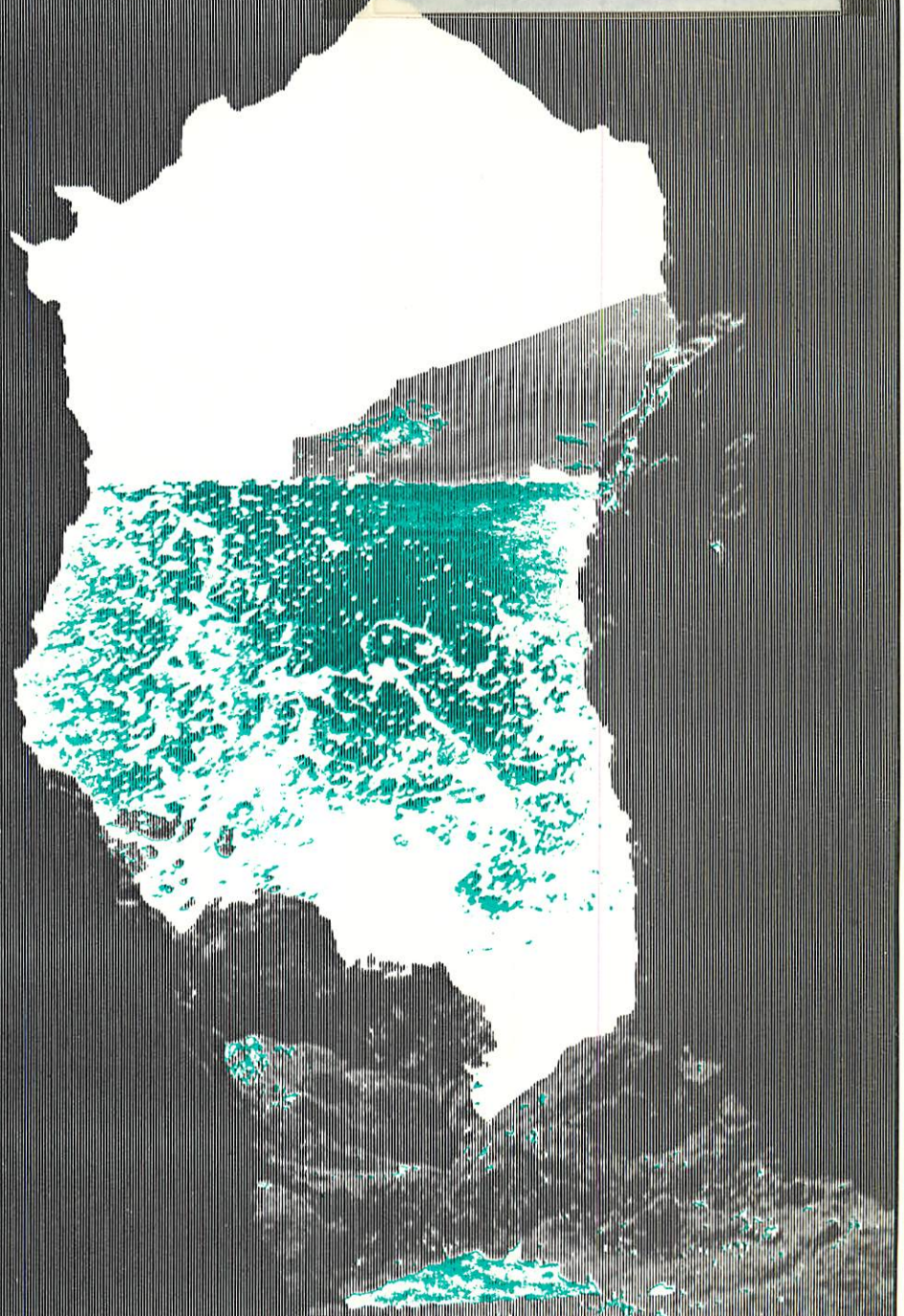
TWO DECADES

of achievement in the ocean

UNIVERSITY OF HAWAII
SEA GRANT COLLEGE PROGRAM



1968 — 1988

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January 1988

Sea Grant Miscellaneous Report
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The National Sea Grant College Program is a network of institutions working together to promote the wise use, development, and conservation of the nation's coastal, marine, and Great Lakes resources. Provisions of the National Sea Grant College and Program Act of 1966 called for the creation of Sea Grant Colleges, and in October 1972, the University of Hawaii was designated one of the first five Sea Grant Colleges in the nation. Locally, Sea Grant is a unique partnership of university, government, and industry focusing on marine research, education, and advisory/extension service.

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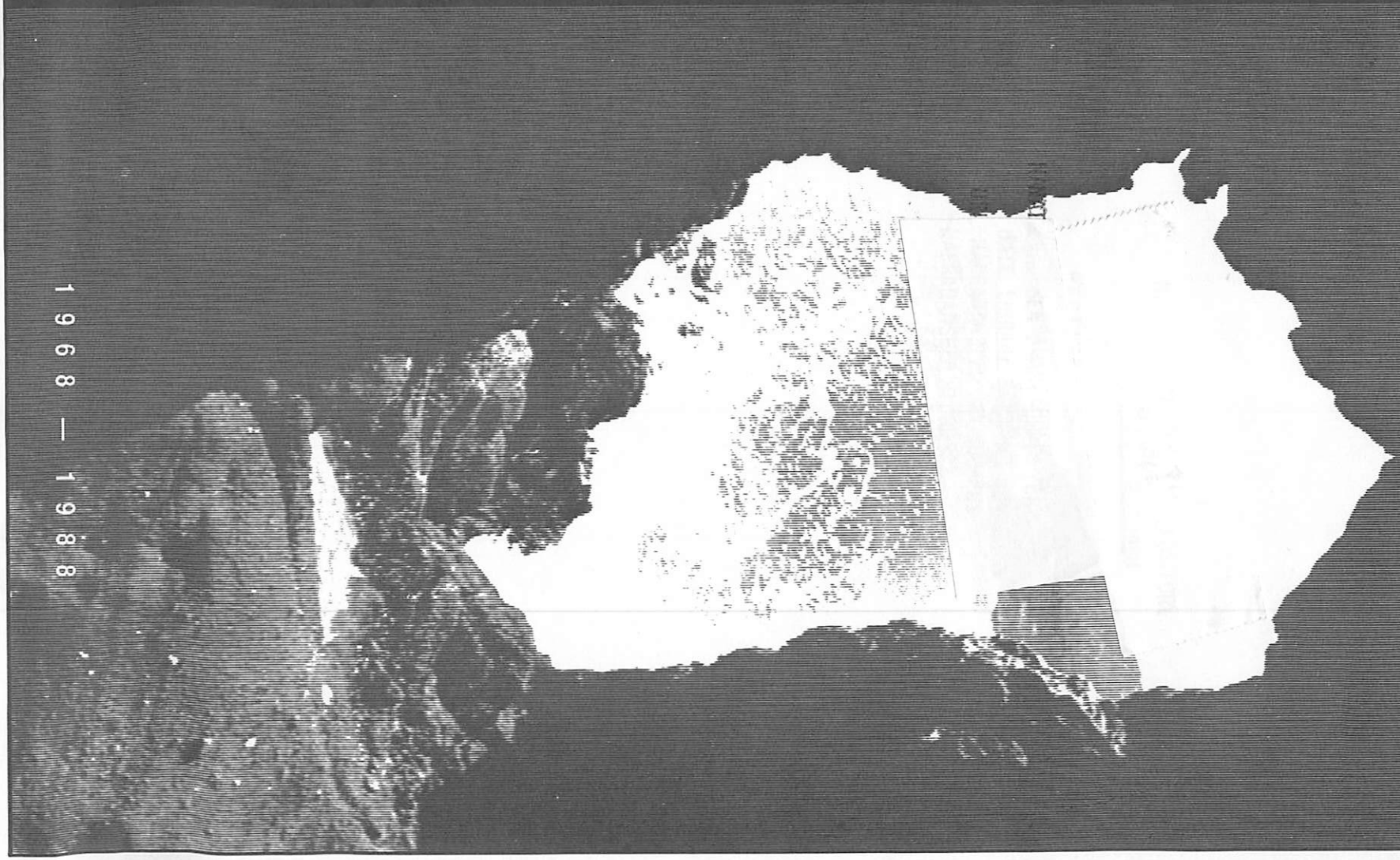


UNIVERSITY OF HAWAII
SEA GRANT COLLEGE PROGRAM

1968 — 1988

PREFACE

This document truly represents the collective effort of Sea Grant people who were themselves actors in the 20-year drama of the University of Hawaii Sea Grant College Program (UHSGCP) at work in the ocean with ocean people. It is the story of the meeting of university scientists at the last frontier of the earth — the ocean — a beautiful but formidable environment.

The compilation of this 20-year history was for all almost as challenging as the activities that are described in the pages that follow. Principal investigators were asked to describe their own research areas because of their special insights and perceptions. This effort provided them an opportunity to view their work at arm's length and to take a long view of their accomplishments.

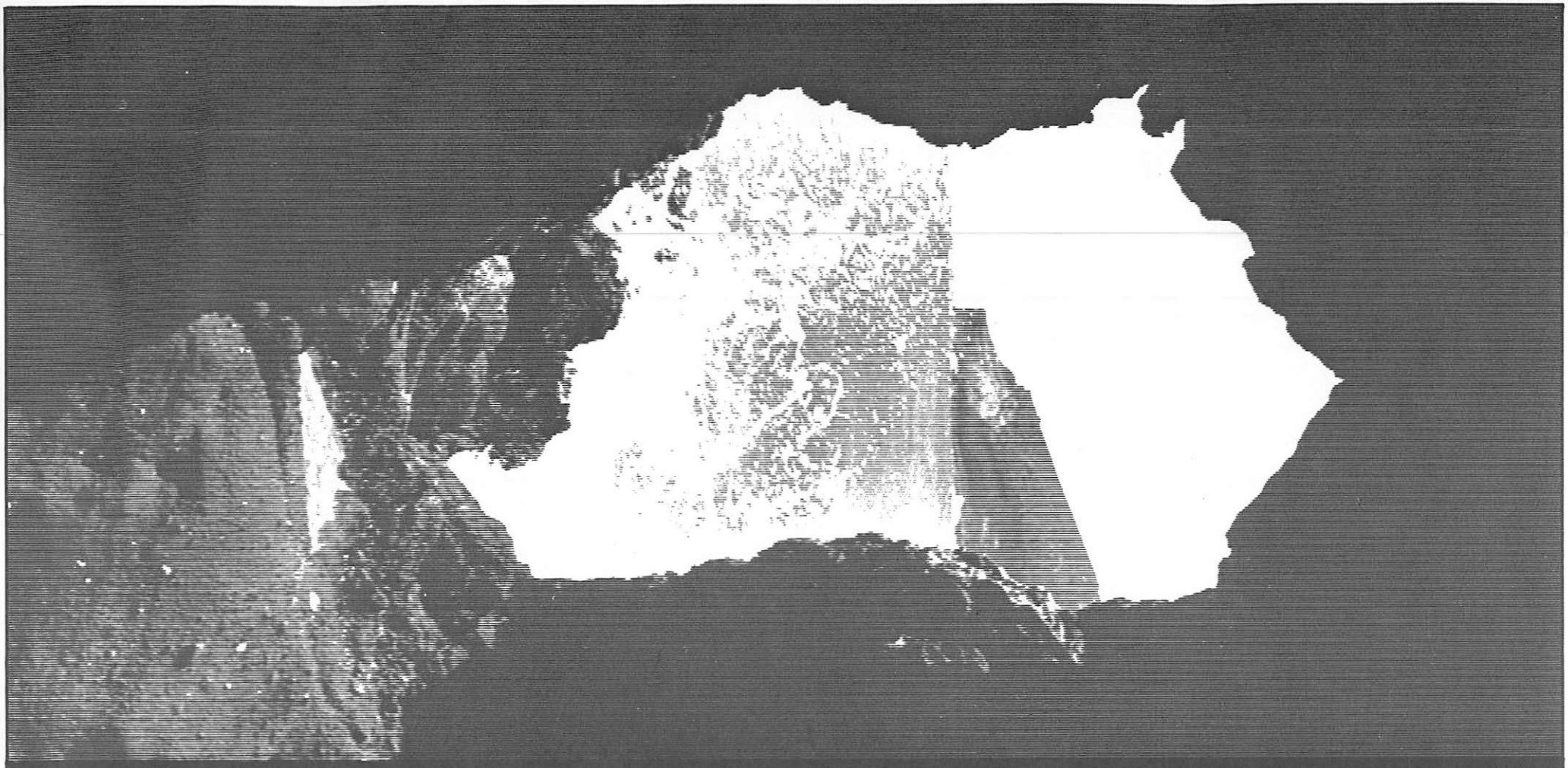
The major endeavors and contributions of the UHSGCP are described in the three major divisions of this report:

Part I.	Overview: Program History and Program Management
Part II.	Major Programs and Achievements
Part III.	Long-Range Effects

These three divisions cover in some detail the 20-year program of UHSGCP beginning with a broad brush historical summary of its significant activities and the development and management of research programs which are carried on in the ever-changing milleux of the ocean and ocean-related social institutions. The role of program management has been largely the management of change and the development of procedures to accommodate change. However, change has never been abrupt. The procedures for effecting a smooth transition from one programmatic focus to another stand as a hallmark of UHSGCP.

This summary statement of the programmatic accomplishments of UHSGCP is not so much a record of hardware and software, but a record of human achievement — the earning of degrees, the achievement of personal and professional goals, and the enhancement of public understanding of marine affairs. It is also a record of support and building of marine institutions in the state, the region, and the nation.

The foundation has been laid; the challenge is to continue to build the institutions, hardware, and software to offer opportunities to future generations to use and enjoy their marine environment.



OVERVIEW

Program History and Program Management

PROGRAM HISTORY

The National Sea Grant Program and the University of Hawaii Sea Grant Program were initiated in an era of commitment to ocean programs reflected in the Stratton Commission report, *Our Nation and the Sea.* This document provided a set of national goals and a framework for action programs to accomplish these goals. The state of Hawaii responded with a parallel set of goals in *Hawaii and the Sea* (1969, revised 1974).

In broad terms, the mission of the University of Hawaii Sea Grant College Program (UHSGCP) and the National Sea Grant College Program reflects the mandate under PL 89-688 "to provide for the establishment of a program of sea grant colleges and education, training, and research in the fields of marine science, engineering, and related disciplines" and the expansion of the mission 5 years later, under PL 94-461, to increase the "understanding, assessment, development, utilization, and conservation of the Nation's ocean and coastal resources by providing assistance to promote a strong educational base, responsive research and training activities, and broad and prompt dissemination of knowledge and techniques."

Although the general mission of the National Sea Grant College Program has remained much the same over its two decades of history, programmatic emphasis has shifted somewhat with perceptions of change in national goals under four administrations. As a Sea Grant Program since 1968 and a Sea Grant College since 1972, the University of Hawaii Sea Grant College Program has been an effective catalyst in implementing these national goals by effecting university/private sector/government partnerships within the state and region. These linkages lend a unique localized character to the national program that allowed important contributions to be made in economic development, institutional change, and problem resolution in Hawaii, the insular Pacific, and beyond, as visualized in *Hawaii and the Sea.*

MISSION

Besides the National Sea Grant Colleges and Programs Act of 1966, the mission of UHSGCP has been influenced by several institutional documents that affect the University of Hawaii as the state institution of higher education. These include the *Hawaii State Plan, Revised 1986*, the Higher Education Functional Plan, the Aquaculture Development Plan, the Fisheries Development Plan, and the Hawaii Ocean Management Plan. The aquaculture and ocean management plans include a major role for UHSGCP.

The *University of Hawaii Strategic Plan (1985-95)* documents the university's mission in the state and the Pacific region. In part, the aspects of this long-range plan that affect the UHSGCP's mission are:

> *Strategic objective*: To serve as a bridge between the culture of east and west and to become a leader in international cross-cultural education by:
>
> > Maintaining and further developing the university's resources of Pacific and Asian expertise and continuing to serve as a national resource for the development of future area experts
> >
> > *Priority Action*: Develop an action plan for telecommunications and information technology development with Pacific and Asian nations and affiliated U.S. universities
>
> *Strategic objective*: To become the research, training, and cultural center of the Pacific Basin
>
> > To increase the international stature of the University of Hawaii, stepped-up research activity is of crucial importance. An environment and

> structure must be developed whereby faculty research is greatly strengthened, whether this is basic or applied research. Strengthening research will attract Federal and other funds and enhance the research ties with other institutions, locally, regionally, and internationally.
>
> *Priority Action*: As a member of the world university community and the network of land grant and sea-grant colleges, develop national leadership in the areas of ocean and alternative energy research and tropical agriculture research and training (emphasis added).
>
> *Priority Action*: Develop programs to gain a reputation as the foremost university for the study of contemporary humanistic, social, economic, and political issues. . .

As indicated in these excerpts from the university's *Strategic Plan*, the recognition of the importance of research in the institution's reach for excellence, tempered by a clear understanding of the significance of the state's geographical location in the center of the Pacific Ocean, parallels that of the UHSGCP. Hence, Sea Grant's activities in research, education, and extension services fit nicely within the university's strategic plan that was designed to carry it into the next decade as a major institution of higher education. The narrative that follows capsulates the programs carried out by UHSGCP over the last two decades and attempts to provide a programmatic context for their outcomes and influence on the institutions and people of the state, the Pacific region, and the nation.

GOALS

The goals that guide UH Sea Grant in fulfilling its mission in research, extension, and education are as follows:

Research Goals

1. To encourage studies that advance the state of knowledge of marine resources and facilitate their efficient exploration, orderly economic development, and management for Hawaii and the Pacific region

2. To assess the socioeconomic, political, and legal consequences of proposed or alternative strategies for development, use, and management of marine resources and the marine environment

3. To encourage the development of engineered systems, structures, and technologies to develop, protect, restore, and enhance the marine ecosystem

Extension Goal

To provide a Sea Grant Extension Service equipped to effect region-wide transfer of current marine knowledge and technology

Education Goal

To encourage and facilitate the development and dissemination of formal marine education in educational systems in Hawaii and the Pacific

SUMMARY OF ACTIVITIES

Research

Sea Grant has continuously supported projects and programs in several major research areas for almost two decades. These long-standing areas of focus include plant and animal aquaculture, fisheries, and human physiology under hyperbaric conditions (earlier designated as human performance in the sea). Within each area, the emphasis changed dramatically over time as particular study objectives were completed and new initiatives emerged and new directions were charted. These major programs are summarized below.

The first Sea Grant-funded animal aquacultural research was centered on biological screening to identify suitable tropical species from Hawaii and elsewhere. The early hope (and faith) was that a local species would prove economically viable for culture. Nineteen species, many of which had traditional significance to Hawaii, were screened. Although this research was directed toward the mitigation of the state's diminishing stocks of commercially valuable reef and nearshore fisheries, it was clear that any knowledge gained would be transferable to other tropical insular environments.

Unfortunately, the inability to effectively close the biological cycle, lack of markets, and/or uneconomical dietary requirements precluded the consideration of local species. However, the knowledge gained enabled the state to put a closure to the recurring question of "Why not a local species?" and to focus its attention on *Macrobrachium rosenbergii*, a species of prawn that was imported from Malaysia.

A joint state-Sea Grant effort in *Macrobrachium* research and development was begun in 1976, with the Sea Grant portion primarily centered on the domestication of the giant prawns, their nutritional needs, pond management, and extension outreach to prawn farmers. This joint effort expanded the scientific investigation of *Macrobrachium* spp. which was begun by the director of the state's Anuenue Fisheries Research Center (AFRC) in the 1960s. At its zenith, the 10-year UHSGCP multidisciplinary effort included the time and talents of more than a dozen researchers in a number of departments including animal sciences, agricultural engineering, chemistry, genetics, food technology, and microbiology; and the staff of the UHSGCP marine extension service, Hawaii Institute of Marine Biology, and AFRC.

