WASHINGTON SEA GRANT PROGRAM

WASHINGTON SEA GRANT: THE FIRST FIVE YEARS

An Evaluation of Selected Projects

By Robert F. Goodwin

WSG-PM 74-1
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DIVISION OF MARINE RESOURCES
UNIVERSITY OF WASHINGTON 98195
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Mr. Goodwin, a consultant to the Washington Sea Grant Program, wrote this series of papers while on leave from the University of Washington Department of Geography, where he is pursuing a Ph.D. program in urban geography. A 1968 graduate of the University's Department of Architecture, Mr. Goodwin subsequently established a consulting firm that performed evaluation studies of health care programs. This manuscript was supported by Grant No. 04-3-158-42 under the National Sea Grant Program. The National Sea Grant Program is supported by the National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

CONTENTS

INTRODUCTION

The following evaluation study of Washington Sea Grant activities responds to a general expression of public concern: the demand for accountability in publicly funded programs. Competition among and within the many federal agencies for appropriations from a finite federal budget clearly places upon each entity the responsibility of reviewing past performance, scrutinizing current projects, and assessing probable consequences of future endeavors.

The task of evaluating a Sea Grant program in a completely quantitative fashion borders on the impossible; for, like the institution of higher education with which it is integrated, its goals are diffuse and the results of its programs often impalpable. Investment of resources in education is more an act of faith than a decision based on strictly defined, expected economic benefits. Yet the decision to commit Sea Grant funds to particular programs or departments must be based on more tangible principles.

Awareness of regional needs in marine resource areas and an understanding of attainable educational objectives which respond to those needs are necessary prerequisites for allocating Sea Grant funds. The following study will examine the mechanisms by which Sea Grant identifies such needs, coordinates the development of educational objectives, selects courses and programs which satisfy them and, finally, commits funds for their operation.

The report will similarly examine the mechanisms used to, first, identify existing research activities relevant to regional marine resource needs;

second, to define new research programs in hitherto neglected, but important areas; and, finally, to integrate often fragmented research efforts into need-oriented, cohesive programs.

The role of advisory services throughout these processes will be described and documented.

Choice of Method: Conventional benefit/cost analysis techniques were rejected in this evaluation study for the following reasons:

1. Washington Sea Grant has a short history and many of its research projects are in an embryonic state. The ultimate benefits accruing to society are still, in many cases, far in the future.

2. Benefits derived from higher educational programs are largely qualitative. The "market value" of knowledge is a function not only of society's willingness to utilize it, but also of the student's aspiration level, personal goal structure, and economic behavior.

3. The network of economic channels through which returns accrue to society from investments made in Sea Grant projects is labyrinthian and indeterminate, both in space and time. Knowledge acquired here, today, may have application at many "there's" for many "tomorrows." Its meaning for society will shift in accordance with changing goals in changing cultural contexts.

4. Science and technology advance by both the acceptance and rejection of hypotheses. The outcome of research and development projects cannot be discounted because adoption of products or processes did not occur. Information concerning the failure of a project has real value: identical failure will not (or should not) be repeated as long as the outcome is promulgated.

5. The consequences of supplying information and advice to a differentiated public are not easily measured. Not only might the ultimate user be several times removed from the party requesting information, but acknowledgment of credit for the advice used may not be forthcoming. Furthermore, the cost of follow-up contacts, both in terms of time and personnel is often prohibitive.

Having rejected conventional benefit/cost analysis, then, the decision was made to conduct an ex post evaluation of Washington Sea Grant programs.

First, we have described our activities in terms of interactions: the establishment of relationships. A broad taxonomy of cooperative relationships is presented in Chapter 1 of this report. Successful examples are presented in context.

Second, a particular set of projects oriented toward the total utilization of living marine resources, which seemed successfully to illustrate the operation of Washington Sea Grant's interactive role, is described in detail. Its genesis, development, present and potential benefits are described and documented in Chapter 2.

Third, a project that required heavy, early investment in theoretical and analytical research is commanding the attention of public agencies whose missions involve the assessment and regulation of pelagic fish stocks. Chapter 3 documents the progress of this Program in Marine Acoustics and presents quantitative evidence of the successful adoption of a technological innovation, using a model developed in Chapter 1.

Chapter 4 describes a research project in algal aquaculture--seaweed farming--which further illustrates the importance of relationships developed and maintained by Washington Sea Grant among several entities whose cooperation is essential to the successful development of seaweed farming in Puget Sound.

Finally, Chapter 5 illustrates the rapid response capability of Washington Sea Grant in providing limited technical assistance to a small corporation with a unique and commercially promising innovation. The Sequential Sea Mesh Hull-cleaning System, with our help, has emerged from near disaster to a highly visible technology that has caught the eye of private maritime and naval fleet managers.

Each chapter has been prepared separately and then compiled into this publication. Appendices with supporting documentation appear at the end of each chapter, rather than at the end of the document, so that the reader can readily evaluate claims made for each project against documenting material.

Chapter 1. PROGRAM OVERVIEW

While Sea Grant's activities might be characterized by their diversity, one issue is pervasive: Sea Grant's primary role of promoting and maintaining relationships among all the participants in the use and management of marine resources. Four broad categories of participants can be defined:

1. Institutions of higher education with marine-oriented research and/or education capabilities.

2. Regional marine resource-oriented industries whose development, profitability and survival are dependent upon awareness and application of technological and management expertise.

3. Public agencies whose regulatory or advisory activities impinge upon regional marine resource use and management.

4. The Interested public whose newly awakened concern for the preservation and wise use of our marine resources is affecting resource management decision-making.

Two implicit assumptions are made:

1. Limited cooperative relationships within and among the four participant groups already exist, and Sea Grant can build upon them.

2. Independent, unrelated activities occurring within the participant groups can usefully be integrated to produce coherence of effort.

One of Sea Grant's major objectives, then, is to transform a set of marine resource-oriented activities into a coherent system of activities, by developing "critical linkages"[1] among them.

Washington Sea Grant efforts in this respect are analyzed and evaluated below. First, the sets of relationships within each of the participant groups are described under the headings:

Multidisciplinary Research

Multidisciplinary Education

Industry Cooperation

Interagency Cooperation

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[1]Critical linkages are defined as those channels and consequent flows of information necessary to produce synergistic behavior of the system.

Measures of the effectiveness of these efforts, where appropriate, are included. Second, one major set of projects undertaken by Washington Sea Grant is analyzed to demonstrate the integrated roles of Washington Sea Grant's three missions -- research, education, and advisory services -- in establishing a coherent program for the total utilization of the fishing industry's catch.

Multidisciplinary Research

The role of Sea Grant in establishing "critical linkages" among disparate researchers goes beyond the voguish term "interdisciplinarity," or "multidisciplinary studies"; for while encouraging academic departments to interact is a laudable goal, a more crucial need is to match perceived marine problems with extant research activities showing promise of direct applicability. Any multidisciplinary research which emerges from the Sea Grant effort might be considered an incidental windfall to the University community.

The composition of the research team must be responsive to the nature of the perceived marine problems. Credible past performance of individual researchers in related projects is a more appropriate criterion than the number of disciplines represented. Marine resource utilization problems, however, are never without their social, economic and institutional considerations, and the importance of complementary knowledge derived from the social scientist, lawyer and business expert must be acknowledged by the natural scientist and engineer.

Where researchers from several disciplines are required to accomplish a Sea Grant objective, the institutional barriers between them must be surmounted. Internecine rivalries, departmental tenure and promotion mechanisms, and the greater attraction of basic, or nondirected, research mitigate against interdisciplinary effort. Hence, Sea Grant directors must satisfy at least the following set of conditions before a coherent program can be developed:

1. Awareness of existing research activities in the academic institutions of the region.
2. Awareness of their mutual, or potentially mutual interests.
3. Credibility of and respect for Sea Grant staff.
4. Establishment of communication channels among researchers.

5. Provision of a reward structure sufficient to overcome departmental or disciplinary barriers to cooperation; e.g., seed-funding, publication of results, and application of findings.

6. Maintenance of information flows among researchers.

Where cooperative relationships already exist among departments, Sea Grant may utilize them. Usually, such relationships are focused within institutes established by colleges, or departments, for applied research programs. At the University of Washington, several such institutes[1] are tailor-made for marine resource utilization problems and their inclusion in Sea Grant programs contributes useful sets of ongoing relationships.

Interdisciplinary Education

Washington Sea Grant support for University curricular innovation has been concentrated upon problem-oriented courses and programs. Where marine resource problems are defined at a broad, general level, individual disciplines or departments rarely have the teaching resources to deal with them. In such cases[2] an interdisciplinary approach is favored. Conversely, where the problem is tightly circumscribed within one discipline,[3] the inclusion of teaching staff from peripheral disciplines would not be productive. Essentially, then, the mix of teaching staff for problem-oriented courses must reflect the scope of the problem under consideration.

It should be pointed out that multidisciplinary education is a function not only of the number of disciplines represented in a single course; the

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[1]Institute for Food Science and Technology, Fisheries Research Institute, Applied Physics Laboratory, Office of Engineering Research, Center for Quantitative Science in Forestry, Fisheries and Wildlife, Institute for Environmental Studies, and the Institute for Marine Studies.

[2]Two courses have been developed with such breadth: "Interdisciplinary Ocean Engineering Systems" and "Program in Marine Affairs."

[3]An illustrative case is "Ocean Law."

total package of course offerings constitutes a set of multidisciplinary opportunities[1] from which a student can select an individual mix.

Criteria used to evaluate benefits accruing to educational programs are difficult to define since the demand for skills learned is not entirely independent of the supply of students who have acquired them. This apparent paradox evaporates when education programs offered at the graduate level are considered. Here, the distinction between research and education is obscure and new knowledge created can become an inducement for the development of new products or processes. Thus, those students whose education contributed to new knowledge are, in turn, employable in new positions they "created," albeit indirectly.

The inference, therefore, is that Sea Grant responds not only to existing societal needs for trained skills, but the interrelationships between Sea Grant-supported research and education create new employment opportunities in areas useful to society[2].

Industry Cooperation

Cooperation with marine resource industries, the most direct recipients of Sea Grant effort, is an essential precondition for an effective Sea Grant program. Without their cooperation, regional needs cannot accurately be gauged, nor can research activities, educational programs, or advisory services have practical application.

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[1] A graduate program in law, leading to the LL.M. degree, offers courses in marine-oriented problems drawn from eight departments at the University of Washington.

[2] One student finished his doctoral dissertation while employed by Washington Department of Natural Resources, where he is continuing the development of his work in algal aquaculture. Another has established a private business in Washington State, growing cultchless oysters for domestic consumption.

Industries' acceptance or rejection of Sea Grant's products -- trained personnel, applied research findings, services rendered -- is a salient metric by which a Sea Grant program is measured. Development of a new industry as a consequence of Sea Grant-supported research in seafood technology[1]; industry hiring of technicians trained by Sea Grant-initiated programs[2]; assistance in resolving an agency/industry controversy on fisheries management standards[3]: these are all direct measures of Sea Grant effectiveness.

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[1] Total Utilization Concept (TUC) examined in depth below.

[2] Community colleges in western Washington have several two-year courses for technical training, developed and partially funded by Sea Grant; e.g., Grays Harbor College: Fish and Game Management Technology.

[3] Washington Sea Grant Advisory Services' "Long Line Fishing Seminar." Resolution of a controversy concerning catch-per-unit-effort standards for halibut long-liners was accomplished shortly after this seminar. Changes in hook-spacing were responsible for divergence between industry's and agency's views on an acceptable standard.

Interagency Cooperation

Marine and marine-related industries navigating, or located in the coastal zone, are under the jurisdiction of a multiplicity of regulatory and advisory agencies. Some are resource-specific: state agencies reponsible for shoreline management; yet others have specific missions related to both marine and land-based activities: environmental protection, public health, etc. Were the regulatory and advisory functions of all these agencies static even, individual industries would have unequal access to them, due to divergent interests, motivation and resources. Where agencies' missions are dynamic, however, the problem of maintaining access to current information becomes staggering, the smaller businesses being particularly vulnerable to the information explosion. Furthermore, each agency suffers a similar plight; each, too, must assimilate a plethora of information from other agencies and answer requests for information from the private sector.

There exists, then, a clearinghouse function between all the diverse information sources and the marine resource activities upon which they impinge. Washington Sea Grant has a selective clearinghouse role working with marine problems in this state. While the promulgation and exchange of information relevant to marine resource industries play a major role in all Sea Grant missions -- education, research and advisory services -- Advisory Services predominates in these functions.

Three categories of responsiveness to information needs can be identified: passive, reactive, and active.

1. Passive response: Assembling and classifying information relevant to the marine resources industry.

2. Reactive response: Responding to requests for information.

3. Active response: Searching out information needs of the regional marine resource community and matching needs to sources; and, searching out information sources to be matched with potential users.

In an industry characterized by many small businesses, the active response of Advisory Services is clearly the most important. For example, a change in regulatory agency standards can have drastic consequences for the small producer. When changes occur in an information vacuum, enforcement of the changed regulations can precede an industry's awareness of the change, with potentially drastic results. Sea Grant, by maintaining close contact with relevant agencies' publications, can and does seek out impacted industries to anticipate shutdowns, short-run emergency capital outlays, or other drastic measures needed to comply with new regulations[1]. Washington Sea Grant, further, can play an "ombudsman" role in bringing regulatory agency personnel in face-to-face contact with the impacted businesses. The missions of the agency and the problems of industry's conformance can then be discussed to their mutual advantage.

Where agencies have evolved through time and without drastic rationalization of their functions, jurisdictional and operational redundancies can and do occur. Washington Sea Grant provides mechanisms by which agencies can be informed more fully of their mutual concerns and thereby plan their activities more rationally and thus avoid redundancy. Such mechanisms have been particularly useful in rationalizing data gathering in local waters and their abutting shorelands[2].

The cost-effectiveness of relationships established with government agencies by Sea Grant must remain conjectural, since they are rarely necessary and sufficient conditions for promoting changes in an agency's behavior. However, where industries for which Sea Grant has provided necessary technological information have survived more stringent health regulations, or where interagency redundancies have been rationalized following a Sea Grant-sponsored forum, some credit for public money being saved, or private industry smoothly adapting, must accrue to Washington Sea Grant. Similarly, where ongoing interagency cooperation is initiated by Sea Grant

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[1]Advisory Services has assisted smoked fish processors in western Washington to conform to new F.D.A. regulations for smokehouses. Information on monitoring equipment has been furnished; an architectural researcher was commissioned to provide graphic interpretation of F.D.A. standards; and sample product testing was conducted by S.G. advisory staff.

[2]"Puget Sound Watch" conference, held in September, 1971, brought together participants from all the agencies and institutions conducting research, developing regulatory policy or managing resources on Puget Sound.

efforts, and new research seeking to fill data gaps is undertaken, the results cannot be disassociated from Sea Grant's original involvement.

Support Level Profiles: A Technique for Comparing Projects

One method for evaluating the successful immediate impact of a Sea Grant College upon the region it serves consists of qualitatively assessing the cash outlays of Sea Grant vis-à-vis other institutions, agencies, and industries that are involved in a particular project or set of projects.

Let us assume that Washington Sea Grant initiates an R&D project, provides seed-funding, and acquires local matching funds. If the innovation shows promise, it will be adopted by potential users who will begin to invest their own funds in the product or process. We will examine a method of illustrating this process through time and suggest interpretations to be drawn (Figure 1-I).

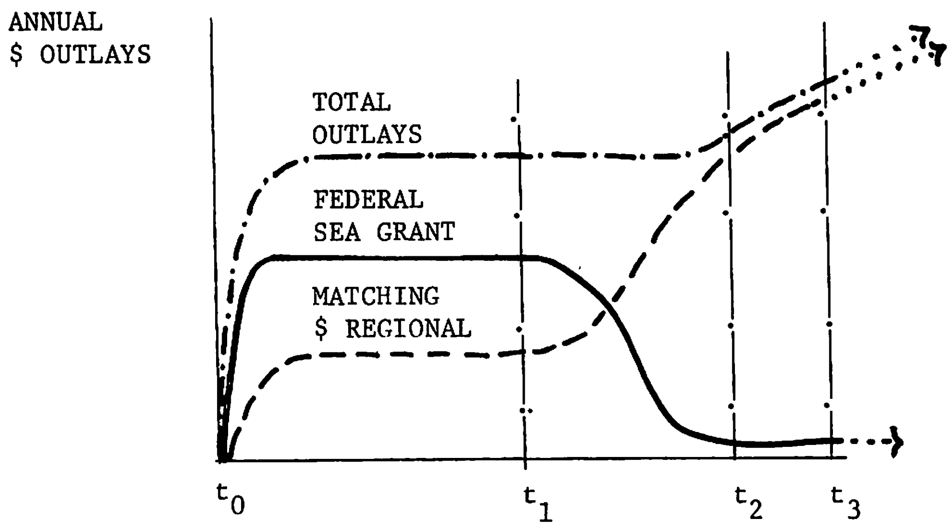

FIG. 1-I: SUPPORT LEVEL PROFILE (Retrospective view)

In this retrospective view, Sea Grant began funding the project at t_0. By t_1 Advisory Services and the project investigators had successfully interested outside parties in either supporting promising further research, or continuing the commercial development of the innovation. Sea Grant's financial involvement by t_2 had fallen to a level necessary to just maintain information flows among the involved parties. At t_3 (the present) any future expenditures by non-Sea Grant parties will be based on their forecasts of the program's potential benefits--that is, the program will continue if it can be justified in economic terms defined by its potential users.

The Diagnostic Utility of the Profiles

If, as in Fig. 1-II, no additional non-Sea Grant monies are being invested after a considerable time has elapsed, serious questions must be raised by the Sea Grant decision-makers concerning future funding. Are the findings to date indicative of failure? Or, do they appear promising enough to continue support? Why has no non-Sea Grant party expressed willingness to provide continued funding? Are the findings of such potential importance to society that even without support from non-Sea Grant sources, the project should be continued?

Clearly, each project must be examined on its individual merit; but surveillance of the levels of support can prompt ongoing reevaluation of the project, leading to firmer control of expenditures.

