee of harmful chemicals and other pollutants against predators and provision for periodic inspection of the leased area by conservation officials for verification of such ban.

FAILURE OF AQUACULTURE LAW TO DEAL WITH CONFLICTING INTERESTS

The statute provides for public notice and hearings in the county where a proposed lease will be located. (Sec. 253.70) Unfortunately, the only objections to the proposal considered are those from upland owners whose property is within 1,000 feet of the proposed site. Under Florida law this limitation is similarly applicable to dredge and fill permits and sales of submerged sovereign land. Also, regretfully, the legislature did not distinguish between onshore and offshore aquaculture in which the general public has a vested interest.

The failure of the act to provide a proper forum for consideration of the views of other affected interests, such as navigation and fishing, is without question its more egregious weakness. If proof of the damaging effect of this omission were needed, a prime example would be the current suit of the Organized Fisherman of Florida, a commercial fishermen's association, against the State of Florida and Marifarms Inc. The latter is the holder of 2,500 acres of water column in the vicinity of Panama City under Florida's first aquaculture lease. The suit charges that the leasehold is contrary to the public interest and asks that it be vacated. A ruling in favor of the association would imperil the constitutionality of the statute.

There is ample Florida authority to the effect that the state may make use of limited portions of its territorial waters, provided the use is not contrary to public interest and there is no substantial impairment of traditional uses. Thus, by neglecting to give all interested parties an opportunity to take part in the proceedings leaves in question the legality of the lease. On the other hand, by providing a "day in court" for all affected interests to participate in the determination of whether or not the proposed lease is in violation of the public interest, would not necessarily foreclose future lawsuits, but would serve to nullify their effectiveness.

INADEQUATE PROVISION FOR ONSHORE INSTALLATIONS

In addition to requiring written consent of adjoining landowners for an aquaculture lease (Sec. 253.70), the statute also provides that the lease have the approval "by a majority of the County Commission within whose boundaries...the proposed leased area will lie" (Sec. 253.68).

While this measure provides a county government with an opportunity to reject the use of its offshore water column, the law is completely silent about the shore-based installations necessitated by such use, even though these ventures would be futile without onshore facilities for storage, processing, and transportation of aquaculture products. Since the establishment of such onshore facilities entails local zoning, is it reasonable to assume that the applicability of local zoning laws has been waived or negated by a mere acquiescence to the lease by the County Commission? As the lease itself is specifically concerned with the use of the water column, its approval by county authorities could conceivably be interpreted by a court as intended for offshore areas only without any commitment of any kind for shore-based installations. In such event would this not provide an opportunity for local zoning officials to frustrate the operability of the venture or, perhaps, even nullify it?

Shore facilities for the handling and processing of fish products suggest several collateral problems, such as health and sanitation. The state, of course, possesses the inherent police power to preempt local authority over zoning practices.

Hence, in order to insure the viability of the lease and prevent possible obstruction by local zoning officials of construction and maintenance of onshore facilities, apparently all that is needed is the inclusion of state regulations for such installations either in the guidelines or by an amendment to the statute.

STATE INDECISION ABOUT COMPETITIVE BIDDING

While the Aquaculture Act itself contains no provision for competitive bidding, Guideline 4 states that "no lease shall be made without an opportunity provided for competitive bidding among prospective lessees similar to the bidding outlined in Ch. 253.54 F.S. (concerning oil and gas leases)."

Whatever the purpose of Guideline 4, it seems rather strange that the general counsel for the trustees of the Internal Improvement Trust Fund would be unaware of its existence and applicability. In a recent communication (Oct. 7, 1970) he asserts "To my knowledge there has never been any requirement for competitive bidding in the issuance of an aquaculture lease." Since this prestigious state agency is charged with the responsibility of negotiating such leases, its official policy, at least for the present, appears to deny the use of competitive bidding.

It is quite possible, of course, that the agency is unaware of some of its promulgations, in which case it may reverse its stand on competitive bidding, or it may take positive steps to eliminate Guideline 4. In the latter event, it seems difficult to reconcile such action with Sec. 253.68 of the Act which states that "the Trustees shall publish a list of guidelines to be followed in considering applications for lease." More importantly, perhaps, it avers that "such guidelines shall be designed to protect the public interest in submerged lands and the public water column." In what measure the elimination of competitive bidding would serve the letter and spirit of Sec. 253.68, however, is beyond comprehension.

LEGAL LIMITATIONS ON AQUACULTURE VENTURES

By long established precedent, Florida's coastal waters are said to be in the public domain. Beginning with the 1908 decision of Ellis v. Gerbing (47 So. 353) it has been consistently held that except for limited portions and unless deemed to be in the public interest, they may not be exploited for private use. In this connection it is particularly important to take note of the 1967 Supreme Court decision of Bryant v. Lovett (201 So. 2nd 720), in which an old statute authorizing exclusive oyster leases in offshore waters was held to be contrary to the public interest, as well as unconstitutional. This question will have to be weighed again by the court in the current attack on the Marifarms Inc. lease by the Organized Fishermen of Florida. It is my considered opinion, however, that whatever the outcome of this suit in the Circuit Court, ultimately the Florida courts will uphold limited use of coastal waters by the state for aquaculture ventures. It should be emphasized, however, that, unless they are amended, the 1969 law and the guidelines offer an inviting target for legal attack.

EXHIBIT A

AQUACULTURE LAW: State of Florida

CHAPTER 69-46

Committee Substitute for House Bill No. 526

AN ACT relating to submerged lands; amending chapter 253, Florida Statutes, by adding sections 253.67, 253.68, 253.69, 253.70, 253.71, 253.72, 253.73, 253.74, and 253.75; authorizing the Trustees of the Internal Improvement Fund to lease submerged lands and the water above to persons desiring to engage in aquaculture activities; prescribing procedures; prescribing the essential features of lease contracts; providing penalties; authorizing the trustees to adopt rules and regulations; requiring the trustees to request recommendations from the Board of Conservation or Game and Fresh Water Fish Commission prior to granting a lease; authorizing the Board of Conservation and Game and Fresh Water Fish Commission to designate areas of state-owned submerged land for which they recommend reservation for uses that are possibly inconsistent with aquaculture activities; directing the Board of Conservation and Game and Fresh Water Fish Commission to supervise and report on the operations of lessees; providing an effective date.

Be it Enacted by the Legislature of the State of Florida:

Section 1. Chapter 253, Florida Statutes, is amended by adding sections 253.67, 253.68, 253.69, 253.70, 253.71, 253.72, 253.73, 253.74, and 253.75 to read:

253.67 Definitions.--As used in this act:

(1) "Aquaculture" means the cultivation of animal and plant life in a water environment.

(2) "Water column" means the vertical extent of water, including the surface thereof, above a designated area of submerged bottom land.

(3) "Board" means the State Board of Conservation.

(4) "Trustees" means the Trustees of the Internal Improvement Fund.

253.68 Authority to lease submerged land and water column.--To the extent that it is not contrary to the public interest, and subject to limitations contained in this act, the trustees may lease submerged lands to which they have title for the conduct of aquaculture activities and grant exclusive use of the bottom and the water column to the extent required by such activities. Such leases may authorize use of the submerged land and water column for either commercial or experimental purposes. Provided however that no lease shall be granted by the trustees when there is filed with them a resolution of objection adopted by a majority of the county commission of a county within whose boundaries if the same were extended to the extent of the interest of the state the proposed leased area would lie. Said resolution shall be filed with the trustees within 30 days of the date of the first publication of notice as required by section 253.70, Florida Statutes.

Prior to the granting of any such leases the Trustees shall establish and publish a list of guidelines to be followed when considering applications for lease. Such guidelines shall be designed to protect the public's interest in submerged lands and the publicly owned water column.

253.69 Application to lease submerged land and water column.--Any applicant desiring to lease a portion of the submerged lands of this state for the purpose of conducting aquaculture activities shall file with the trustees a written application in such form as they may prescribe, setting forth the following information:

(1) The name and address of the applicant.

(2) A reasonably concise description of the location and amount of submerged land desired and either:

(a) Attaching a map or plat of a survey of such lands; or

(b) Enclosing a sum sufficient to defray the cost of such a survey as estimated by the board.

(3) A description of the aquaculture activities to be conducted, including a specification whether such activities are to be experimental or commercial and an assessment of the current capability of the applicant to carry on such activities.

(4) Such other information as the trustees may by regulation require.

253.70 Public notice and hearings.--

(1) Upon receiving an application under this act that satisfactorily sets forth the information required by section 253.69, Florida Statutes, the trustees shall give notice of the application by publication in a newspaper published in the county in which the submerged lands are located not less than once a week for three (3) consecutive weeks and mail copies of such notice by certified or registered mail to each riparian owner of upland lying within one thousand (1,000) feet of the submerged land proposed to be leased, addressed to such owner as his name and address appears on the latest county tax assessment roll.

(2) If no written objections are filed within thirty (30) days after the date of first publication of the notice and if the trustees find that the proposed lease is not incompatible with the public interest, the trustees have authority to consummate the lease contract as hereinafter provided. However, failure to mail the notice to the riparian upland owners shall not invalidate such lease.

(3) If written objections are filed, the trustees or their designee shall hear and consider the same at a public hearing which shall be held in the county from which the application was received. Timely notice of such hearing shall be given by at (leaset) least one (1) publication in a newspaper published in the county in which the submerged lands are located and by certified or registered mail to each riparian owner of upland lying within one thousand (1,000) feet of the submerged land proposed to be leased, addressed to such owner as his name and address appears on the latest county tax assessment roll.

253.71 The lease contract.--When the trustees have determined that the proposed lease is not incompatible with the public interest and that the applicant has demonstrated his capacity to perform the operations upon which the application is based, they may proceed to consummate a lease contract having the following features in addition to others deemed desirable by the trustees:

(1) TERM.--The maximum initial terms shall be [twelve (12) years for commercial leases and five (5) years for experimental leases.] ten years. Leases shall be renewable for successive terms up to the same maximums upon agreement of the parties. However, before renewing the term of any lease, the trustee shall invite objections by following the publication procedures of section 253.70, Florida Statutes.

(2) RENTAL FEES.--

(a) The lease contract shall specify such amount of rental per acre of leased bottom as may be agreed to by the parties and shall take the form of:

1. Fixed rental to be paid throughout the term of the lease; or

2. A basic rental charge which will be supplemented by royalties after the productivity of the aquaculture enterprise has been established.

(b) In setting the amount of the rental charge or royalties the trustees shall consider such factors as the probable rates of productivity and the marketability and value of the product of the enterprise.

(c) All leases shall stipulate for the payment of the annual rental in advance on or before January 1. Failure of the lessee to pay such rent within thirty (30) days of such date shall constitute ground for cancellation of the lease and forfeiture to the state of all works, improvements, and animal and plant life in and upon the leased land and water column.