In the 1987-89 institutional program proposal, the prawn research program was temporarily placed on hold, awaiting the development of adequate experimental facilities to test the concepts developed for increasing production. A new research program, modeled after the prawn research program, was initiated to support the development of marine shrimp production enterprises in Hawaii and the United States. Crustaceans, including both marine shrimp and prawns, are expected to remain the major aquaculture species in Hawaii over the next decade.

Fisheries research from 1968 to 1975 focused on the development of tuna fisheries and precious coral resources. With the failure of numerous attempts to culture and to reduce mortality in *nehu* (*Stolephorus purpureus*), the preferred baitfish of the Hawaiian skipjack tuna fleet, research turned to the identification of an acceptable alternative baitfish. These attempts either failed completely or produced only marginal results. To date, no reliable baitfish has been found in the wild or successfully cultured to replace nehu. An ongoing study utilizing chemical attractants to enhance and/or replace baitfish has had some success in preliminary sea trials. However, the biological processes related to the skipjacks' sense of smell are not well understood.

Sea Grant-sponsored research on precious corals is credited with helping to develop the fishery management plan and to establish a local industry which was worth $17 million by 1983.

From 1979 to 1983, under the Northwestern Hawaiian Islands Fisheries Investigations program, a comprehensive assessment of the living resources of this remote region was conducted to guide the development and management of the fisheries resources in the Hawaiian Archipelago. The study results, documented in 113 papers in the proceedings of 2 major symposiums, were used in the development of fisheries management plans by the Western Pacific Regional Fishery Management Council and by the U.S. Fish and Wildlife Service.

Fisheries research emphasis since 1983 has been on fishery enhancement with fish aggregation devices (FADs) and artificial reefs. Recent national and state interest in habitat

research is reflected in the comprehensive program to assess the Penguin Bank fishery ecosystem. An initial phase of this program was begun in 1987.

Diving physiology research began with breath-holding experiments and gradually increased in sophistication to include large and small animal experiments to study bubble formation *in vivo*. Simultaneously, corollary *in-vitro* experiments on the physics of bubble formation were done in agar medium. With the recent discovery that experimental results using animals as research subjects are transferable to human applications, the way has been paved for the development of more accurate diving tables.

Serendipitous medical and clinical applications of human physiological research findings include treatment of apnea and sleep disorders and redistribution of body fluids through use of the immersion methodology as an alternative to traditional chemical diuretics. The bubble physics work produced the varying-permeability (VP) model to explain the existence of stable gas nuclei. It was discovered that the spherical gas nucleus is prevented from collapsing because of the compression strength of an elastic skin membrane composed of surface-active molecules. Changes in the radius of a VP model nucleus take place through the accretion or deletion of surfactant (surface-active) molecules by the skin. This phenomenon was observed directly in 1981 with an electron microscope. The presence of osculating nuclei and clusters of nuclei, although unexpected, was explained by the tendency of surfactant films to attract one another and form bi-layers. It was noted that, in both water and gelatin, some nuclei accrete solid debris.

Research areas which received special but not continuous attention during Sea Grant's first decade in Hawaii include marine environmental studies, emphasizing the quality of Hawaii's coastal waters; marine natural product chemistry; coastal processes; development of stable floating platforms; survey of manganese nodule sites; laboratory studies of manganese nodule processing; coastal and ocean policy and law studies and programs; and development of marine agronomy for farming seaweeds. The latter resulted in a supply of industrially important seaweeds for the U.S. market through the development of seaweed farms in the South Pacific, Southeast Asia, and Asia.

Research programs with significant contributions in terms of scientific achievement, institution building, and/or more effective management of marine resources initiated during Sea Grant's second decade in Hawaii include the 5-year Northwestern Hawaiian Islands Fisheries Investigations (NWHIFI); the fisheries enhancement program; and ocean thermal energy conversion (OTEC) aquaculture research projects, which allowed researchers to test the feasibility of culturing a wide variety of marine plants and animals in the nutrient-rich, cold, deep-ocean water. Although the NWHIFI program was completed, spinoff benefits for the scientific community and for management of marine resources can be expected to continue for many years. Benefits arising from the "proof of concept" experiments comprising the OTEC aquaculture program are limitless. The knowledge gained from work in the fisheries enhancement program is benefiting both fishermen and tourism-related ocean recreation businesses.

Programs still in early stages of development but which are expected to produce major results and benefits in terms of scientific knowledge and development of marine resources include the Marine Shrimp Aquaculture Program, the Ocean Minerals Program, the Marine Natural Products Chemistry Program; and the Ocean Recreation and Marine Tourism Program.

Marine education and training

The UH Sea Grant College Program has participated in a broad spectrum of marine education programs and projects, including the development of high school, undergraduate, and graduate

marine programs and curricula. It initiated and supported the development of the Blue-Water Marine Laboratory, a shipboard high school ocean science program; the undergraduate Marine Option Program; a marine technician training program at Leeward Community College; and a graduate research and training program in tropical marine studies at the Hawaii Institute of Marine Biology. Currently, the marine education programs focus primarily on college-level education within the University of Hawaii system. However, as in the past, assistance is provided to other education levels as the opportunity arises. Sea Grant has assisted the UH College of Education in upgrading the high school marine curricular materials that were developed earlier with UHSGCP funding and in providing teacher training opportunities in American areas of influence in Micronesia.

Although UHSGCP took an early lead among the Sea Grant colleges in stimulating the development of marine education at all levels, its education component in the 1980s is much smaller than in the previous decade. This coincides with a decrease in emphasis on marine education by the National Sea Grant College Program and in the proliferation of marine education projects throughout the Sea Grant network. Along with national deemphasis on education, the reduction in the size of the UHSGCP marine education programs in Hawaii is due to their adoption by the state's school system.

Marine extension services

The Sea Grant advisory/extension program was established at the University of Hawaii in 1970 with one employee, the Marine Advisory Program coordinator. The coordinator acted as an assistant to the Sea Grant director and defined, developed, and managed the advisory program. In subsequent years, the program passed through a number of changes, generally characterized by increases in scope and staffing as budgets increased. Between 1971 and 1974, a staff of specialists was hired to identify information and technology transfer needs, primarily on Oahu. Areas of emphasis included fisheries, management of coastal environments, and beach and diving safety.

As the various user groups on the neighbor islands and their needs became more clearly defined, it was determined that the advisory program needed the public contact that locally based agents could provide. Extension agents were hired to serve the counties of Maui, Kauai, and Hawaii during 1975 and 1976.

In 1979, Sea Grant advisory services were expanded to U.S. flag territories in the Pacific with marine agents in Guam, the Commonwealth of the Northern Mariana Islands (CNMI), and American Samoa. Despite the well-developed plans for expansion in the Pacific, a series of budgetary cutbacks at the federal level, starting in 1981, diminished efforts in all program areas. The Northern Marianas, American Samoa, and one of the County of Hawaii agent positions were not filled when vacancies occurred. The Kauai and Maui agent positions were reduced to part-time status and subsequently eliminated.

Under the leadership of a new coordinator, hired in 1982, a more focused program, better designed to meet the current needs of the marine communities in Hawaii and Guam, has evolved. The result is an extension service program which is integrated into public and private marine communities that provide substantial nonfederal matching funds.

Pacific Sea Grant programs

The University of Hawaii is, by virtue of its geographical location, much involved in the events and problems of the Pacific. Commonality of ethnic origins and island-oceanic-climatic setting and a large reservoir of scientific expertise in tropical subject areas make the University of Hawaii the logical place to turn for information and guidance. Moreover, the university has built a reputation for having the capability and desire to help with problems of small Pacific nations.

Sea Grant programs began in the Asian and Pacific regions with the development of seaweed farming in the Philippines in 1968. This was followed by a number of fisheries, aquaculture, and education projects in the then Trust Territory of the Pacific Islands, Guam, American Samoa, and Christmas Island.

In addition to the programs in Guam, CNMI, and American Samoa, a cooperative training program for extension personnel for 11 island nations in the South Pacific was initiated with the University of the South Pacific under International Sea Grant Program funding. In conjunction with this effort, a communications network was developed which eventually served the informational needs of the region through the print media and via satellite hook-up. The International Sea Grant Program was terminated after 4 years because of funding cutbacks. Subsequently, from 1977 to 1984, the University of Hawaii and the University of California Sea Grant College Programs have conducted joint marine education programs, primarily curriculum development and teacher training for secondary schools in Palau, Truk, Ponape, and the Marshall Islands.

Despite budget constraints in the 1980s, and the need to curtail many of the efforts started in 1979, much valuable experience and good will was gained from the UHSGCP-directed programs in the Pacific. Using this as a building block, the UHSGCP and University of Guam Sea Grant Program are well prepared with experience and expertise to develop and conduct needed research, education, and extension programs in the western Pacific. If and when such help is seen to serve the United States' interest in the area and funds are provided, a pool of talent is available in the two universities.

Law of the Sea Institute

The Law of the Sea Institute (LSI) moved to the University of Hawaii in 1977. The Law of the Sea Institute, with UHSGCP as one of its primary sponsors since 1977, is unique in terms of both its characteristics and its accomplishments. The Law of the Sea Institute is not a program of research, education, or advisory services, but it combines the sophisticated features of each. Currently, it serves as a major international forum for the scholarly examination of international ocean law and policy and for continuing professional and public education. Through its annual conferences, workshops, and published proceedings of scholarly deliberations, LSI performs a worldwide extension mission.

CONCLUDING STATEMENTS

This brief history has focused primarily on some of the major projects and programs of the University of Hawaii Sea Grant College Program. Many projects, the results of which are provided in UHSGCP progress reports, have gone unmentioned here for lack of space. However, these projects, together with many program development initiatives, have had positive effects and spinoffs which are described in various Sea Grant reports. Several new major programs initiated in the 1987-89 biennium that can be expected to continue into the next biennium and in some cases well into the next decade are not included in this 20-year historical summary.

For example the long-range plan for UHSGCP calls for work on the domestication of marine and freshwater crustaceans to continue as major programmatic foci in the next century. This work can be expected to include fundamental and applied aspects of pond management, nutrition, genetics, and engineered systems to increase production and marketing efficiency. The current marine shrimp program is conceived to be part of a multiregional Sea Grant effort to accelerate the development of profitable shrimp aquaculture in the United States. Other major participants in this effort include the Texas, California, and South Carolina Sea Grant programs.

Fishery enhancement work, focusing on such aspects as fish aggregation devices (FADs), chemical attractants, augmentation of natural stocks through release of cultured juveniles, and use of artificial reefs, can be expected to continue. However, it is likely that the major living marine resources program will be a 5-year multiagency scientific investigation of the marine resources of the main high islands of the Hawaiian Archipelago. This program is currently being developed. The Penguin Bank Fisheries Program would be appropriately integrated into this broader framework. Partners in this effort will include the Honolulu Laboratory of the National Marine Fisheries Service, U.S. Fish and Wildlife Service, Hawaii Department of Land and Natural Resources, and UHSGCP. UH Sea Grant will be expected to play a major role in those aspects of research and extension that are appropriate to the Sea Grant mission and to a university.

The comprehensive Ocean Minerals Program, initiated in 1987 in cooperation with the Hawaii Undersea Research Laboratory, will continue to receive emphasis in the University of Hawaii Sea Grant College Program institutional research program. The goal of this program, to assess and characterize metallic crusts and other seamount resources in the Hawaiian Archipelago and other American flag and affiliated island groups, is a response to national and state interest in ferromanganese-cobalt crusts and other seamount resources in the Pacific. This interest was heightened by the 1983 presidential proclamation of a 200-mile exclusive economic zone (EEZ) off the coast of the United States and its territories. Because these crusts contain significant quantities of cobalt and are located within the U.S. EEZ at a depth of about 1,000 meters, they are more attractive for commercial development than nodules which are found in international waters at several times that depth.

The Marine Natural Products Chemistry Program, initiated in 1987 to determine the composition and characteristics of the chemical defense and prey capture systems of marine organisms, is expected to continue well into the next decade and beyond if initial results warrant it. The ultimate goal of the program is to synthesize analogs of natural chemical compounds for commercial production of pharmaceuticals and agrochemicals.

The Ocean Recreation and Tourism Program, with emphasis on tourism and ocean recreation industry uses of marine resources, is expected to expand as a programmatic area. Tourism and recreation constitute the major economic use of the ocean and the shoreline not only for the state, but for most of the U.S. flag and affiliated insular states in the Pacific.

Hawaii faces a number of problems related to the use of marine resources for the development of the tourism industry. Rapid growth in the number of visitors, limited oceanfront public facilities, shortfalls in funding for maintenance and repair of beach facilities, uneven deployment of water safety personnel caused by segmented state-county management of the coastal zone, and lack of parking areas have resulted in crowded beaches and conflicting uses of limited space. These conditions affect the quality of the recreation experience for all beach and beach facility users and exacerbate risk management problems for both public and private beachfront property owners and users. Although the immediate mitigation of these problems suggests the need for and the management of use and allocation of marine resources, including the regulation of tourism-related businesses, such a move requires a positive approach which supports economic development without adversely affecting the marine environment and its resources.

Growing cognizance of these problems at the governmental level prompted the state legislature to establish the Governor's Ocean Resources Tourism Development Task Force in 1987 to look at the broad scope of ocean resources use for tourism development. It is expected that the work of this task force will be used as a general guideline for the development of future programs for state initiatives and where appropriate and compatible

with Sea Grant and university missions, it will be used to direct future University of Hawaii Sea Grant College Program research.

PROGRAM MANAGEMENT

OVERVIEW

The Sea Grant director's office has line responsibilities for the Sea Grant College Program, the Waikiki Aquarium, and the Marine Option Program. Administratively, the University of Hawaii Sea Grant College Program (UHSGCP) is a line program under the Vice-President for Research and Graduate Education. This relationship has provided UHSGCP direct access to the president's office, and equally important, it signifies that Sea Grant is a university-wide program. UHSGCP's relationships within the administrative structure of the University of Hawaii and its internal management relationships are shown in Figures 1 through 4. A proposal in process would bring the Sea Grant College along with other marine units in the university into the School of Ocean and Earth Science and Technology. An organizational chart for the proposed new school is shown in Figure 5.

The UHSGCP director, together with the Sea Grant management team and the Sea Grant Advisory Council (SGAC), determines the priorities and scope for the institutional program. The Sea Grant management team consists of the director, two associate directors, and the administrative officer. As research, education, and extension programs are developed and funded, they are administered by the director and his staff.

The Sea Grant institutional program is conducted primarily within geographical boundaries extending from the main Hawaiian islands west and south to American flag possessions and affiliated states in the tropical and subtropical Pacific. However, researchers and the extension staff and their publications extend the outreach of the UHSGCP well beyond the state and Western Pacific region. During 1987-89, UHSGCP will collaborate and/or participate with 44 governmental organizations, 89 academic institutions, and 53 industrial organizations to carry out its programs.

FUNCTIONS OF THE DIRECTOR'S OFFICE

The responsibilities for the development and administration of the UHSGCP includes (1) advance planning and program development; (2) development of a biennial institutional proposal encompassing programs of research, education, and extension services; (3) administration of projects and programs funded by Sea Grant and cooperating agencies; (4) program evaluation; (5) coordination of the publication and dissemination of research and extension information; and (6) performance of professional and public service.

Advance planning and program development

The Sea Grant Advisory Council, made up of marine leaders in public and private life in the state, works with the director and the management team to establish program goals and priorities and to provide expert advice on the quality of projects and programs. In the development of future programs, particular emphasis is given to the needs, opportunities, and problems in which state, regional, and national interests coincide.

When a research area, identified by the advisory council or a state or federal agency, is targeted as high priority for program development, qualified scientists and/or educators are requested to submit preliminary research proposals either as groups or as individuals. For example, the 1987-89 institutional program features several research programs that focus on national, regional, and state

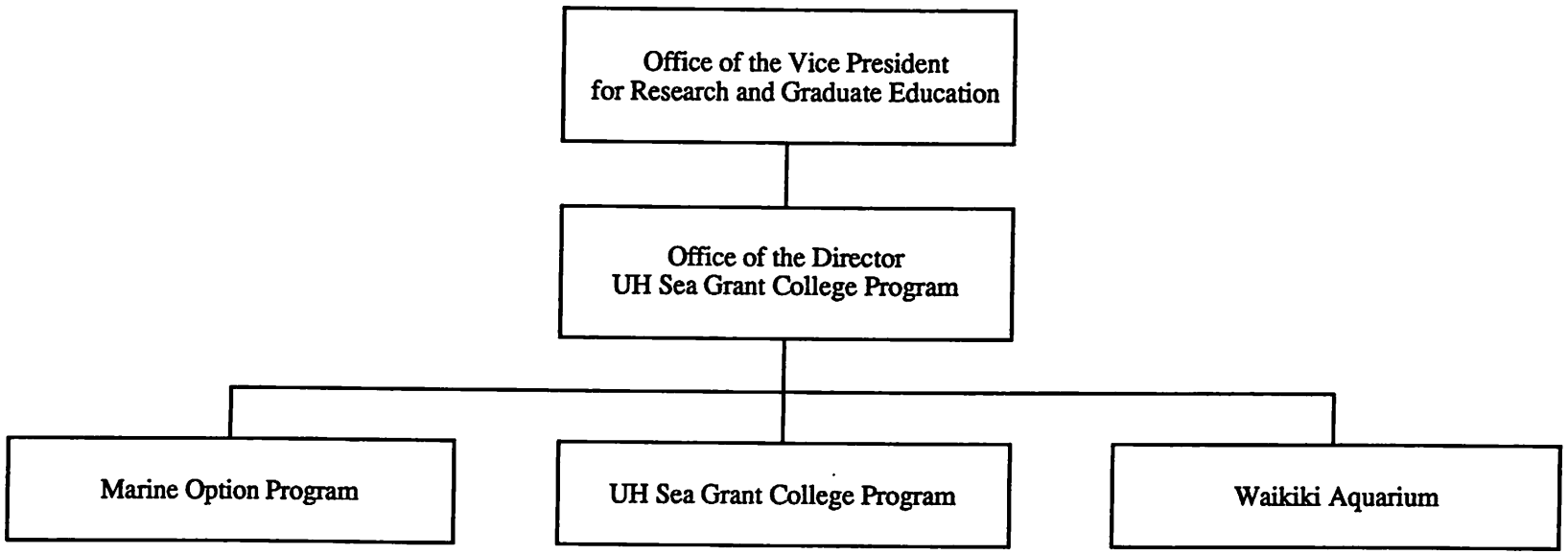


Figure 1. Organizational Structure of the Office of the Director of the UH Sea Grant College Program