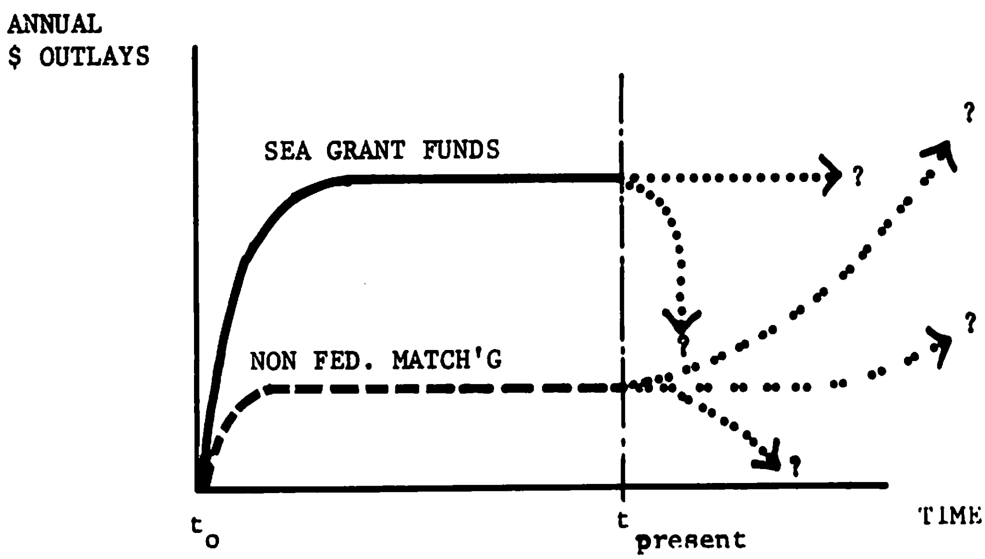

Fig. 1-II. SUPPORT LEVEL PROFILE (Diagnostic Value)

Conclusions

The effectiveness of Washington's Sea Grant programs has been assessed in a qualitative, anecdotal fashion for reasons specified in the introduction to this document. Where monetary benefits have been mentioned, they are largely conjectural and depend for their actualization upon the continued initiative of private sector industries.

Washington Sea Grant has promoted productive relationships among institutions of higher education, regional marine industries, public regulatory agencies, and the interested public, as a result of which the following benefits have accrued:

-Interdisciplinary research and education in marine-oriented areas leading to creation of skilled personnel and new industrial ventures.

-Industry/Sea Grant cooperation resulting in industrial applications of research efforts; technical training, and joint industry/Sea Grant ventures.

-Interagency cooperation resulting in rationalization of agencies' missions and operations.

-Intervention between regulatory agencies' decisions and impacted industries through technical assistance and information services.

Chapter 2. TOTAL UTILIZATION CONCEPT: THE EVOLUTION OF A COHERENT PROGRAM IN RESEARCH AND DEVELOPMENT

The development of the Total Utilization Concept (T.U.C.) and related projects is illustrative of Washington Sea Grant's capabilities in creating a coherent, systematic research and development program through the creation of cooperative relationships among several existing entities.

Recognizing the Problem

Advisory Services' seafood specialist initiated Washington Sea Grant's interest and action in a marine waste-disposal problem of particular concern to the crab and shrimp industry in Alaskan waters. Because of pressure from the federal Environmental Protection Agency, fish processors in Alaska will be required to develop alternative methods for the disposal of crab and shrimp wastes. The common practice of dumping in coastal waters creates a serious water pollution problem. The short-run solutions are land-fill disposal, or deep-sea dumping, both of which involve transfer costs for the producer and/or the municipality. In addition, a substantial and hitherto nonrecoverable quantity of protein-rich waste is lost in the dumping process.

The finfish industry incurs a similar loss of protein since its total catch includes unmarketable fishes, which currently are ground up for animal feed and fertilizers, or discarded at sea. Methods for extracting marketable fish protein at low cost, either at sea or at a shore-side processing plant, could eliminate these industry losses and increase food production from existing fishing grounds. These two problems--shellfish and finfish waste disposal--constituted a regional need for which Sea Grant embarked on a search for solution.

Developing Linkages

A. Fish Protein Extraction

Several ongoing research projects in scattered departments and institutions showed promise of applicability to the "Total Utilization" goal. The University of Washington's Institute for Food Science and Technology had long been working on a program of extracting protein from fish processing wastes. State-of-the-art techniques--enzyme digestion and organic solvent extraction--yielded an unpalatable, high-cost protein, unsuitable for human consumption. Promising new techniques, however, have been identified for which Sea Grant has provided substantial research funding. At this time a pilot plant has been constructed with the goal of producing odor-free, tasteless protein, at reduced cost, suitable for human consumption, using a brine extraction process.

B. Utilization of Marine Polymers

Individual wood chemistry researchers in the University of Washington's College of Forest Resources were exploring the properties of natural polymers (polysaccharides) in wood. Since it was known that the shells of crab and shrimp contain 25-35% chitin, whose derivative, chitosan, has similar polymeric properties, Sea Grant sponsored a research project designed to investigate the marketable properties of this material. Currently, chitosan has been shown to have marketable value in the following processes:

1. Wet and dry strength additive in pulp and paper industry, competitive with currently employed resins.

2. Bonding additive in papermaking which reduces beating time required in current practices.

3. Binding agent in the nonwoven fabric industry.

4. Dye assistant in the dyeing industry.

5. Controlled (time) release vehicle for herbicide applications.

6. Water flocculation agent for treatment of effluents and water clarification.

Concurrent research on polymers (polysaccharides) derived from marine plants is being conducted by co-workers at the University of Puget Sound, Chemistry Department. Structurally different from the chitin polysaccharides, these polymers derived from red and green algae have been shown to have the following applications:

1. Food gum (similar to gum arabic).
2. Anti-viral agent (shown to be effective against tobacco mosaic virus (TMV)

C. Aquaculture of Marine Algae[1]

Though related only indirectly to the T.U.C. project, Sea Grant-sponsored botanists and oceanographers at the University of Washington, investigating the aquaculture of marine algae, share basic scientific information with the marine polymer group and provide them with a source of cultured algae. Furthermore, the long-term potential for developing commercial sources of marine plant polymers has been enhanced by Washington Sea Grant's coordinative activities. Thus, while this project's goals have little in common with T.U.C., there has been established a cooperative relationship to their mutual advantage.

D. Industry's Involvement

Food, Chemical & Research Laboratories, Inc., a Seattle firm, had been investigating, since 1967, industrial processes by which shellfish waste can be transformed into three marketable products: chitosan, protein, and calcium chloride. NMFS, and more recently, EPA and the City of Kodiak, Alaska, have supported their research efforts. In 1971 it became apparent that continued development of their process would require a semi-works, chitosan production plant to be constructed in Seattle. 1,000 pounds of the total output of 8,000 pounds per month of chitosan or chitin would be purchased for Washington Sea Grant to provide researchers with experimental quantities of the product. Since a production plant of this size could not suitably be located at the University of Washington because of space needs

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[1]See Chapter 4 for a detailed analysis of this project.

and odor problems, FC & RL negotiated a lease for space adjacent to the Seattle Rendering Works (SRW). This arrangement is fortuitous for three reasons: first, a supply of raw material -- shellfish waste -- is available from SRW; second, any odors generated by the process at that location are nonoffensive; and third, waste-disposal can be handled by SRW at any stage in the process.

The agreement with FC & RL provides for Sea Grant, through the Oceanographic Institute of Washington, to purchase for investigators 1,000 pounds of chitin or chitosan per month at a price of $2.00 per pound for two years (total $48,000). Should sales to other parties exceed $6,000 per month for six months, however, Sea Grant support can be curtailed. FC & RL, through such an arrangement, will have a modest revenue to support market research and sales promotion during the development period. O.I.W., in addition to acting as a procurement agent, actively collaborates with FC & RL in identifying markets and providing other Sea Grant-approved researchers with experimental quantities of the products.[1] The entire capital cost of the pilot plant is borne by FC & RL.

In addition, arrangements have been made to incorporate a fish-protein extraction plant, operating in parallel with chitosan production, on the same site. Similar arrangements for raw material acquisition and waste disposal have been expedited with SRW. This cooperation will enable researchers to evaluate production costs and quality-control for the brine extraction process referred to above.

Summary

Figure 2-I. summarizes the set of critical linkages developed by Washington Sea Grant. Pre-Sea Grant research activities are shown at the top of the diagram; relationships developed among them and new Sea Grant-supported projects, into which they have been incorporated, are shown on a vertical time scale.

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[1] See page 24 for list of researchers supplied and quantity of chitin or chitosan delivered.

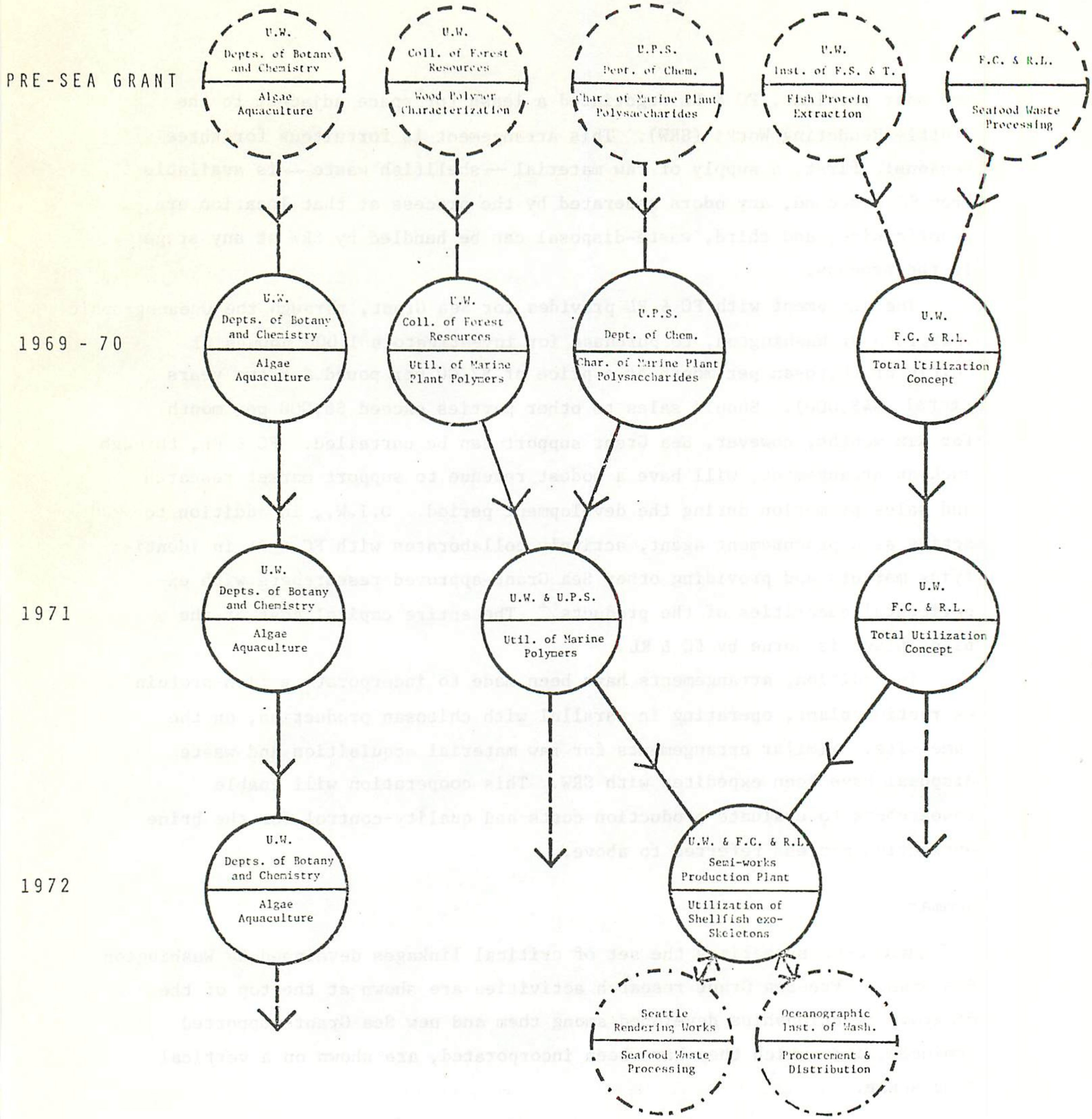

Fig. 2-I. EVOLUTION OF A COHERENT PROGRAM

Potential Benefits Derived from Total Utilization Concept and Related Projects

Benefits which accrue to society in general and to the Pacific Northwest in particular remain conjectural at this stage of development. Some indicative measures, however, can be inferred from results to date. Total utilization of marine fishing catch would produce benefits not only to the fishing industry, but also to municipalities with port facilities and to processing plants utilized by the marine fishing industry. Two new technologies affecting the fishing industry and seafood processor will be considered. First is the brine extraction process, referred to above, which produces fish protein from unmarketable species, or fish processing waste. The second technology is an integrated system for producing protein concentrate, chitosan, and residual minerals, soon to be functioning in the semi-works plant operated by FC & RL.

The brine extraction process could be utilized either on shipboard plants, or at shore-side facilities. Aboard ship, the input to the process would consist of unmarketable species in the total fishing catch. At processing plants, fish scraps would provide the raw material for the process.

The integrated system utilizes shellfish waste from the shrimp and crab industry and its application, therefore, would be limited to shore-side facilities.

Benefits Accruing to the Fishing Industry

Production of fish protein using the brine extraction process will occur: (1) when the revenue from delivering the unwanted catch to shoreside fish-processing plants (for the production of feed or fertilizer) exceeds the cost of transporting it to shore, or (2) when the net revenue from onboard production of fish protein is greater than the net revenue from sales to shoreside processing plants.

Unfortunately, accurate revenue and cost estimates are not yet available for the brine extraction process. And, it will have to be demonstrated to a fragmentized and conservative industry that there would be a payoff from adopting such an innovation. Such a task would fall logically within the role of Sea Grant Advisory Services.

Benefits Accruing to the Seafood Processing Industry

The Kypro Company, an affiliate of Food, Chemical & Research Laboratories (FC & RL) submitted a proposal for a chitosan plant to be constructed at Tampa, Florida. A net return of 10.6% on the investment was projected for a plant which would produce protein, chitosan, sodium acetate and calcium chloride from the dried wastes of the Gulf shrimp industry. The plant capacity would be 1,000,000 pounds of dried shrimp waste per year, or 4% of the total output of shrimp waste on the Gulf Coast. In view of an existing market for dried shrimp wastes in the pet food and animal feed industries, a factor price for raw material of $50 per ton, f.o.b. Tampa, was projected. Revenue was based on a market price of 25¢ per pound for chitosan, 15¢ per pound for protein, 5¢ per pound for sodium acetate and 1¢ a pound for calcium chloride.

Seafood processing plants in Kodiak, Alaska currently process 63,000 tons of crab and shrimp each year, of which 38,000 tons is discarded as waste. The discarded material contains equal quantities of chitin, protein, and $CaCO_3$--3,800 tons each--and 26,000 tons of waste water (70%).

Figure 2-II summarizes the existing utilization of crab and shrimp and the alternative total utilization made possible by the integrated system. At projected market prices, annual sales of protein, chitosan, and calcium carbonate from Kodiak's waste output alone would be valued at $3.1 - 13.7 million per year. (See Table 2-I.) The only material to be returned to the immediate natural environment would be 26,500 tons of cleaned water. [1]

Seafood processors at Kodiak, Alaska, are currently negotiating with the Bio Dry Corporation for construction of fish-waste drying plants on the island. Should the plants be built, all the fish waste from that port would be processed at the plants. The output would consist of three products:

1. Dried, ground fish meal.
2. Dried crab waste.
3. Dried shrimp waste.

In a previous proposal to the City of Kodiak, Bio Dry suggested that the market price for their products would be $42 to $62 per ton, f.o.b. Kodiak.

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[1] For a full description of Kodiak's pollution abatement problem see: CRESA: Pollution Abatement and By-Product Recovery in Shellfish and Fisheries Processing. EPA, Water Pollution Control Research Series 12/30 FJQ 06/71.

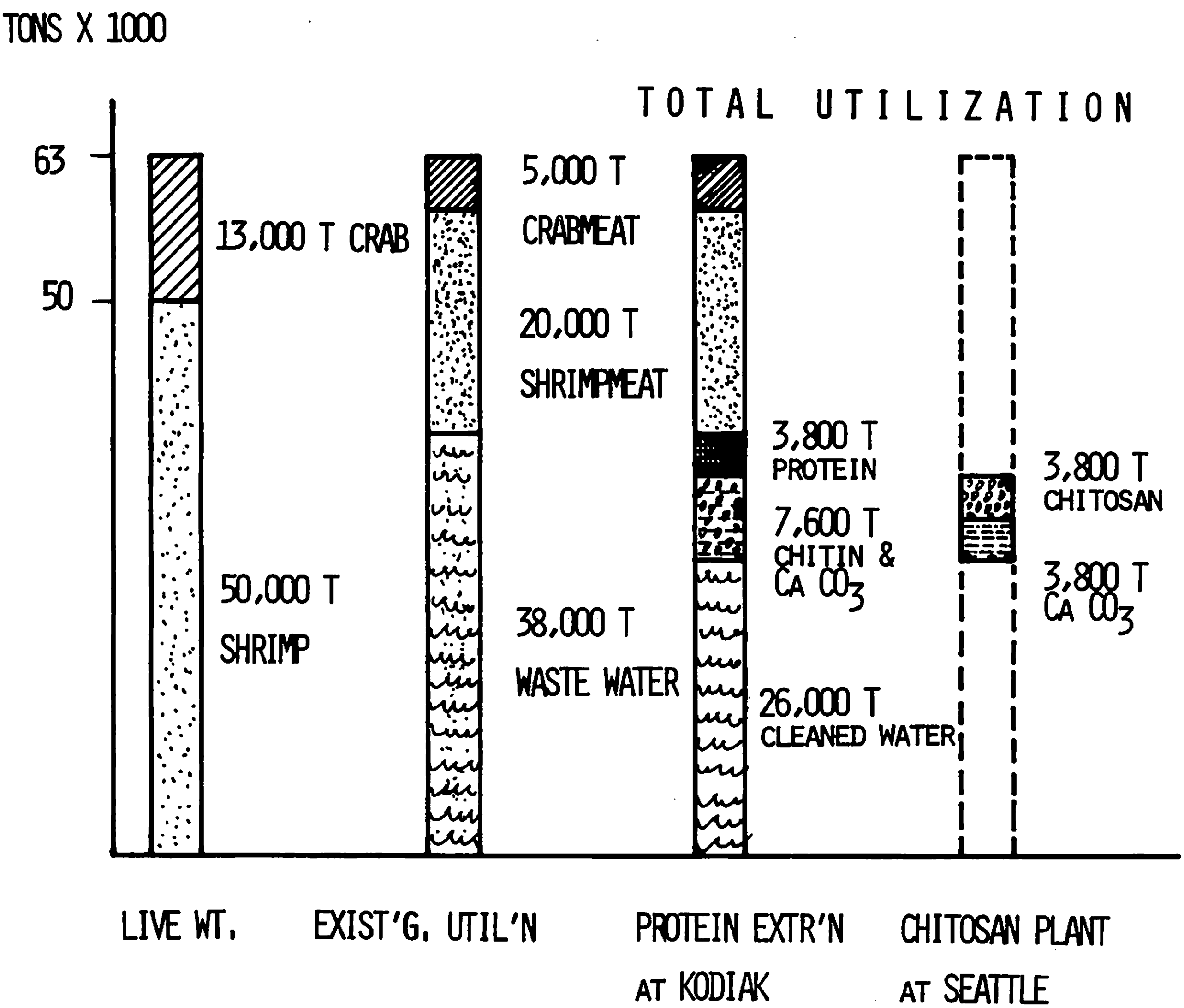

Fig. 2-II. EXISTING & TOTAL UTILIZATION OF SHELLFISH: KODIAK

PRODUCT	QUANTITY	UNIT PRICE (Per Ton)	VALUE
Protein	3,800 T	300.00	1,140,000
Chitosan	3,800 T	500.00 - 3,300.00*	1,900,000 - 12,540,000
Ca CO_3	3,800 T	20.00	76,000
			3,116,000 - 13,756,000

*The $3,300.00 figure is based on a price of $1.65 per pound. See page 53 of *Pollution Abatement and By-Product Recovery in Shellfish and Fisheries Processing*.