[(d) No taxes, assessments, or licenses other than those imposed or authorized by this act shall be levied or imposed on said leases or leased lands, but the annual rent or royalties exacted and paid shall be held and considered all that can be exacted by the state or any of its instrumentalities, including municipalities.]

[(d) At periodic intervals, not less frequent than annually the lessee shall file with the trustees a certified balance sheet and profit and loss statement showing in detail all expenses paid and all receipts from its activities under the lease.]

(3) MAXIMUM AREA TO BE LEASED.--The trustees shall not lease a larger area of submerged land to any single lessee than has been demonstrated to be within his capacity to utilize efficiently and [consistently] consistent with the public interest. However, the trustees may hold a reasonable area of adjacent bottom land in reserve for the time when a holder of an experimental lease will begin operation under a commercial lease. Successful conduct of aquaculture activities on an experimental basis may be accepted as a demonstration of capacity to conduct such operations on a commercial basis.

(4) PERFORMANCE REQUIREMENTS; BOND. Failure of the lessee to perform substantially the aquaculture activities for which the lease was granted shall constitute ground for cancellation of the lease and forfeiture to the state of all the works, improvements, and animal and plant life in and upon the leased land and water column. In addition, the trustees shall require execution of a bond in an amount and with a surety satisfactory to them and conditioned upon the active pursuit of the aquaculture activities specified in the lease.

(5) DISPOSITION OF IMPROVEMENTS AT TERMINATION OF CONTRACT.--Each contract entered into under this act shall stipulate the disposition of improvements and assets upon the leased lands and waters, including animal and plant life resulting from aquaculture activities.

(6) ASSIGNABILITY OF LEASES.--Leases granted under this act shall be assignable in whole or in part with the approval of the trustees.

253.72 Marking of leased areas; restrictions on public use.--

(1) The trustees shall require all lessees to stake off and mark the areas under lease by appropriate ranges, monuments, stakes, buoys, and fences, so placed as not to interfere unnecessarily with navigation and other traditional uses of the surface. All lessees shall cause the area

under lease and the names of the lessees to be shown by signs appropriately placed pursuant to regulations of the trustees.

(2) Except to the extent necessary to permit the effective development of the species of animal or plant life being cultivated by the lessee, the public shall be provided with means of reasonable ingress and egress to and from the leased area for traditional water activities such as boating, swimming, and fishing. All limitations upon the use by the public of the areas under lease that are authorized by the terms of the lease shall be clearly posted by the lessee pursuant to regulations by the trustees. Any person wilfully violating posted restrictions shall be guilty of trespass and shall be punished by imprisonment for not more than sixty (60) days or by fine not exceeding fifty dollars ($50), or both.

253.73 Rules and regulations.--Subject to the requirements of chapter 120, Florida Statutes, the trustees may adopt rules and regulations necessary and appropriate to carry out the provisions of this act.

253.74 (Penalty) Penalties.--

(1) Any person who conducts aquaculture activities in excess of those authorized by lease agreement with the trustees or who conducts such activities on state-owned submerged lands without having previously leased the same shall be guilty of a misdemeanor and subject to imprisonment for not more than six (6) months or fine of not more than one thousand dollars ($1,000), or both. In addition to such fine and/or imprisonment, all works, improvements, animal and plant life involved in the project, may be forfeited to the state.

(2) Any person who is found by the Board or the Air and Water Pollution Control Commission to have violated the provisions of chapter 403, Florida Statutes, shall be subject to having his lease of state owned submerged lands cancelled.

253.75 Studies and recommendations by the board and the Game and Fresh Water Fish Commission; designation of recommended traditional and other use zones; supervision of aquaculture operations.--

(1) Prior to the granting of any lease under this act, the trustees shall request a recommendation by the board, when the application relates to tidal bottoms, and by the Game and Fresh Water Fish Commission, when the application relates to bottom land covered by fresh water. Such recommendations shall be based on such factors as an assessment of the probable effect of the proposed leasing arrangement on the lawful rights of riparian owners, navigation, commercial and sport fishing, and the conservation of fish or other wildlife or other natural resources, including beaches and shores.

(2) The board and the Game and Fresh Water Fish Commission shall both have the following responsibilities with respect to submerged land and water column falling within their respective jurisdictions:

(a) To undertake, or cause to be undertaken, the studies and surveys necessary to support their respective recommendations to the trustees;

(b) To institute procedures for supervising the aquaculture activities of lessees holding under this act and reporting thereon from time to time to the trustees; and

(c) To designate in advance areas of submerged land and water column owned by the state for which they recommend reservation for uses that may possibly be inconsistent with the conduct of aquaculture activities. Such uses shall include, but not be limited to, recreational, commercial and sport fishing and other traditional uses, exploration for petroleum and other minerals, and scientific instrumentation. The existence of such designated areas shall be considered by the trustees in granting leases under this act.

Section 2. This act shall take effect immediately upon becoming a law.

Approved by the Governor June 4, 1969.

Filed in Office Secretary of State June 4, 1969.

EXHIBIT B

AQUACULTURE LEASE GUIDELINES: State of Florida

1. The proposed use of the leased lands shall have no appreciable detrimental effect on any existing industry.

2. The proposed use of the leased lands shall have no permanent effect on the wildlife or ecology of the leased lands, and surrounding areas.

3. The wildlife and ecology of the leased lands must be able to be naturally restored within one year of the termination of the lease.

4. No lease shall be made without an opportunity provided for competitive bidding among prospective lessees, similar to the bidding outlined in Ch. 253.54, F. S., (concerning oil and gas leases).

5. The Department of Natural Resources shall make a survey of each site as required by Sec. 253.75, F.S., that is the subject of an application to lease. Based upon the survey data, an estimate will be made of the quantity of marine resources that will be forfeited by the general public to the private lessee. In those cases where the surveys indicate that the resources that would be denied to the public by exclusive lease are substantial enough to require restitution, the Board may require the lessee to perform rehabilitation, stocking or other remedial projects as would tend to improve the marine productivity diminished for the general public by the lease concerned.

6. The findings and conclusions of such survey shall be permanently filed as public information with the State of Florida Board of Trustees of the Internal Improvement Trust Fund.

7. Only that amount of the bay bottoms in any County will be leased which shall be considered reasonable and fair as determined by the Board.

8. The maximum initial terms shall be ten (10) years with leases renewable for successive ten (10) year periods upon agreement of the parties.

9. A basic rental charge which will be supplemented by royalties after the productivity of the aquaculture enterprise has been established.

The lessee shall maintain adequate accounting records of their operations. Annual statements of financial position and net income shall be prepared by the lessee and audited by a certified public accountant.

After the initial year of operations, a review of the lessee's financial statements shall be made by the lessor.

Following each year of operation under the lease, the lessee shall forward to the lessor a statement of gross receipts audited by a certified public accountant.

10. All leases shall be subject to cancellation by the Board in the event the cultivation of animal and plant life within the leased area or areas ceases to be actively pursued.

11. All leases to contain a clause holding the Board and the State harmless.

12. Written approval from the upland riparian owner or owners must be filed with the Board prior to issuance of proposed lease.

13. Leased area or areas will be marked and identified as follows:

> Along the shoreline boundaries of each leased area, the lessee shall place at least one (1) sign every 1,000 feet, and additionally at every location on the shoreline where the public is afforded access to the sovereignty waters under lease.

Where the leased area is enclosed by a net, fence or other type of enclosure, the lessee shall place along said enclosure at least one sign every 1,000 feet. When the enclosure is less than 1,000 feet in length, a sign shall be located at each end of said enclosure and at the midway point between the ends.

At least one opening shall be provided for by the lessee to allow ingress and egress by the public to and from each leased area for water activities, such as boating, swimming and fishing. Said opening or openings shall be appropriately marked and identified.

All signs required above are to be a minimum of 4 feet high and 6 feet long, of a durable material, and erected in such a manner above the average high water level to be clearly visible to the general public.

Each sign shall be conspicuously lettered as follows:

R E S T R I C T E D

Aquaculture Area

Leased to (lessee)

By
State of Florida Board of Trustees of
the Internal Improvement Trust Fund

and each sign shall also be lettered to reflect any restriction on public use authorized by the Board of Trustees of the Internal Improvement Trust Fund.

Each lease area shall also be marked in accordance with U. S. Coast Guard and U. S. Army Corps of Engineers regulation concerning structures in navigable waters.

August 26, 1969

APPENDIX A: HATCHERY DESIGN AND OPERATION INFORMATION (From a Slide Presentation)

Ronald D. Mayo*

(The following figures were used by Mr. Mayo in his presentation on engineering considerations for designing and operating trout and salmon hatcheries. Many are based on original research and not yet available in the published literature. Key factors and their interrelationships include capital cost, operating cost, hatchery size, production capacity, product value, type of production system, biological requirements and physico-chemical properties of water.)

List of Figures

* Kramer, Chin and Mayo, Consultant Engieers, 1917 First Avenue, Seattle, Washington 98101.