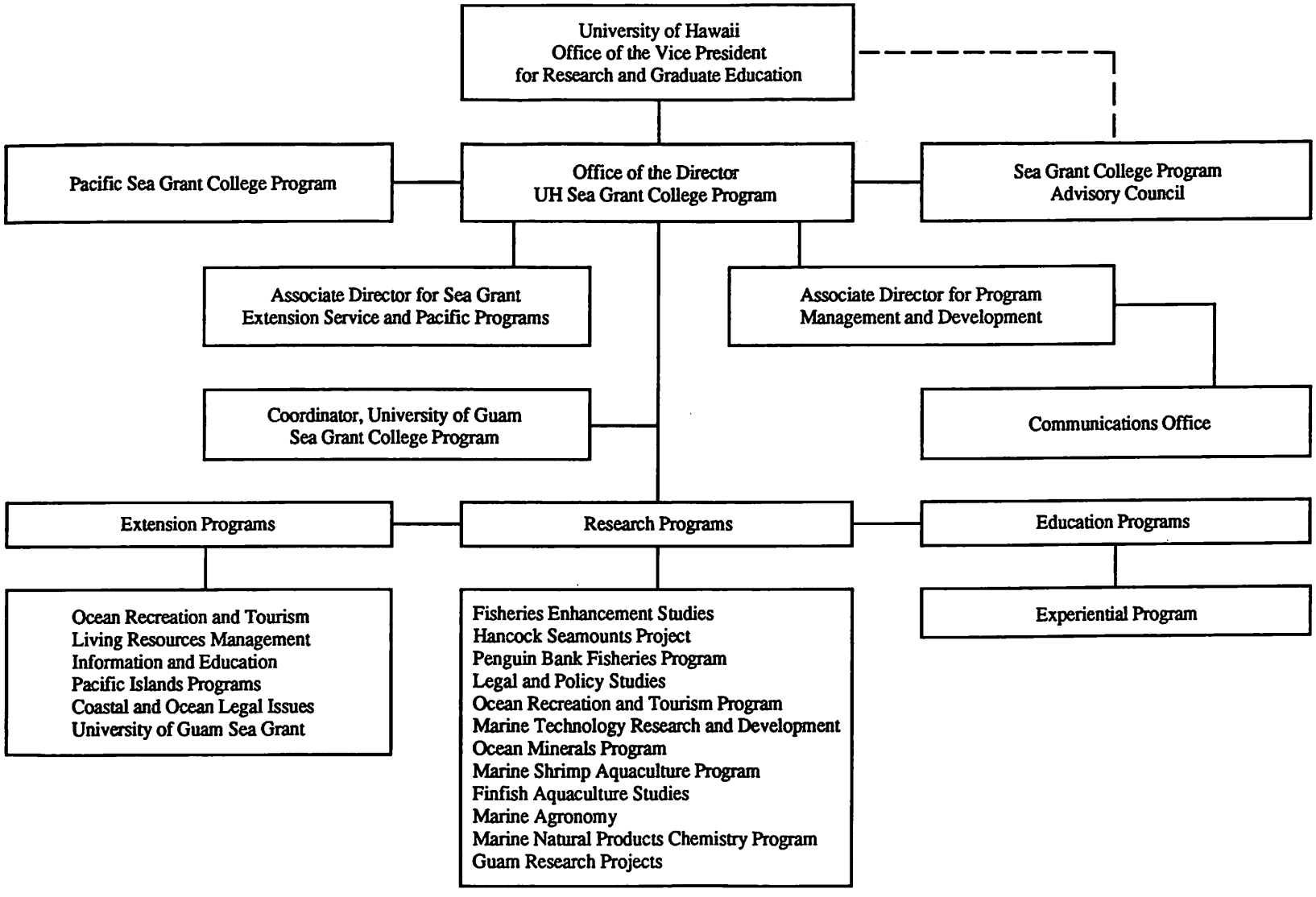


Figure 2. The University of Hawaii Sea Grant College Program

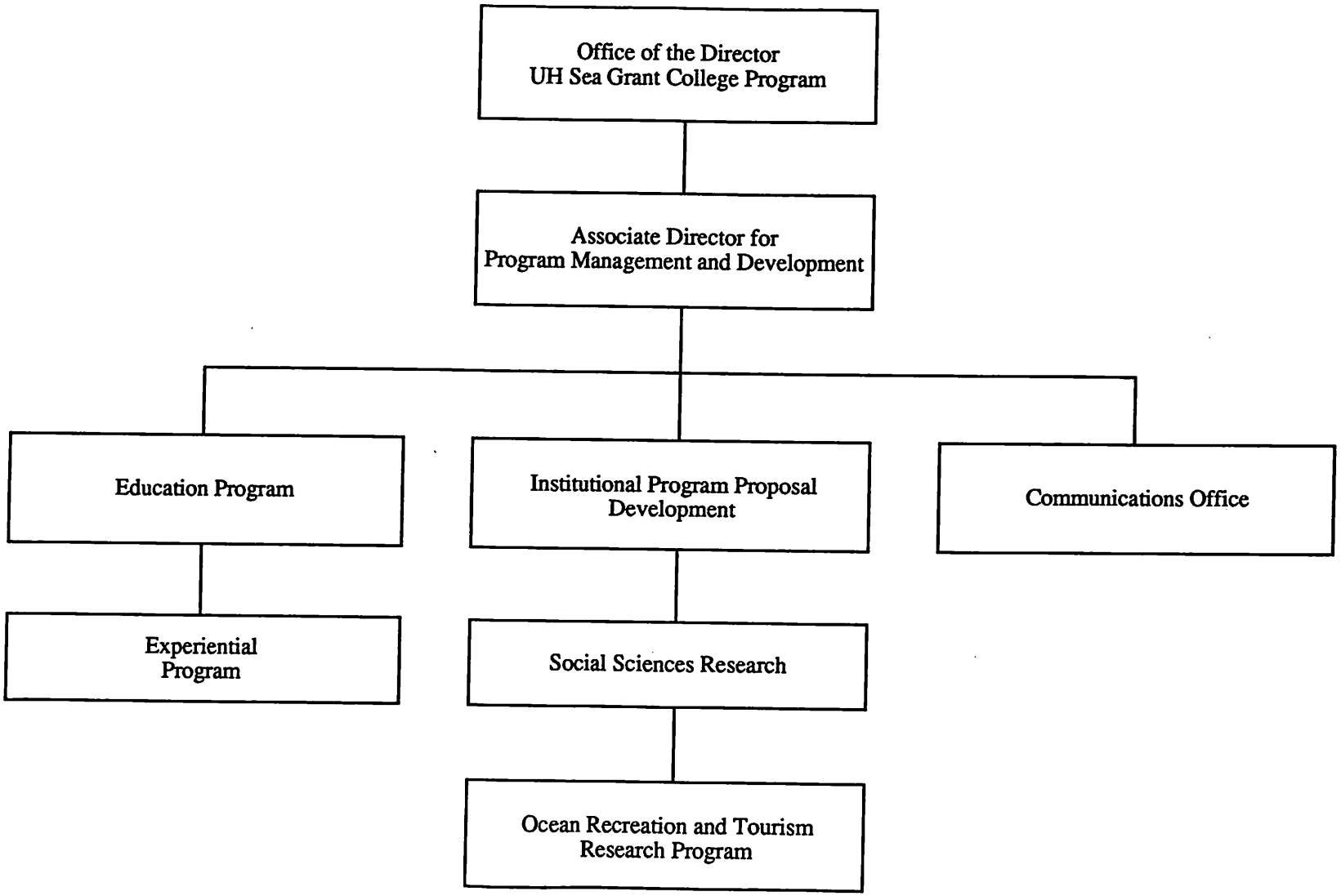


Figure 3. Programmatic Responsibilities — Associate Director for Program Management and Development

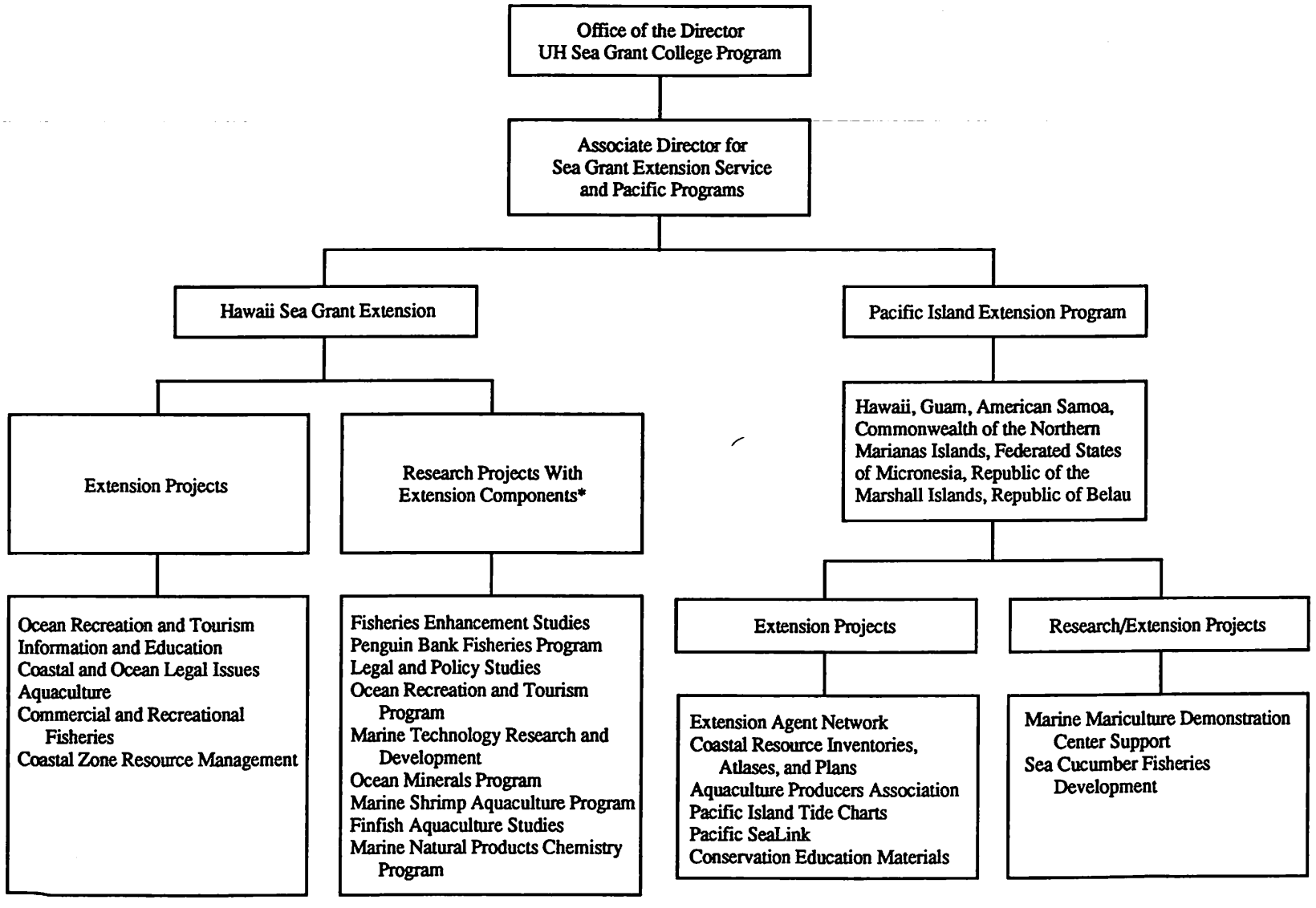


Figure 4. Programmatic Responsibilities — Associate Director for Sea Grant Extension Service and Pacific Programs

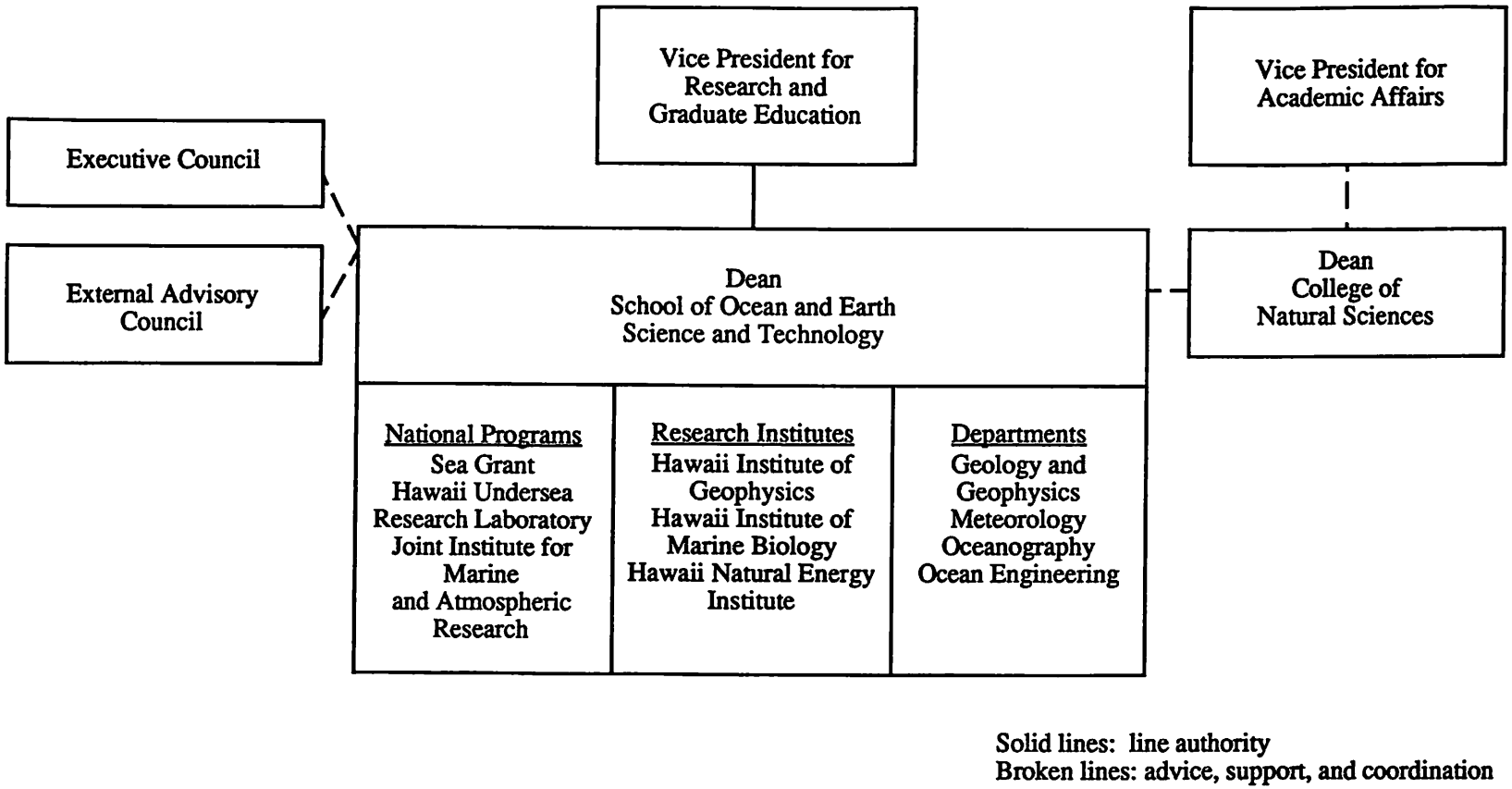


Figure 5. Proposed Organizational Structure of the School of Ocean and Earth Science Technology

priorities that are the results of advance planning. These include ocean minerals, shrimp and finfish aquaculture, marine natural products, Penguin Bank fisheries, and ocean recreation and tourism.

The director's office also makes a general solicitation throughout the university system for preproposals as part of the regular biennial program development process to encourage a wide range of new initiatives and to offer research opportunities to new faculty.

Developing the institutional proposal

Whether subject to advance planning or a result of open solicitation, all projects are judged on the basis of the following criteria: appropriateness to the Sea Grant College Program mission; need; the scientific quality of the proposed procedures and methodology; and qualifications, professional and personal, of the people who will be involved. The criteria for determining the appropriateness of proposed research to the Sea Grant mission are provided in the Sea Grant College Program enabling legislation and by the National Sea Grant College Program annual guidelines. Potential principal investigators of projects are required to submit preproposals at the beginning of the formal institutional program development cycle.

The formal review process starts with the review and evaluation of all preproposals by the Sea Grant Advisory Council (SGAC). The council members provide advice on the need and quality of the proposed work. The preproposals that survive SGAC review are developed into full proposals that are evaluated by peers for scientific quality, appropriateness, and adequacy of the methodology. Where proposals relate to the missions of state and federal agencies, the affected agencies are also requested to review the proposals. The SGAC members have the opportunity to make further input on the selection of proposals by commenting on the full proposals. The final selection of proposals to be included in the institutional program proposal is based on staff, peer, and agency reviews and budget expectations.

Because peer review is considered a critical test of the quality of proposed research, proposals are submitted to four to six professionals who are national or international experts in the subject area. The objective is to obtain a minimum of three reviews that fully judge the merits of each proposal. When several projects are considered to be integral parts of a research program, reviewers are asked to consider each proposal discretely and the program as a whole.

For major multidisciplinary or interdisciplinary programs, e.g. ocean minerals, a technical leader or coordinator is designated from among the participating scientists to help design the program and to integrate the scientific efforts. If appropriate, this person coordinates the scientific efforts and use of joint resources. Each program leader serves for the duration of the program and works closely with the director and his staff in evaluating results and planning and developing changes as required.

Administration of projects and programs

The Sea Grant director's office is responsible for the administrative oversight of all projects and programs, including performance with respect to accomplishment of project objectives, reporting, and fiscal compliance. Typically, the director's office oversees about 70 to 80 projects per year, ranging from new starts to projects in the process of completion.

Formal progress reports and project summaries are required annually of all projects and program initiatives. These reports show the extent to which project objectives have been met, provide the principal investigators' assessment of the significance of the results, and pinpoint important findings to be communicated to users and professional audiences. They also document student involvement and list any publications, patents, or other products resulting from each grant.

Besides the reports, the director and the Sea Grant management team keep abreast of progress more informally. They meet regularly with directors of cooperating research institutes, program coordinators, and cooperating state and federal agency staff, as well as individual principal investigators (to ensure thorough knowledge of the status of the program.)

Fiscal compliance is monitored on two levels. The expenditures and day-to-day fiscal compliance for most projects are handled by the fiscal officer in the home department of the principal investigators. All expenditures are reflected on computerized budget status reports which are received and reviewed monthly in the Sea Grant director's office for compliance to spending limits and as an indication of project activity level.

While administrative requirements of UHSGCP have steadily increased to meet expanded federal and state compliance requirements, so has the proportion of the university's matching contribution. The university now provides most of the resources for program management and administration. This includes staff, space, and computer equipment. Computer hardware and software for administrative support and for publication have enabled UHSGCP to meet large workload increases without increasing the Sea Grant portion of administrative costs.

Program evaluation

Program evaluation has many facets. Tools for evaluation include: (1) peer review, (2) annual progress reports, (3) symposiums, (4) special review teams, and (5) postmortem assessments.

All projects that continue for more than 2 years are subject to re-review by peers and the Sea Grant *site visit team* during its review of the biennial institutional program proposal. Annual progress reports are evaluated to determine progress and accomplishments. In those instances when a large, multidisciplinary program, such as the Ocean Minerals Program, is expected to last 5 years or more, the holding of a midterm symposium is encouraged to present the findings to date and get feedback and evaluation from the professional community.

The period between initiation and completion of major research efforts may range from 5 to 10 years. Within this period, scientists will have had time to achieve early and intermediate-stage objectives, alter working hypotheses and methodologies, and introduce more sophisticated science. They will also have had opportunities to interact with peer audiences and user publics. In such cases, special peer and user teams may be formed to review and evaluate the program.

Finally, an after-the-fact evaluation is done to complete, record, and provide a comprehensive assessment of the program accomplishments. The most visible artifacts of research, education, and extension programs are publications documenting project and program procedures and results. Publications usually continue to be produced for several years after a research project is officially completed and remain as both quantitative and qualitative measures of research. In theory, there are also measurable effects on users and the state of the science. In the case of applied research, these effects are the visible impacts research findings have on policy and management decisions, the use of marine resources and environments, and the spinoffs and economic benefits that have positive effects on individuals and governmental units. Finally, Sea Grant programs affect the careers and the lives of students, technicians, researchers, and educators. The effects of UHSGCP activities on the quality of life in the community are difficult to measure, but they are of the highest significance to society. The major accomplishments and benefits of UHSGCP are described in Part III of this document.