Table 2-I. REVENUES FROM T.U.C. APPLIED TO KODIAK SHELLFISH WASTE

Side-payments would be made to or from the City of Kodiak in order to guarantee a fair return to the company building and operating the plant.

According to Dr. Peniston of FC & RL, the high cost of transporting hydrochloric acid to Kodiak from available sources would preclude the production of chitosan at that location. The plant could be bifurcated, however. Extraction of protein from shellfish waste could be accomplished economically at Kodiak using the brine-extraction process. The residual, dried chitin could then be transported to Seattle for production of chitosan.

The precise cost-structure of a bifurcated plant operating in Washington and Alaska is yet to be calculated; figures for Tampa, Florida are not directly applicable to this region and additional transportation costs would be incurred. However, there are specialty chemical markets for chitosan which will support prices substantially higher than 25¢ per pound.[1]

Other Regional Benefits

The pulp and paper industry in the Pacific Northwest generates a significant contribution to regional income and has been identified as one potential market for chitosan. Dr. Graham Allan of the University of Washington, College of Forest Resources, states that: "It (chitosan) is particularly suitable for low-strength papers derived from low-cost ground wood and other high-yield pulps. In these areas chitosan may be ecologically favored because the production of these pulps does not create the pollution problem of the sulfite or Kraft processes. If chitosan can be made available at 25¢ per pound and used at the 2% level in ground wood, the cost of the finished paper could be reduced from $55 to $45 per ton. Also in nongroundwood areas the use of chitosan can reduce the amount of power required per ton of paper by eliminating part of the beating cycle. The beating step in which fibers are mechanically agitated to develop bonding surfaces is very inefficient (less than 1%) and is the most costly in paper manufacturing."

As a substrate for controlled release of herbicides, chitin has a potential market. In the forest products industry, controlled release herbicides can suppress deciduous brush in reforested areas. This technique has been shown to double conifer seedling growth in the first year after application.

[1] Eastman Kodak, for example, quotes a price of $6.25 for 25 grams of chitosan. (=$113.25/lb)

Economic analysis has shown that consequent yield increases are worth between $20 and $80 per acre.

While it would be irresponsible to claim that the production of chitosan in the Pacific Northwest/Alaska region would have dramatic consequences for the forest products industry, it is nonetheless reasonable to indicate that recoverable waste from one industry can become a factor input to another industry in the same region.

Benefits to the Academic Community

The opportunity for multidisciplinary research is a direct benefit to the academic community. Six faculty members, 19 graduate students, and three undergraduate students have been partially supported by Washington Sea Grant for their work on the Total Utilization Concept and the Utilization of Marine Polymers. The disciplines represented include: chemistry, chemical engineering, biology, fiber science, wood chemistry, mechanical engineering, forestry, biochemistry, and food science. Two Ph.D. dissertations and one master's thesis have been completed under the T.U.C. project and three Ph.D. dissertations and two master's theses are forthcoming. Four Ph.D. dissertations and six master's theses are forthcoming from Sea Grant-supported students in the Utilization of Marine Polymers project[1].

Washington Sea Grant's Role in Creating Economic Benefits

The question must be posed: Would the development of a seafood waste-processing industry[2] have occurred without Sea Grant's involvement and funding? Even were the answer " Yes," Sea Grant's role could not be discounted, since, in the absence of a coherent program and provision for its funding, delays would have occurred with measurable financial consequences.

Dr. Peniston, of FC & RL, estimates that the involvement of Sea Grant in establishing relationships and providing a short-term, guaranteed market for chitosan produced at the semi-works production plant has accelerated the development of the industry by no less than one year. Thus, the economic

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[1] Pages 29 and 30 are a bibliography of published materials and unpublished theses which have developed out of Sea Grant-supported programs.

[2] The proposed drying plant at Kodiak represents only a primitive first step toward total utilization, since it does not extract any new products from seafood waste.

benefits of the earlier realization of revenues for the chitosan industry and the earlier realization of savings resulting from industrial applications of chitosan are directly attributable to Sea Grant involvement.

Proprietary Research

International interest in chitin and chitosan has been stimulated by Sea Grant-supported research findings. Among those firms[1] who have subsequently conducted their own proprietary research on these products are:

Weyerhaeuser Company	Kendall Corporation
Ciba-Geigy Corporation	KemaNord (Sweden)
Kimberly-Clark Corporation	Papeteres Bollore (France)
Texon, Inc.	Tokai Pulp Company (Japan)
Johnson & Johnson	Toyo Pulp Company (Japan)
FMC Corporation	

In addition, the following organizations requesting samples of chitin or chitosan have been referred to the Washington Oceanographic Commission. These concerns have almost certainly also carried out research on chitin and chitosan:

Name of Organization	Quantity Purchased	
	Chitin	Chitosan
Department of Microbiology University of Miami	50 lbs	50 lbs
Department of Food Science Louisiana State University	10 lbs	10 lbs
College of Marine Studies University of Delaware	1 lb	1 lb
Oregon State University Seafoods Laboratory		25 lbs
Sea Grant Projects Office Massachusetts Inst. of Tech.	5 lbs	50 lbs
Hemostasis-Thrombosis Research Department of Physiology University of Saskatchewan	1/2 oz	1/2 oz
Paul Mulvihill, APARI Homestead, Florida	50 lbs	

[1] Communication from Dr. G. Graham Allan, College of Forest Resources, University of Washington

Name of Organization	Quantity Purchased	
	Chitin	Chitosan
Swedish Forest Products Research Laboratory Fibre Building Board Dept. Stockholm, Sweden	1 lb	1 lb
Professor Leon Ciereszko University of Oklahoma	1 lb	1 lb
SEAWARD, INC. Falls Church, Virginia	100 grams	100 grams
National Marine Fisheries Service, NOAA Southwest Fisheries Center La Jolla, California	1 lb	1 lb
Department of Pharmacology Mount Sinai School of Medicine New York, New York	1 lb	
College of Agriculture and Environmental Science Dept. Biochemistry and Microbiology, Rutgers New Brunswick, New Jersey	500 grams	500 grams
Swedish Forest Products Research Laboratory Stockholm, Sweden	1 lb	1 lb
Laboratory of Food Chemistry and Food Microbiology Department of Food Science Agriculture University The Netherlands	1 lb	1 lb
Department of Pharmacognosy School of Pharmacy University of Mississippi	10 lbs	25 lbs
Hawaii Institute of Marine Biology, University of Hawaii	50 lbs	
Prof. Riccardo Muzzarelli Universita di Bologna Bologna, Italy		100 lbs
Freyco Equipment, Inc. Huntington, New York	1 lb	1 lb

In an effort to identify new industrial applications for chitosan and to assess their economic impact, a questionnaire was mailed to all recipients of chitin/chitosan samples.

In all cases, potential new applications were at the investigative stage; no business volume data were available. Several new applications were identified, however, and these are listed below:

A. *"Our objective in using chitosan, is as a substrate for a microbial fermentation to produce a new enzyme CHITOSANASE. The use of this enzyme is to lyse fungi pathogenic to man that infect burn wounds; e.g., Mucor and Rhizopus. These fungi contain chitosan in their cell wall. Enzymatic dissolution of the cell wall results in release of the cell contents and death of the pathogen. We now have such an enzyme . . . and are currently moving to clinical trials.*

The enzyme acts by an endo-splitting action, i.e. decreases the chain length of chitosan in a mild manner. The enzyme would thus be useful for preparing a range of shorter chitosan oligomers, if such products have a use."

B. *"We are using these materials for coating and encapsulating particles. Our work is exploratory research and development, but we find the materials can be handled by our processing techniques."*

C. *"We are beginning research to discover and develop complexes of dyes with chitosan and other polymers which are able to sensitize the photo-oxidative destruction of waste organic materials, such as phenols in industrial effluents. Chitosan is particularly attractive for its polycationic quality, because many strongly photosensitizing dyes are anionic."*

D. *"The use of chitosan as a coagulating agent for treatment of food processing wastes is being investigated. Laboratory studies indicate chitosan to be an effective coagulating agent. Full-scale trials are planned in the coming year. The full-scale tests may result in an industrial application for chitosan in physical-chemical treatment systems."*

E. *(Investigation is) "Still in progress. We are looking at two possible pharmaceutical applications."*

F. *(Investigations involve) "atomic arrangements in bulk chitin and chitosan; structure of chitosan films deposited from acid solutions; effects of water vapor on chitosan bulk; crystallization of chitosan films.*

Intend to study effects of source and processing of chitosan on the structure and properties."

G. *"I have demonstrated that chitin and chitosan have chelating capacities toward transition metal ions. They are therefore suitable for metal ion pollution prevention and monitoring. Our results are described in the new book: R. MUZZARELLI NATURAL CHELATING POLYMERS Pergamon Press Ltd, New York, 1973; and the U.S. PATENT 3,635,818 (1972), to M.G.F. MUZZARELLI.*

Chitosan can be applied industrially to prevent discharging ionic copper, lead, mercury, nickel, etc. For copper and lead I have developed complete reprocessing schemes, but up to now no pilot plant has been installed."

H. ". . . emphasis on new solvents to improve purification methods and extend utilization of chitin, for example, as unsupported film."

Washington Sea Grant is continuing to monitor these and other proprietary and nonproprietary investigations of chitin/chitosan properties and applications.

Program Cost Analysis

Table 2-II and Fig. 2-III summarize program expenditures on the total utilization concept and related projects. Non-federal Sea Grant and regional contributors have grown absolutely and their relative share of project expenditures is 46.1% for the current year (FY 74). Significantly, federal Sea Grant funding has turned downwards in FY 74 as the chitin semiworks project shifts towards self-sufficiency. Dr. Peniston believes that commercial sales of chitin and chitosan will exhaust current inventories and absorb all future pilot-plant output; thus, under the terms of O.I.W.'s contract, Sea Grant purchases of the plant's output are expected to fall to zero during the current year. Even were this self-sufficiency not to obtain, private funding for market research in chitin/chitosan industrial applications exceeds federal Sea Grant funding by almost five times.

Chitin/Chitosan's parent projects--utilization of marine polymers and T.U.C.--continue at level funding through FY 74. Promising new developments and consolidation of previous research in both projects are expected to produce new applications of marine polymers and better utilization of the fishing industry's catch.

Conclusions

The development of a marine industry producing marketable products from shellfish and finfish wastes can be encouraged by Sea Grant-sponsored programs, but willingness to commit private capital for plant construction and operation will depend not only upon results obtained from the semi-works plant operation, but upon external economic forces surrounding product development.

Competing uses for fish and shellfish wastes in the animal feed and fertilizer industries could restrict raw material acquisition; current FDA restrictions on FPC for human consumption mitigate against economical production of high grade fish protein concentrate, and, even were such restrictions relaxed, transforming much of the world's dire protein need into economic demand remains to be accomplished. While recognizing these limiting factors, however, tangible benefits accruing to Sea Grant's involvement in TUC/chitosan have been identified:

-Essential information on production costs and potential markets for chitin/chitosan and FPC to be gleaned from operation of the semi-works production plant.

-At least a one-year lead time on development of a new marine industry accomplished with only a modest outlay of Sea Grant funds.

-Worldwide distribution of chitin/chitosan samples to interested researchers through Sea Grant sponsorship.

-Researchers from diverse disciplines cooperating in the TUC/chitosan program, resulting in nine completed or forthcoming Ph.D. dissertations and numerous technical publications.

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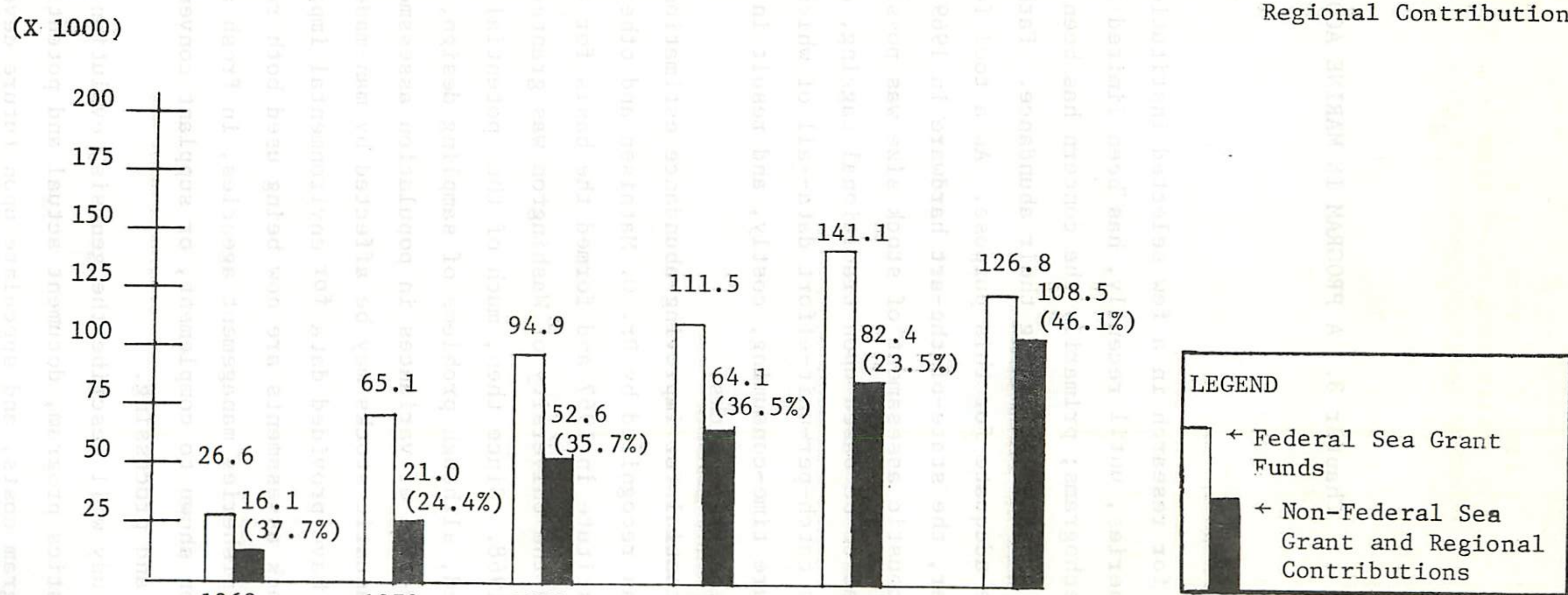
	1969	1970	1971	1972	1973	1974
UTILIZATION OF MARINE POLYMERS	13,900 7,000	36,300 19,500	49,900 21,100	52,300 21,800	53,800 33,600	53,800* 21,600**
TOTAL UTILIZATION CONCEPT	12,700 9,100	28,800 1,500	45,000 31,500	47,200 21,300	61,000 27,800	61,000* 29,600**
UTILIZATION OF EXOSKELETONS	----	----	----	12,000 21,000	26,300 21,000	12,000* 57,300**

*Federal Sea Grant Funds
**Non-Federal Sea Grant and Regional Contributions



ANNUAL BUDGETS FOR TUC AND RELATED PROJECTS

APPENDIX 2-A

Chapter 3. A PROGRAM IN MARINE ACOUSTICS

Introduction

Except for research in a few selected institutions, the use of acoustic gear in fisheries, until recently, has been limited to qualitative inferences drawn from echograms; primarily the concern has been for locating pelagic fish schools and grossly estimating their abundance. Fathometers aboard fishing vessels were adequate for this purpose. As a tool for aquatic stock management, however, the state-of-the-art hardware in 1969 was inadequate; no accurate, acoustic assessment of stock size was possible and management decisions had to be based upon traditional tagging, direct-capture methods, or fisheries catch-per-unit-effort data--all of which are subject to wide variances, are time-consuming, costly, and result in mortality or behavioral changes in the fish stocks.

The potential for improving abundance estimation through underwater acoustics was recognized by Dr. O. Mathisen and others at the Fisheries Research Institute in 1967 and formed the basis for the original Sea Grant program when the University of Washington was granted Sea Grant Institutional Support in 1968. Since then, much of the potential for marine acoustics has been realized, although problems of sampling design, species identification, and further reduction of variances in population assessments yet remain to be solved.

Where aquatic stocks may be affected by man-made structures, acoustic assessments have provided data for environmental impacts studies. Rapid, low-cost stock assessments are now being used both routinely and experimentally by regional fisheries management agencies, in fresh and salt-water habitats and have been shown to complement, or supplant conventional methods of data acquisition and processing.

This study will describe the genesis, evolution, and maturation of the marine acoustics program, document actual and potential benefits accruing, analyze program costs, and speculate upon future development.

Genesis

The Marine Acoustics Program of Washington Sea Grant had its genesis in a 1967 proposal for Sea Grant Institutional Support. It was recognized that the potential for underwater acoustics in marine resources management could be realized by developing coherence among a number of extant research groups on the University of Washington campus. They were:

A. Applied Physics Laboratory.

B. Fisheries Research Institute, College of Fisheries.

C. Electrical Engineering Department, College of Engineering.

D. Department of Oceanography.

E. Division of Marine Resources.

A. Applied Physics Laboratory

APL, by virtue of its research and development work for the Ordnance Systems Command, U.S. Navy, possessed capabilities in both theoretical research and hardware development in underwater acoustics. Since the entire facility was classified, direct involvement with other, nonclassified departments was tightly constrained by security requirements. Partly because of student activism in the late 1960s, the facility has now become more openly involved in joint ventures with other University departments and programs for peaceful applications of hitherto almost exclusively military technology and development of new technology.[1]

B. Fisheries Research Institute

Aquatic stock management has been a principal concern of fisheries researchers. Rapid, accurate assessment of fish population and identification of species by acoustic method would complement or supplant existing net-haul, tagging, and catch-per-unit-effort data gathering methods, would assist in understanding fish population dynamics, and, hopefully, lead to more effective fisheries management decisions.

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[1]The Ocean Engineering Research Laboratory now resides in APL.