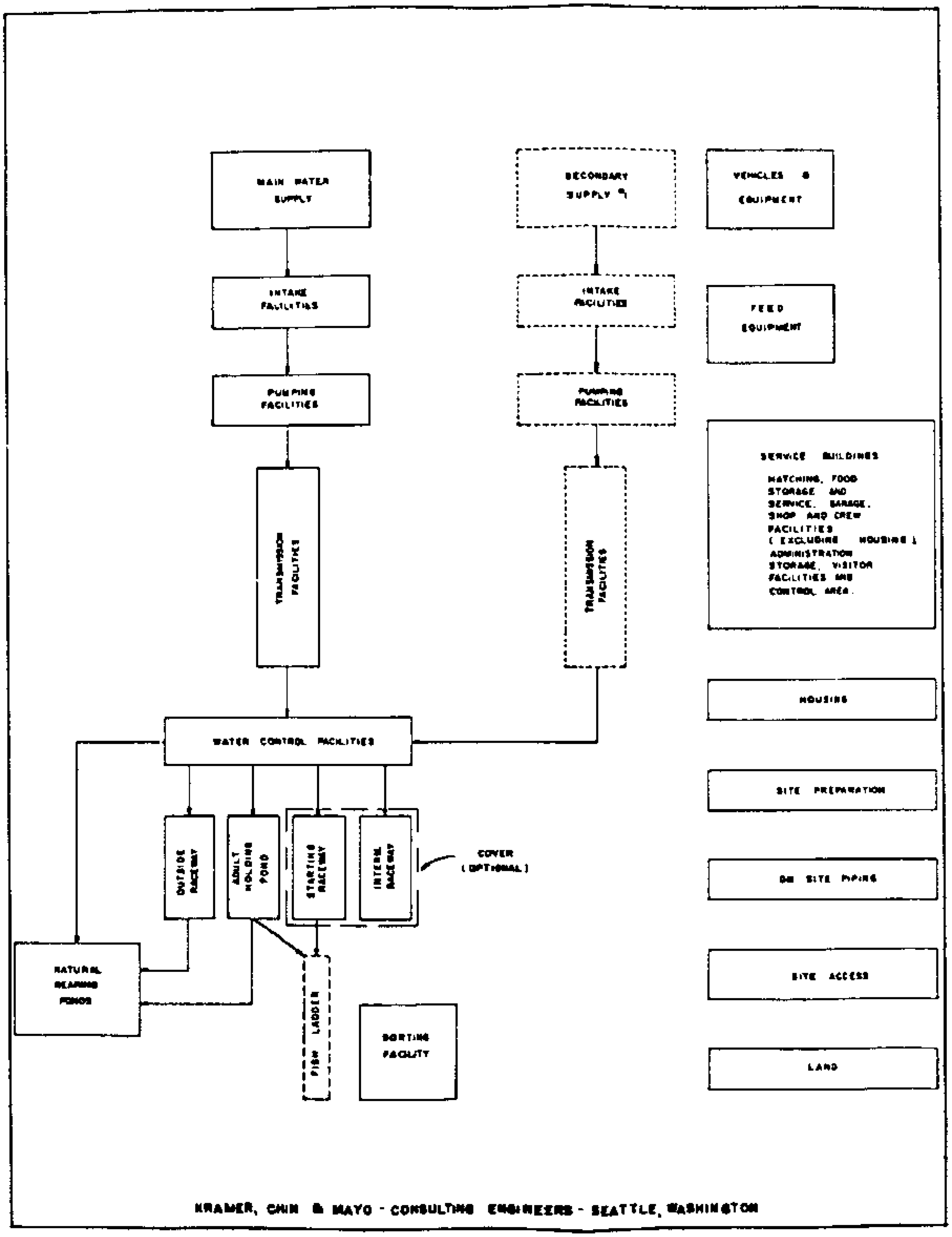


Fig. 1   Elements of a fish hatchery.

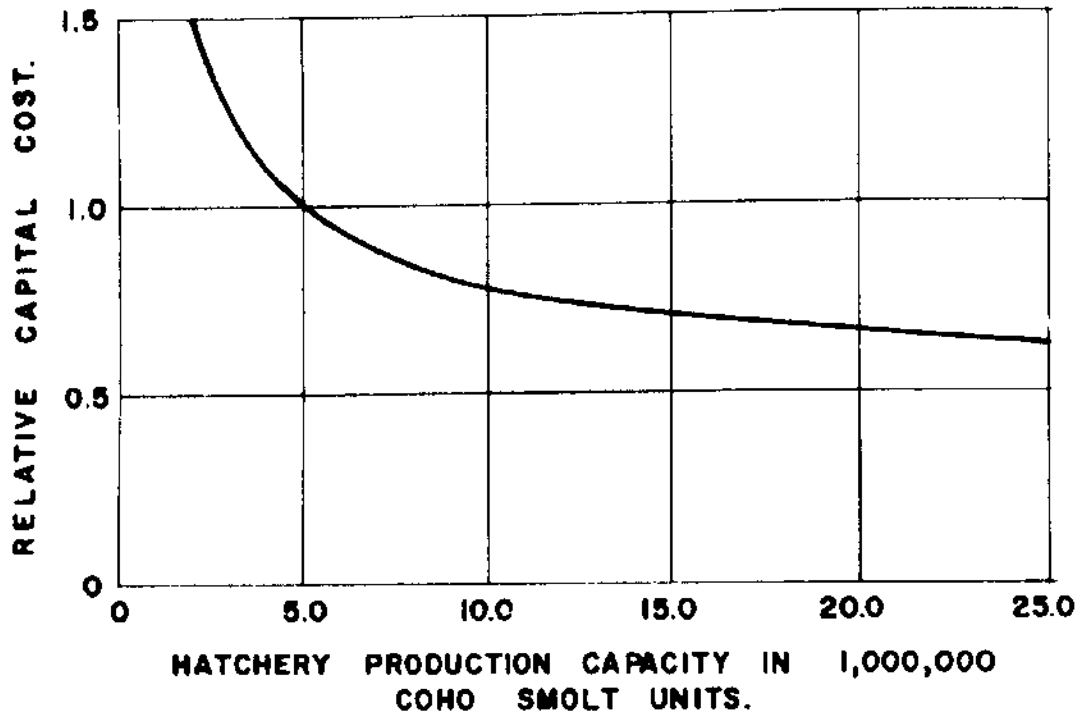


Fig. 2 Relative unit of production capital cost for various sized hatcheries.

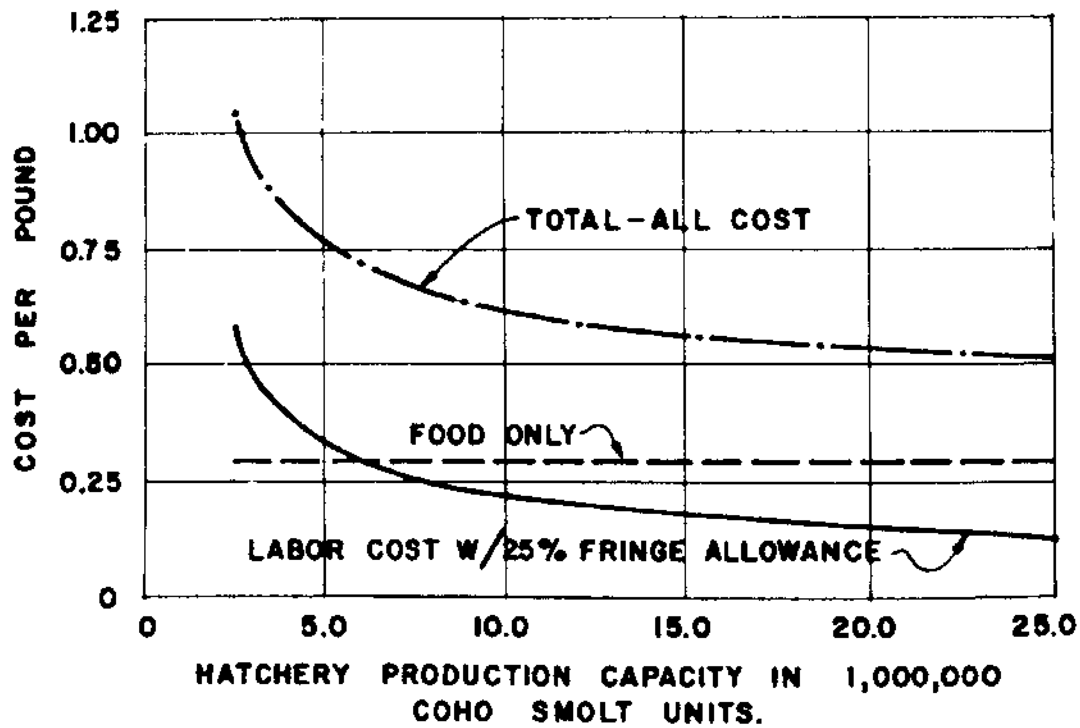


Fig. 3 Production cost per pound for hatcheries of various sizes (State of Michigan program).

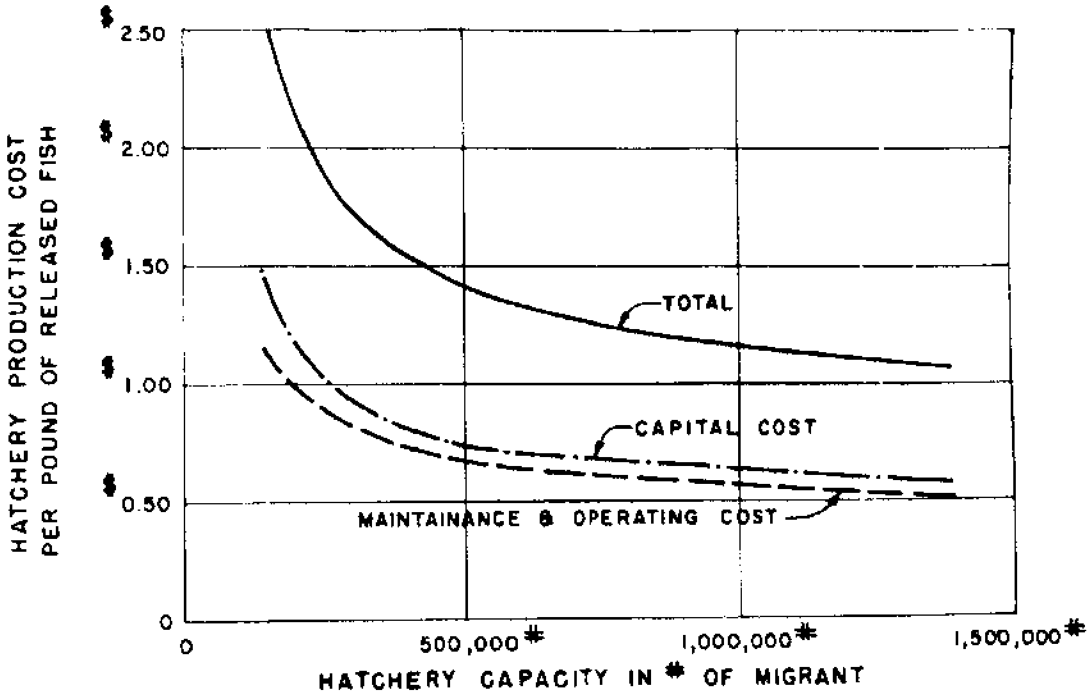


Fig. 4 Maintenance and operating cost as a function of hatchery size.