Publication and dissemination of information

The communications unit is an integral part of the Sea Grant director's office. Responsibilities of

this unit include public information services and publication production. Public information activities consist of conveying — to targeted audiences and the general public — the results of Sea Grant research, education, and extension activities. Newsletters, news releases, newspaper feature articles, and radio and television programming are among the major methods used to reach audiences. Public information services include assisting other Sea Grant professional staff and researchers in the planning and preparation of informational materials and activities, such as posters, workshop flyers, publicity, and communications support for workshops and conferences.

The printed record of research results is held in the publications office. Principally, the publications staff (1) edits, produces, and distributes all Sea Grant publications; (2) edits and publishes the institutional proposal; (3) conducts conferences with authors on research proposals and education reports; (4) institutes reviews and recommends procedures for editorial review and publishing; (5) produces camera-ready copy and arranges for publication; (6) edits, prints, and distributes two newsletters — the *Sea Grant Quarterly* and the *Makai*; (7) institutes sales programs and reviews expenditures and income from sales; and (8) monitors the distribution of publications.

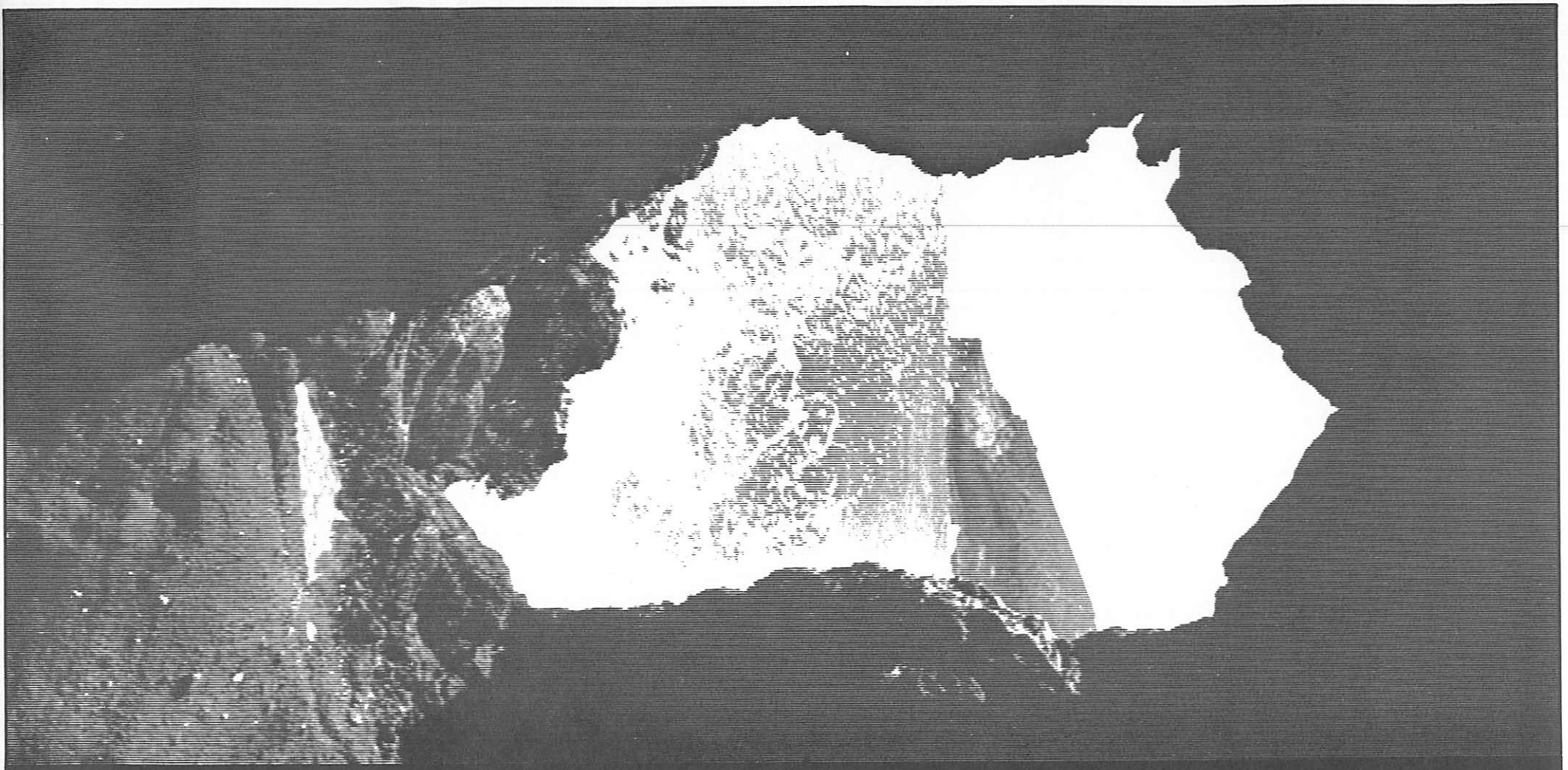
Professional and public service

In meeting the challenges implicit in the UHSGCP mission statement ". . . to provide research, education, and advisory [extension] services to promote the understanding, development, utilization, and conservation of marine resources . . . ," the planning and program development activities project the director and associate directors into active leadership and advisory roles in the community, the region, and the nation. These roles provide the program administrators with the dual advantage of first-hand ability to assess opportunities for Sea Grant contributions and to make personal contributions to the decisions which shape the marine futures of these areas.

For the state of Hawaii, the UHSGCP director serves as a member of the Governor's Hawaii Fisheries Coordinating Council and the Governor's Aquaculture Coordinating Council. These councils, composed of industry and agency representatives, were created by the legislature and its members appointed by the governor. On a regional level, the director serves on the Board of Directors of the Center for Tropical and Subtropical Aquaculture (Pacific region) and as a member of the Pacific Sea Grant Directors' Council, which includes the Sea Grant programs of Alaska, California, Hawaii, Washington, Southern California, and Oregon. Nationally, the director serves on the Board of Governors of the National Coastal Resources Research and Development Institute and on the executive committee of the Council of Sea Grant Directors. He also represents the University of Hawaii at the annual meetings of the Sea Grant Association and at meetings of the Marine Division of the National Association of State Universities and Land Grant Colleges.

The associate director for program management and development represents the University of Hawaii as a member of the Governor's Ocean Resources Tourism Development Task Force. She is the Region IX liaison (Alaska, Hawaii, Washington and Oregon) to the National Council of the American Society of Public Administration and also serves on its National Committee for Program Planning and Evaluation.

The associate director for Sea Grant Extension Service and Pacific programs serves on the Board of Directors of the Honolulu Maritime Center and is a member of the Governor's Task Force on the Honolulu Waterfront. He also serves as the regional representative for the Pacific Sea Grant College Program extension programs. The assistant director for Sea Grant Extension Service is on the Hawaii Visitors Bureau Public Relations Committee and on the City and County of Honolulu Council's Ad Hoc Committee on Public Access. She is also the chairperson of the Research Needs Committee of the Governor's Ocean Resources Tourism Development Task Force.



MAJOR PROGRAMS AND ACHIEVEMENTS

OCEAN WATER QUALITY

ACTIVITY

In 1970, Sea Grant funded a planning project to address the widespread concern for coastal water quality. The project involved University of Hawaii faculty and researchers, as well as members of governmental agencies and business groups in the state. The planning effort resulted in the development of the "Quality of Coastal Waters" project, the first major Sea Grant multidisciplinary program in environmental research.

The coastal water quality project, conducted from September 1971 through August 1974, was concerned with finding solutions to specific instances of existing pollution and with finding means for preventing future pollution from such sources as land development and population growth in sparsely populated areas of the state. The specific objectives included identifying and measuring various pollutants and possible pollutants entering coastal waters, monitoring changes in water quality, evaluating the adequacy of present coastal water quality standards, developing scientific data on which to base water quality protection measures, recommending changes in policy and practice necessary to protect coastal waters (and also assessing the economic and social effect of those recommended changes), and maintaining an informational and advisory program to keep the public informed of the project's findings and the implications of the project's recommendations.

Twenty-three faculty from many disciplines participated including environmental engineering, soils, agronomy, geology, hydrology, agricultural biochemistry, oceanography, marine biology, microbiology, public health, resource economics, and urban planning. Key participating governmental agencies were the Hawaii Department of Health and the City and County of Honolulu Department of Public Works and Department of Wastewater Management. Supplemental funds of $96,000 were obtained through HB 1533, which was passed during the sixth state legislative session in 1971.

As the emphasis of "water pollution" shifted away from the quality of discharges to the quality of resources themselves, oceanic and estuarine waters were recognized as a part of the overall water resource to be protected. Protective measures followed the familiar pattern of classifying waters and specifying the concentrations of constituents which might characterize each class. In 1973-74, therefore, chemical, physical, and bacteriological constituents continued to be the measures of water quality, although a great deal of concern for their effects on living creatures emerged.

During 1974-75, the field site for coastal water studies was the Kona coast of the island of Hawaii. Sea Grant and the County of Hawaii funded a project, "Ecology of West Hawaii Coastal Waters," to provide baseline data to county administrators to plan for large-scale developments along this coast and also to provide input to the state and county's overall study on the carrying capacity of this locale.

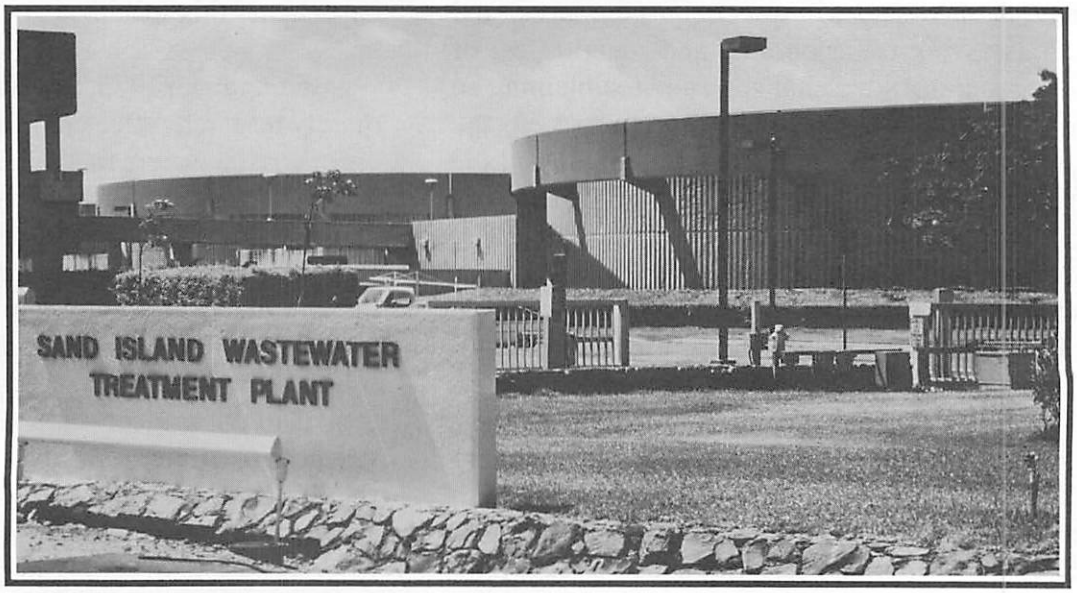
Beginning in 1975, Sea Grant-sponsored water quality research reflected an expansion from studies in coastal waters to studies in all ocean waters. A 2-year project, "Pathogenic Enteric Viruses in Hawaiian Ocean Environment: Viability and Die-Off," was designed to answer questions regarding the presence, concentration, types, distribution, and die-off rate of sewage-discharged viruses in ocean water at existing sewer outfalls. An outgrowth of this project was a newly focused project, "Pathogenic Enteric Viruses in *Hawaiian Ocean* Environment: Role and Effects of Antiviral Agent(s)." This and two other spinoff projects from the "Quality of Coastal Waters" project

comprised the Ocean Water Quality program from September 1977 through August 1979. The "Microbiological Indicator for Ascertaining Fecal Contamination of Marine Recreational Waters" project focused on evaluating candidate indicators of fecal pollution in select coastal receiving and recreational waters. The "Marine Mollusks as Indicator Organisms in Benthic Communities" project concentrated on using mollusks as indicators of stressed benthic environments and on determining their tolerance limits and carrying capacity for viruses and bacteria.

The Ocean Water Quality program was organized as one of the many components of the Sea Grant institutional program in concert with its new program approach and with its continuing and expanded concern for water quality. Under this multidisciplinary program, concern focused on developing methods and technologies to assess marine water quality and on minimizing the effects of degradation of ocean water quality on human health and beneficial uses of marine resources. The operational objectives included identifying the origin and measuring water quality parameters in the ocean as well as those entering the ocean from various land-based developments and other sources, monitoring changes in water quality and in the associated biota, developing scientific data parameters and collection and monitoring methods for establishing water quality protection measures, evaluating the adequacy of ocean water quality criteria from the viewpoint of safe and beneficial use, and assessing the ocean water quality education needs at the primary, secondary, and continuing education levels.

Three new ocean water quality projects were begun in 1979. "Micromolluscan Indices to Marine Benthic Communities in the Central and Western Pacific" was a spinoff project to analyze micromolluscan assemblages as indicators of stressed environments in other Pacific island areas. "The Significance of the Bactericidal Effect of Sunlight on Indicator and Pathogenic Bacteria in Marine Waters on Measurements and Interpretations of Water Quality" project examined mechanisms by which sunlight destroys marine bacteria, especially fecal coliform, fecal streptococci, and *Salmonella.* In 1981, the third project underwent a title change from "Distribution, Isolation, and Characterization of the Natural Antiviral Agents (MAVAs) from Hawaiian Ocean Waters and Other Pacific Regions" to "Characterization of Marine Microorganisms from Hawaiian Ocean Waters With Antiviral Properties of Human Enteroviruses." This project involved isolating, identifying, and culturing marine antiviral agents which inactivate certain human viruses, as well as studying conditions for their adaptation to brackish and fresh waters.

The biological impact of sewage discharged from an ocean outfall was again studied beginning in 1981, but from a different approach. A 2-year study, "Response of the Benthic Ecosystem to the Sand Island Sewage Outfall: A Community



Metabolism Approach," focused on integrating the community structure characteristics of the benthic and microbial populations impacted by the ocean outfall with the functional metabolic characteristics of the ecosystem in order to quantitatively determine the fate and effects of effluent.

The last ocean water quality study conducted in the first two decades of Sea Grant activities at the University of Hawaii centered on vibrio bacteria. In the "Ecological Assessment of Vibrio Bacteria in Marine and Brackish Water Environments Used for Aquaculture, Commerce, and Recreation in Hawaii" project, researchers sought to determine the distribution and relative concentrations of the various species of vibrio in four select types of coastal water environments on Oahu. Emphasis was placed on locations which constituted sites for mariculture activities.

RESULTS AND ACHIEVEMENTS

Out of the intensive multidisciplinary effort which produced extensive scientific data, the "Quality of Coastal Waters" project succeeded in satisfying several uncommon needs. In the area of land-use coastal water quality relationships, the project identified (1) land-use activities detrimental to coastal water quality and marine biological resources, (2) relatively simple land-use management or wastewater management changes that would prevent serious damage to coastal quality and marine biological resources, and (3) situations where land use exerts relatively little impact on coastal water quality.

The axiom — that water quality standards for Hawaii should be specifically geared to a data base for Hawaii's tropical and ocean environment — needed proof which the project provided. Otherwise, serious consequences would result as they had actually happened with the first set of Hawaii water quality standards promulgated in the late 1960s. Undesirable consequences can range from misjudging the actual environment quality, misguided use of coastal water resources, unenforceability of regulations, and discredibility of governmental authority. The warm water, relatively low ambient nutrients, lack of continental shelf and hence shallow waters and island-influenced ocean currents, and volcanic origin of soils and rocks — all contribute to Hawaii's unique coastal water quality that demands locally developed knowledge and data base. Thus, as a result of their findings, researchers provided necessary data to the state Department of Health for use in obtaining a reconsideration of federal water quality standards imposed on Hawaii. The concentration of heavy metals in Hawaiian soils precludes the state's conformity with standards generated for the mainland because the iron content of local waters, for example, is largely a function of soil composition and not necessarily an indication of abateable pollution caused by human activities. Other information resulting from the multidisciplinary project was used for coastal zone management planning by the state, 208 planning by the Environmental Protection Agency (EPA), and an urban water resources study by the U.S. Army Corps of Engineers.

The virus project established scientific data regarding the presence, but quick die-off and limited extent of sewage-borne viruses in ocean water surrounding the Sand Island sewage outfall. In addition, the project developed firm evidences of antiviral agents in ocean water in Mamala Bay and Pearl Harbor, suggesting a potential biological means for virus inactivation.

The project which monitored marine waters for water quality and evaluated its health risk to humans found that fecal streptococci is superior in stability in marine waters than fecal coliform. This suggests that the former may be a better indicator of fecal contamination than the latter, which was the sole accepted indicator at the time of the study. In other studies in both Hawaii and other tropical Pacific areas, marine micromollusks were used as a measure of ocean water quality in benthic

communities over time. Analyses of micromolluscan assemblages were a basic part of the City and County of Honolulu's study of the effects of the sewage outfall and deepwater diffuser system in Mamala Bay.

These studies produced notable accomplishments which relate specific water quality parameters to state and federal management plans and urban resources studies. Scientific data regarding range and mortality of sewage-borne viruses and bacteria in ocean water surrounding sewage outfalls have afforded a rational assessment of probable health hazards associated with ocean disposal. These studies served as the foundation for Hawaii's request to the Environmental Protection Agency to modify the secondary treatment requirement of municipal wastewater for ocean disposal and for NOAA's 5-year plan on marine pollution research. Marine antiviral agents, which consume viruses contained in wastewater, were discovered as a result of the unexpected near-absence of sewage-originated viruses around a major ocean outfall. UH scientists are exploring ways to ultimately package MAVAs for sale as a pharmaceutical agent to clean up virus-infected water.

BENEFITS

A monetary and relatively short-range benefit of the biological monitoring of Oahu's ocean sewage outfalls is a spinoff from the original Sea Grant project conducted by the University of Hawaii Water Resources Research Center. The City and County of Honolulu was seeking — from the Environmental Protection Agency — section 301(h) waivers of secondary treatment requirement for four Oahu ocean outfalls (Sand Island, Barbers Point, Waianae, and Mokapu). The granting of a waiver requires implementation of a biological monitoring program to demonstrate compliance with relevant standards for the 5-year period of the waiver. The completed work was reported in an article, "City Turns to University for Water Resources Help," in *Malamalama* (vol. 9, no. 1, p. 7). In June 1985, the EPA issued a tentative approval for a waiver to the City and County of Honolulu for the Sand Island sewage outfall, permitting less than secondary treatment of municipal wastewater before its discharge into the ocean. The "bottom line" of the program is the monetary saving that accrues to taxpayers as a result of the waivers. By the city's 1988 estimate, the capital cost savings alone will be $88 million annually for the Sand Island outfall; tremendous savings will also occur in annual operation and maintenance expenses ($3.5 million).

The database established by the micromollusk projects has been in continuous use by the City and County of Honolulu in its monitoring program of offshore sewage outfalls. The city has also used it in its application for waiver of certain EPA requirements at such outfalls.

The results of the project focusing on the metabolic processes of ocean-bottom dwellers near the Sand Island sewage outfall showed that bottom communities are very sensitive to introduced nutrients. Although the structure of the communities studied was not affected, it is highly possible that sewage treatments producing larger particles that more readily settle on the bottom could cause some structural changes. This knowledge can be used to predict ecosystem responses in similar situations and help in fashioning more effective management and policy decisions.