Fisheries experts could provide important information on fish behavior to be used in acoustic survey design and estimation techniques, and furthermore, become the recipients of empirical research findings. FRI's prior relationships with fisheries management agencies--Washington State Department of Fisheries, Bureau of Commercial Fisheries (National Marine Fisheries Service), and others--could provide "clients" for field-testing acoustic assessment technology. The College of Fisheries' research vessel--RV COMMANDO-- would be available for shipboard data gathering.

C. Department of Oceanography

Oceanographers at the University of Washington have had a two-pronged set of applications for underwater acoustics: geophysical investigations of the ocean floor and continental shelves and biological sampling of marine organisms. The latter application had more commonality with those of other departments described in this section.

In addition to field studies involving acoustic matters, the department has offered an upper division course in underwater acoustics and seismic techniques in geological oceanography.

The oceanographic research vessels - RV's HOH and ONAR - would also be available.

D. College of Engineering

At the core of underwater acoustic techniques are the electronic systems necessary to transmit, receive, and process acoustic signals. Faculty of the Department of Electrical Engineering had served as consultants in the application of theoretical work in communications theory to underwater acoustic problems and in the design of acoustic equipment.

E. Division of Marine Resources

Charged with coordinating the University of Washington's efforts in marine resources exploitation, the Division had become the focus of information concerning interdisciplinary research and education in marine-related fields. Thus, an existing system of contacts was available to integrate the efforts of departments and institutes having underwater acoustic interests and capabilities.

In addition to DMR's coordinating role, the Division's director had been previously head of the acoustics program at APL; therefore, both management expertise and technical knowledge resided at the top administrative level of DMR and the choice of this division for marine acoustics program management was fortuitous and obvious.

Program Development

A. Problem Definition

The problem of acoustically locating schools of pelagic fish is relatively simple: a fathometer, normally used for measuring water depth below a vessel's hull, transmits acoustic signals and receives echoes from the ocean floor, lake bed, or from any underwater object whose size, shape, and density will permit reflection of acoustic signals. These reflected signals appear as "blips" on a cathode ray tube, or recording chart paper. From the appearance of the displayed echoes an experienced eye can determine the presence of a fish school, its approximate magnitude and, with sufficient foreknowledge of the area, perhaps identify the species involved. Fathometers are used routinely in this way by commercial fishing vessels.

The problem of acoustically assessing pelagic fish stocks is vastly more complex, requiring more sophisticated hardware, carefully designed surveys, and data processing techniques.

By 1968 a variety of echo-sounding devices had been developed, but not extensively applied in acoustic abundance estimation. The Simrad Company of Norway had developed, for example, an echo integrator. Echo counters, which had been develped elsewhere,aggregate the total number of individual echoes received through time, yielding an actual count of fish within the equipment's range and the vessel's track. Where fish densities are high and echoes overlap, the echo counter loses accuracy. In such situations, an echo integrator should be used. Here, the returning echo signals are integrated (summed) through time and, if the strength of the average fish echo is known, the number of fish can be ascertained.

B. Initial Hardware Development and Testing

Sea Grant-supported researchers, in March, 1968, had hoped to purchase the SIMRAD echo integrator, but it was commercially unavailable. Instead, an engineering program was initiated to design and fabricate an echo counter and an echo integrator for use with the SIMRAD H2E echo sounder. A graduate student in the Electrical Engineering Department completed the project as a Master's Thesis (Lahore, 1969).

Preliminary testing of the equipment was conducted as part of a Ph.D. dissertation (Thorne, 1970) by Fisheries Research Institute researchers aboard the RV COMMANDO during 1968 and 1969. The objective was to compare integrated output with other measures of fish densities. Simultaneous acoustic and midwater trawl net-haul data were acquired and subsequent analyses showed close correlation between integration rate and catch. Population assessments of hake in Puget Sound and juvenile sockeye salmon in Lake Washington (Thorne and Woodey, 1970) were supported by WSDF funds, demonstrating early recognition of the potential for acoustic assessment techniques in aquatic stock management.

The echo integrator was used by BCF aboard the RV COBB during a U.S.-Soviet acoustic survey of the Pacific during the summer of 1969. The estimates obtained by each nation independently were very similar.

The prototype employed a depth-gate circuit which enabled echo counting and integration to be performed within one pre-established depth interval, conforming closely to the volume of water swept by a sampling trawl net. Several shortcomings in the analog prototype equipment were identified: the dynamic range of the analog circuitory was insufficient; the system exhibited instability and required frequent recalibration; and the equipment was limited to real-time data processing. To overcome these deficiencies, it was proposed to develop a Digital Data Acquisition and Processing System (DDAPS).

C. Theoretical Studies

Concurrent theoretical studies were conducted by researchers from the Department of Electrical Engineering and the Applied Physics Laboratory to gain an understanding of the statistical characteristics of acoustic stock assessment systems. Both analytic and Monte Carlo simulation models of acoustic signal processing techniques were developed in order to understand sources of variance in acoustically derived population estimates. Comparisons of echo integration and echo counting techniques were achieved and are described elsewhere (Ehrenberg 1971; Moose, 1971; Ehrenberg and Lytle, 1972; Ehrenberg, 1973).

D. Digital Data Acquisition and Processing System (DDAPS)

Concurrent efforts were initiated at APL late in 1970 in hardware modification and computer program development for automatic acoustic data processing, for which NMFS contributed partial funding. While a complete technical description of the DDAPS system is beyond the scope of this paper,[1] several salient features should be identified.

The DDAPS is designed around a general purpose computer, the PDP/8L, 4K memory, manufactured by Digital Equipment Corporation. Data input is provided by one or two echo sounders. A time-varied-gain circuit corrects for signal strength decay due to depth and a calibration signal, introduced at the transducer terminals, eliminates errors due to equipment instability.

E. A Portable Analog Data Acquisition System

Where surveys are to be conducted in areas unsuitable for large vessel operation, a portable data acquisition system, deployed from a small boat, appeared to have great utility. Such a system was constructed (Thorne and Green, Unpubl.)[2], financed partly by funds from the Alaska Department of Fish and Game.

Using a towed transducer, the system consists of an echo sounder and recorder interfaced to an analog magnetic tape recorder. It is monitored by an oscilloscope and the whole package powered by a 12-volt battery and invertor. Successful surveys have been performed using this system from 16-foot outboard boats. Since the transducer is towed, repair and maintenance can be accomplished without dry-docking - an advantage over hull-mounted transducers used on larger vessels. No data processing is performed in real time; instead, the magnetic tape recording is digitally processed in the laboratory using the DDAPS system.

F. Current Status

As a result of four years' effort in both theoretical and applied research, the DDAPS system exceeds the capabilities of currently available commercial devices.

The SIMRAD Company, for example, has recently marketed the QM Integrator, a two-channel analog echo integrator. By contrast, the DDAPS has the processing power of 10 QM Integrators with much greater precision and the advantage of operating in either real-time aboard a large vessel, or in the laboratory using magnetic tape analog input acquired from the portable analog system. A single modified DDAPS is being produced commercially for the Canadian Department of

[1] See Moose, Ehrenberg, and Green (1971)

[2] 1971 Research in Fisheries, University of Washington College of Fisheries, Cont. No. 355, pp. 11-12.

Environment at a price of approximately $18,000.[1] The QM Integrator, by contrast, is priced at $30,000.

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[1]An electrical engineer who had collaborated in the development of the original DDAPS served as a consultant to a small Seattle manufacturer who has produced a new DDAPS, built around the PDP-11/45 computer, utilizing completely new software and redesigned electronic circuitry. Washington Sea Grant is benefiting directly from this new technology.

Future Research and Development

Field applications of the DDAPS and the portable analog system (see next section) have demonstrated the value of acoustic assessment techniques in aquatic stock management. Future efforts will be directed at refinement of these methods toward reducing variances in fish population estimation.

A. Direct Target Strength Measurement

As mentioned in a previous section, the value of the mean target strength of a single fish must be known in order to scale the output of an echo integrator and obtain an absolute abundance estimate. The necessary scale factor can be determined by comparing the integrator output with net-haul data. Net hauls, however, have high variances and net efficiency is usually unknown. The mean target strength can also be determined acoustically. The method presently used obtains the target strength estimate indirectly from the distribution of single fish echo levels and is inaccurate for many types of fish populations, or where the number of single echoes is small. An alternative method for directly estimating the target strength of each individual fish echo using two or more acoustic transducers is presently being investigated.

B. Combination Echo Integrator-Echo Counting System

Previous analysis (Ehrenberg and Lytle, 1972) has shown that in low fish densities the variance of the estimate obtained with an echo counter is lower than that obtained with an echo integrator. In high fish densities, the reverse is true: the integrator is superior. It would be desirable, therefore, to have a processor that adapted to the population being surveyed. Theoretical analysis (Ehrenberg, 1973) has shown that such an adaptive processor would result in an estimate with a mean squared error that is a factor of six better than either the integrator or the counter at medium fish densities. Additional analysis and simulation must be performed before such a processor could be incorporated in an acoustic assessment system.

C. Species Identification

Acoustically identifying fish species is part of the ultimate goal of the Marine Acoustics Program, but the theoretical and operational problems it presents are vast. Two avenues of research are being pursued: identification of species through its "acoustic signature" and by its schooling characteristics.

D. High Density Effects

The present application of the echo integrator is based on a linear relationship between the integrator output and the spatial density of the fish. In very high fish densities, the linear relationship does not hold due to the effect of shading. Further experimental and analytical work on high density scattering is needed to determine the magnitude of this effect as a function of fish density.

Associated Non-Sea Grant Research and Development

Other R & D efforts funded by non-Sea Grant sources are proceeding within the Marine Acoustics Program at the University of Washington. Since these efforts have antecedents common to Sea Grant-sponsored research, they are considered to be associated with the Sea Grant Program.

A. Free-Floating Echo Counting System (FFECS) (APL/NMFS)

Where the migration path of returning salmon can be located with accuracy and is known to be spatially stable, a free-floating, unmanned echo-counting system has advantages over other traditional methods of abundance estimation. Simultaneous data can be obtained from multiple locations and the buoys are less susceptible to weather conditions than a manned vessel.

The FFECS consists of an upward-looking 250-KHZ transducer suspended from a free-floating buoy. Telemetry from up to six buoys can be monitored simultaneously by a multi-channel receiver and digital recorder aboard a monitoring vessel within a 15-mile range. A new, lower frequency telemetry system will increase the range to 40-60 miles.

The advantages of FFECS over manned systems enable continuous monitoring of the depth, dispersion, and abundance of migrating salmon to be accomplished under conditions which preclude purse-seining. Reliable operation has been achieved in moderately rough seas.

Four buoys were deployed successfully in 1972 and more will be deployed this year off Adak Island, Alaska.

B. Coastal Upwelling Ecosystems Analysis (Oceanography/NSF)

The Marine Acoustics group will provide technical support for this international effort to develop an understanding of processes involved in the food chain of upwelling areas. Information on fish populations will provide a vital input to understanding these dynamic processes.

An improved version of the DDAPS, utilizing the PDP 11/45 computer, will greatly expand the processing capabilities of the system, becoming operational in 1973. Shipboard operations in 1973 --MESCAL and CUE II --and in 1974-- JOINT I-- will use a towed transducer, operating in either upward- or downward-looking modes. Biomass estimates will provide information for real-time modelling programs.

Applications[1]

Since development of the first analog acoustic echo integrator, field testing and applications have received financial support from public regulatory agencies, utility companies, and private corporations. The Marine Acoustics Program has provided assistance to two principal groups of clients: first, to fisheries management agencies in the northeast Pacific and second, to public utility companies. The first group has sought more rapid and accurate stock assessments for fisheries management decisions; the second has required data on extant fish stocks subject to environmental impact from new electrical power facilities.

Field applications have provided researchers with a wide variety of fish populations. Some, like the herring in Puget Sound, are highly schooled at high densities (1-10 fish/meter^3), while others, such as the Port Susan hake, appear at intermediate densities (0.01-1.0 fish/m^3). The juvenile sockeye salmon school at low densities (0.001-0.01 fish/m^3).

Wintering herring schools in S.E. Alaska, while remaining numerically intact, exhibit significant diurnal changes in schooling density, thus offering an opportunity for empirically examining the high density effects in acoustic assessment. Subject to an intensive fishery, these stocks will be surveyed frequently during the 1973-74 season, enabling real-time stock management decisions to be made.

Each major application of the Marine Acoustics Group's technical capabilities and the consequent benefits accruing to clients in the region will be treated separately below.

A. South Puget Sound Herring Fishery: A Conflict Resolution

Herring schools in south Puget Sound provide a 500,000-pound annual harvest for the bait-fish industry. Sports fishermen groups, perceiving the commercial fishery as a threat to the stock upon which salmon feed, sought closure of the commercial herring fishery in that area. Since accurate assessments of stock size were unavailable, Washington State Department of Fisheries requested the assistance of the Marine Acoustics Group.

A rapid, low-cost acoustic assessment of the stock was initiated and the data acquired showed that only one percent of the stock was being harvested

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[1] A list of applications appears as Appendix A by permission of Martin Nelson, NMFS.

each year. Contrary to the sports fishermen's fears, the WSDF was able to demonstrate that the stocks were being adequately maintained.

Had sufficient political pressure been brought to bear upon the WSDF or the state legislature, an industry with an annual catch value of $350,000 - $500,000, dockside, might well have been shut down or curtailed.[1] Furthermore, the goodwill generated, although nonquantifiable in dollar terms, cannot be discounted; indeed, the credibility of the state fisheries' regulatory agency has been demonstrated to two important, and often conflicting, interest groups.

B. Acoustic Assessment of Sockeye Salmon

More precise methods of predicting the magnitude of salmon runs are urgently needed for accurate and efficient management. A case in point is the Lake Washington sockeye salmon run. Adult sockeye salmon returning in 1971 were overharvested by commercial fisheries in Puget Sound and Lake Washington, resulting in an escapement of only 60 percent of the number of spawning fish necessary for sustained yield. The cause of the stock management error lay in the inaccuracy of the conventional management techniques, namely tagging and spawner-recruit analysis. Dr. Richard E. Thorne of the Fisheries Research Institute estimates that it will take 12 - 16 years for the run to restabilize at 570,000 fish, resulting in an accumulated loss to the industry of about 500,000 fish.

Acoustic assessment of Lake Washington sockeye salmon presmolts was initiated in 1969 and has been conducted annually. These studies have resulted in determination of oceanic mortality rates on the stock, so that future runs can be predicted accurately from the acoustic assessment of presmolts. In addition, acoustic techniques have been developed for measuring adult salmon population size in Lake Washington prior to spawning, so that precise harvests can be made.

Had present acoustic techniques been available two years earlier, the loss due to overharvest in 1971 would have been averted. At current prices, averaging five dollars per fish, the present value of the 16-year loss would be about one and one-half million dollars.[2]

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[1] A similar dispute in Bellingham Bay was quickly resolved by acoustic assessment of herring stock.

[2] Discounted at 6 percent per annum over 16 years.

The foregoing is only speculative, but it is clear that the inaccuracy of present conventional stock management techniques is resulting in economic losses. The Lake Washington sockeye salmon run is only one stock, and 1971 only one year. The cumulative losses due to imprecise stock management tools must be staggering.

Many agencies are recognizing the potential of forecasting adult sockeye salmon runs by acoustic assessment of juvenile sockeye populations. Techniques developed by the Sea Grant Marine Acoustics Program are presently being applied on Lakes Washington, Sammamish, Quinault, Wenatchee, and Osoyoos in Washington, Lake Shuswap in British Columbia, and Lake Illiamna, Alaska.

C. Port Susan Hake Fishery[1]

A new hake fishery was established in 1965 in the Puget Sound waters. Unmarketable for human consumption, hake is utilized for animal feed and fishmeal production. An acoustic stock assessment[2] was made in Port Susan Bay, the local winter spawning ground, during February, March, and April, 1969, at the request of the Washington State Department of Fisheries. Although no precise estimate of annual, maximum sustainable yield has yet been calculated, the acoustically derived data confirm that no restrictions are yet necessary on the fishery.

Market saturation has stalled this fishery's expansion, but the acoustic assessment of the spawning stocks, performed annually at low cost (approximately $1,500 per annum), provides a useful tool for effective future management of the fishery.

D. Sports Fisheries: Lake Washington Sockeye

In the summer of 1971, NMFS, WSDF, and the Marine Acoustics Group collaborated in a sports fishing information service. Acoustic assessments of the adult sockeye population in Lake Washington were conducted at frequent intervals and the resulting information was published in map form. Location, depth, and magnitude of the schools were promulgated through the local media during June, July, and August of that year.[3]

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[1] Milliken, Allan E. "The Puget Sound Hake Fisher: Past, Present, and Future" in Technical Report No. 5, Washington State Department of Fisheries, 1970.

[2] The accuracy of the population estimate was ± 20% at the 95% confidence level.

[3] See Appendix B for sample map.

While the effects of this information upon catch-per-angler are not yet known, aerial photographs revealed a remarkable conformance between the published fish distributions and the location of anglers' boats! Not unexpectedly, the largest catches appeared around the periphery of intensive fishing areas.

The Lake Washington sockeye sports fishery is young and growing; how much impact the information had upon the number of anglers in the lake is therefore highly speculative. Nonetheless, NMFS' involvement with sports fishermen through this effort has contributed to a shift away from an exclusively commercial fisheries image persisting from BCF days.

E. Environmental Impact Studies

Two important consequences for fish habitats are produced by electrical power generation: (1) thermal effects from nuclear power plant cooling waters, and (2) alteration of the size and shape of water bodies impounded by hydroelectric plants. Two studies were performed by the Marine Acoustics Group dealing with the latter problem.

An environmental impact study of the effects on Ross Lake of raising Ross Dam (Seattle City Light) entailed estimating the abundance and distribution of trout - predominately rainbow. This was performed acoustically, using the portable analog system in 1971, and was repeated in 1972.

Concurrent tagging data provided an opportunity to compare acoustic methods with conventional methods. At the 95% confidence level there was no significant difference between the results obtained, and the confidence limits - ± 20% (acoustic), ± 22.8% (tagging) - were comparable. Furthermore, short-run (diurnal) movements of fish populations could be inferred only from the acoustic data. Tagging was, of course, necessary for species identification, species abundance, and long-run migration data.

The cost of tagging was five times that for the acoustic survey[1] and required an entire season for data acquisition. By contrast, each acoustic survey was performed in just two days, using the portable DDAPS. Subsequent laboratory data processing produced population estimates within two weeks.

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[1]Source: Fisheries Research Institute, University of Washington

During the same year, a similar study was conducted for the Chelan PUD on an area in Lake Chelan where a pumped storage plant is to be built.

An ex post acoustic assessment survey was undertaken for the Argonne National Laboratory to determine the effects of warm water effluents from the Point Beach nuclear power plant on the distribution of fish in that part of Lake Michigan.