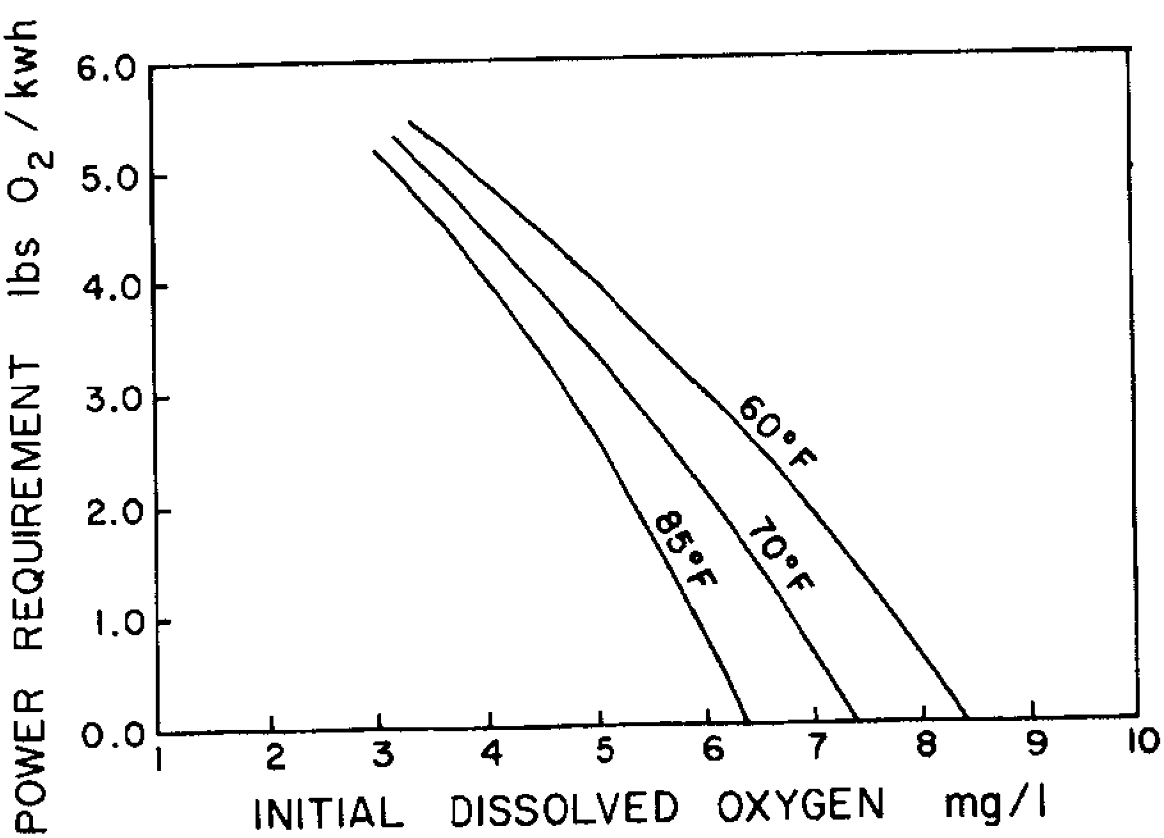


Fig. 5 Oxygen uptake and energy requirements in anticipated conditions for a bubble-type system in water 10-12 feet deep (Puget Sound saltwater study).

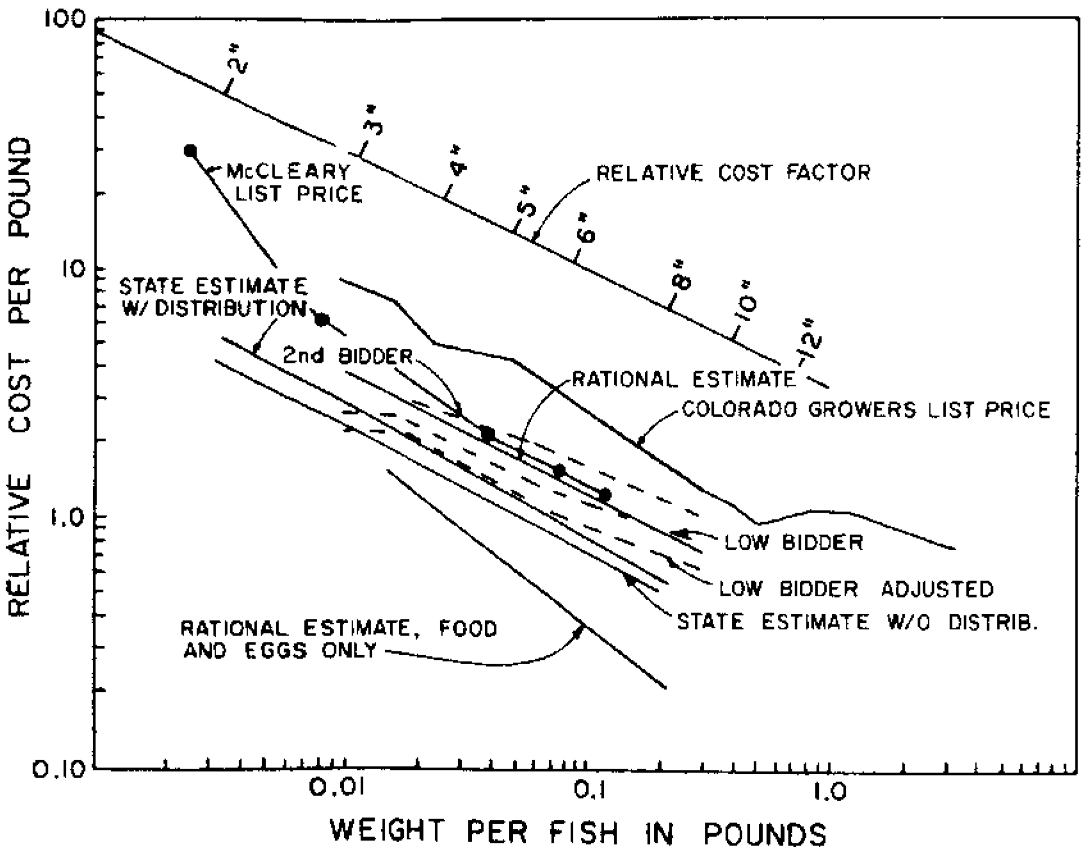


Fig. 6 Relative value per pound for trout of various sizes.

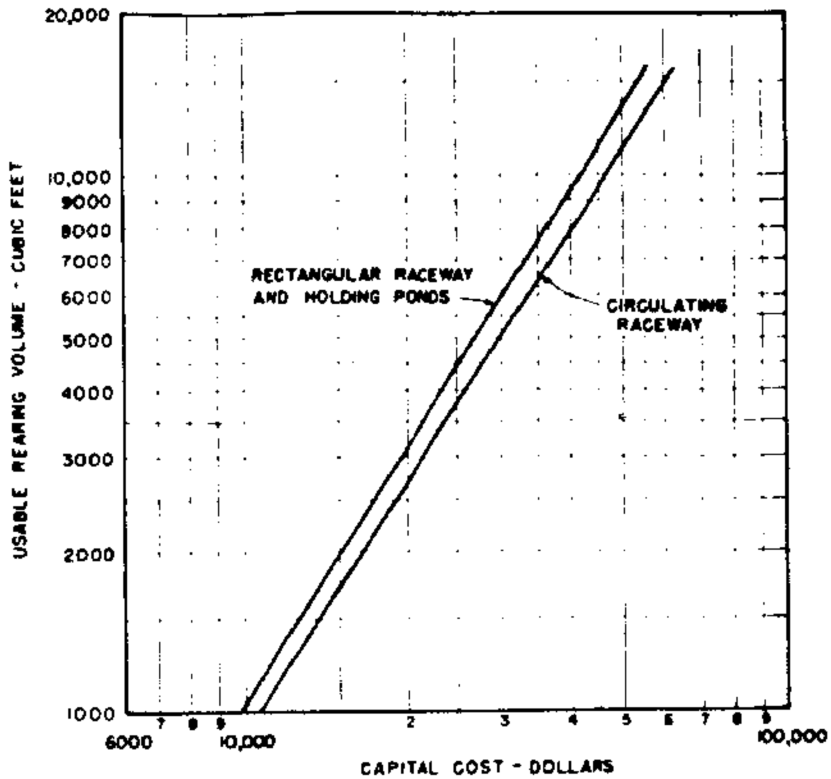


Fig. 7 Capital cost for rearing raceways and holding ponds.

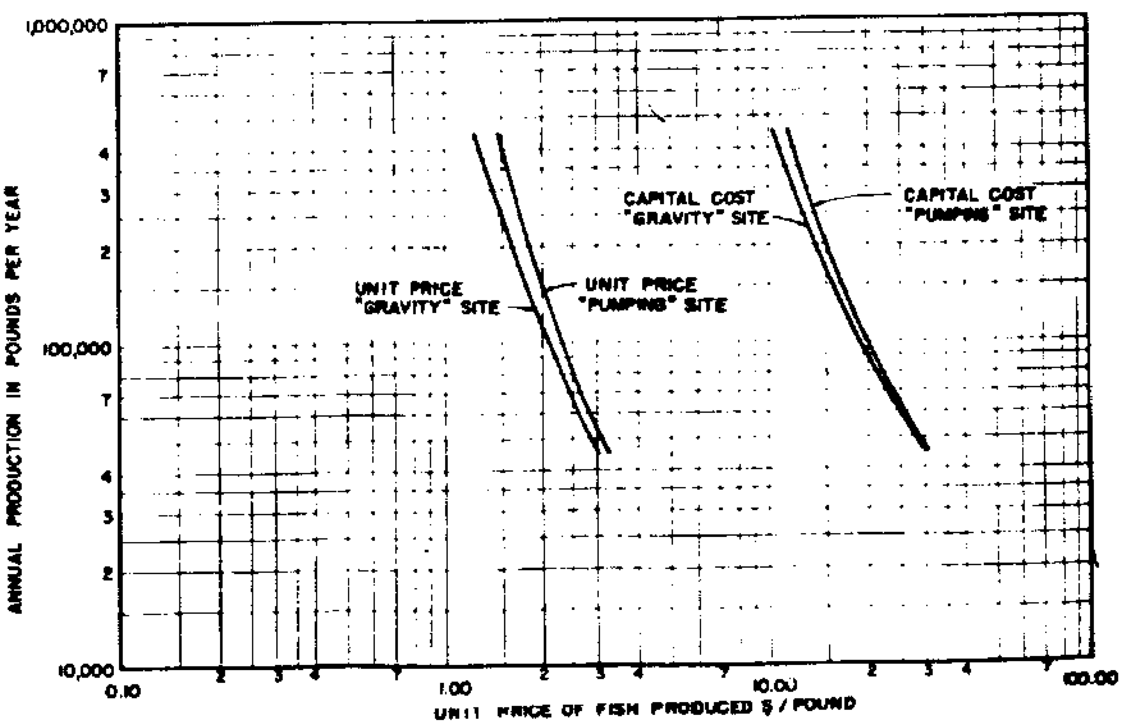


Fig. 8 Relative hatchery cost.