Beyond the usual expectations, the project accomplishments are exceptional in providing direct knowledge — heretofore nonexistent — and in showing the direction to take to resolve crucial social, economic, and environmental concerns in a tropical oceanic setting. People will continue to benefit from the project achievements as long as Hawaii continues to be a tropical paradise with a pure water environment.

SEAWEED AGRONOMY

ACTIVITY

For nearly two decades, the University of Hawaii Sea Grant College Program (UHSGCP) has supported the culturing of industrially significant seaweeds principally in Southeast Asia. For most of the 20 years, Marine Colloids, a division of FMC Corporation, was a partner in the introduction of this seaweed culture as a cottage industry, initially, in the Philippines. The long-term support began when the Indonesian supply of *Eucheuma* was cut off by a coup in 1962. Marine Colloids provided the first of many increments of funding and other support to farm *Eucheuma* in the Philippines.

The twofold goal of the UHSGCP project from its inception was to develop a reliable supply of *Eucheuma* for the U.S. market and to provide maximum benefit to the farmers. The accomplishment of this goal required many operational objectives which changed almost as soon as they were articulated because the project's venue in the Sitangkai area of Tawi Tawi Province, a remote coastal area of the Philippines, presented cultural and environmental challenges. Moreover, the agronomic technology evolved on-site by trial and error.

Attempts to develop the agronomic technology to farm *Eucheuma* began in Singapore in 1966. Although the effort failed to produce a workable cultivation method, it was determined that, unlike many terrestrial crops, it was not necessary to complete the entire biological cycle. The breakthrough in the research on agronomic technology occurred in 1968, under UHSGCP funding, while researchers were working in Batangas Province near Manila. This technology was implemented, first, in Zamboanga and, then, in Sitangkai. Essentially, the critical factor was the placement of cuttings tied to polyethylene line so they were held very near the sandy-coral rubble substratus when this bottom material was about 25 cm below the mean level of the lower low spring tides.

A unique component of the UHSGCP seaweed agronomy research program was the extension teams that were developed to disseminate information and to train artisanal coastal villagers to farm. These mobile (boat-transported) technical assistant teams of local natives transferred the new technology to the people of Sitangkai in less than 5 years and changed the basis of their economy drastically from artisanal to cash.

RESULTS AND ACHIEVEMENTS

Although the number of *Eucheuma* farms escalated geometrically over a 10-year period from a few hundreds to thousands, few empirical records remain of the domestication of the two species involved, *Eucheuma denticulatum* and *Eucheuma alvarezii*. However, the societal imprints remain as evidence that *Eucheuma* was successfully cultured in the conversion of Sitangkai from an artisanal to a cash economy and in the increase in population from about 3,500 individuals in the mid-1960s to 35,000 by the early 1970s.

The prosperity of these farm families has had secondary economic "spinoffs" in the rise of a merchant class and the establishment of commercial infrastructures such as banks in Sitangkai. Shipping expanded from one interisland boat every 2 weeks to several per week. The need for labor, a sign of an expanding economy, not only added a new economic dimension to the community, but also changed the individualistic lifestyle of the subsistence-based fishermen to one that is in part service-based.

SEAWEED AGRONOMY PROJECTS

Over the past 20 years, studies on the cultivation of seaweed have been funded under the following projects.

Year Funded	Number	Title
1986-87	R/AQ-40	Terrestrial Seaweed Farming
1985-86	PM/M-20	Terrestrial Seaweed Farming
1982-83	A/R-11	Technology Transfer of *Eucheuma* Farming Information to Ponape
1981-82	A/R-11	Technology Transfer of *Eucheuma* Farming Information to Ponape
1980-81	MR/R-12	*Eucheuma* Farming in Ponape
1979-80	PM/M-1d	*Eucheuma* Farming in Ponape
1976-77	R/A-02	Tropical Marine Agronomy
1975-76	R/A-02	Tropical Marine Agronomy
1974-75	R/A-02	Tropical Marine Agronomy
1973-74	R/A-02	Tropical Marine Agronomy
1972-73	R/05-01	Tropical Plant Aquaculture
1971-72	E/2a-04	Education-Marine Agronomy
	A/5-05	Marine Agronomy Advisory Service
	R/1e-01	Production of Food Colloids from Tropical Marine Algae
	R/1e-02	Seaweed Agronomy
	R/1e-03	Algal Food for Aquatic Organisms
1970-71	—	Food Colloids
	—	Hawaiian Seaweed
	—	Aquaculture Sites

Additional *Eucheuma* farming areas were developed in Palawan and Bohol. The latter area was developed by Antonio-Agro Trade, Inc., Shemburg Trading, Genu, and MCPI (affiliate of Marine Colloids), all of whom export their products to Europe and the United States.

In 1984, the Copenhagen Pectin Company established *Eucheuma* farming in Indonesia. No agronomic data are being kept on the cultivation of a mix of the same two introduced species with native species. No record is available on the social, economic, and demographic impacts.

Eucheuma farms are also being developed on the shores of Hainan in South China. As yet, production has not reached "acceptable growth rates." Other countries have attempted to introduce *Eucheuma* farming into their communities, but only the Philippines and Indonesia have been successful in establishing a viable industry.

Since about 1982, Sea Grant-funded activities in seaweed agronomy has turned to Hawaii and *Gracilaria* spp., seaweeds that are superior to the traditional agar sources. They thrive on the polluted high-fertilizer waters of mud flats or nearshore sand flats. There appears to be considerable potential for the establishment of *Gracilaria* farming on the island of Molokai.

With the growth of the world's agar market it is not surprising that Indonesia and Thailand are interested in developing *Gracilaria* farms. They have explored use of the Sea Grant method of setting spores on lines in culturing *Gracilaria*.

Since 1985, Sea Grant has funded the laboratory phase of terrestrial production of seaweeds in Hawaii. The successful completion of this proof-of-concept test has enabled the researcher to obtain state, county, and federal funds to upscale agronomic technology and hardware for farm production.

BENEFITS

The UHSGCP-sponsored work on seaweed agronomy has gone far beyond the fulfillment of its broad mission of developing a reliable source of industrially important seaweeds. The most remarkable contribution made by this project, in partnership with industry and several foreign governments, is the introduction of an economic stimulus that triggered a dramatic change in the socioeconomic characteristics of several coastal communities in the Philippines. Within a space of about a decade, a small community of subsistence fishermen was ushered into a cash economy. The social structure was altered with the evolving of a merchant class, and an infrastructure that supports the trade of goods and services developed where there was none because the lure of profit attracted financial institutions to these coastal areas. An additional benefit to these communities is the increased frequency of transportation linkages to main ports.

The Sea Grant marine agronomy program has not only contributed societal benefits to poor regions of the world; it has also contributed to the U.S. economy by establishing reliable sources of *Eucheuma*. To agricultural arts, the program contributed a methodology for farming seaweed by tying propagules of *Eucheuma* and setting *Gracilaria* spores on plastic lines. To scientific knowledge, the program has advanced the understanding of algal taxa and the chemical composition and properties of algal derivatives.

PRAWN AQUACULTURE

ACTIVITY

The Anuenue Fisheries Research Center (AFRC) of the Hawaii Division of Fish and Game (since renamed the Division of Aquatic Resources) began cultivation studies of the Malaysian prawn *Macrobrachium rosenbergii* in 1965. After the initial success by Mr. Takuji Fujimura, AFRC's director at the time, in developing the mass larval culture techniques, prawn research and development took two separate paths. One led from Fujimura's work directly into farming practices initiated with high-production expectations (which were never met); the other, to university-based research. Unfortunately, the former path led to the commercial industry starting way ahead of the research programs and coming to perceive itself as state of the art when, in fact, it was not that at all.

The initial problems encountered by the Sea Grant-sponsored research all were related to the almost complete lack of knowledge about the freshwater prawn *M. rosenbergii*. No information was available to guide research and development efforts to commercial production. The life cycle of the prawn had been "closed" by Dr. Shao W. Ling, but beyond this nothing else was known; all research essentially had to start from scratch.

As knowledge was accumulated from the Sea Grant-sponsored research (described below), the behavioral and biological characteristics of the prawn became more clearly understood and finally after about a decade of work the knowledge base for successful prawn farming is in hand. Oddly, the final problem encountered in UH Sea Grant-sponsored prawn research and development was more "sociological" than technical.

The initial successes of small-scale prawn farming and the expectations derived from them were as much a testament to the biological resiliency of the prawn itself as it was of any fundamental understanding and control of prawn biology and husbandry. Unfortunately, the production levels of 1,000 to 1,500 lb/acre/year that were achieved with minimal management and knowledge were below the break-even point for large operations — some of which failed. These commercial failures and the lack of awareness of the solid research and development knowledge base contributed to the perception that prawn culture is "uneconomical" and "doesn't work." As a result, the present industry is refractory to the transfer of the new technology which is the outcome of the Sea Grant research and development efforts. This is the situation today: because of the mistaken perception that prawn production is uneconomical, there is a lack of technology transfer to the industry of the solid technological-knowledge base which has been developed. In short, Sea Grant- and state-funded research results which show extremely promising potential for successful industry development are not being utilized or put to the final commercial-level test.

The different stages of Sea Grant-funded prawn aquaculture research are discussed below. They provide the progression of research and the shifts in research philosophies, priorities, and approaches over time. All research were aimed at assisting in the development of a commercially successful prawn culture industry in Hawaii.

Stage 1. The founding project "Tropical Animal Aquaculture"

Formal Sea Grant-funded work on the prawn began under the aegis of the "Tropical Animal Aquaculture" project which was administered from the Hawaii Institute of Marine Biology (HIMB). This project, which began in 1970, was essentially a screening program for species with economic potential. Project researchers identified

the prawn *M. rosenbergii* as a specific species for research in 1973. In this regard laboratory studies were conducted in the areas of feed development and disease identification. The disease work came under a separate project, "Diseases of the Malaysian Prawn, *Macrobrachium rosenbergii*."

The "Tropical Animal Aquaculture" project continued through mid-1977. In 1975-76, the disease work was complemented by new pilot subprojects involving research in the areas of aquacultural engineering and genetics. Under the latter effort the large variation in growth and size in prawn populations was recognized and the first efforts to manipulate it genetically was initiated. In 1976-77, the "Tropical Animal Aquaculture" project was formally divided into subprojects which continued the work begun in the preceding year with emphasis on the importance of work in nutrition, genetics, and stock management systems.

The "Tropical Animal Aquaculture — Nutritional Requirements of *Macrobrachium rosenbergii*" subproject was conducted at HIMB. The genetics work conducted under the "Tropical Animal Aquaculture — Genetics of *Macrobrachium rosenbergii*" subproject began with a traditional approach patterned after terrestrial animal agriculture. This work was conducted at the Anuenue Fisheries Research Center under the aegis of the UH Department of Genetics. The stock management system work was conducted by researchers of the UH Department of Agricultural Engineering under the "Tropical Animal Aquaculture — Prawn Production and Management Systems Development" subproject. This work was the first attempt to understand and manage prawn populations in ponds.

Stage 2. The Hawaiian Prawn Aquaculture Program

The work conducted under the "Tropical Animal Aquaculture" project laid the foundation for Sea Grant-sponsored prawn research to be carried out under 7 separate projects during the following 2 years. In the 1977-79 biennium, a small commercial prawn industry was developing based on postlarvae raised in the AFRC hatchery and stocked in commercial ponds.

Compared with hatchery technology, pond management technology was well developed. Consequently, research was needed to develop practical pond water management techniques by measuring various biotic and abiotic parameters and relating them to pond yields. In this regard scientists of the "Hawaiian Prawn Aquaculture — Pond Productivity Determinants" project recognized the pond as an aquatic ecosystem which provided not only shelter but food for the prawn. Consequently, seminal work on determining the direct and indirect roles of applied feeds in prawn pond nutrition was begun. This work formed the basis of future prawn nutrition work.

The "Hawaiian Prawn Aquaculture — Aquacultural Engineering and Systems Analysis" project focused on improving hatchery technology, increasing prawn survival by instituting a nursery phase prior to pond stocking, exploring the advantages of new pond designs, and modeling the pond production systems. The "Hawaiian Prawn Aquaculture — Economic Analysis and Information Systems" project grew out of the work which initially emphasized the assessment and management of the prawn stock in the ponds. Indeed, commercial farmers were unable to assess the instantaneous prawn pond standing crop or the characteristics (age class, size class, etc.) of the population. This realization led to the Sea Grant-sponsored work on alternative stock management systems.

Sea Grant researchers, recognizing heterogeneous prawn growth as an important biological characteristic, emphasized the study of its behavioral basis in the "Hawaiian Prawn Aquaculture — Behavior Biology" project. Research centered on establishing the behavioral contributions to heterogeneous growth rates and their relationship to developing optimal pond management systems. The pond population structure was quantified, the relationship of feed characteristics to size variation

Cooperative Efforts

The University of Hawaii Sea Grant Prawn Aquaculture Program was a cooperative effort among state agencies, private sector farms, and UH departments and principal investigators.

The first research activities in prawn culture was conducted within the Sea Grant "Tropical Animal Aquaculture" project for 4 years beginning in 1973 and carried out at the Hawaii Institute of Marine Biology (HIMB), the Anuenue Fisheries Research Center (AFRC) of the Hawaii Division of Fish and Game (since renamed the Division of Aquatic Resources), and the UH Department of Animal Sciences.

The state government supported the Sea Grant-funded prawn program in nearly every year of research from 1973 to mid-1987 — when the species of study shifted from prawns to shrimp. Cash matching funds for prawn research were always above the 2:1 ratio of federal to nonfederal funds.

From 1977 to 1980, the prawn aquaculture program — which focused on selective breeding, nutrition, pond ecology, behavior biology, and growth pattern variation — was headquartered at AFRC, the lead extension agency of the incipient industry. Within the University of Hawaii, the Departments of Genetics, Agricultural Engineering, Agricultural and Resource Economics, Oceanography, and Food Science and Human Nutrition cooperated in various areas of the prawn research. In 1980, the Department of Animal Sciences of the College of Tropical Agriculture and Human Resources joined in this research effort with studies in pathology and nutrition. Significant cooperative efforts were coordinated with the Kahuku Prawn Company and Amorient Inc., as well as many small aquafarms which were assisted by the Department of Agricultural Engineering's extension and research program.

Strong liaison was maintained among researchers of the Sea Grant effort in Hawaii and the Sea Grant-sponsored prawn work in South Carolina and California. Other liaisons included those with the Illinois Natural History Survey for prawn-carp polyculture and the Dor Research Station in Israel for cooperative work funded by the BARD (Israel-U.S. Binational Agricultural Research and Development) program on prawn breeding and growth pattern variation. In addition, the Department of Food Science and Human Nutrition developed a cooperative program with Israeli colleagues.

was determined, and the economically important behavioral differences of genetic stocks were assessed.

The "Hawaiian Prawn Aquaculture — Genetic Improvement" project, which followed the pilot work conducted under the "Tropical Animal Aquaculture" project, focused on maintenance and evaluation of geographic stocks of prawns developed from founders collected through the species range. It was thought that economically important intraspecific variation could be found and used outright for increased production. This, rather than traditional selection, was the research strategy chosen since heterogeneous individual growth (HIG), a major characteristic of the prawns, was beginning to reveal itself as a nongenetic behavioral phenomenon. In this regard, the Sea Grant project focused on estimating (using selective experimental crosses) the degree to which prawn size is genetically determined.

In the 1977-79 biennium, the commercial prawn industry was small but vigorous. The "Hawaiian Prawn Aquaculture — Engineering Advisory Services" project was directed at solving the immediate extension problems confronting the developing industry. About this time the commercial harvest product was entering the Honolulu market. The "Hawaiian Prawn Aquaculture — Post-Harvest Handling and Processing" project was directed at developing the handling, holding, processing, and storage techniques to preserve prawn quality and extend shelf-life.

Stage 3. The prawn is unique: changing goals

Once research began under the Hawaiian Prawn Aquaculture Program, it became apparent that the prawn possessed unique biological characteristics which required dramatic shifts away from the use of traditional agriculture and aquaculture research philosophies and approaches. This was recognized in research conducted under "Hawaiian Prawn Aquaculture Program — Biological Bases of Production." For example, the nutrition work was directed away from a traditional agricultural approach emphasizing biochemical nutritional requirements as in the 1976-77 research to one focusing on the relative role of applied and natural feeds. Similarly, the genetics work shifted from a traditional breeding approach to one of stock management which concentrated first on understanding the prawns' unique size variation at the laboratory level and then on testing management systems at the pond level.

Nutrition, feeds, and feeding

The nutrition work in the Department of Animal Sciences' program began as a result of a prawn industry mandate to test the various commercially available feeds for their ability to sustain prawn growth. This work was carried out under the "Feeds and Supplements for Optimum Pond Production" project in the 1981-83 biennium.

In the 1983-85 biennium, under the "Development of Feeds and Feed Management Strategies for Optimizing Prawn Production in Ponds" project, research focused on methods to maintain prawn standing crops at "semi-intensive" levels using feed management systems which were compatible with the necessity of applying feeds to mud-bottomed commercial ponds. Researchers needed to know not only some specific prawn nutrient requirements but also the relative contribution of formulated feed in directly nourishing the prawn itself and in enriching the pond food web. To do this, researchers had to shift their general research strategy and rely on energy-flow models characteristic of nonagricultural disciplines such as aquatic ecology and limnology. Models employed in studies of terrestrial farm animals were inappropriate because they considered energy flow in feeding as food "chain": (input—> food—> animal—> output). The prawn pond production system was a food "web," whereby energy in applied feeds flow through a number of ecological niches — including some *direct consumption* — prior to entering the prawn itself. This characteristic posed unique research problems which were approached in feeding trials conducted in aquaria,

small research ponds, outdoor pools, and in-pond cages whose bottoms are buried in the mud, allowing the detritivorous prawns access to the pond benthos.

In other research prawns were found to respond strongly to chemosensory cues. This behavior was observed in research conducted under the project "An Investigation of the Chemosensory Feeding Biology of the Freshwater Prawn *Macrobrachium rosenbergii*" during the 1983-85 biennium.

Pond ecology

The work initiated in the 1979-81 biennium continued through aspects of the "Hawaiian Prawn Aquaculture Experimental Research Project" in the 1981-83 biennium, wherein the major ecological parameters in experimental ponds were assessed. This work emphasized productivity of the water column and benthos. This work was continued and expanded in the 1983-85 biennium under the project "A Study of Benthic and Water Column Microbial Activities in Hawaiian Aquaculture Ponds and the Relationship of These Activities with Pond Production."