While the effects on fishes are of obvious concern in environmental impact studies, zooplankton and micronekton, because of their more restricted mobility, may be better indicators of environmental degradation than fish which occupy higher trophic levels in the food chain. The implications of the ecology of sonic-scattering layers for environmental impact studies have been recognized and further investigations of both acoustic methods and net-sampling gear have occurred. Measurement of back-scattering volumes with a storage oscilloscope appear promising.

F. The Ecology of Sonic Scattering Layers

Researchers at the Department of Oceanography received Sea Grant support under the Marine Acoustics Program for investigating the distribution of zooplankton and midwater fishes in Puget Sound. Simultaneous acoustic data and net-haul samples were collected and stomach-content analysis of all fish species was performed. Diurnal migration of the sonic-scattering layers was investigated and preliminary results suggested that this application of underwater acoustics would be valuable in further marine ecological studies.

G. Future Applications

In addition to technical support of the CUEA effort in 1973, two new field applications of the DDAPS are planned for the current biennium: (a) an acoustic abundance estimate of sockeye smolt migration from Lake Chilko, B.C., where concurrent time-lapse photographic assessment will provide a direct and accurate (± 5%) "control" for calibration. (b) Sockeye salmon estimation in Lake Wenatchee and Lake Osoyoos.

Ongoing annual assessments will continue through 1974 and will include:

a. Port Susan hake population
b. Puget Sound herring stocks
c. S.E. Alaska wintering herring stocks
d. Lake Washington sockeye
e. Lake Iliamna sockeye

Summary of Benefits Accruing to Applications

A. Cost-Savings

Where assessment of known pelagic species abundance is sought, acoustic methods have shown to be at least equal in accuracy, more rapid and substantially cheaper to perform than conventional tagging, net-haul, and cost-per-unit effort methods. Savings range from 1/5 of tagging costs in lakes where the portable DDAPS has been used, to perhaps several hundred times the cost of oceanic net-haul surveys.

B. Unique Applications

"Our feeling is that there is no acceptable alternative to acoustic fish location for obtaining the needed information." [1]

"The alternate means of collecting the fish abundance data was (sic) *to purchase similar acoustic instruments and conduct the work ourselves...The instrumentation costs were reasonable enough but we did not have the expertise necessary to conduct the studies without outside assistance. It would have been necessary to hire such assistance if it had been available."* [2]

"... reliable data would have been most difficult to have acquired by conventional technique." [3]

"Determining abundance (of wintering herring) using traditional methods was judged not practical in Southeast Alaska... hydroacoustics was selected as a practical tool..." [4]

These comments from "clients" testify to the unique capabilities of the Marine Acoustics Program.

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[1] Correspondence from Gerald P. Romberg, Argonne National Laboratory, March 19, 1973.

[2] Correspondence from Bernie D. Leman, Chelan PUD, March 1973.

[3] Correspondence from John F. Roos, International Pacific Salmon Fisheries Commission, March 14, 1973.

[4] Correspondence from Stan Moberly, Alaska Department of Fish and Game, January 30, 1973.

C. Management Decision-Making

Rapid, low-cost acoustic assessment of fish stocks conducted at frequent intervals provides information by which harvest levels can be set and adjusted in real time. Therefore, more realistic quotas, or seasons, can be set than by methods requiring the previous season's catch data:

> *"This information (hydroacoustic assessment) . . . is used to set harvest levels (of wintering herring) . . . As a result . . . all previously fixed quotas were removed."*[1]

Any increase in harvest of wintering herring in S.E. Alaska can be directly attributed to Sea Grant's efforts in marine acoustics.

D. Scientific and Educational Benefits

Field applications provide researchers with opportunities to evaluate acoustic assessment techniques, offer field experience and training for technicians, and constitute empirical studies for advanced degree candidates.

Empirical results indicate that the pessimistic views expressed by MIT researchers (Lozow and Suomala, 1971) were unwarranted.[2]

Five Masters' theses and three Ph.D. dissertations have depended, in part, upon data gathered in the field. Numerous technical papers have been published which describe significant field applications.

Representatives of the Marine Acoustics Program presented papers at an international symposium on "Acoustic Methods in Fisheries Research" held in Bergen, Norway, in June, 1973. Experience gained by the Sea Grant program was promulgated to a wide audience of researchers, drawing broader attention to their progress, and eliciting useful feedback from the international community of fisheries experts.

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[1] Stan Moberly correspondence (op. cit.).

[2] Lozow, J., and J. Suomala, Jr. 1971. The application of hydroacoustic methods for aquatic biomass measurements--A note on echo envelope sampling and integration. MIT, Charles Stark Draper Laboratory, Cambridge, MA.

Program Cost Analysis

A. Marine Acoustics Program: Annual Budgets

Table 3-I summarizes annual expenditures on marine acoustics since 1969. Nonfederal matching funds, while showing absolute annual growth since 1970, have consistently fallen below the required threshold for the overall Sea Grant program budget (33 1/3%). This statistic reflects the heavy, early investment in theoretical analysis of signal processing, equipment design, and continuing efforts toward reduction of variances in population assessments.

Since 1970, Analysis and Design of Acoustical Systems and more recently, Technical Support (APL), have received little regional support (0 - 19%). Of the remaining projects, Evaluation of Acoustic Techniques of Resource Assessment and Estimation of Stocks of Fish by Echo Sounding reveal a more favorable response from the regional community. Combined, current nonfederal funding for these projects amounts to 43.7 percent of their budgets! Nor does this figure completely represent the projects' attraction for regional funding.

	1969			1970			1971			1972			1973		
PROJECT NAME	S.G. INPUTS $ X 1000	NON FED MATCHING $ X 1000	% NON-FEDERAL MONEY	S.G. INPUTS $ X 1000	NON FED MATCHING $ X 1000	% NON-FEDERAL MONEY	S.G. INPUTS $ X 1000	NON FED MATCHING $ X 1000	% NON-FEDERAL MONEY	S.G. INPUTS $ X 1000	NON FED MATCHING $ X 1000	% NON-FEDERAL MONEY	S.G. INPUTS $ X 1000	NON FED MATCHING $ X 1000	% NON-FEDERAL MONEY
ANALYSIS & DESIGN OF ACOUSTICAL SYSTEM	9.8	8.8	47.3	34.8	8.2	19.1	14.6	2.5	14.6	--	--	--	13.3	2.7	16.9
TECHNICAL SUPPORT	--	--	--	--	--	--	--	--	--	29.0	0.0	0.0	12.9	0.0	0.0
EVALUATION OF ACOUSTIC TECHNIQUES	--	--	--	--	--	--	8.9	5.2	36.9	4.0	9.0	75.0	13.7	16.5	54.6
ESTIMATION OF MARINE STOCKS BY ECHO SOUNDING	18.8	7.9	29.6	28.0	7.5	21.1	19.8	7.5	27.5	23.9	7.5	24.0	19.7	9.4	32.3
ECOLOGY OF SONIC SCATTERING LAYERS	9.8	7.1	42.0	25.8	4.5	14.9	27.7	2.5	8.3	19.8	2.6	11.6	--	--	--
PROGRAM MANAGEMENT	--	--	--	--	--	--	33.3	6.4	16.1	35.2	10.5	23.0	27.6	10.4	27.4
TOTAL PROGRAM[1]	38.4	28.3	46.3	88.6	20.2	18.5	109.4	24.0	18.7	111.9	29.6	20.9	87.2	39.0	30.9

[1] Errors due to rounding

Table 3-I. MARINE ACOUSTICS PROGRAM: ANNUAL BUDGETS, 1969-73

B.. Support Level Profiles

In Chapter I, I speculated upon a proposed method of evaluating the effectiveness of a Sea Grant research and development project, "Support Level Profiles." The willingness of outside parties - industry, agencies, or institutions - to commit funds for R & D or experimental applications is assumed to be an early indicator of the successful adoption of an innovation. The model presented in Figure 3-I represents a successful outcome, where non-Sea Grant expenditures have overtaken Sea Grant funding and Sea Grant support has been withdrawn. Any residual Sea Grant investment in the program would be for Advisory Services' role in maintaining information flows to and among users, or potential users.

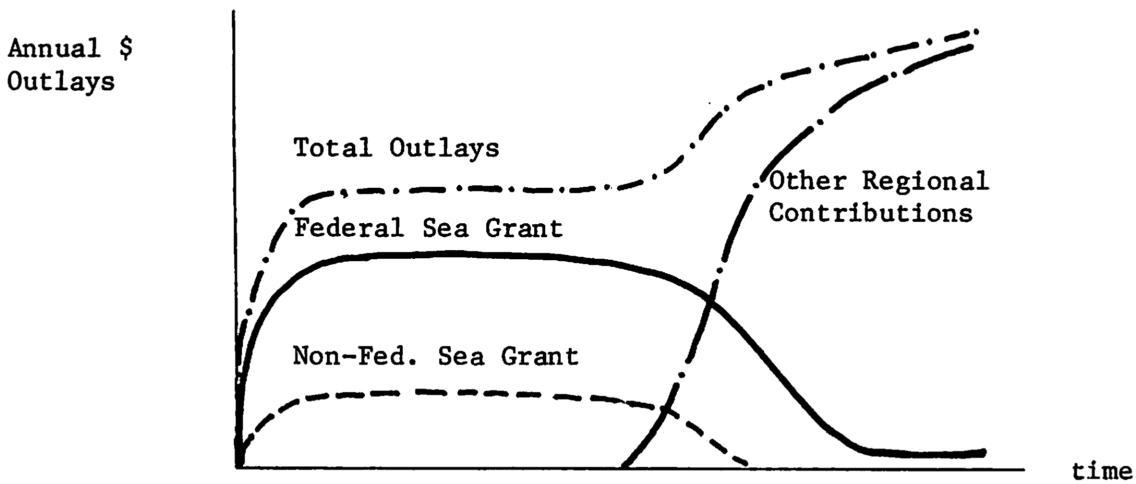

Fig. 3-I. SUPPORT LEVEL PROFILES

Substantial funding for acoustic stock abundance estimates has come from regional fisheries management agencies, public utilities, and marine industries. All such field applications are now self-sufficient; Sea Grant funding for these projects supports only the research component of field applications.

While much of the regional support is disallowed for matching purposes - because it originates in other federal agencies or fails to meet the project's explicit mission - to ignore or underestimate its importance would unfairly discredit the program. The exponential growth of regional funding, as illustrated in Figure 3-II, is an early indicator of the successful adoption of acoustic stock abundance estimating techniques.

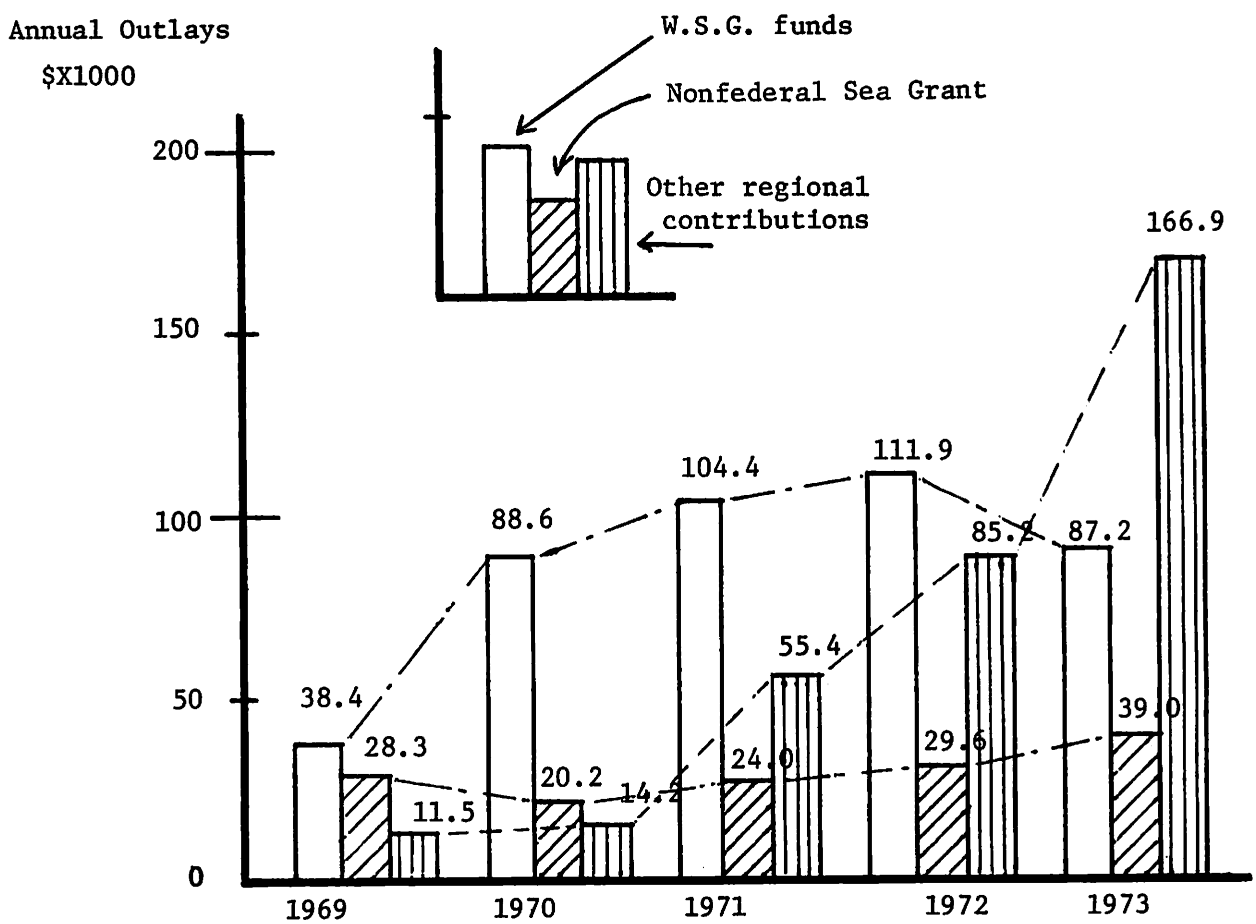

Fig. 3-II. MARINE ACOUSTICS PROGRAM: LEVELS OF SUPPORT

Table 3-II shows the distribution of "other regional contributions" by source, year, and whether direct - salaries, cash payments, etc. - or indirect - ship-time, supporting personnel, per diem, etc.

FUNDING SOURCE	1969 DIRECT	1969 INDIRECT	1970 DIRECT	1970 INDIRECT	1971 DIRECT	1971 INDIRECT	1972 DIRECT	1972 INDIRECT	1973 DIRECT	1973 INDIRECT
NMFS (BCF)	3.5	- -	8.2	- -	13.3	10.0	24.0	10.0	7.0	10.0
WSDF	- -	8.0	2.0	4.0	3.1	4.0	1.5	15.0	9.5	15.0
ADF&G	- -	- -	- -	- -	9.5	10.0	6.9	30.0	7.0	30.0
IBP (NSF)	- -	- -	- -	- -	5.0	- -	5.0	- -	5.0	- -
CHELAN P.U.D.	- -	- -	- -	- -	3.0	- -	- -	- -	- -	- -
SEATTLE CITY LIGHT	- -	- -	- -	- -	2.0	2.4	2.0	1.2	1.3	.8
KODIAK SALMON PACKERS	- -	- -	- -	- -	- -	- -	- -	- -	9.4	- -
C.U.E.A. (NSF)	- -	- -	- -	- -	- -	- -	- -	- -	100.0	- -
TOTALS	3.5	8.0	10.2	4.0	34.4	26.4	37.9	56.2	138.2	55.8
TOTALS--INDIRECT & DIRECT	- -	11.5	- -	14.2	- -	60.8	- -	94.1	- -	194.0
LESS AMOUNT USED FOR NON FEDERAL MATCHING	- -	- -	- -	- -	- -	5.4	- -	8.9	- -	27.1
TOTAL--OTHER REGIONAL CONTRIBUTIONS	- -	11.5	- -	14.2	- -	55.4	- -	85.2	- -	166.9

Table 3-II. DERIVATION OF "OTHER REGIONAL CONTRIBUTIONS"

Summary and Conclusions

Under the direction of the Division of Marine Resources, Washington Sea Grant Marine Acoustics Program has utilized the scientific resources of five separate University departments and institutes.

Concurrent theoretical research, equipment design, and testing resulted in the first operational echo-counter and analog echo integrator being applied to marine stock assessments in 1969. A digital data acquisition and processing system (DDAPS), designed to overcome serious deficiencies in analog circuitry, followed in 1971. During the same year, a portable analog data acquisition system was developed for use in lakes and inland waters. Taped data were processed later in the laboratory.

Current research efforts are being directed at methods of directly measuring fish target strength for accurate calibration of stock estimates derived from integrated echo voltages and at the problem of species identification.

Stock abundance estimates of many species have been conducted in a variety of marine habitats using DDAPS and the portable analog system.

Benefits accruing to the Marine Acoustics Program field applications are:

Substantial cost reduction over conventional methods of stock abundance estimates, with variances usually lower than traditional methods.

Unique field applications where conventional methods are unsuitable or impossible.

Real-time fisheries management decision-making resulting in more realistic harvest levels being set, with measurable economic benefits.

A successful adoption of an innovation in aquatic stock management as indicated by the exponential growth in non-Sea Grant support, from $40,000 in 1969 to $206,000 in 1973.

Finally, scientific, educational and advisory services benefits can be enumerated:

Five masters' theses and three Ph.D. dissertations have been produced by students wholly or partially supported by the Marine Acoustics Program, and numerous technical articles on marine acoustics have been published. Papers were presented by marine acoustics researchers at the International Symposium on "Acoustic Methods in Fisheries Research," held in Bergen, Norway, in June, 1973.