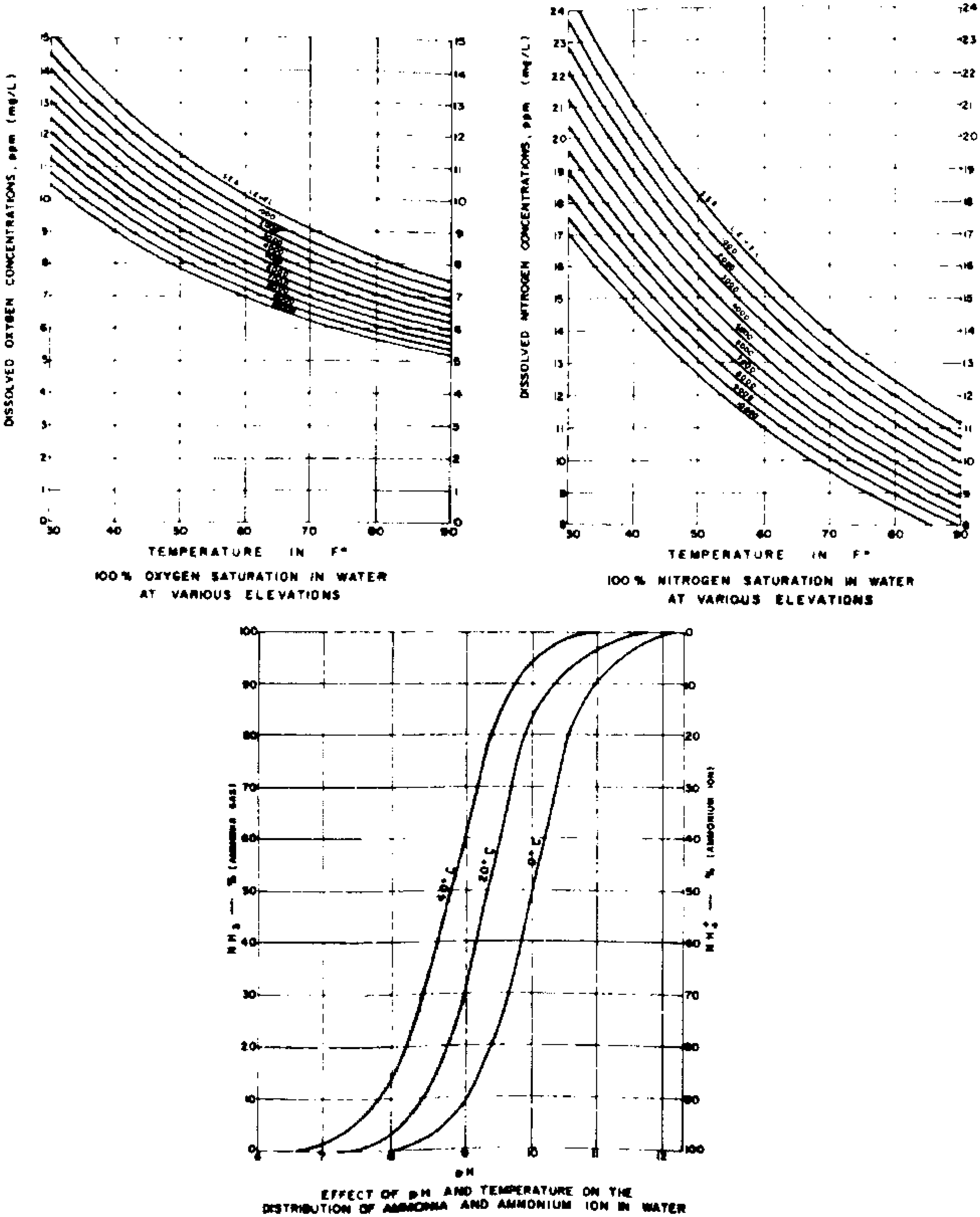
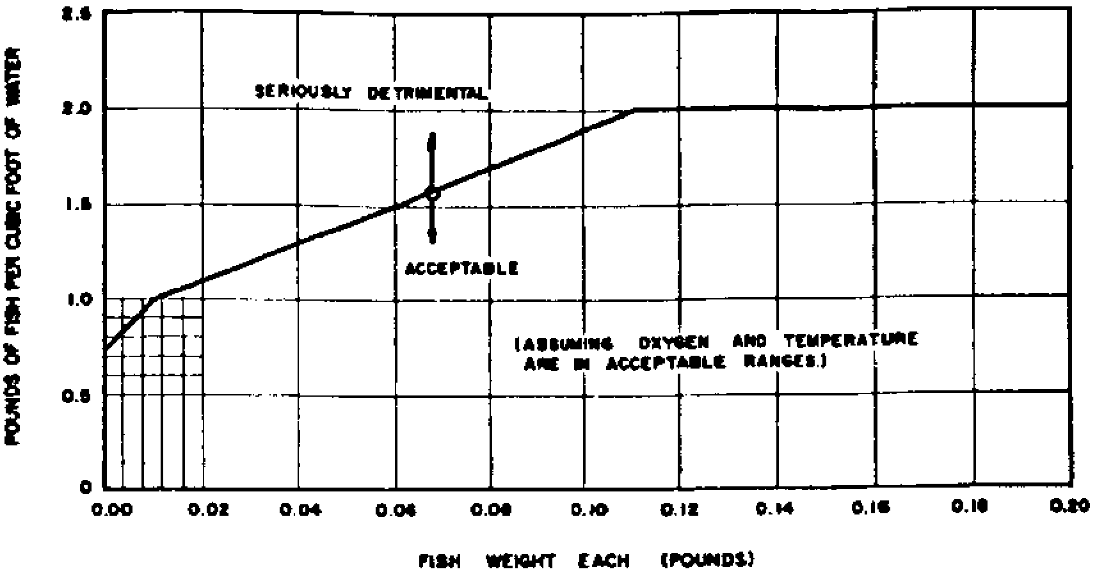
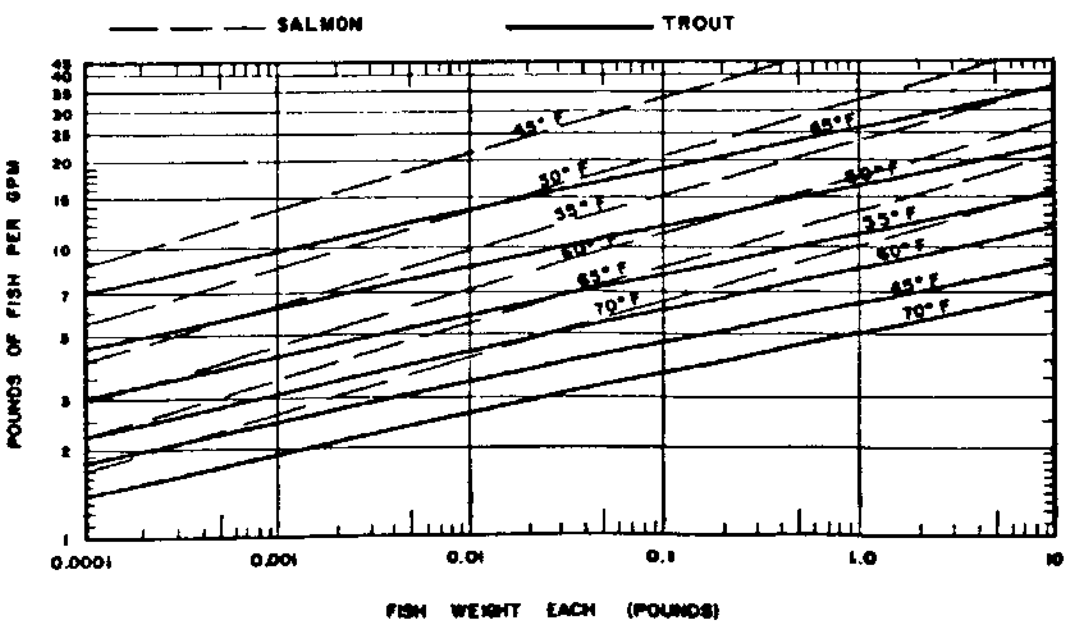


Fig. 9 Basic physical constants for water.



REQUIRED REARING VOLUME



REQUIRED FLOW VOLUME

(AT ELEVATION 1,300 FT. D.O. CONC. 95 % SATURATION, MIN. D.O. ≥ 5)

Fig. 10 Design criteria for raceway flows and volumes (State of Minnesota study).