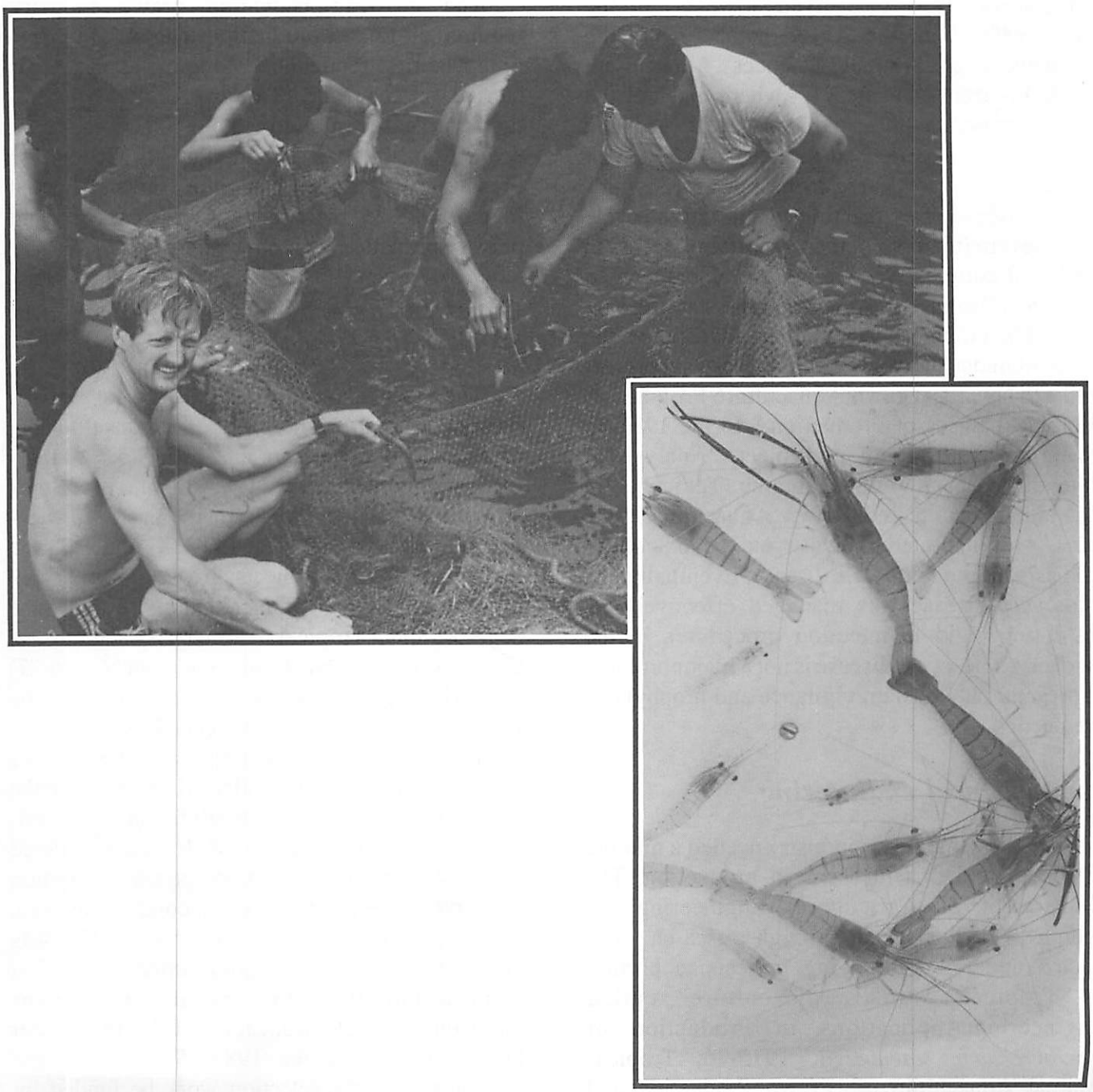
Comparison of the results of the pond ecology work with those of the pond stock management work (described below) showed that further detailed understanding of the pond ecosystem was not going to overcome the major limitation of prawn production shown to be linked to the prawn growth pattern. Indeed, the pond ecosystem, for all practical purposes, could be managed as a "black box" with emphasis on dissolved oxygen and other major water quality parameters which may become acute problems from time to time. In this regard, dissolved oxygen management was given emphasis in the 1983-85 biennium under the "Development of Pond Oxygen Management Devices and Predictive Procedures for Increasing Prawn Production" project. Similarly, the pond ecology work took a different track in the 1985-87 biennium. Instead of emphasizing a detailed understanding of microbial production in prawn ponds, water conservation was emphasized in the "Effects of Low Densities of Silver Carp on Prawn Production, Water Quality, and Water Use in Freshwater Prawn Ponds in Hawaii" project. This was done because it became clear that growth of prawn aquaculture in Hawaii — especially on the island of Oahu — would be strongly influenced by freshwater availability. Government agencies had developed a policy that showed a limit on water use by the year 2000.

Food science and technology

Once pond culture had been established and prawns became available in the commercial market a "handling" problem occurred: improper postharvest handling led to mushiness of the prawn. Initially many believed that something was biologically wrong with the prawn and that it deteriorated more rapidly than similar types of products. However, such products, mostly marine shrimp, were stored frozen solid and therefore were not as much at risk as were prawns which were stored fresh on ice and/or refrigerated. Most of the problems arose from inexperience in handling fresh prawns. The Department of Food Science and Human Nutrition at UH-Manoa conducted the "Hawaiian Prawn Aquaculture — Post-Harvest Handling and Processing" and "Low Temperature Storage of Freshwater Prawn, *Macrobrachium rosenbergii*" projects from 1977 to 1984 to respond to this industry problem and conducted studies on freezing of whole prawns and on the causes of mushiness of ice-chilled whole prawns.

Disease

Research on prawn disease was one of the first Sea Grant-sponsored efforts directed specifically on prawns. Conducted under the "Diseases of the Malaysian Prawn, *Macrobrachium rosenbergii*" project in 1973-74 and the "Tropical Animal Aquaculture — Diseases of Aquaculture Species" project in 1975-76, the initial work was centered on the effect of calcium concentration and molt-related mortality. As pond production gained more emphasis, Sea Grant-sponsored research focused



on the relationship of the chronic exposure to certain levels of pond state variables with the development of latent disease and survival.

Throughout the 1960s and 1970s prawn culture remained free of major, debilitating diseases. This was lauded as a major advantage of culture. Complacency was short-lived however. In the early 1980s, both the AFRC hatchery and the Department of Animal Sciences Aquaculture Prawn Program's hatchery — where much of the genetic, growth pattern, and feeds work was being conducted — experienced a devastating outbreak of a disease which came to be known as "mid-cycle" disease after the time in the larval cycle when severe (up to 95 percent) mortality occurs in the larval cultures. Sea Grant researchers teamed up with colleagues at AFRC and the state Aquaculture Development Program to investigate the problem under the aegis of the disease subproject of the "Hawaiian Prawn Aquaculture Program — Biological Bases of Production." In the 1981-83 biennium, an autonomous project, "Analysis of Potential Organic and Inorganic Toxicants in Hawaiian Shrimp and Prawn Aquaculture Systems," was instituted to investigate the toxicological basis for the mid-cycle disease. Eventually, the mid-cycle disease was managed effectively by instituting rigid disinfection procedures in the hatchery. Mid-cycle disease is not a major problem at present, but constant vigilance and prophylaxis are needed.

Aquacultural engineering

The growing prawn industry needed a number of hardware items to assist in production. The Department of Agricultural Engineering responded to this need through research conducted under the following projects: a portion of "Tropical Animal Aquaculture" called Engineering Applications in Production of *Macrobrachium rosenbergii*, 1975-76; "Tropical Animal Aquaculture — Prawn Production and Management Systems Development," 1976-77; "Hawaiian Prawn Aquaculture — Aquacultural Engineering and Systems Analysis" and "Engineering Advisory Services," 1977-79; "Aquacultural Engineering for Prawn Farming," 1981-83; and "Prawn Aquacultural Engineering," 1983-85 and 1985-87.

Agricultural and resource economics

The growing Hawaiian prawn industry required up-to-date production economic information. The first production economic analysis was carried out under the "Tropical Animal Aquaculture" project. An autonomous UH Sea Grant project entitled "A Bioeconomic Model for Freshwater Prawn Production in Hawaii," funded in the 1983-85 biennium, provided the second prawn production economic analysis.

Genetics, heterogeneous growth, and stock management

The stock management work in the Department of Animal Sciences, e.g., the "Development of Techniques for Prawn and Fish Stock Assessment and Management" (1983-85) and the "Stock Management, Stock Assessment, and Feed Management of Freshwater Prawns and Marine Shrimp" (1985-87) projects, grew out of the work on prawn genetics conducted initially under the aegis of the "Tropical Animal Aquaculture — Genetics of *Macrobrachium rosenbergii*" (1976-77) and "Hawaiian Prawn Aquaculture — Genetic Improvement" (1977-79) projects. First, work was initiated to acquire, develop, and test stocks derived from founders collected throughout the species range because the small founding population of the cultured prawn stock was considered a limited sample of prawn genetic variation available to the aquaculturist. Second, a long-term breeding program was undertaken. It was agreed that the state government and Sea Grant would fund the initial work under the "Controlled Domestication of the Freshwater Prawn" project in the 1983-85 biennium and that the rest of the selection work be funded by other agencies. Work is now being conducted under a grant from the Israel-U.S. Binational Agricultural Research and Development program.

Third, the genetic control of prawn growth was investigated in the genetics portion of "Hawaiian Prawn Aquaculture Program — Biological Bases of Production" (1979-81). However, a characteristic such as growth is complex and controlled by both environmental and genetic factors. One aspect cannot be researched without the other. Consequently, an examination of the environmental control of prawn growth was initiated because the prawn's growth pattern, called heterogeneous individual growth, constituted one of its most economically important biological characteristics; prices paid for crustaceans are a function of their size.

As laboratory investigations progressed, it became clear that the research results provided strong clues to the poor performance productivity of the commercial sector. Consequently, UH Sea Grant researchers began examining the actual practices of the traditional prawn pond stock management system and the initial work that led up to it for guidance on use of the laboratory results as a basis for designing and testing an alternative prawn production system.

Originally, the current stock management system was designed in Hawaii by Fujimura to take advantage of the fact that prawns in a pond population exhibit heterogeneous individual growth. The system, based on selectively harvesting (culling) large animals from the population with seines, allows smaller animals to undergo compensatory growth into the vacated size classes so that market-sized animals could be produced continuously. It had been assumed from the pilot studies that an industry utilizing periodic stocking and harvesting with seines could be developed to sustain production over many years. However, Sea Grant-sponsored research indicated that perhaps stocking cohorts do not completely differentiate into clear modal size-classes when harvesting is inefficient. Sea Grant researchers concluded that inter-size-class competition between stocking cohorts was minimized in the Fujimura pilot studies, as it is in all twice-stocked systems, but is maximized in continuously stocked and inefficiently harvested, but rarely drained, commercial prawn ponds. Indeed, the Agricultural Engineering program researchers demonstrated that seine harvests captured only 50 percent or less of the large, harvest-eligible animals. Based on their research Sea Grant investigators hypothesized that the large animals remaining in the pond not only represent lost revenue but suppress the growth of smaller animals, thereby delaying the latter group's entry into the harvest class. Over time, a mixture of year classes comprises the pond population and newly stocked cohorts must compete with slow-growing, long-term residents and production is lowered significantly.

It became clear that field trials which led to the development of the prawn industry were unintentionally misleading since they were conducted over a short term in small ponds and results were extrapolated to an acre and because they may have underestimated the growth suppression effects of large prawns on small ones and the compensatory growth potential of the latter. Consequently, Sea Grant researchers in the Department of Animal Sciences conducted pond trials on an alternative system to the traditional one. Based on preharvest size-grading and pond drain-harvesting using a machine grader, this system was designed to incorporate state-of-the-art knowledge of prawn growth pattern gleaned through Sea Grant-sponsored research as described herein. Based on this research and the characteristics of the current stock management system, it is now clear that the major constraint to increased prawn yields is inefficient harvesting with seines. This practice undermanages the size distribution of prawns by not allowing the smaller size classes to reach their growth potential.

In summary, work which initially started as part of the genetic work, eventually encompassed the biology and management of prawn growth variation. Work was conducted on many prawn sizes from larvae to market-sized adults and on many levels in the laboratory and pond. This represented a full spectrum of applied aquaculture research and development with each

year's work building on the previous one and making a complete story which pointed clearly to the necessity for an optimal stock management strategy.

RESULTS AND ACHIEVEMENTS

Nutrition, feeds, and feeding

Differences were not found among several leading brands of feed, confirming the hypothesis that prawns derive a good portion of their direct nutritional needs from the pond ecosystem rather than from the applied material. Research testing agricultural by-products as a way of optimizing the prawns' food needs while minimizing costs showed that these materials are of low nutritional quality, and that using them exclusively as feeds would not support the prawn standing crops necessary for economical semi-intensive prawn farming. Agricultural by-products are best utilized as a supplement to commercial prawn pellets rather than as the sole feed.

Other research showed that a non-water-stable pellet and/or a non-pelleted feed is appropriate for use as feed in mud-bottomed pond systems either as food for natural pond food organisms or as feed directly available to the prawn. Results showed that prawns are capable of direct consumption of and growth on the small, non-pelleted feed particles. Drawbacks are loss of nutrients owing to leaching and problems of delivery of the feed.

Using the cage method, research trials were conducted to assess the relative nutritional role of applied and natural food and to assess the relationship between standing crop and prawn size and their effect on prawn growth when feed varied in nutrient density and the ratio of nutrient to energy levels.

In nearly all in-pond cage trials, animals in nonfed control groups regularly grew half as well as fed animals, indicating a nutritional contribution from available natural pond foods. Indeed, it was found that mud-bottomed ponds can sustain a low level of prawn production without the addition of high-quality feeds.

In trials which tested the effect of standing crop size on prawn growth using feeds of different quality, results showed that nutrients (including available energy) become limiting as standing crop increases. It was found that to optimize feed efficiency and maximize pond output it was necessary to develop a management scheme which varies the quality and quantity of feeds over the complete prawn growout cycle in order to compensate for decreased natural foods and/or age-specific growth requirements. Without these adjustments prawn biomass reaches a plateau and remains constant, or even decreases, if grazing-pressure-induced nutrient limitation is not balanced with appropriate input of quality feeds.

Pond ecology

Sophisticated analytical techniques were employed to show that prawn feeding rates, types of feeds, and prawn-fish polycultures directly affect the rate of pond microbial production as measured by protein and DNA synthesis. All in all, research results showed that the state-of-the-art analytical techniques, largely developed for oceanographic and to some degree limnological research, could be applied to studying the prawn pond production ecosystems. However, although the relationship of microbial production to feed and fertilizer (manure) inputs was established, it remained unclear how heterotrophic production could be manipulated to drive prawn production, even if it could be established as a major limiting factor in prawn production systems.

Silver carp were found to have beneficial effects on water use and conservation. Additionally, by constructing an oxygen budget of a prawn pond it was found that significant consumption and

production of dissolved oxygen was attributed to phytoplankton. This meant that prawn density per se is not a major factor in dissolved oxygen management.

Food science and technology

A technology for freezing and frozen storage of freshwater prawn was developed. This technology can now be used to preserve the prime quality of the prawn. The causes of mushiness were explained as collagenolytic and other proteolytic actions on the prawn tail tissues during the initial ice-chilled period of 2 to 3 days, followed by microbial proteolysis.

Disease

The prawn was found not to be susceptible to devastating disease epidemics of the type characteristic of domestic terrestrial animal populations. Consequently, disease was not ipso facto found to be a limitation to the development of commercial prawn aquaculture. A number of disease states in prawn have been described through the extension work of specialists in the state Aquaculture Development Program and elsewhere. However, these diseases are generally attributed to poor water quality in ponds. Moreover, no prominent disease states could be induced by Sea Grant researchers. However, growth and survival were shown to be affected by subnormal levels of nutrients and temperature.

Aquacultural engineering

Under the aquacultural engineering projects, a prawn pond populations growth and dynamics model was developed. This work showed that the uniqueness of the heterogeneity of prawn growth and the continuous stocking and harvesting of undrained commercial ponds present formidable problems for inventory assessment and financial modeling.

In response to the extension needs of the industry the following systems, procedures, and advisory services were developed to assist prawn culturists:

- A mechanical blower feeder that results in reduced labor for feeding, reduced wasted feed, and better distribution of feed in the pond.
- A paddle-wheel aerator that reduces kills due to low dissolved oxygen concentration.
- A prawn size-grader that can be used for both nursed juveniles and marketable prawns.
- A procedure for estimating the average seine harvest efficiency of prawns without having to drain down ponds. (This led to the development of a more efficient seine harvesting system.)
- A seine harvesting system that improves the average harvest efficiency up to 60 percent. The average harvest efficiency of the prawn industry was 30 percent.
- A pond bank grass management system that can lead to higher production.
- A silt dredge for removal of excessive silt in prawn production ponds that cannot be drained down completely.
- An extension program to provide engineering assistance to the aquaculture community.

In addition, under the Agricultural Engineering program some initial trials were conducted using nursery ponds, which, along with the work conducted under the Animal Sciences prawn program, resulted in the implementation of nursery ponds in the industry.

Agricultural and resource economics

Two prawn production economic analyses were published. These analyses, the second an update of the first, showed that prawn production was economically feasible. Break-even points for various farm sizes were established and clearly indicated that the most important limitation of the prawn industry, from an economic analysis point of view, was not costs but revenues, i.e., production. Costs were reasonable — even moderate — and not prohibitive. Break-even production on moderate- to large-sized farms (100 acres) was achievable (1,500 lb/acre to 2,000 lb/acre). Despite this, prawn farming in Hawaii was not a resounding success.

A bioeconomic model of the pond production system was developed in the 1983-85 biennium. Existing data sets were examined and found inadequate. New empirical data were then obtained and used to develop a model that proved to be extremely useful in a heuristic sense. It was clear that the limitation of the model was related to the underlying limitation of prawn production as a whole. Heterogeneous growth of the prawn population in rarely drained ponds containing cohorts from multiple stockings made it difficult to assign a growth function to age classes. The moments of an instantaneous prawn size-class distribution in ponds could be ascertained, but the age-class structure could not be determined with the precision needed. Once again, agricultural economists were confronted, just as their colleagues were in other projects, with the importance of prawn growth pattern variation.

Genetics, heterogeneous growth, and stock management

It was found that *M. rosenbergii* is divided into three major races, but that the characteristics which defined these groups were economically trivial and that genetic variation per se should be conserved and used in a population (called the "base population") composed of the gene pools of all the individual geographic stocks collected. A base population, the first of its kind, was created and is being used to select for growth rate.

Growth in individual prawns in a population was observed to be highly variable. This heterogeneous individual growth, or HIG, led to size distributions that were highly skewed. Prawns in the right-hand tail of the distribution have been referred to as "bulls" and are analogous to "jumpers" in the common carp and to "shoot carp" in the ornamental carp. Individual prawns whose sizes lie around the population mode are called "runts." In prawns, it was shown by UH Sea Grant researchers that the genetic control of HIG in juvenile male prawns is low. In addition, researchers using genetically tagged larval groups established the relationship between harvest-sized animals and their larval growth pattern. Results showed that initial differences in larval stages, which are due to random variation among individual egg hatching times, are magnified into the size differences characteristic of HIG as prawn populations grow.

In extensive laboratory tests it was found that HIG does not develop in populations of individually housed animals to the degree that it does in free-living populations; populations of animals individually housed in aquaria are not self-growth-inhibitory and grow at the same rates as position-segregated individuals sharing common water. It was also found that tactile, visual, and water contact across a barrier does not induce large animals to suppress the growth of smaller animals and that no significant differences exist between the HIG patterns in monosex populations and in populations of the same sex in bisexual populations. It was concluded that the prawn male growth pattern is due to some sort of interpopulational behavior interaction and that it can occur without "indication" by females.

UH Sea Grant researchers also tested whether water from a free-living population of animals in rearing tanks could affect the HIG in a "population" of individually housed animals when passed over them. HIG developed in the latter populations but not in matched populations with clear water

passed over them, suggesting that a long-lived water-bourne factor could be involved with the animal-to-animal communication necessary for HIG to develop.

The positive skewness of the male size characteristic of prawn HIG distribution was shown to be due to three male morphotypes: large, dominant; smaller, subdominant; and undifferentiated small males. Small males and subdominant males are transitory states. As large males are removed from a population they are replaced by subdominant males which transform into the large, dominant male morphotype. It became clear to UH researchers that since small males develop into subdominant males, their growth is best managed by completely removing all the dominant males whose presence restricts the transformation of subdominant males into dominant males.