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APPENDIX 3-A

Table of Applications of Marine Acoustics

Stock Abundance Estimates

STOCK	LOCATION	DATES	VESSEL	ECHOSOUNDER (model/frequency)	DATA ACQUISITION AND PROCESSING EQUIPMENT AND TECHNIQUES	REFERENCES/COMMENTS
Pacific hake (spawning adults)	Puget Sound, Washington	Feb-April, 1969	RV Commando (67')(Univ Wash)	Simrad EHZE (38KHz)	Analog voltage integrator; calibrated by trawl hauls	Thorne (1970 and 1971) Thorne, Reeves, and Millikan, (1971)
"	"	Mar-April, 1970	"	Simrad EK38A (38KHz)	Analog voltage squared integrator; calibrated by hauls	Thorne, Reeves and Millikan (1971)
"	"	March 1971	RV John N. Cobb (93')(NMFS) RV Research I(23') (Wash. State Dept. Fish.)	Ross 200A(105KHz)	Portable tape recording system; analysis by DDAPS integrator program; calibration by trawl hauls	Thorne (1973, in press)
"	"	March 1972	RV John N. Cobb RV Research I	Simrad EK38A Ross 200A	(Same as for March, 1971, except analyzed effect on variance estimates of combining data from two frequencies and from an increase in the duration of trawl hauls)	Contract report to National Marine Fisheries Service
Sockeye salmon (juveniles)	Lake Washington, Washington	Feb 1969; Nov 1969	RV Commando	Simrad EH2E Simrad Partner (38KHz)	Analog integrator; calibrated by trawl hauls	Thorne (1970); Thorne and Woodey (1970)
		Monthly survey, Nov 1969 to Aug 1971; continuing on bimonthly basis	RV Commando 19' inboard/outboard (Commando used for trawl sampling)	Simrad Partner (to Feb 1970) Ross 200A	Analog integrator; calibrated by trawl hauls (to Feb 1970); portable tape recording system; analysis by DDAPS integrator program; calibration by trawl hauls and comparison with echo counting	Thorne (Unpublished MS, 1971) Dawson (1972) Thorne (Unpublished MS, 1973)
"	Lake Iliamna, Bristol Bay, Alaska	Summer 1971-72	Small outboard	Ross 200A	Portable tape recording system; analysis by DDAPS integrator program; calibration by echo counting	Results to be incorporated in graduate thesis
"	Lake Quinault, Washington	"	"	"	"	"
"	Lake Shuswap, British Columbia	"	"	"	"	Contract reports to International Pac. Salmon Fisheries Commission

STOCK	LOCATION	DATES	VESSEL	ECHOSOUNDER (model/frequency)	DATA ACQUISITION AND PROCESSING EQUIPMENT AND TECHNIQUES	REFERENCE/COMMENTS
Sockeye salmon (juveniles)	Lake Sammamish, Washington	Bimonthly since Dec 1971	Small outboard	Ross 200A	Portable tape recording system; echo counting	Results to be incorporated in graduate thesis
Primarily juvenile sockeye salmon	Lake Wenatchee, Washington	April 1972	"	"	"	Nunnallee and Mathisen (1972)
Sockeye salmon (adults)	Lake Washington, Washington	Sept 1971, June-Oct 1972	19' inboard/outboard	"	Portable tape recording system; echo counts (1971); echo counts and target strength measurements (1972)	Thorne and Dawson (paper submitted to J. Fish. Res. Bd. Can.)
Rainbow trout	Ross Lake, Washington	Various, from Sept 1970	Small outboard and tugboat	"	Portable tape recording system; echo count	Contract reports to Seattle City Light
Midwater targets	Lake Chelan, Washington	Summer 1971	Small outboard	"	Portable tape recording system; echo counting by target strength categories	Croker and Mathisen (1972)
Pacific herring	Southeast Alaska	Winter 1970-72	RV Kittiwake (80') (Alaska Dept. of Fish and Game)	"	Portable tape recording system, analyzed by oscilloscope amplitude measurements and by DDAPS integrator program; calibrated by target strength measurements	Contract reports to Alaska Dept. of Fish and Game
"	Puget Sound, Washington	Various, 1971-72	RV Commando RV Research I	"	Portable tape recording system; analysis by DDAPS integrator program; calibrated by trawl	Contract reports to Washington State Dept. of Fisheries

APPENDIX 3-B

Correspondence from W.S.D.F. Regarding Lake Washington Juvenile Sockeye Sports Fishery; Sample Press Release and Salmon Location Map

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THOR C. TOLLEFSON
DIRECTOR

February 15, 1973

Dr. Stanley Murphy, Director
University of Washington
Sea-Grant
3716 Brooklyn Avenue NE
Seattle, Washington 98115

Dear Dr. Murphy:

It has only recently occurred to us that you may be interested in our reactions to the acoustical survey program conducted last summer on Lake Washington as a service to sockeye salmon anglers. We believe that this cooperative program, involving the National Marine Fisheries Service, Sea-Grant, the University of Washington's Fisheries Research Institute, and our Department, was a complete success. Furthermore, we hope that this effort can be a forerunner of a program expanded to our marine waters that would utilize acoustical surveys, test fishing, and other methods to increase the recreational yield of our local waters.

Drs. Richard Thompson and Richard E. Thorne did an excellent job of collecting and disseminating the Lake Washington data, and their techniques and innovations could be used to good advantage in future surveys.

We are enclosing our Information Booklet No. 2 outlining our salmon angling enhancement program for the Puget Sound region. On page 21 of the booklet is a passage that may interest you, relating to the "fish-finder" concept.

On our own behalf, and that of Lake Washington anglers, we thank you for your participation in the program.

Sincerely,

Thor C. Tollefson
Director

Enclosure — Filed

cc: Dr. Richard Thompson
Dr. Richard E. Thorne
Dr. Dayton L. Alverson

Sockeye Survey

UNIVERSITY OF WASHINGTON
College of Fisheries
Fisheries Research Institute

WASHINGTON
Department of
FISHERIES

National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
NORTHWEST FISHERIES CENTER

FOR IMMEDIATE RELEASE:

Source: Dr. Dayton L. Alverson, Director
Northwest Fisheries Center
National Marine Fisheries Service
NOAA
2725 Montlake Boulevard East
Seattle, Washington 98112
Telephone: 442-4760

LAKE WASHINGTON SOCKEYE SURVEY--JULY 5, 1972

Numbers and concentrations of sockeye salmon are increasing in the south end of Lake Washington--but not quite as fast as the numbers of fishing boats.

The acoustical survey of July 5, 1972, found about twice as many fish in the south end of the lake as the previous week. The points of concentration continue to move further south towards the mouth of the Cedar River. The heaviest densities of fish yet found were directly south of South Point on Mercer Island, from about 500 yards to 1,000 yards offshore. Secondary concentrations were found along the southwestern shore of Mercer Island from 100 to 500 yards offshore and in a band extending from Atlantic City southeasterly along the Rainier Beach shoreline from 500 to 800 yards offshore. Depths in these areas are from 100 to 120 feet.

-----More----

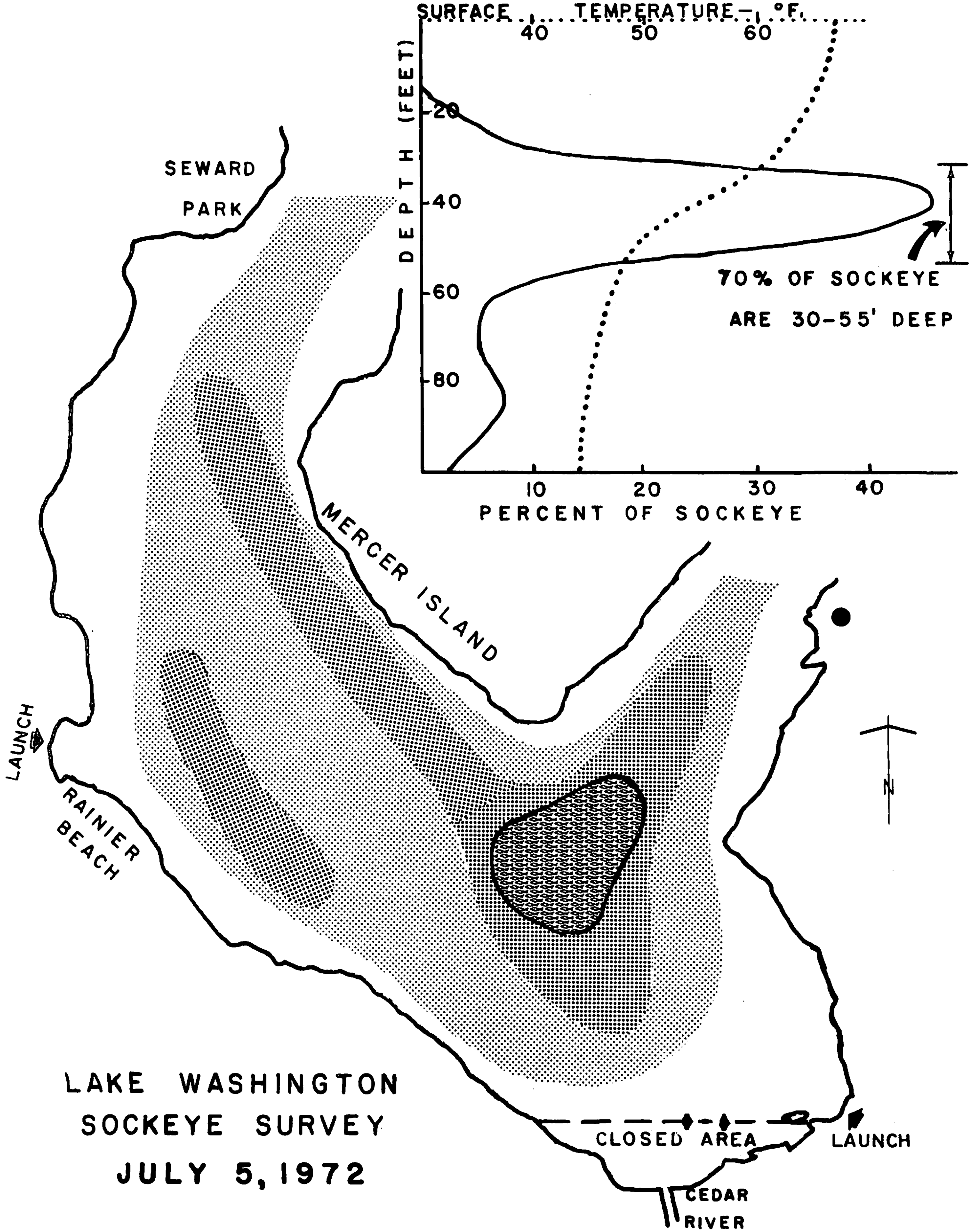
Sockeye salmon were found at shallower depths than the previous week. Most fish were at the 40-foot level. Over 70% of all sockeye detected were between 30 and 55 feet. A weak secondary abundance occurred at 85 feet, but these targets were less than 10% of the total.

The Washington Department of Fisheries reports that an estimated 96,000 sockeye salmon have moved through the Ballard Locks as of July 5. These fish will gradually congregate in the southern portion of the lake, taking from two to six days to reach there. They will then await sexual maturation and the fall cooling of the waters of the lake and the Cedar River before moving into the river to spawn ... if not taken in the meantime by lucky and/or skillful anglers.

On Saturday, July 1, over 600 boats were on the lake at 7 AM after sockeye salmon, although catch rates were about one fish for every 10 anglers. Department of Fisheries' creel checks on July 4 found this ratio to increase to about one fish for every five anglers. During Wednesday morning's survey, 75 boats were on the lake at 5:30 AM and 105 at 8:30. Three boats containing 8 anglers were contacted on Wednesday; they had a total of seven large, bright sockeye salmon. These anglers were all fishing in the area south of Mercer Island that was found by the sonar gear to contain the highest numbers of fish.

The next survey will be on Wednesday, July 12, 1972.

For further information, contact: Dr. Richard B. Thompson
Northwest Fisheries Center
National Marine Fisheries Service
National Oceanic and Atmospheric Admin.
2725 Montlake Boulevard East
Seattle, Washington 98112
Telephone: 442-5327; 442-4445.



LAKE WASHINGTON
SOCKEYE SURVEY
JULY 5, 1972

Chapter 4. AQUACULTURE OF MARINE ALGAE

Introduction

Now entering its fourth year of operation, Washington Sea Grant's "Aquaculture of Marine Algae" Project is emerging as a successful venture.

**Fundamental knowledge has been gained about two species of macro-algae (seaweed) - Iridaea and Gigartina - necessary for development of a regional seaweed industry.*

**Cooperative arrangements among several entities, representing a vertical section through the seaweed production system have been developed.*

**Field trials of innovative culturing techniques are under way, and promising relationships with pen-reared salmon aquaculture operations are being explored.*

**Information and samples of marine algae are shared with other Sea Grant supported research projects.*

**In addition to their seaweed investigations, project investigators have cultured other polymer-producing microalgae, on a laboratory scale, for analysis by other researchers of marketable polymers and their products.*

This report will document the project's progress to date and identify the relationships developed among researchers, industries, regulatory agencies and other developmental projects. Monetary benefits are dependent upon further research and field trials, and upon public and private sector capital investments, sea-use conflicts resolution and market-feasibility studies.

Seaweed Aquaculture: Products

While there is little cultural preference for seaweed as food in the U.S., seaweed byproducts have important industrial applications. Of the numerous polymers produced by marine algae, carrageenan has the most obvious commercial value. Used in the food processing industry, as a thickening agent for ice cream, fillings, instant desserts and dressings, and in other industries for sprays, paints, stains, cosmetics and pharmaceuticals, carrageenan has consistently commanded the highest price among substitutable vegetable gums and gels, with the exception of agar.[1]

Since there is an established and growing market for carrageenan, Washington Sea Grant's algal-aquaculture project has concentrated its macro-algae investigations on two species of red algae, native to the northeast Pacific and Puget Sound -- Iridaea cordata and Gigartina exasperata -- which produce high yields of this polymer.

Regional Ventures

Naturally occurring stands of Iridaea and Gigartina have been harvested by the Lummi Indian tribe in Western Washington, and the dried, carrageenan-rich plants sold to Marine Colloids, Inc., the nation's largest commercial producer of seaweed byproducts. NMFS has been exploring commercial production of an edible seaweed - Porphyra - for the local Japanese-American markets. Nori (edible processed Porphyra) represents a large regional market and possibly an export market in the orient, as increasing demand and deteriorating marine environmental conditions exhaust local supplies in Japan. Experimental aquaculture of Porphyra species native to Japan has not occurred in Washington waters, since the impact of foreign species upon local marine ecosystems is unknown, but there are at least 16 native species of Porphyra in Washington waters, and the commercial value of these remains to be explored.

Washington State Department of Natural Resources (DNR), the manager of all state-owned lands and waters, has been investigating for two years the potential of seaweed farming in Puget Sound. The recent addition of an algologist to their staff promises to accelerate this effort. Washington Sea Grant's algal aquaculture project is involved intimately with the regional efforts; flows of information and algae samples are maintained among all the entities conducting algal aquaculture research and marketing studies.

---

[1] Ffrench, R. A., The Irish Moss Industry, Current Appraisal, Nov., 1970. Department of Fisheries and Forestry, Ottawa, Canada, February, 1971, pp. 65 and 154, n. 9.

Program Coherence

Consistent with Sea Grant's commitment to interdisciplinarity, relationships between algal aquaculture and other related projects have been fostered. Industry, represented by Marine Colloids, Inc. and, more recently, General Mills Chemicals, has been provided samples of both micro- and macroalgae, which they have assayed, at no cost, for marketable products. Their determination of yields and quality of carrageenan from plants of varying ages sampled and cultivated at different locations has provided researchers with important data on the environmental parameters for optimum aquaculture site selection. Naturally, the potential mass-culturing of seaweed in United States waters would provide the industry with new domestic sources of high-yield plants, and cooperation at this stage of research is to their long-run advantage. Industry representatives also can provide the best overall information on the latest work of other researchers engaged in similar projects at domestic and overseas laboratories.

Other Sea Grant researchers at the College of Forest Resources, University of Washington, in cooperation with the Department of Chemistry, University of Puget Sound, are extracting and characterizing polymers derived from marine microalgae supplied to them by algal aquaculture researchers and others in the University. This project--"Utilization of Marine Polymers"-- assisted in the development of chitosan, a polysaccharide derived from the chitin shells of crab and shrimp.

"Improved Invertebrate Aquaculture," a project centered in the Fisheries Research Institute, exploring the use of algae as feed in oyster aquaculture, receives samples of microalgae cultured by the algal aquaculturists. Through this relationship new potential sources of algal feed are identified and tested.

The breadth and applicability of this project's findings are enhanced by the inclusion of two public agencies -- Washington State Department of Natural Resources and National Marine Fisheries Service--whose roles have already been defined. In addition, the Washington Seaweed Council , a community of individuals with seaweed aquaculture interests, serves as a forum and clearinghouse for information on the latest research findings.

Fundamental Knowledge Requirements

Before a large-scale algal aquaculture industry can develop in Washington State waters, uncertainty and risk must be minimized for the potential producer. Accurate information concerning the biological, environmental, technological and institutional aspects of seaweed farming must first be obtained before economic analyses can be undertaken.

A. Biological Research

1. Reproduction, Propagation and Development Studies:

Successful cultivation of seaweed will depend upon the application of basic biological knowledge of processes involved in the life history of the plants. Both Iridaea and Gigartina produce large annual "blades" from perennial crustose basal sections. Spores are released from the blade upon reaching maturity, and it is these spores which are deposited on, or inoculated into, artificial substrates for propagating new plants.

Growth, maturation and degeneration of blades continue to be investigated, and mechanisms for delaying fertility and controlling the carrageenan content of the blades are being explored. If successful, higher yields of carrageenan-rich blades might become possible, with obvious economic benefits to the aquaculturists. Conversely, inducing fertility in the blades could produce spores for artificial propagation "on demand."

Researchers are also investigating the possibility of propagating new plants from blade segments cut from high-yield parent stocks.

2. Growth and Yield Patterns:

Laboratory-cultured seaweed growth rates have been monitored under varying ambient light and temperature conditions, and results obtained have enabled optimal depth-placement of plants growing on artificial substrates. Field studies, conducted in naturally occurring beds of Iridaea and Gigartina, are yielding information about these and other physical parameters essential for optimum growth - currents, turbidity, and water quality - which will enable suitable sites for seaweed aquaculture to be chosen in areas where there are no naturally occurring seaweed beds.

Using tissue cultures of a close relative of Gigartina under sterile lab conditions, researchers will investigate the mechanisms by which carrageenan is produced in the plant and possibly released into the culture medium itself. Studies of the life history of Iridaea reveal that of the two large types of plants (sexual and asexual), the sexual plant produces a higher quality carrageenan.

3. Ecological Studies:

Successful "crop management" in seaweed aquaculture will require an understanding of the ecosystem within which Gigartina and Iridaea function. Simulated and natural field studies of predation, grazing and types and effects of pathogens in the microhabitat will be conducted.

4. Colonization and Maintenance Studies:

Efficient seaweed culturing and harvesting depends upon successful deployment of artificial substrates. For this purpose, the Japanese "Nori" industry uses nets which can be retrieved easily and passed through a harvesting machine, in which the blades are removed in situ. The nets are then returned to their marine habitat and a new growth of blades regenerates from the intact "holdfasts."

Researchers at the University of Washington are experimenting with plants inoculated into substrates of nylon and polypropylene rope, hung from floats, and free-growing plants held in vats at the NMFS Manchester facility. Information gained is shared with the DNR researchers, where aquarium-scale and tank-scale studies, using spooled rope substrates are underway. In 1974 DNR expects to scale up to a pilot project. One mile of rope, on which nursery plants have been grown from spores, will be transplanted from tank to open waters in southern Puget Sound.

The experience gained from the Lummi Indian seaweed program and from recent experiments by U. of W. researchers shows that artificial substrates can be colonized in naturally occurring beds of Gigartina and Iridaea. Should this experience be routinely repeatable, laboratory colonization of substrates would become unnecessary. Substrates colonized naturally could be transplanted to other suitable locations where natural beds do not occur.