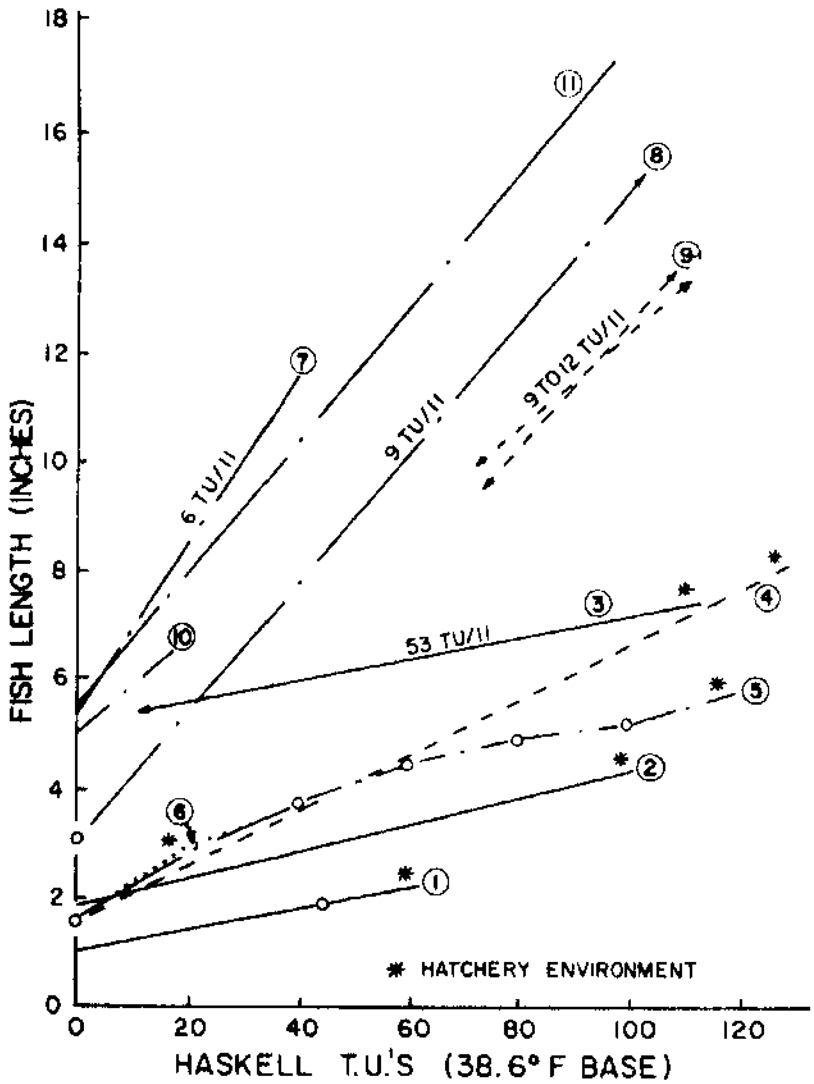
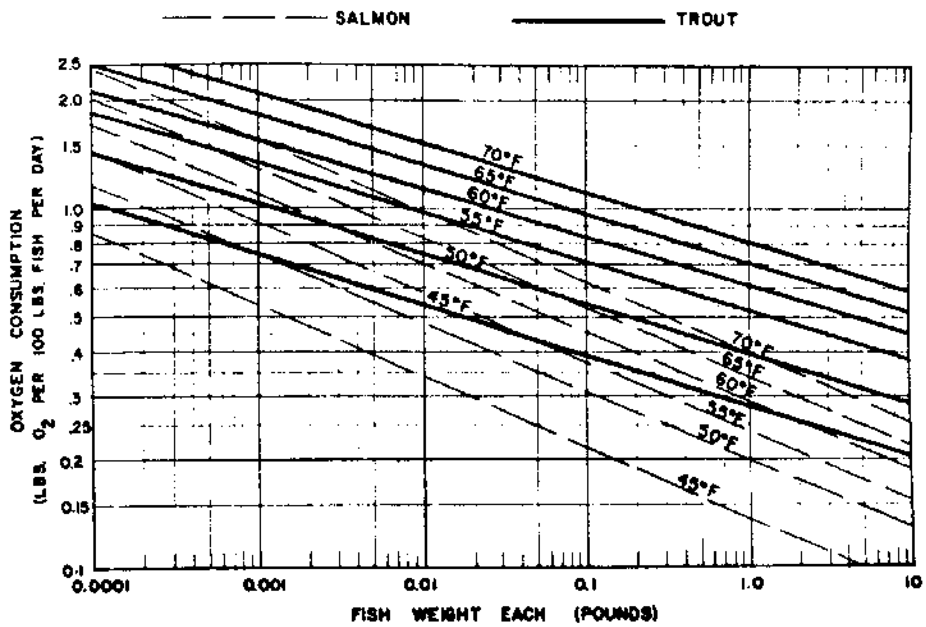
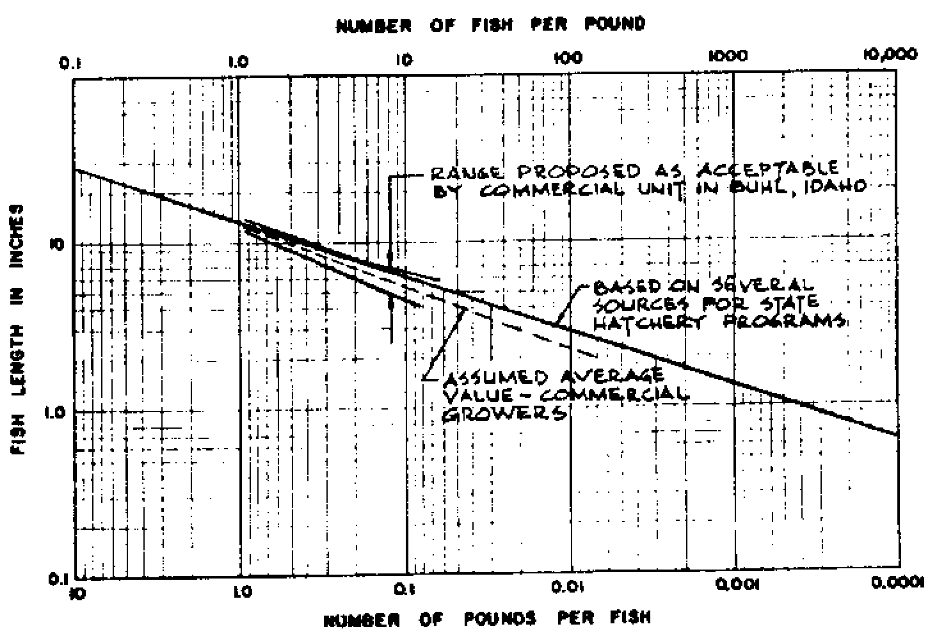


Fig. 11 Growth-cumulative temperature relationships.

1. Atlantic salmon. Adirondack freshwater (fw).
2. Atlantic salmon. Assumed Craig Brook (fw).
3. Atlantic salmon. Projected Mactaguac (fw).
4. Trout. As suggested for New York trout (fw).
5. Coho. Six Oregon hatcheries (fw).
6. Chinook. Five Oregon hatcheries (fw).
7. Coho. First 3½ months saltwater (sw).
8. Coho. First 18 months (sw).
9. Chinook (sw).
10. Coho. Test, BCF (sw).
11. Coho. Lake Michigan (fw).



OXYGEN CONSUMPTION AT VARIOUS TEMPERATURES



LENGTH - WEIGHT RELATIONSHIP

Fig. 12 Assumed constants for salmonids.

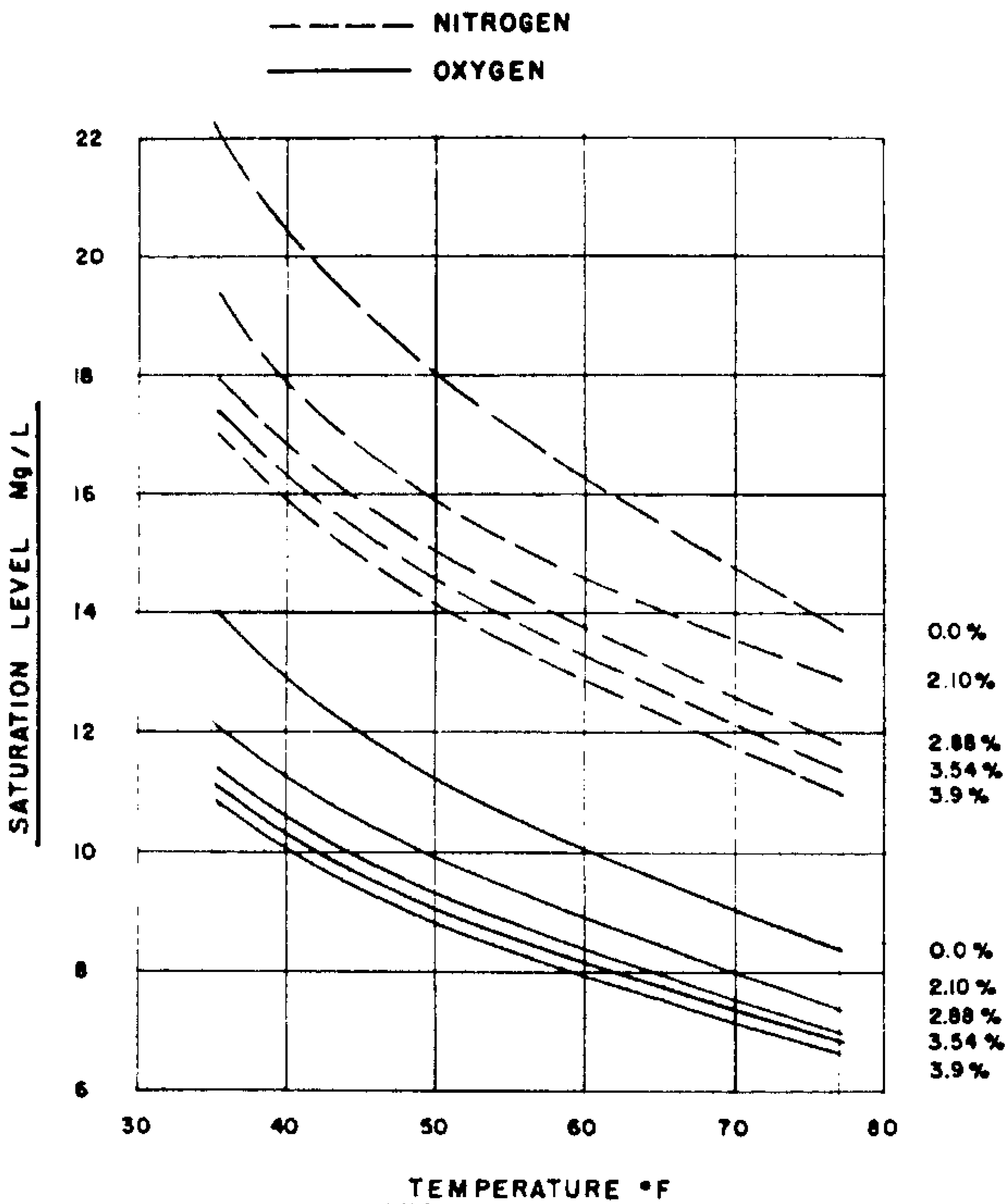
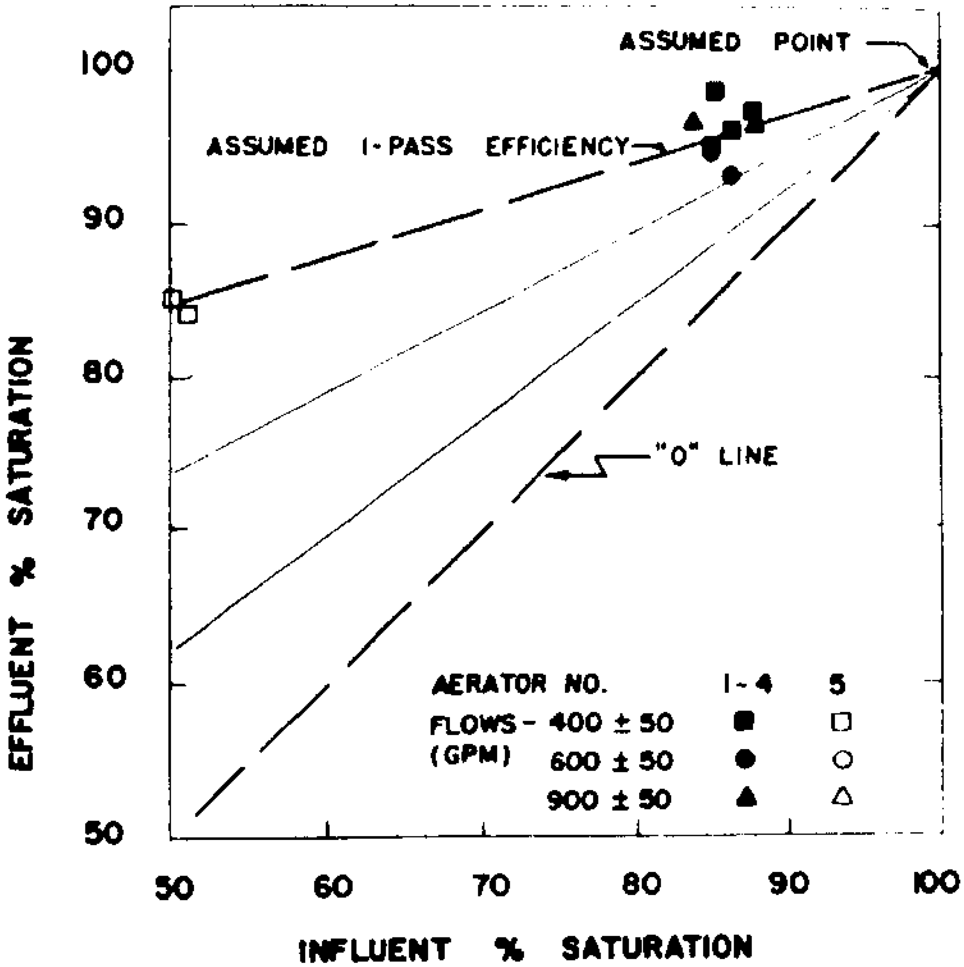
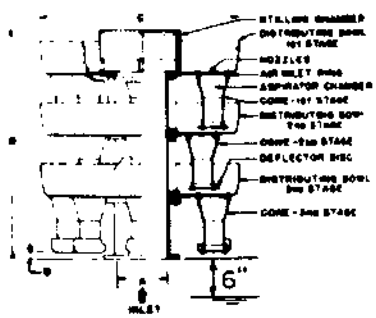


Fig. 13 Nitrogen and oxygen solubility at 100 percent saturation (atmospheric aeration at various salinities).