Overall, the results from work on HIG showed that small prawns retain an inherent capacity for compensatory growth. Their sizes are largely ephermeral conditions brought on by nongenetic, intrapopulational behavioral factors. HIG appears to be a biological and behavioral equilibrium situation in a prawn population and as such has high adaptive value and probably cannot be changed through genetic domestication. Translated into practical terms, these results clearly indicate that the inefficient, selective, seine harvesting currently practiced in the industry may not only represent lost revenue by leaving animals "behind" but also allows a growth suppression of the smaller animals by the large ones. The results of laboratory experiments led to field trials which tested a new prawn stock management system. This system relies on high-density nursery culture using shelters and then periodically grading the prawn population into size classes (generally large and small) in an attempt to create populations of large prawns that can complete their growth cycle and be harvested sooner and create a homogeneously sized class of smaller prawns that can undergo "compensatory growth" once the behaviorally dominant, large prawns are removed.

Experimental results showed the superiority of the newly tested system over the currently used seine harvesting system. The results showed that efficient harvesting has a dramatic effect on the compensatory growth capability of smaller prawns and that size-grading of prawns and stocking by size classes shortens the time to first harvest and the overall turnover time of the pond population. High production rates were achieved because the test populations were harvested with 100-percent efficiency using pond draindown and a machine harvester. All animals were "harvested out" of both experimental and control populations within 12 months. Production per unit of time and area (not total production) was greatest in the size-graded system owing to the high turnover of the large animals and the increased compensatory growth of the smaller animals. Also, time to first harvest was sooner in the size-graded system.

Stock assessment

The stock assessment work included the development of a computer-assisted, semi-automatic, prawn-sampling and data-logging system. This system consists of a waterproof camera mounted on a platform floated in the pond. Slide photographs are taken of prawns and then prawn lengths are "measured" using a sonic digitizer from the slide image which is projected on the back of a screen in a cabinet. The signals from the digitizer are automatically input to an IBM personal computer; software which was custom-written automatically converts each measurement to an individual weight. A complete size-frequency distribution for each pond on the farm is printed out. This system has been field tested on a commercial farm. An enormous amount of time and labor is saved using this system, and farmers can now afford to sample their ponds and maintain more accurate inventory control, predict harvests, and do more precise financial, cash flow planning.

It was shown that pond management could also be improved by using the results of genetic research. Through a process called electrophoresis, broodstock individuals can be

genetically differentiated (marked) and then tracked in a pond where different types are periodically stocked. Data on growth and mortality rates can then be collected for each stocking and harvesting and analyzed by computer to project feeding and harvesting strategies. With this capability, the farmer is assured that the standing crop information is field tested and not just theoretical. This capability has never been available before. Prawn production models have been very inaccurate because of the mixing of stocking cohorts ("year classes") in undrained ponds. However, it is now possible to establish very accurate production functions of single stockings.

BENEFITS

The prawn research program between the state government and Sea Grant assisted in establishing semi-intensive, earthen pond aquaculture as a viable economic activity for Hawaii. The commercial prawn industry has provided the base from which commercial aquaculture activities have diversified and expanded.

Prawn research has contributed the overall technical knowledge base for production in earthen ponds. Important contributions include those in ecology, construction, stock management, harvesting efficiency, labor reduction, and yield improvement. By virtue of the institution and staff infrastructure built during the course of the program, Hawaii has been able to carry out several international training programs as well as develop a pool of management personnel for the aquaculture industry.

Approximately $2 million in state funds was spent on prawn research from fiscal year 1977-78 to fiscal year 1986-87. During this period, 2.2 million pounds of prawns were produced by the industry at a wholesale value of $10.6 million. The number of farms grew from 13 to a high of 24 and is currently at 16. Approximately $8 million was spent on large-scale pilot demonstration projects and commercial farm construction.

FISHERIES RESEARCH

Except for the mid-1970s, research in fisheries at the University of Hawaii has been a major element in the Sea Grant institutional program for 20 years. Emphasis initially was placed on developing underutilized fishery resources, improving harvesting efficiencies of local fisheries, culturing select marine animals, and conducting economic analyses and studies of Hawaii's marine industries — particularly the tuna industry. Several research projects ultimately resulted in the development of new fisheries in Hawaii, such as Hawaiian deep-sea shrimp *(Heterocarpus ensifer* and *H. laevigatus)* and precious corals (pink coral, *Corallium secundum,* and gold coral, *Gerardia* sp.). Neither fishery developed without complication and the need for continuing research, however. Before it got off the ground, the deep-sea shrimp fishery had to await discovery of much larger stocks in the Northwestern Hawaiian Islands in the late 1970s and development of more efficient traps. The precious coral fishery developed in the mid-1970s. Maui Divers of Hawaii, Ltd. harvested precious corals utilizing a small submersible for 7 years before changes in the global economics of the fishery forced its shutdown. Imported resources were cheaper and a glut in the market occurred between 1980 and 1984. However, by 1985 a precious coral industry worth $17 million had been established.

In a similar way, early research results were effective in reducing the mortality of nehu *(Stolephorus purpureus),* the preferred baitfish of the skipjack tuna fishery in Hawaii, by improving procedures for oxygenating baitwells on boats. But the baitfish problem in Hawaii is far from solved. Research on nehu and alternate species is continuing, particularly with regard to baitfish culture.

In the early 1970s, however, some rather significant results were produced in fisheries research. In the research on precious corals, five beds found in the Hawaiian Archipelago were mapped, a method of selective harvesting was developed, and a management plan for the state and federal governments was produced. Another project resulted in the production of an atlas of reef fish larvae for the Hawaiian islands in which 210 different species were described. Prior to this research, fewer than 5 percent of the larvae of 580 species of reef fish in Hawaii were known. Yet another project led to a description of the Kona crab fishery and a characterization of the life history of the major species, *Ranina ranina.*

Despite these gains, fisheries in Hawaii in general in the early 1970s was viewed by many as a waning industry in need of a major new thrust in research and development. Such a program was in fact recommended by Sea Grant researcher Garth Murphy in 1974. Murphy's fishery development plan called for great involvement of Sea Grant in support of both commercial and recreational fisheries in cooperation with state and federal agencies. Murphy keynoted the resource potential of underutilized species such as skipjack tuna, Kona crab, and bottomfish and emphasized the utility of advisory services.

The decline in Sea Grant fisheries research that occurred in the mid-1970s was due, in part, to technical and economic problems which plagued the industry; it was also due to a shift of emphasis in the Sea Grant institutional program toward aquaculture. In 1975, aquaculture research accounted for about 30 percent of the overall program. In that year, only one fisheries project was funded; it dealt with biology and management of reef fish for aquarium use.

As the 1970s moved forward, many of Murphy's concerns attracted the attention of agencies at both state and federal levels. In 1975 and 1976, the Hawaii Department of Land and Natural

Resources began a major planning effort with the Honolulu Laboratory of the National Marine Fisheries Service to study, survey, and assess the fishery resources of the Hawaiian Archipelago. Both agencies perceived that the Northwestern Hawaiian Islands (NWHI) represented a huge natural resource both from the standpoint of opportunities for developing underutilized species and from the need to manage and protect unique ecological habitats and wildlife. A third agency, the U.S. Fish and Wildlife Service, joined the study, focusing on the terrestrial and avian resources of the Northwestern Hawaiian Islands. A contract, known as the Tripartite Agreement, was formally signed in 1977 by the three agencies. This occurred a year after the U.S. Congress passed the Fishery Conservation and Management Act which extended U.S. jurisdiction to 200 miles. At the local level, there was also a need to develop policy regarding the boundaries of the Hawaiian Islands National Wildlife Refuge which today includes most of the Northwestern Hawaiian Islands. Baseline information was needed, especially for threatened and endangered species such as the green sea turtle and Hawaiian monk seal, in order to establish critical habitat boundaries.

The major objectives of the Tripartite Agreement dealt with surveying and assessing marine resources throughout the Northwestern Hawaiian Islands. These islands, including various banks and shoals, comprise about three-fourths of the length of the Hawaiian Archipelago. They extend across 1,150 miles of ocean between Nihoa Island and Kure Atoll. Most of the islands are part of the Hawaiian Islands National Wildlife Refuge created by President Theodore Roosevelt in 1909 by Executive Order. In terms of resource assessment, the tripartite agencies were well equipped to cover the entire spectrum of resources ranging from terrestrial ecosystems to nearshore, offshore, and even deep-shelf (600 meters) benthic species populations. However, for conservation and management purposes, studies were needed to address questions of primary productivity and ecosystem dynamics. This was a role ideally suited for Sea Grant researchers, who, recognizing the need, joined the tripartite effort in 1978 with a major program designed to address these questions. Called the Northwestern Hawaiian Islands Fisheries Investigations (NWHIFI), this program was planned to run at least 5 years. Over this period, it consisted of between 7 and 12 projects annually. Funding for the program was approximately $1 million annually but only about 25 to 30 percent came from Sea Grant. The balance was provided by the state government. Shiptime was provided by the National Marine Fisheries Service.

Much of the results of the NWHI studies were presented at two major symposiums held in Honolulu in 1980 and 1983. One hundred thirteen papers were published in the conference proceedings. In terms of direct benefit-use to society, this research has led to the development of management plans for three commercial fisheries — lobster, deep-sea shrimp, and bottomfish — and a major new 5-year plan for management of the wildlife refuge. The latter plan was produced by the U.S. Fish and Wildlife Service. The NWHI studies represented one of the largest multidisciplinary, multiagency cooperative research programs ever attempted in Hawaii. One of its major research products was a set of papers entitled "Model of a coral reef ecosystem, Part I, II, and III." These papers represent the first ecosystem model ever developed for a coral reef and should prove to be of continuing value for management purposes in the future. Whereas Sea Grant involvement in the NWHI studies was a limited-term effort, research concerning the major issues continues within the tripartite agencies.

In the early 1980s, several new Sea Grant initiatives in fisheries research began to emerge. Two of these, fish aggregation devices (FADs) and artificial reefs, had to do with habitat improvement. Given the rather complete effort at utilizing and managing natural resources as emphasized within the NWHIFI, the next logical step was to improve upon the environment. A program on FADs, developed initially in 1981, was to become the major program in fisheries at the University of Hawaii by the 1983-85 biennium. Similar to

the NWHI studies, it represented a cooperative research effort with the state government. Currently, about 52 FADs are located in Hawaiian waters, most of which are situated near the 1,000-fathom bathymetric contour where fishing success has been best. Sea Grant research has helped in the engineering design of the state FADs and also in terms of their emplacement in the ocean. Some very recent and exciting results of this program include research which demonstrate very predictable swimming patterns of tuna which undoubtedly will be used by fishermen to improve their catch per unit of effort around FADs.

The present fisheries program at the University of Hawaii contains a diverse array of studies, including elements of the NWHI research, the FAD program, a new study dealing with methods to improve the design of artificial reefs, as well as basic research designed to better understand reef fish ecology and offshore "tuna oceanography." The latter project is studying the unique properties of tuna grounds for purposes of improving catch and long-range forecasting of tuna abundance in Hawaiian waters. Several new projects from the University of Guam on coral reef fish ecology and habitat improvement (transplanting seagrasses) complement the existing program in fisheries at the University of Hawaii.

For the past 7 years, fisheries research has accounted for less than 25 percent of the UH Sea Grant institutional program. With the recent emphasis on habitat improvement, there is an opportunity for fisheries and aquaculture to join hands. Restocking the environment with cultured young is just one means of habitat improvement. With the long commitment to aquaculture at the University of Hawaii, a competent team of researchers and body of knowledge have been gradually built up. A brand new initiative in the 1987-89 biennium involves the culture and release of mahimahi, one of Hawaii's favorite food fish. This project is an example of the potential for cross-fertilization between fisheries and aquaculture. It is but one of the many new exciting opportunities for future Sea Grant research in fisheries. Other major programs envisioned are continued efforts with FADs and artificial reefs, genetic engineering studies, methods to improve harvesting and processing, and economic analyses of future trends in the market place.

Research is also needed to address the problem of declining nearshore fisheries stocks around the major Hawaiian islands, to identify causes such as overfishing and pollution, and to develop better management strategies for fisheries conservation. With regard to the latter problem, habitat improvement, stocking, and enhancement with artificial reefs may offer new opportunities.

FISHERY ENHANCEMENT

ACTIVITY

The University of Hawaii Sea Grant College Program, in cooperation with state and federal agencies and private industry, initiated studies in the areas of habitat and fisheries enhancement beginning in 1980. Sea Grant research and technological developments have centered around studies on fish aggregation devices (FADs) for pelagic fisheries improvement and high-tech artificial reefs for enhancement of nearshore fisheries.

Fish aggregation device studies

High seas or pelagic species comprise 85 percent of the commercial fisheries landings in Hawaii. By weight, tunas make up 80 percent of the reported landings. Over the last 7 years reported landings have been down; however, with the use of moored fish aggregation devices, production has greatly increased.

The first Sea Grant-sponsored fishery enhancement project, "The Potential Enhancement and Aggregation of Fishery Resources Due to Floating Objects," was conducted from June 1980 through May 1982. The state Division of Aquatic Resources, the then Office of the Marine Affairs Coordinator, and the Honolulu Laboratory of the National Marine Fisheries Service contributed to the support of this project to study colonization and turnover of fish at FADs. It involved monitoring the relative effectiveness of selected state-deployed buoys in aggregating fishery resources as well as documenting the establishment, growth, and turnover of fish communities associated with the floating devices. In the 1983-85 biennium, this research was continued and expanded under a new project, "Attraction, Enhancement, and Modeling of Pelagic Fishery Resources Around Floating Objects." The project aimed at refining the model of colonization produced under the first project and at examining the trophic relationships of some important fish species in the buoy community. Its activities included both developing a hypothesis as to why fish aggregate and performing some preliminary experiments on the role and effects of shelter space beneath FADs. Because of logistical problems with the deployment and monitoring of structures under FADs, work continued into the 1985-87 biennium. The title for the continuing project was changed to "An Analysis of Pelagic Fish Aggregation to Floating Objects."

The "Determination of Prey Odor Components to Increase the Effectiveness of Fish Aggregation Buoys and Live Bait" project dealt with another

Buoy Experiments Conducted by Federal and State Agencies

In the late 1970s, the Honolulu Laboratory of the National Marine Fisheries Service deployed surface buoys in deep offshore waters. The moored buoys were effective in aggregating migratory pelagic fish in one location for short periods of time, making them more accessible to fishermen.

In 1980, the state Division of Aquatic Resources embarked on a FAD program deploying 26 buoys around the main Hawaiian islands in waters ranging from 180 to over 1,000 fathoms in depth. The buoys were an immediate success, as measured by an increase in reported landings of about 10 percent. In short, FADs represented an important technological advance that resulted in more efficient utilization of pelagic fishery resources.

aspect of fishery enhancement — namely, the development of fish attractants using prey odors. In 1981-82, much of the effort concentrated on onshore testing of prey odors using various time-release devices to assay the responses of captive tuna to them. In the following year, work was expanded to include sea testing of aggregation enhancers and feeding arousal initiators on wild tuna. In the 1983-85 biennium, work on chemosensory techniques was continued under the "Development of Prototypical Chemical Attractant Systems for Pacific Tuna Fisheries" project. Designing and testing of equipment to store and disperse either synthetic or crude stimuli under typical fishing conditions were central to the project, as was the development of stimulus binders with appropriate dissolving characteristics. The latter was done in cooperation with researchers of the University of Florida Sea Grant College Program's synthetic bait project. The United Fishing Agency in Honolulu and the Ika Corporation in Fiji cooperated in the sea testing of odors. As for FAD-related research, the focus was on testing the effect of natural and synthetic odors in improving FAD "start-up" times. The ultimate goal — that of refining prey odors to specific compounds, synthetically duplicating them, and developing release mechanisms for use by tuna fishermen and FAD users — was not achieved because of difficulty in identifying and duplicating the compounds.

In addition to the two projects that explored aspects of making FADs more effective, two other projects comprised the Marine Fisheries Enhancement Studies component of the UH Sea Grant institutional program in the 1983-85 biennium. The "Investigation of Technical Failures of Fish Aggregation Buoys and Development of an Improved Design" project focused on *in-situ* engineering studies to determine the weak points in the Hawaiian FAD system and to make recommendations for improvement. The "Short-Term Tracking of Yellowfin Tuna in the Vicinity of Fish Aggregation Devices" project involved the use of ultrasonic telemetry to track local movements of tagged tuna, which is a highly migratory species, from a small research vessel. The Japan Tuna Fisheries Cooperative Association contributed funds in support of this research. The tracking study was continued in the 1985-87 biennium. The title change to "Ultrasonic Telemetry of Horizontal and Vertical Movements of Pelagic Fish Species Associated with Fish Aggregation Devices" reflected the expanded investigation to include larger yellowfin tuna, skipjack tuna, and mahimahi — all of which are of great commercial, recreational, and academic importance, as are the FADs with which they are associated.

Two projects — "Feeding and Energetics Telemetry of Free-Swimming Tuna" and "Enhancing Juvenile Fish Recruitment for Coral Reef Fisheries" — comprise the fisheries enhancement studies for the 1987-89 biennium. The former, a spinoff from the 4-year tracking project, involves collecting feeding and energetics data from free-swimming tuna equipped with transmitters to monitor jaw movements, tail-beat frequency, body temperature, depth, and geographic location. The latter focuses on developing appropriately designed artificial nursery reefs to enhance recruitment of juvenile coral reef fish. The amount and quality of refuge space are important design considerations.

Artificial reef studies

Although not exceeding more than 15 percent of the total reported commercial landings, Hawaiian inshore or coral reef fishery resources are particularly important to noncommercial users because of the diversity and accessibility of the species present. Coral reef fishery resources are dwindling, however, owing to high fishing pressure and numerous perturbations caused by such factors as nutrient loading and pollution, runoff, infilling and dredging, and the introduction of exotic species.

In response to these inshore fisheries problems, an artificial reef program was established by the state Division of Aquatic Resources in the early 1960s. The early reefs, built of unmodified scrap

materials, worked well initially, but over time proved to be relatively poor fish attractants. They had low profiles, little refuge space, poor stability characteristics, and short lifespans.

In the mid-1970s, Japan embarked on an ambitious national program of coastal fisheries enhancement through the construction and deployment of artificial reefs. Under this continuing program, which is funded at about $100 million annually, the Japanese have developed reef units or modules that are specifically engineered for stability, durability, and economy and designed for biological effectiveness. The wealth of information generated has considerable potential for application in U.S. fisheries.

It appeared that Sea Grant's goal to improve inshore fisheries could be met by a transfer of Japanese technology with design modifications to suit Hawaiian conditions. The Hawaii Department of Business and Economic Development and Sea Grant sponsored a preliminary study in 1983-84 to ascertain the feasibility of this technology transfer; the conclusions reached were that such a program was possible. However, because the costs of designing, building, deploying, and monitoring an experimental reef were large, funds were sought from outside sources. In 1985, Sea Grant researchers were awarded $250,000 from the Saltonstall-Kennedy Fisheries Development Program to develop the technology for Hawaiian waters.

The design chosen was an open framework cube and the material used was concrete. The design incorporated refuge space for fishes. Undersea engineering experiments were conducted to test the stability characteristics of the components. Following analysis, concrete cubes were built and deployed as a small demonstration high-tech reef in November 1985.