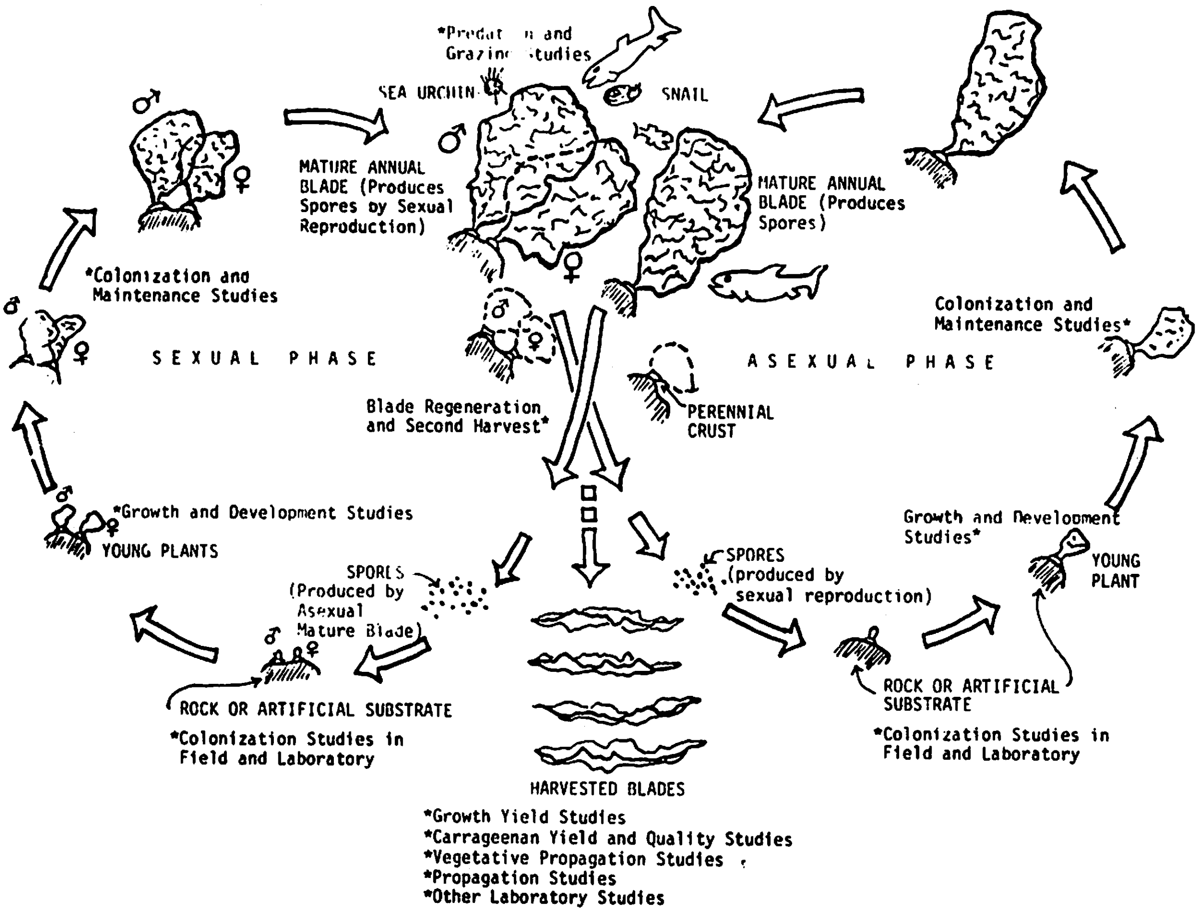


Fig. 4-I. DIAGRAMMATIC SUMMARY OF LIFE HISTORY AND CURRENT RESEARCH ACTIVITIES: *Iridaea cordata* and *Gigartina exasperata*.

Figure I summarizes the life history and current research activities being conducted on I. cordata and G. exasperata; Table I, below, lists in detail the distribution of these activities among the participating institutions, agencies and industries.

B. Institutional/Legal Considerations

While much of the knowledge concerning the biological feasibility of, and environmental parameters for, seaweed farming has been acquired, such an industry is unlikely to develop until use-conflicts in Puget Sound waters have been resolved. Washington State Department of Natural Resources is in the process of inventorying suitable sites, based on oceanographic data.

	Univ. of Wash.	Dept. of Nat. Res.	NMFS	Industry
A. RESEARCH ACTIVITIES				
<u>Basic Biology and Ecology</u>				
Systematics	*			
Life histories	*			
Reproductive cycles	*	0		
Spore release, dispersal, attachment germination	*	*		
Interactions with plants and animals	*			
Effects of harvesting on *Iridaea*	*			
Geographical distribution and abundance of seaweed resources in Puget Sound	0	*		
Morphology	*			
Relation to environmental parameters	*			
Races or strains of *Iridaea* (geographical, physical, genetic)	*	0		
Carrageenan analysis	*			0
Role of carrageenan in algal/animal biology	*			
B. SEAWEED FARMING ACTIVITIES				
Substrate setting — research	*	0		
Substrate setting — pilot	0	*		
Seaweed growth — research	*	0		
Seaweed growth — pilot	0	*		
Substrate/structures engineering	0	*		
Culture/harvesting techniques	0	*		
Market research		*		0
Aquaculture site selection — socio/legal		*		
Aquaculture site selection — biological	0	*		
Economic analysis		*	0	0
New species development	0	*	0	
Disease	*	0		
Crop depredation	0	*		
Product development	0	*	0	0

Legend: * - Lead investigators
0 - Cooperative investigators

Table 4-I. SEAWEED AQUACULTURE ACTIVITIES AND PARTICIPATING INSTITUTIONS

But before DNR can develop aquaculture sites (or lease them to private parties), they must first satisfy the requirements of the Shorelines Management Act and acquire a use-permit from the U.S. Army Corps of Engineers.

In its guidelines for permissible aquaculture in Washington State waters, the Department of Ecology states:

Aquaculture

(WAC 173-16-060(2))

Aquaculture (popularly known as fish farming) is the culture or farming of food fish, shellfish, or other aquatic plants and animals. Potential locations for aquacultural enterprises are relatively restricted due to specific requirements for water quality, temperature, flows, oxygen content, and, in marine waters, salinity. The technology associated with present-day aquaculture is still in its formative stages and experimental. Guidelines for aquaculture should therefore recognize the necessity for some latitude in the development of this emerging economic water use as well as its potential impact on existing uses and natural systems. Guidelines:

(a) Aquacultural enterprises should be located in areas where the navigational access of upland owners and commercial traffic is not significantly restricted.

(b) Recognition should be given to the possible detrimental impact aquacultural development might have on the visual access of upland owners and on the general aesthetic quality of the shoreline area.

(c)As aquaculture technology expands with increasing knowledge and experience, emphasis should be placed on underwater structures which do not interfere with navigation or impair the aesthetic quality of Washington shorelines. (emphasis added)

Seaweed aquaculture, using artificial substrates set at optimum depth, would generate conflicts with, and be sensitive to conflicts from, other uses. Fishing, navigation of deep-draft vessels and some recreational uses would be curtailed; seaweed farms would in turn, be sensitive to propeller eddies, fishing gear and any polluting use on the same site.

Trade-offs among competing uses, within the context of the Shorelines Management Act, would have to be made in the legal/political arena and, at this time we can only speculate upon the outcome.

Institutional mechanisms which appear promising are: harvesting contracts on state-owned seaweed farms, similar to current forestry management practices; leases of state-owned land to private parties, where payments would reflect the public uses withdrawn by seaweed aquaculture - the social opportunity cost.

While the guidelines appear to be permissive for the development of aquaculture, seaweed farming on a large scale in Puget Sound will require the resolution of these limiting, institutional constraints.

Economic Prospects for Seaweed Farming

An unpublished, preliminary study about the economic aspects of seaweed farming suggests a favorable financial outcome for the algal aquaculturist.[1] Current prices for I. cordata are available in the London International Seaweed Exchange, Market Intelligence Report and form the basis for Hruby's income data.

An elegant economic study of the "Irish Moss" industry in the Canadian maritime provinces provides further insights into seaweed-gathering economics. Irish moss is not being commercially cultivated in Canadian waters but, rather, it is gathered by fishermen during off-season, providing supplementary income. Nonetheless, valuable information is presented on the market facing producers - or gatherers - who are in turn a set of intermediate producers selling to final producers in the processed foods and pharmaceuticals industries. Marine Colloids Inc. was demonstrated to be the undisputed price leader in a market characterized by few buyers (oligopsonistic). Presumably a producer in Washington State would face a similar market for I. cordata and G. exasperata.

Two levels of activity are possible for seaweed farming in Washington State. First, harvesting and drying seaweed grown on state-owned subtidal lease-lands for sale to the intermediate producer - as in the Irish Moss model. Second, harvesting, drying and extracting carrageenan for sale to the final producer, thus eliminating the intermediate producer and the oligopsonistic market.[2]

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[1] Hruby, Tom: "Farming of Seaweeds," reproduced in part as Appendix 4.

[2] Ffrench, R. A.: The Irish Moss Industry, op. cit.

Ffrench concludes that an extraction firm, to be viable, must have annual sales of $2 million or more. Assuming a wet-weight carrageenan content of 5% and a price of $1.75 per pound for carrageenan, then the quantity of seaweed to be processed locally would be 22.8 million pounds wet, or 2.8 million pounds dry. According to Hruby's calculations, this quantity of seaweed could be produced on less than 200 acres of subtidal lands. Rhuby concludes that returns of up to $5,000 per acre would accrue to the seaweed producer in Puget Sound; but in the absence of carefully documented cost figures, this figure must be considered tentative.

Washington Sea Grant's algal aquaculture project will provide information essential to the development of such an industry. First, an experimental manual for algal aquaculture will be published at the conclusion of the project. This will contain guidelines and procedures for growing and harvesting *Iridaea cordata* and *Gigartina exasperata* commercially. Second, the close liaison maintained with the Washington State Department of Natural Resources will continue to enhance the prospects for demonstration algal aquaculture projects in Puget Sound, leading to either public or private sector development of commercial seaweed farming. Third, cooperative relationships with two large buyers - Marine Colloids and General Mills Chemicals - provide vertical linkages between potential producers and markets.

Budget Analysis

Table II, below, lists annual budgets for Aquaculture of Marine Algae. Figure II summarizes them.

"Other contributions" of $2,000 for FY 1973 and 74 are the value of equipment and space provided by NMFS, Manchester facilities: boats, sea-water hatchery systems, floating pens and nets. This sum is disallowed for matching purposes.

	1971	1972	1973	1974
Sea Grant ($1,000)	35.0	36.8	33.1	40.6
Non-Sea Grant matching	4.0*	8.0*	4.0*	4.0*
	8.4**	8.9**	10.1**	12.3**
				4.0***
TOTAL	47.4	53.7	47.2	60.9

***Marine Colloids, Incorporated**

****University of Washington**

*****General Mills Chemicals**

Table 4-II. AQUACULTURE OF MARINE ALGAE: ANNUAL PROGRAM OUTLAYS, 1971-74

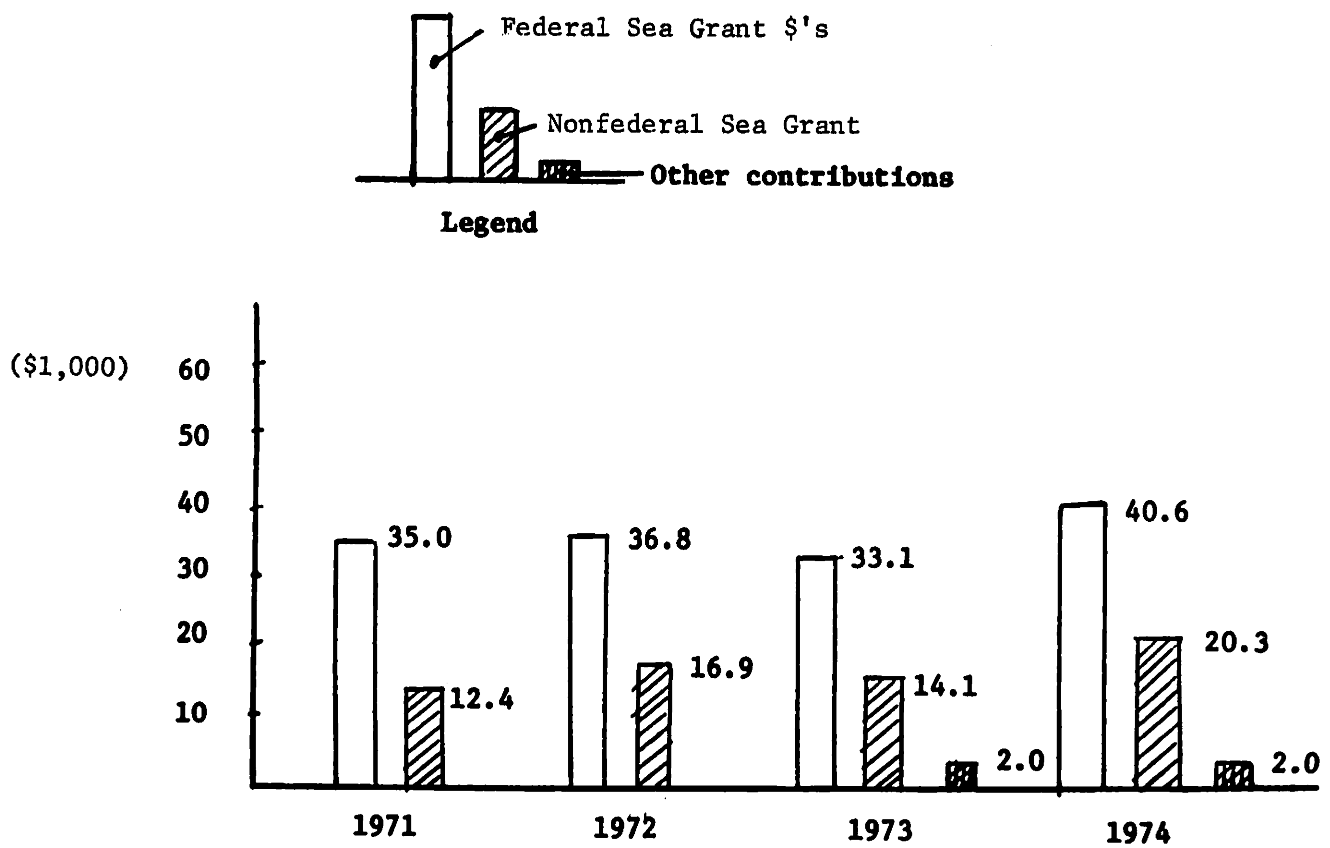

Fig. 4-II. LEVELS OF SUPPORT

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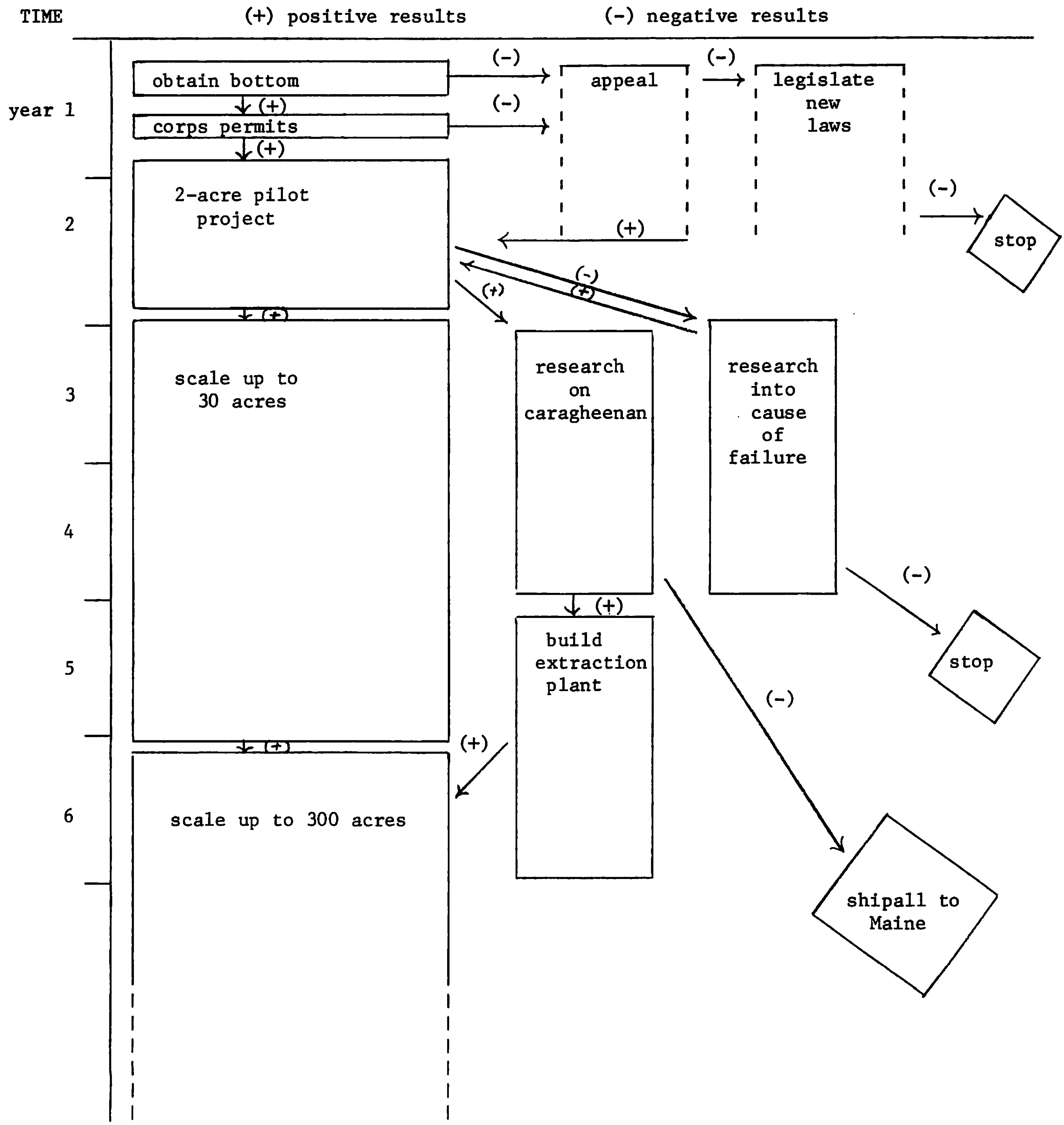
APPENDIX 4

Development Schedule and Cash Flow for Seaweed Farming in Puget Sound

from: Hruby, T. "Farming of Seaweeds" unpublished paper, U.W., 1972

DEVELOPMENTAL SCHEDULE FOR SEAWEED FARMING
INCLUDING ALTERNATIVE COURSES OF ACTION



COSTS AND CASH FLOW FOR SEAWEED FARMING OPERATION

	Cash Inflow	Cash Outflow	Net
year 1	none	leasing %% permits ??	??
2	2 acres @ 75 tons dry/acre $30,000	pilot project $120,000 includes purchase of large dryers to be used in later operations thereby eliminating duplication	-$90,000
3 4 5	scale up to 30 acres over three years. Inflow of $15,000 per acre includes cost of shipping (Inflow calculated as $200/ton instead of 245) total $675,000	projected costs of $12,000/acre make for total farming costs of $540,000 over three years cost of caragheenan research $100,000 cost of research into pilot failure $100,000	$35,000 or -$65,000 if pilot fails
	income from caragheenan per acre (including lower wholesale value of $1.25 per lb. and processing costs of 10¢/lb. product) $16,500/acre this value assumes that one company runs extraction and farming operation and seaweed not shipped to Maine	projected farming costs of $10,000/acre and harvesting. This value may go as low as $8,000 per acre cost of extraction plant $1,000,000	can expect return of $5,000 per acre after plant paid for

Chapter 5. SEA MESH HULL-CLEANING SYSTEM

Introduction

Naval and commercial fleet operations incur considerable cost from marine growth fouling of vessel hulls. First, increased drag reduces hull efficiency, causing higher fuel consumption. Second, hull cleaning requires the vessel either to enter drydock, or remain in port, reducing the fleet's operating capacity during "down-time." Finally, there are the direct costs of the hull-cleaning process. Total costs due to hull-fouling probably exceed $200,000,000 per year in the free world alone.