Max Capacities G.P.M.	Size	A	B	C	D	Shipping Wt. lbs
450	42A	12"	6'0-1/4"	3' 9-1/2"	2'	1400
600	42B	12"	6'0-1/4"	3' 9-1/2	2'	1450
800, 1,000 or 1200	52A	16"	6' 4-3/8"	5' 2-1/2"	2-1/2"	1650
1500 or 1800	52B	16"	6' 4-3/8"	5' 2-1/2"	2-1/2"	1750
2250	62A	20"	6' 4-3/4"	6' 4-1/2"	2-1/2"	2900
2800	62B	20"	6' 4-3/4"	6' 4-1/2"	2-1/2"	3100

INSTALLATION DETAIL

Fig. 14 Aeration efficiency of Cowlitz-type aerators at high inlet dissolved oxygen.

APPENDIX B: USEFUL REFERENCES

NATURAL RESOURCE DATA SOURCES

Freshwater Data

WATER RESOURCE DATA

Prepared by the U. S. Department of the Interior for Massachusetts, New Hampshire, Rhode Island, and Vermont, these include annual summaries through 1968 and surface water records and water quality records for selected sites. Copies may be obtained from:

District Chief, Water Resources Division
U. S. Geological Survey
Room 2300, John F. Kennedy Building
Boston, Massachusetts 02203

WATER RESOURCE DATA FOR MAINE

These include annual summaries through 1969. Yearly editions for 1968 and 1969 include surface water, water quality, and groundwater records. Copies may be obtained from:

District Chief, Water Resources Division
U. S. Geological Survey
Vickery-Hill Building
Court Street
Augusta, Maine 04330

GROUNDWATER FAVORABILITY MAPS

These are available for selected areas in each of the following three states. They provide some predictive information on aquifer location and yield. Copies may be obtained from the Boston address above.

Maine

1. Geologic Map of the Surficial Deposits of Part of Southwestern Maine and Their Water-Bearing Characteristics. Atlas HA-76 (1963). Glenn C. Prescott, Jr.

2. Surficial Geology and Availability of Ground Water in Part of the Lower Penobscot River Basin, Maine. HA-225 (1966). Glenn C. Prescott, Jr.

3. Ground Water Favorability Areas and Surficial Geology of the Lower Androscoggin River Basin, Maine. HA-285 (1968). Glenn C. Prescott, Jr.

4. Ground Water Favorability Areas and Surficial Geology of the Lower Kennebeck River Basin, Maine. HA-337 (1969). Glenn C. Prescott, Jr.

5. Maine Basic-Data Report No. 5, Ground Water Series, Lower Aroostock River Basin Area (1970). Glenn C. Prescott, Jr.

New Hampshire

1. New Hampshire Basic-Data Report No. 1, Ground-Water Series, Southeastern Area (1962). Edward Bradley and Richard G. Petersen.

2. Ground-Water Favorability Map of the Nashua-Merrimack Area, N. H. (1963). James M. Weigle.

3. Ground-Water Favorability Map of the Salem-Plaiston Area, N. H. (1964). James M. Weigle.

Vermont

1. Batten Kill, Walloomsac River and Hoosic River Basins (1966). Arthur L. Hodges, Jr.

2. Lamoille River Basin (1967). Arthur L. Hodges, Jr., assisted by David Butterfield.

3. Lake Memphremagog Basin (1967). Arthur L. Hodges, Jr., assisted by David Butterfield.

4. Missisquoi River Basin (1967). Arthur L. Hodges, Jr., assisted by David Butterfield.

5. Nulhegan-Passumpsic River Basin (1967). Arthur L. Hodges, Jr., assisted by David Butterfield.

6. Otter Creek Basin (1967). Arthur L. Hodges, Jr.

7. Winooski River Basin (1967). Arthur L. Hodges, Jr., assisted by David Butterfield.

8. Wells-Ompompanoosuc River Basin (1968). Arthur L.Hodges, Jr. assisted by David Butterfield.

9. Ottauguechee-Saxtons River Basin (1968). Arthur L. Hodges, Jr. assisted by David Butterfield,

10. West-Deerfield River Basin (1968). Arthur L. Hodges, Jr., assisted by David Butterfield.

11. White River Basin (1968). Arthur L. Hodges, Jr., assisted by David Butterfield.

Composite Area, New England

1. Ground Water Favorability of the Connecticut River Basin, New England States, HA-249 (1967). D. J. Cederstrom and Arthur L. Hodges, Jr.

United States

1. Index to Catalog of Information on Water Data, Water Quality Stations, compiled by K. F. Harris, J. R. Rapp, and W. W. Doyel, U. S. Department of the Interior, Geological Survey, Office of Water Data Coordination, Washington, D. C. 20242.

2. Index to Catalog of Information on Water Data, Surface Water Stations, compiled by W. W. Doyel, K. F. Harris and J. R. Rapp. U. S. Department of the Interior, Geological Survey, Office of Water Data Coordination, Washington, D. C. 20242.

Marine and Estuarine Data

COASTAL ECOLOGY DATA

Previously classified oceanographic data from coastal waters of the United States, Puerto Rico, and the Canal Zone, originally collected for programs concerning defense of the areas, has now been declassified. Areas of the East Coast included range from Penobscot Bay, Maine, southward through Mayport, Florida. Requests for further information, special information, or reproduction of original documents should be sent to Data Services Branch, National Oceanographic Data Center, National Oceanic and Atmospheric Administration, Department of Commerce, Rockville, Maryland 20852.

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Bowdoin College, Public Affairs Research Center, Brunswick, Maine 04011. -- Maine Business Indicators, bimonthly, provides economic and business trend information.

Ira C. Darling Center for Teaching, Research and Service of the University of Maine, Walpole, Maine 04573. -- Marine ecology information. Substantial holdings for marine science periodicals, papers and books.

Maine Department of Inland Fisheries and Game, State House, Augusta, Maine 04330. -- Marine and inland wildlife inventory and management; land and water use, fish hatchery information.

Maine Department of Sea and Shore Fisheries, State House, Augusta, Maine 04330. -- Information about commercially important marine and anadromous species and environmental data about major shellfish growing areas. Publishes Maine Landings (in cooperation with the National Marine Fisheries Service), a monthly review of catch statistics by species, with annual summaries, and also supplies data for New England Landings, a regional review of catch statistics. Other technical papers issued periodically.

Maine Environmental Improvement Commission, State House, Augusta, Maine 04330. -- Water quality standards and regulations regarding pollution control. Publishes quarterly newsletter, Maine Water/Air.

New England Marine Resources Information Program (NEMRIP), University of Rhode Island, Kingston, Rhode Island 02881. -- Resource information and retrieval service. Publishes a monthly newsletter Information and a Directory of Academic Marine Sciences Programs in New England.

The Research Institute of the Gulf of Maine (TRIGOM), 96 Falmouth Street, Portland, Maine 04103. -- Consortium of institutions of higher education. Clearinghouse and coordination center for marine science activities and information in Maine. Publishes a quarterly newsletter TRIGOM Communications and a yearly edition of a Directory of Marine Research Facilities and Personnel in Maine.

U. S. Department of Commerce, Washington, D. C. -- Fishery Leaflet Series, Commercial Fishery Abstracts, Commercial Fishery Review.

National Oceanic and Atmospheric Administration, National Marine Fisheries Service Laboratory, West Boothbay Harbor, Maine 04575. -- Information services for commercial fishery industries; hydrologic data source. Most comprehensive marine science library in the state.

Water Resources Center, University of Maine, Bangor, Maine 04401. -- Water Resources Research Interests in the Colleges and Universities of Maine.

Climatological Data

Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Center, Ashville, North Carolina 28801. -- New England Climatological Data, a monthly record of temperature and precipitation data with annual summary. A variety of climatic information is also available.

ECONOMIC DATA SOURCES

TRADE ASSOCIATIONS

American Fish Farmers Federation, P. O. Box 191, Lonoke, Arkansas 72086. Phone (501) 676-6519. Roy Prewitt, president.

Arkansas Fish Farmers Association, Inc., P. O. Box 193, Hunter, Arkansas 72074. Phone (501) 459-2159. Charles W. Files, president.

Catfish Farmers of America, Tower Building, Little Rock, Arkansas 72201. Phone (501) 756-2307. Porter Briggs, executive secretary.

Kansas Commercial Fish Growers Association, 4226 South Gold Street, Wichita, Kansas 67217. Phone (316) 522-1273. L. F. Kepley, president.

Shellfish Institute of North America, 22 Main Street, Sayville, New York 11782. Phone (516) 589-2435. Mrs. Elizabeth Wallace, executive secretary.

U. S. Trout Farmers Association, 67 West 9000 South, Sandy, Utah 84070. Phone (801) 255-0228. Clay Robinson, executive manager.