Since conventional methods--sand-sweeping and brush-scrubbing--are labor-intensive activities, most vessel hull cleaning (possibly 90%) is performed in foreign ports where labor costs are lower. An innovative alternative method, utilizing a low-grain explosive-cord mesh, shows promise of reversing this trend.

Sea-Mesh Development

While engaged in the explosive removal of propellers on scrap vessels, Mr. Brad Meyers noticed that a portion of badly fouled hull, immediately adjacent to the shock-producing cord, had been cleared of marine growth and corroded paint. He astutely recognized that a mesh of explosive cord attached to a vessel's hull might be an effective cleaning method and embarked on a series of tests to develop a commercially applicable system.

Initial tests performed in February 1972 on two scrap aircraft carriers in a Tacoma shipyard, utilizing commercially available explosive cord, succeeded in removing marine encrustations, but also damaged unimpaired paint. Alternative sources of lighter explosive cord were sought.

NASA had developed such a cord for missile staging, and limited quantities were acquired for further tests. Marine encrustation, up to 12 inches in thickness, was removed using this lighter cord. Further testing on two scrap AKC's moored in Puget Sound resulted in complete removal of marine growth and corroded paint with minimal damage to well-bonded paint on the hull. With this experience a commercial contract was drawn up with Todd Shipyards to clean U.S.S. PRESIDENT MONROE. Not only the sides but also the ship's bottom were to be cleaned. Explosive mesh hung from floats was tightly fastened around the hull and the system was initiated. The marine growth was effectively removed, but engine room gauge glasses popped out, some loosely stacked porcelain toilet fixtures were cracked and some light bulbs were broken. While the cost of the damage was small--less than $5,000--a structural survey to establish the vessel's sea-worthiness cost the insurance underwriters $50,000. Clearly, then, before further contracts could be negotiated, detailed research toward refinement of the system was necessary.

Sea Grant Response through Technical Assistance

In September 1972 Mr. Meyers approached the University of Washington for assistance. He was advised to contact the Applied Physics Laboratory, where Dr. Howard Blood concluded that Washington Sea Grant might appropriately underwrite some of the costs for APL's technical assistance to his company, Controlled Dynamics Corporation (CDC).

Accordingly, a $5,000 grant was allocated, matched by personnel from Controlled Dynamics staff, and two APL engineers were assigned to the project for one month.

A welded steel box, deployed from APL's barge served as a test-model for determining shock levels induced by CDC's explosive mesh. Instrumentation recorded the effects produced by the system at various stand-off distances from the hull, and the shock-attenuation achieved by a "bubble screen" positioned between the mesh and the test "hull." The objectives were to determine the threshold levels above which damage would occur to the hull plates and welds, and below which hull cleaning would not be achieved.

Little is known of the "near-shock-phenomenon" involved in the explosive cleaning process, but sufficient data were gathered to greatly reduce the shock levels without loss of cleaning efficiency.

A Navy tug boat--YTM 395--was made available through the 13th Naval District for a demonstration of the revised cleaning method. Marine growth was removed successfully from the hull and the vessel incurred no damage.

Mr. Meyers was still troubled by the amount of released energy, however, and concluded that if, instead of releasing all the energy in the system simultaneously he could introduce delays between sequential detonations, then he could possibly achieve the same cleaning effects, but reduce the shock levels still further. One hard "punch" would be reduced to several lighter "taps" on the vessel's hull; danger of shock damage could be eliminated and noise levels would be tolerable to the crew aboard ship. Such a system was constructed, tested on land, and pronounced workable. APL staff concurred with the principle.

Project Phoenix

A demonstration test of the "Sequential Sea Mesh System" was performed at the Puget Sound Naval Shipyard, Bremerton, on May 25, using a mine-laying destroyer--MMD23--instrumented by APL staff to record shock and noise levels. Initially, an eighteen-foot by sixteen-foot patch of mesh was sequentially detonated in strips, with a manual delay between firings to allow resetting of instruments and repositioning the mesh at various stand-off distances. Subsequently, one whole side of the hull was cleaned. Complete instrumentation and photographic records--still and movie--were made of the operation. For this test CDC provided supporting personnel and $1200 cash to defray APL staff and equipment costs.

Twelve inches of marine growth were removed from the destroyer's hull with no apparent damage to the hull or paint surface. Following Project Phoenix, Mr. Meyers expressed optimism for a successful financial outcome for Controlled Dynamics Corporation.

Constraints upon Sea Mesh Utilization

While tests to date indicate Sea Mesh can be deployed without damage to the vessel, APL staff are concerned about the effects of this explosive hull-cleaning process on specific ships, whose age and condition might present unusual responses to the system's released energy.[1] Furthermore, the fatigue effects of frequent "preventive maintenance" applications are unknown, and it is to such applications that Controlled Dynamics is looking for long-term world markets. Preliminary data from the Bremerton tests indicate, however, that while the sequential system produced shock levels 60% of the

[1]Under these circumstances CDC would conduct an ultrasonic survey of the hull prior to cleaning.

magnitude observed in earlier tests, they occurred only in the immediate vicinity of the cord. At short distances away they were attenuated to very low levels. APL physicist Mr. Elbert Pence felt that problems of fatigue-induced fractures were not serious, but expressed the hope that more detailed testing would be conducted in the future. A proposal by APL and CDC for substantial research funding from other federal sources is currently in abeyance, due to general restrictions on federal expenditures.

Washington Sea Grant's Role

Mr. Meyers concedes that, following the U.S.S. PRESIDENT MONROE contract his credibility and the commerical future of Sea Mesh were in jeopardy. Washington's Sea Grant's role was not to restore Controlled Dynamics' credibility, but, rather, to establish a relationship between a small business, with a promising new process, and a University-based testing facility with unique capabilities.

Identification of Future Benefits

Commercial interest in the use of Sea Mesh has been expressed by sales inquiries from seven foreign countries, who, estimates Mr. Meyers, will purchase approximately $700,000 worth of Sea Mesh annually.

Future markets for Sea Mesh will depend not only upon the system's effectiveness but upon the competitive position, vis-à-vis sand-sweeping and brushing methods. Comparative cost figures are presented below, which indicate that Sea Mesh is competitive with current hull-cleaning practices[1] and, if diver inspection following cleaning indicates that hull repainting is not necessary, then a vessel would not have to be drydocked.

Assuming that there are 20,000 merchant marine vessels operating in the free world, with an average size of 10,000 tons, and they require cleaning once every two years, then at an average cost of $20,000 per vessel, the world market for vessel hull cleaning is approximately 200 million dollars annually. Since approximately 90% of this business is conducted in foreign ports, should Sea Mesh be accepted as a competitive alternative, U.S. ports would stand to benefit from Controlled Dynamics' enterprise.

[1] See proposal to Kerr Steamship Co., Appendix 5.

Method	Cleaning	Drydock Charges	Piloting Fees	Downtime	Total Costs[1]
SANDSWEEPING					
A) Puget Sound	10¢/SF: 3000.00	37¢/T/day: 7400.00	275.00	10,000.00	20,675.00
B) Singapore	6.1¢/SF: 1818.00	26¢/T/day: 5,200.00	200.00	10,000.00	17,218.00
C) World Avg.	8.0¢/SF: 2400.00	26¢/T/day: 5,200.00	250.00	10,000.00	17,850.00
ROBOT U'WATER BRUSHING					
A) Domestic	11-12¢/SF: 3600.00	None	None	1,000.- 10,000.	4,600.- 13,600.
B) Singapore	6.9¢/SF*: 2,070.00	None	None	1,000.- 10,000.	3,070.- 12,070.
SEA MESH					
Puget Sound	8.92¢/SF: 2,676 (6.0¢/SF)*: (1,800)	None	None	less than 1,000.00	<3,676.00 (<2,800.00)*

Table 5-I. COMPARATIVE COSTS FOR CLEANING HULL OF T2 TANKER[2]

1 Hull painting costs are not included.
* Reduction for "Preventive Maintenance" contract.
2 Length: 600 ft., draft: 25 ft., DWT: 20,000 T.

APPENDIX 5

CDC Proposal to Clean ATLANTIC PHOENIX

ATLANTIC PHOENIX

INTERVAL HULL CLEANING FUEL SAVINGS REPORT

SEQUENTIAL SEA MESH SYSTEM HULL CLEANING COST COMPARISON REPORT

ATLANTIC PHOENIX

SHIP'S DATA

Owner-------------- Kerr Steamship Company, Inc.
Length------------- 675 feet, between perpendiculars = 630 feet
Draught------------ 32 feet
Displacement------- 31,716 tons
Trial Speed-------- 22.35 Knots
Propeller---------- 4 blade
Annual Miles------- 216,000
Miles per Month---- 18,000

FUEL CONSUMPTION DATA

Fuel Consumption Rate----------- 100 tons per day
Tons of Fuel per Mile----------- .162 tons per mile
Cost of Fuel-------------------- $ 27.00 per ton
Miles per Hour------------------ 25.72 miles
Miles per Day,(24 Hours)-------- 617.40 miles

FUEL INCREASE DUE TO FOULING = 1% PER MONTH OUT OF DRYDOCK

Months out of drydock	Tons of fuel per mile		1% increase				Miles per month		Tons of fuel per month		Fuel cost		Operating cost in fuel per month
1 ---	.162	+	0	=	.162	X	18000	=	2916	X	$ 27	=	$ 78,732.00
2 ---	.162	+	.0016	=	.1636	X	18000	=	2944	X	$ 27	=	$ 79,488.00
3 ---	.162	+	.0032	=	.1652	X	18000	=	2973	X	$ 27	=	$ 80,271.00
4 ---	.162	+	.0064	=	.1684	X	18000	=	3031	X	$ 27	=	$ 81,837.00
5 ---	.162	+	.0081	=	.1701	X	18000	=	3062	X	$ 27	=	$ 82,674.00
6 ---	.162	+	.0097	=	.1717	X	18000	=	3090	X	$ 27	=	$ 83,430.00
7 ---	.162	+	.0113	=	.1733	X	18000	=	3119	X	$ 27	=	$ 84,213.00
8 ---	.162	+	.0129	=	.1749	X	18000	=	3148	X	$ 27	=	$ 84,996.00
9 ---	.162	+	.0145	=	.1765	X	18000	=	3177	X	$ 27	=	$ 85,779.00
10---	.162	+	.0162	=	.1782	X	18000	=	3207	X	$ 27	=	$ 86,589.00
11---	.162	+	.0178	=	.1798	X	18000	=	3236	X	$ 27	=	$ 87,372.00
12---	.162	+	.0194	=	.1814	X	18000	=	3265	X	$ 27	=	$ 88,155.00
13---	.162	+	.0210	=	.1830	X	18000	=	3294	X	$ 27	=	$ 88,938.00
14---	.162	+	.0226	=	.1846	X	18000	=	3322	X	$ 27	=	$ 89,694.00
15---	.162	+	.0243	=	.1863	X	18000	=	3353	X	$ 27	=	$ 90,531.00
16---	.162	+	.0259	=	.1879	X	18000	=	3382	X	$ 27	=	$ 91,314.00
17---	.162	+	.0275	=	.1895	X	18000	=	3411	X	$ 27	=	$ 92,097.00
18---	.162	+	.0291	=	.1911	X	18000	=	3439	X	$ 27	=	$ 92,853.00
19---	.162	+	.0307	=	.1927	X	18000	=	3468	X	$ 27	=	$ 93,636.00
20---	.162	+	.0324	=	.1944	X	18000	=	3499	X	$ 27	=	$ 94,473.00
21---	.162	+	.0340	=	.1960	X	18000	=	3528	X	$ 27	=	$ 95,256.00
22---	.162	+	.0356	=	.1976	X	18000	=	3556	X	$ 27	=	$ 96,012.00
23---	.162	+	.0372	=	.1992	X	18000	=	3585	X	$ 27	=	$ 96,795.00
24---	.162	+	.0388	=	.2008	X	18000	=	3614	X	$ 27	=	$ 97,578.00

ATLANTIC PHOENIX

COST OF FUEL TO OPERATE SHIP FOR TWO YEARS WITH NO CLEANING -------------------- $ 2,122,713.00

COST OF FUEL TO OPERATE SHIP FOR ONE YEAR --------------------------------------- $ 1,003,536.00

COST OF FUEL TO OPERATE SHIP FOR NINE MONTHS ------------------------------------ $ 741,420.00

COST OF FUEL TO OPERATE SHIP FOR SIX MONTHS ------------------------------------- $ 486,432.00

COST OF FUEL TO OPERATE SHIP FOR THREE MONTHS ----------------------------------- $ 238,491.00

GROSS DOLLAR SAVINGS IN FUEL COSTS IF SHIP IS CLEANING AT THE FOLLOWING INTERVALS

Ship cleaned every 3 months ------- savings in fuel costs = $ 214,785.00 ÷ 2 = $ 107,392.50 gross annual savings

Ship cleaned every 6 months ------- savings in fuel costs = $ 176,985.00 ÷ 2 = $ 88,492.50 " " "

Ship cleaned every 9 months ------- savings in fuel costs = $ 153,441.00 ÷ 2 = $ 76,720.50 " " "

Ship cleaned every 12 months ------ savings in fuel costs = $ 115,641.00 ÷ 2 = $ 57,820.50 " " "

Ship cleaned every 15 months ------ savings in fuel costs = $ 108,594.00 ÷ 2 = $ 54,297.00 " " "

Ship cleaned every 18 months ------ savings in fuel costs = $ 87,318.00 ÷ 2 = $ 43,659.00 " " "

Ship cleaned every 21 months ------ savings in fuel costs = $ 51,894.00 ÷ 2 = $ 25,947.00 " " "

Ship cleaned every 24 months ------ savings in fuel costs = $ 0

ATLANTIC PHOENIX

CLEANING INTERVAL	TIMES CLEANED IN TWO YEARS	×	NORMAL SEA MESH CLEANING COST	-	GROSS TWO YEAR FUEL SAVINGS	=	NET TWO YEAR SAVINGS	÷ 2	=	NET ANNUAL SAVINGS FROM HULL CLEANING
3 mon.	8 times		$ 3,596.00		$ 214,785.00		$ 186,017.00			$ 93,008.50
6 mon.	4 times		$ 3,596.00		$ 176,985.00		$ 162,601.00			$ 81,300.50
9 mon.	2 times		$ 3,596.00		$ 153,441.00		$ 146,249.00			$ 73,124.50
12 mon.	2 times		$ 3,596.00		$ 115,641.00		$ 108,449.00			$ 54,224.50
15 mon.	1 time		$ 3,596.00		$ 108,594.00		$ 104,998.00			$ 52,499.00
18 mon.	1 time		$ 3,596.00		$ 87,318.00		$ 83,722.00			$ 41,861.00
21 mon.	1 time		$ 3,596.00		$ 51,894.00		$ 48,298.00			$ 24,149.00
24 mon.	1 time		$ 3,596.00		$ 0		$ 0			$ 0

CALCULATION OF SEA MESH CLEANING COSTS FOR THE ATLANTIC PHOENIX

Sea Mesh System's pricing is based on the length of the ship between perpendiculars × the draught × 2 (both sides) = = square footage to be charged × Sea Mesh base price = complete cleaning price.

FOR EXAMPLE:

[Length]		[Draught]		[2]		[Sq/ft]		[Base Price]		[Cleaning Price]
630	×	32	×	2	=	40,320	×	.892	=	$ 3,596.00
630	×	30	×	2	=	37,800	×	.892	=	$ 3,371.00
630	×	28	×	2	=	35,280	×	.892	=	$ 3,146.00
630	×	26	×	2	=	32,760	×	.892	=	$ 2,922.00
630	×	24	×	2	=	30,240	×	.892	=	$ 2,697.00

[Propeller cleaning price = $ 25.00 per blade extra]

ATLANTIC PHOENIX

Actual area which will be cleaned by the Sea Mesh System at the $ 3,596.00 price is the area from the waterline to the turn of the bilge plus four feet past the turn of the bilge on the bottom of the ship.

675 x 32 = 21,600 x 2 = 43,200 + 675 x 4 x 2 = Actual square footage which will be cleaned = 48,600

COST COMPARISON WITH OTHER HULL CLEANING SYSTEMS

SHIPYARD "A" = sand blast cleaning method @ 10 cents per sq/ft. + 33 cents per ton drydock fee.
SHIPYARD "B" = sand blast cleaning method @ 10 cents per sq/ft. + 37 cents per ton drydock fee.
SCAMP = underwater brushing method in Singapore, worlds lowest hull cleaning price, $ 3.29 per foot of length.
SEA MESH = underwater energy wave cleaning system.

Area to be cleaned = 48,600 sq/ft.
Displacement tonnage = 31,716 tons.
Downtime rated at $ 7,000.00 per day.

	[SHIPYARD "A"]	[SHIPYARD "B"]	[SCAMP]	[SEQUENTIAL SEA MESH SYSTEM]
[Drydock Fee	$ 10,466.28	$ 11,734.92	$ NONE	$ NONE
[Cleaning	$ 4,860.00	$ 4,860.00	$ 3,626.00	$ 3,596.00
[Pilot Fee	$ 250.00	$ 250.00	$ NONE	$ NONE
[Downtime	$ 7,000.00	$ 7,000.00	$ 3,500.00	$ 145.00
[TOTAL	$ 22,576.28	$ 23,844.92	$ 7,126.00	$ 3,741.00