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FISH HATCHERIES IN NEW ENGLAND

National Hatcheries

BUREAU OF SPORT FISHERIES AND WILDLIFE (Department of the Interior, Division of Fish Hatcheries)

Regional Supervisor: George C. Balzer, Jr., U. S. Court House, Boston, Massachusetts 02202. Phone (617) 223-2991

1. Berlin Hatchery
   RFD 1
   Berlin, New Hampshire
   Daniel F. MacKinnon, manager
   (603) 449-3412

2. Craig Brook Hatchery
   East Orland, Maine 04431
   Michael J. Marchyshyn, manager
   (207) 469-2803

3. Nashua Hatchery
   151 Broad Street
   Nashua, New Hampshire 03060
   David B. Goldthwaite, manager
   (607) 889-1171, ext. 7720

4. North Attleboro Hatchery
   Bungay Road, RFD 2, Box 600
   No. Attleboro, Mass. 02769
   John B. Bierly, manager
   (617) 695-5002

5. Pittsford Hatchery
   Pittsford, Vermont 05763
   Raymond J. Barbush, manager
   (802) 483-6618

State Hatcheries

CONNECTICUT STATE BOARD OF FISHERIES AND GAME

Director: Theodore B. Hampton, State Capitol Building, Hartford, Connecticut 06005. Phone (203) 366-5460.

1. Burlington Hatchery
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   Burlington, Connecticut 06085
   Joseph Holyst, foreman
   (203) 673-2340

2. Quinebaug Hatchery
   Plainfield, Connecticut 06374
   (under construction,
   scheduled completion 1971)

3. Kensington Hatchery
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   Berlin, Connecticut 06037
   Peter Vernesoni, foreman
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4. Windsor Locks Hatchery
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MAINE DEPARTMENT OF INLAND FISHERIES AND GAME

Commissioner: George Bucknam, State House, Augusta, Maine 04330. Phone (207) 289-3371.

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1. Casco Fish Hatchery
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2. Deblois Fish Hatcheries
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   John Willey, foreman
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3. Dry Mills Fish Hatchery
   RFD 1
   Gray, Maine 04039
   Ray Johnson, foreman
   (207) 657-4962

4. Enfield Fish Hatchery
   Enfield, Maine 04433
   Norman Philbrick, foreman
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5. Palermo Rearing Station
   Palermo, Maine 04354
   Anthony French, foreman
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6. Embden Rearing Station
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   James Cameron, foreman
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7. Governor Hill Fish Hatchery
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   Joseph Desrochers, foreman
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8. Grand Lake Stream Fish Hatchery
   Grand Lake Stream, Maine 04637
   John Davis, foreman
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9. New Gloucester Rearing Station
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   Bennington, Vermont 05201

3. Canaan Fish Hatchery
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4. Morgan Center Fish Hatchery
   Morgan Center, Vermont 05854

5. Roxbury Fish Hatchery
Roxbury, Vermont 05669

6. Salisbury Fish Hatchery
Salisbury, Vermont 05769

PUBLICATIONS OF INTEREST

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ABSTRACTS

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Maritimes. Mary Matzinger, ed., Davis Hall, University of Rhode Island, Kingston, Rhode Island 02881. Quarterly journal of the Graduate School of Oceanography. Free.

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APPENDIX C: CONFERENCE NOTES

CONFERENCE PROGRAM OUTLINE

Welcome Address and Introduction
Donald B. Horton, director, TRIGOM

SESSION I: ECONOMICS OF AQUACULTURE

General Economic Considerations
Harlan C. Lampe, professor of resource economics, University of Rhode Island

A Report on Aquacultural Development in New England
John M. Gates, assistant professor of resource economics, University of Rhode Island

Cost and Other Considerations in Feeding and Nutrition
Thomas L. Meade, associate professor of fisheries and marine technology, University of Rhode Island

Cost of Construction, Control and Operation of Hatchery Aquaculture Systems
Ronald D. Mayo, partner, Kramer, Chin and Mayo, Consulting Engineers, Seattle, Washington

Review of Economic Aspects of Aquaculture
Harlan C. Lampe

Workshop Sessions in Economics of Aquaculture

SESSION II: TECHNOLOGICAL ASPECTS OF AQUACULTURE

Introduction
Thomas A. Gaucher, natural resources consultant, Westerly, Rhode Island

General Considerations
Harold H. Webber, president, Groton Associates, Inc. Groton, Massachusetts

Shrimp Culture
Robert M. Lollar, director, Technical Evaluations, Armour and Company, Chicago

Oyster Culture
J. Richards Nelson, president, Long Island Oyster Farms, Inc., New Haven, Connecticut

Salmonid Culture
P. E. Cavanagh, president, Sea Pool Fisheries, Ltd., Lake Charlotte, Nova Scotia

Lobster Culture
Craig B. Kensler, fishery research biologist, U. S. Bureau of Commercial Fisheries, West Boothbay Harbor, Maine

Workshop Sessions in Technological Aspects of Aquaculture

SESSION III: LEGAL/INSTITUTIONAL ASPECTS OF AQUACULTURE

Legal Aspects of Aquaculture - General Problems
Mrs. Harriet P. Henry, attorney, Portland, Maine

Critique of a Modern Approach
Dorian M. Cowan, research associate, University of Miami (Florida) School of Law.

Pollution of Offshore Waters and Regulation of Coastal Land and Water Users
Orlando E. Delogu, associate professor, University of Maine School of Law

Problems of Inter-governmental Conflicts
Stephen Ells, deputy commissioner, Massachusetts Department of Natural Resources

Workshop Sessions in Legal/Institutional Aspects of Aquaculture

Summary and Review of Legal/Institutional Aspects of Aquaculture
Orlando E. Delogu and Harriet P. Henry

SESSION IV: REVIEW AND SUMMARY PANEL

Patrick E. Cavanagh, Dorian M. Cowan, Orlando E. Delogu, Stephen Ells, John M. Gates, Thomas A. Gaucher, Harriet P. Henry, Donald B. Horton, Craig B. Kensler, Harlan C. Lampe, Robert M. Lollar, Thomas L.Meade, J. Richards Nelson, Ronald A. Poitras (Maine State Planning Office), and Harold H. Webber.

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Mr. Cavanagh was director of the Ontario Research Foundation from 1946 to 1957 and has been president of Premium Iron Ores, Ltd., since 1958. He also is president of Ungava Iron Ores Company; and an officer and director of Sea Pool Fisheries, Ltd.; Leaseway, Ltd., and Lyman Tube and Supply Company.

DORIAN COWAN

Currently a research associate with the University of Miami Ocean Law Program, Mr. Cowan has authored several papers dealing with coastal law and is currently completing a three-volume compilation on Florida's Coastal Regime for the Office of Sea Grant Programs.

ORLANDO E. DELOGU

Professor Delogu is on the faculty of the University of Maine School of Law. He has published several major documents and papers relating to legal aspects of land and water use and environmental planning, and he currently is on the Governor's Committee on Forest Land Taxation, the Maine Environmental Improvement Commission, and the executive committee of the University of Maine's Water Resources Center. He also is a consultant to the National Water Commission and project adviser to Ralph Nader's Maine pulp and paper industry study.

STEPHEN ELLS

Mr. Ells is deputy commissioner of the Massachusetts Department of Natural Resources, which has responsibilities for marine fisheries, conservation laws, water pollution and resources, wetlands preservation, offshore mineral resources, and state forests and parks. He is vice president of the Conservation Law Foundation and the author of Massachusetts Open Space Law, published by the Metropolitan (Boston) Area Planning Council.

JOHN M. GATES

Since 1969, Dr. Gates has held the rank of assistant professor of resource economics at the University of Rhode Island. Research activities include market and cost analysis for salmon aquaculture and a bio-economic model of the northern lobster industry.

THOMAS A. GAUCHER

Dr. Gaucher was formerly president and general manager of AQUARAND, Inc., an ocean research development corporation, and is presently a private consultant in fisheries, aquaculture, and oceanography. He has authored numerous technical studies in the field of marine sciences.

HARRIET P. HENRY

An attorney, Mrs. Henry serves as a consultant on coastal usage and marine resources. She was research director and principal author of a Sea Grant and University of Maine School of Law study, Maine Law Affecting Marine Resources (4 vol.), and served as economic analyst for the Office of the Quartermaster General and as research analyst for the National Security Agency.

DONALD B. HORTON

Executive director, The Research Institute of the Gulf of Maine (TRIGOM), and a lecturer in biology, University of Maine at Portland-Gorham, Dr. Horton has been a fisheries biologist with the Rhode Island Division of Fish and Game; assistant professor of zoology, North Carolina State University, and director of the Pamlico Marine Laboratory, Aurora, North Carolina. He is a member of the Maine State Science Policy Committee and the advisory committee of the Maine Water Resources Center and is author or co-author of numerous publications on estuarine ecology and the population dynamics and behavior of fish.

CRAIG B. KENSLER

Currently engaged in shrimp culture research with the Food and Agriculture Organization in Mexico, Dr. Kensler formerly directed the lobster culture program with the U. S. Bureau of Commercial Fisheries Laboratory at West Boothbay Harbor, Maine; directed spiny lobster and fishery research in New Zealand; and was a member of the New Zealand Antarctic Research Expedition Team. He has published 20 articles in scientific journals dealing with marine crustacea.

HARLAN C. LAMPE

At the University of Rhode Island since 1959, Dr. Lampe is professor of resource economics. Currently coordinating a systems' study of

Narragansett Bay and directing the policy committee for the International Center for Marine Resource Development, Professor Lampe is the author of more than 20 papers on various aspects of marine economics.

ROBERT M. LOLLAR

Dr. Lollar is the director of technical evaluation in the corporate development division, Armour and Company, Chicago. He is the manager of the Armour-United Fruit Shrimp Mariculture Project. His professional career in industrial biochemical engineering has included over ten years with Armour and almost 20 years on the Graduate School faculty of the University of Cincinnati.

RONALD D. MAYO

Partner and project manager of the firm of Kramer, Chin and Mayo, Consulting Engineers, Mr. Mayo has charge of major fishery-related planning efforts including comprehensive plans for salmonid hatchery construction in Michigan, Minnesota, Wisconsin, and, currently, New York. He has over 12 years of experience in the design of treatment plants, industrial and domestic water supply systems, pilot plant studies, pump stations, reservoirs, fish hatcheries, and recreation developments.

THOMAS L. MEADE

With the University of Rhode Island since 1968, Dr. Meade has had extensive worldwide experience in fish processing and nutrition. He is currently associate professor of fisheries and marine technology and director of the Marine Experiment Station at the school.

J. RICHARDS NELSON

Dr. Nelson is president of Long Island Oyster Farms, Inc., a company of Inmont Aquafoods. An oyster grower for 38 years, he has spent nine years in oyster research, working in Delaware Bay, New Jersey, under the New Jersey Agricultural Experiment Station.

HAROLD H. WEBBER

In 1952 Dr. Webber established Groton Associates, Inc., a consultant service which, in recent years, has devoted primary attention to marine biological problems with emphasis on the development of mariculture. Dr. Webber is now active in developing technical and economic feasibility data for molluscan, crustacean and finfish culture.

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