As part of the study of specifically designed reefs, a small pilot project — carried out with funds from the pelagic fish aggregation analysis project — was undertaken to ascertain the value of small tautline-moored midwater fish aggregation devices for the enhancement of coral reef fisheries. Preliminary data suggested that these structures could serve as recruitment sites for metamorphosizing juvenile fishes. Support was obtained from Sea Grant and state government sources to develop this technology for possible use in artificial reefs designed specifically to increase the recruitment of juvenile fishes to the adult habitat. This study commenced in June 1987 under the "Enhancing Juvenile Fish Recruitment for Coral Reef Fisheries" project.

In an effort to explore the use of materials of opportunity suitably modified for artificial reefs, Sea Grant supported habitat enhancement research utilizing scrap automobile tires. The researchers of this mini-project, "Investigation into the Development of a Design for the Construction of Artificial Reefs in Hawaii Using Scrap Tires," developed a small demonstration reef using tires bolted together and to the substrate for stability; a reef of this design has very low construction and deployment costs.

Other Sea Grant habitat enhancement research is focusing on the suitability of various materials for the construction of artificial reefs with respect to the settlement and growth of corals and other sessile invertebrates. In 1983-84 and 1986-87, a mini-project, "The Suitability of Artificial Reef Materials for the Recruitment and Survival of Juvenile Corals," was undertaken. These studies are important for the development of effective reefs because many benthic species serve as forage for fishes whereas others such as corals and coralline algae may help to cement artificial reef materials to the substratum, thus increasing the stability of the reef.

These studies are providing documentation and a quantitative foundation for the rational enhancement of inshore fishery resources. However, further work is needed, particularly with the documentation of biological attributes of reefs larger than any built to date. Final experiments need to be conducted at ecologically relevant

scales to complete our understanding of how and why reefs "work." Because of funding restrictions, present experiments have been carried out at less than full scale. Larger high-tech reefs need to be built.

RESULTS AND ACHIEVEMENTS

Fish aggregation device studies

From the study on colonization and turnover of fish to FADs, a simple mathematical model describing the initial colonization process was developed. In addition, some patterns of residency in FAD-associated fish were delineated, and the trophic biology of FAD-associated fish was quantitatively described. Trophic analysis showed that some species (e.g., mahimahi, skipjack tuna, wahoo, and billfish) appear to consume whatever prey are present around the aggregation device. This suggests that any improvement in the recruitment of prey or their subsequent survival around a device could enhance the attractiveness of a FAD to the larger predators. Addition of shelter space beneath FADs does enhance the abundance of prey around the device, but it also increases drag on the FAD mooring system. Thus, such an addition is of questionable value.

The tracking study developed low-cost techniques to tag and track FAD-associated tuna from a small vessel. It found that small tuna appear to spend considerable time well below the surface and thus out of reach of fishermen using surface fishing methods.

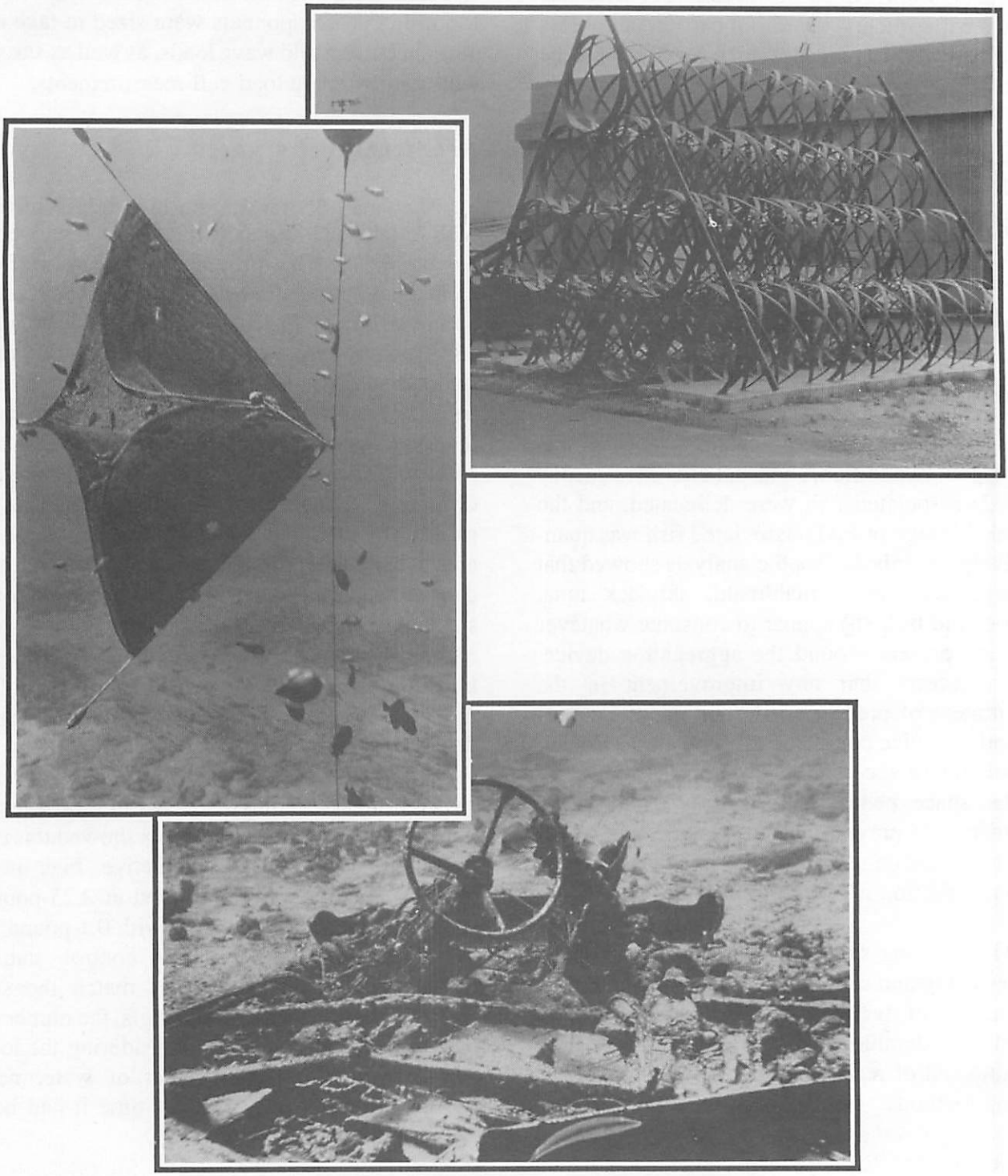
New design features were developed for the FAD system. Nylon insets were placed where the buoy and anchor meet to prevent metal-to-metal contact. The polypropylene line was replaced with another type that is not subject to creep failure at low but steady loads. The near-surface multicomponent line was replaced with a plastic-coated and impregnated steel cable, which is not as vulnerable to damage from shark bites or fish hook snags. Mooring line components were sized to take into account current and wave loads, as well as stresses indicated by wave load cell measurements.

Artificial reef studies

The small demonstration high-tech reef built with Saltonstall-Kennedy funds and deployed in November 1985 has proved the value of artificial reefs in attracting and colonizing fish in sufficient numbers. The peak density of fish on the concrete cube modules equaled an estimated 2,600 grams (more than 5.5 pounds) per square meter as compared with about an average of 40 to 60 grams (a few ounces) of fish per square meter on natural reefs in Hawaii. Based on the data gathered, Sea Grant researchers are confident that the reef has not merely attracted fish but has, in fact, increased the area's fish population. Furthermore, monitoring data showed that under high fishing pressure the standing crop of commercially valuable fishes was maintained on the artificial reef at more than seven times the most productive natural reefs and five times the biomass on other types of artificial reefs deployed in Hawaiian waters.

Preliminary studies on the use of scrap tires for the construction of artificial reefs showed this type of reef to be biologically effective. Fish at the scrap-tire module were observed at 2.25 pounds per square meter as compared with 0.1 pound per square meter at the nearby control station. Although this count does not match the success at other types of artificial reefs, the number of fish attracted is remarkable considering the location of the reef — in 40 feet of water near Kewalo Basin — and the short time it had been installed at the time of the study.

In the past, designs did not include any strong fastening device to secure the scrap-tire reefs to the ocean floor. The model developed by Sea Grant researchers, after considerable thought and tests on components, consists of 38 tires set in a pyramid shape fastened together with nylon bolts and fixed



to the ocean floor with threaded fiberglass rods imbedded in the coral.

Sea Grant researchers have found a hierarchy of preference in substrate material for settling corals; among artificial substrates, concrete is the most acceptable.

BENEFITS

Through the fishery enhancement studies conducted over the last 7 years, Sea Grant has contributed to the development of a more productive pelagic fishery in Hawaii. The information generated has helped to improve the design and life expectancy of FADs, to define the most effective spacing and placement of FADs to maximize the aggregation process, and to provide fishery managers with quantitative data needed to manage the resource. Furthermore, from the fisherman's perspective, these studies translate into more and better fishing. But the utility of this information goes beyond Hawaii; it has been incorporated into FAD programs in the Pacific and Indian oceans and the Caribbean Sea. For many new island nations, particularly in the Pacific, the fishery resources in their 200-mile exclusive economic zones represent one of their greatest known economic assets. Many of the same fish species studied and caught in Hawaii are exploited in these tropical FAD fisheries. With the rising cost of fuel and the prohibitive expense of modern methods of capture, these resources are difficult to tap. Fisheries development utilizing the FAD concept allows artisanal fisheries to expand at minimal cost and successfully exploit offshore resources. The technology developed in Hawaii has been successfully transferred to many of these island areas.

The private sector has seen the positive results of Sea Grant habitat enhancement research. Atlantis Submarines, Inc., a submarine dive tour operation, is currently seeking necessary permits to construct full-scale high-tech artificial reefs using the technology developed by Sea Grant researchers. The reefs will be located on the islands of Hawaii, Oahu, and Maui. The cost for each reef will be between $.5 million and $1 million. Sea Grant researchers will assist in the design and deployment of the artificial reefs and, with financial support from the tour company, will conduct pertinent studies on them. The tour operations are expected to generate considerable revenue and create new jobs.

The commitment by private industry demonstrates the validity of the Sea Grant fisheries and habitat enhancement studies. State officials are embarking on a renewed program of artificial reef construction incorporating high-tech designs to improve inshore fisheries. Key state legislators are monitoring these public and private efforts with interest. The Sea Grant fisheries and habitat enhancement program has also attracted attention at both national and international levels with requests from commercial and recreational fishermen and fisheries agencies for information on modern methods of fisheries improvement.

The Sea Grant fisheries and habitat enhancement program is one of the most advanced and innovative of any in the United States today. It is expected to grow and evolve to meet the needs of Hawaii's people and contribute significantly to the future management of fisheries resources in the state.

NORTHWESTERN HAWAIIAN ISLANDS FISHERIES INVESTIGATIONS

ACTIVITY

With the enactment of the Magnuson Fishery Conservation and Management Act in 1976, the need for data to develop fishery management plans for the resources of the Northwestern Hawaiian Islands (NWHI) became urgent. To meet this need, the resources of federal and state government sectors and the University of Hawaii were combined to assess the levels of the standing stocks of commercially valuable species in the Northwestern Hawaiian Islands. Sea Grant funds — along with matching state funds from the Office of the Marine Affairs Coordinator — enabled university scientists to join a tripartite group of state and federal agencies to launch a comprehensive 5-year resource assessment and ecological investigation program.

Sea Grant's Northwestern Hawaiian Islands Fisheries Investigations (NWHIFI) program, initiated in 1978-79, was specifically designed to provide information to fill gaps in the research conducted under the tripartite study. The major goal of Sea Grant's fisheries investigations was to determine the potential of the fisheries of the NWHI for economic development compatible with needs for preserving and conserving various species of wildlife.

The initial NWHIFI program included eight studies, seven of which received funding for 1978-79. Over the 5 years, the number of studies changed as some were completed and others added. A brief description of each project in the program is given below.

The Tripartite-Sea Grant Study of the Northwestern Hawaiian Islands

In 1977, Sea Grant entered into a cooperative research agreement with state and federal agencies to conduct the most comprehensive study of the marine ecology of the Northwestern Hawaiian Islands ever attempted. The goals of the multidisciplinary research were aimed primarily at stock assessment and resource management. A council consisting of the heads of participating agencies was established to coordinate the research activities.

The Hawaii Division of Fish and Game (since renamed the Division of Aquatic Resources) was responsible for surveying and assessing fishery resources of the nearshore zone from the shoreline to depths of 20 meters. The resulting inventories would be used to produce maps of the distribution and abundance of significant species.

The National Marine Fisheries Service was responsible for surveying and assessing the insular, seamount, and pelagic resources in waters overlying depths between 20 meters and 600 meters. The major focus was to better

understand the commercial and recreational potential of resources in this zone within the framework of the need to preserve the ecosystem. In this regard, its Marine Mammal Division supported a study on the life history of the monk seal, an endangered species, at Laysan Island in 1977 and 1978 in order to estimate the effects of potential fishing activities on monk seal populations.

The U.S. Fish and Wildlife Service was responsible for assessing the avian resources of the Hawaiian Islands National Wildlife Refuge, the nesting habitat of an estimated 10 million seabirds. The potential impact of commercial and recreational fishing on the food budgets of seabirds was a major concern.

Sea Grant was responsible for addressing questions dealing with the potential productivity of the Hawaiian Archipelago as a system (or a set of systems) with emphasis on the Northwestern Hawaiian Islands. Alternative management strategies, population dynamics of specific fishery resources, community dynamics of reef and nearshore ecosystems, and the social and economic implications of alternative management and development strategies were addressed.

The "Primary and Secondary Plankton Productivity and Potential Fishery Yields in the Hawaiian Archipelago" project was concerned with developing information concerning *in-situ* productivity of the waters surrounding the Hawaiian Archipelago and relating this to potential fishery yields. Under this 2-year project, the dynamics of five trophic levels were investigated.

The "Reef and Precious Coral Resources: Comparative Ecology Within the Hawaiian Archipelago" project was initially designed to determine what ecological differences exist for reef and precious corals at the opposite ends of the archipelago and the causes of these differences, as well as to determine the abundance of precious corals in the NWHI. During the second and third years, under a new title, "Reef and Shelf Benthic Ecology of the Hawaiian Archipelago," it focused on creating an information base for the management of commercially important species which depend on the reef or slope for food or shelter. This refocusing to address more fundamental issues of biology increased cohesion among projects in the NWHIFI program.

The "Ecology of Top-Level Carnivores in the Reef Communities of the Northwestern Hawaiian Islands" project was included as part of the NWHIFI program for the first year but was not funded. It was funded for 3 years beginning in 1979-80 under a new project title, "Trophic Analysis of Shallow-Water Fish Communities in the Northwestern Hawaiian Islands: Effects of Natural and Human Predation." It involved defining the major trophic relationships of nearshore reef fish communities and identifying the routes and rates of reef/lagoon production out to deeper water and vice versa. It also involved an assessment of the effects of apex predators on reef community structure and the short-term impacts of increased fishing pressure. It was an important link in assessing the interaction and effects of competition for resources among seals, turtles, fish, seabirds, and humans.

The "Survey and Assessment of the Green Sea Turtle Resource of the Northwestern Hawaiian Islands" project began a year before the NWHIFI program was initiated. The designation of the green sea turtle as a threatened species in September 1978 increased the need — and national attention on the need — to effectively

manage and conserve remaining stocks of this species. The primary objective of the 1979-80 effort was to assist the National Marine Fisheries Service in establishing a permanent marine turtle management program.

The "Population Biology of Spiny Lobsters Throughout the Hawaiian Archipelago" project centered on collecting and interpreting data critical to the development of a fishery management plan for lobsters. The primary focus of the first 3 years of this study was on improving estimates of maximum sustained yield, measuring density, determining population autonomy, and investigating patterns of larval recruitment — factors which determine year class strength and the rate at which juveniles enter the fishery. During the second 3 years, this project expanded its scope, as indicated by its new title, "Population Biology and Test Fishing of Hawaiian Spiny Lobsters."

"An Analysis of Some Aspects of the Fishery Biology of Snapper and Grouper Populations in the Hawaiian Islands" dealt with two of the most valuable commercial groups of fish species found in the area of study. During the second year of this 3-year project, the title was changed to "Development of a Biological Basis for Managing the Handline Fishery for Snapper and Grouper Populations in the Hawaiian Archipelago." The researchers focused on producing a yield model based on single species methods such as the Beverton-Holt model and exploring the application of new approaches to modeling multispecies fisheries.

The "Genetic Aspects of Population Structure of Spiny Lobsters and Snappers in the Northwestern Hawaiian Islands" project also focused on management-related research to identify the population boundaries for selected species on the basis of their commercial importance and reproductive habits and ecology. In the second and third years of this research, two other species — limpets and pomacentrids — were added for study. This is reflected in the title change to "Genetic Aspects of Population Structure of Four Species in the Northwestern Hawaiian Islands." Central to the research was the production of a model or at least a relative measure of interbreeding between island populations of species which exemplify biological extremes (completely mixed versus isolated populations).

The "Economics of Fisheries Development for the Hawaiian Archipelago" project involved an analysis of the potential socioeconomic impacts of further fishery development in the area of study. Based on best available biological estimates of stock abundance for species of commercial importance and projected cost and price relationships, researchers centered on synthesizing efficient fishing industry development models. They also focused on determining the cost of an alternative management system and comparing social and economic benefits and costs. During the last year of this 4-year project, the title was changed to "Socioeconomic Implications of Resource Management Options for the Northwestern Hawaiian Islands."

In 1980-81, two new projects were added to the Sea Grant NWHIFI program. The first, "Hydrography, Primary Productivity, and Inshore Planktivorous Fish Production at French Frigate Shoals and Kawaihae Bay, Hawaii," represented a shift from a 2-year study of *in-situ* productivity at offshore stations to a 2-year study at nearshore sites. The second, "Laboratory and Field Studies of Ciguatoxigenic Dinoflagellates in the Hawaiian Archipelago," constituted a 3-year effort focusing on mass culturing and ecological studies of *Gambierdiscus toxicus*.

In 1981-82, three new projects were begun. The "Benthic Primary Productivity at French Frigate Shoals" project placed major effort on obtaining annual estimates of the area. The "Hawaiian Seabird Bioenergetics: The Impact of Seabirds on Marine Food Resources" project focused on determining the metabolic needs of seabirds in terms of nearshore and pelagic fishes that make up their diet. The "Institutional Policymaking on the Management of the

Resources of the Northwestern Hawaiian Islands" project was an effort to clearly outline the infrastructure and mechanisms of the decisionmaking process and the extent to which Sea Grant and tripartite research had an impact on that process.

RESULTS AND ACHIEVEMENTS

In 1979, it was decided by the heads of the tripartite agencies and Sea Grant that sufficient progress had been made to convene a symposium to interchange research results and ideas and to incorporate this information in planning the remaining 3 years of research. The symposium was held on April 24-25, 1980, on the University of Hawaii Manoa campus. Twenty-seven papers were presented to 151 invited representatives of government agencies, industry, the University of Hawaii, environmental groups, and the private sector. The proceedings of the symposium was published.

A second and final symposium was held on May 25-27, 1983. Overviews of the research conducted in the NWHI on each major topic of concern were presented to the 211 registered individuals representing state and federal government agencies, academia, and the private sector — particularly fishermen and environmentalists. Reports containing more detailed descriptions of more specific subject areas were published in the two-volume proceedings. An attempt was made to make these volumes as complete a reference document as possible on the results of the tripartite-Sea Grant cooperative NWHI study.

Some results of the 5-year Sea Grant NWHI fisheries investigations are given below.

Researchers estimated that the potential fishery yield in Hawaiian waters is two to four times (9,000 to 18,000 metric tons) greater than the annual catch (4,500 metric tons) of tuna in the preceding two decades. A "top down" look at the food web helped scientists and resource managers estimate fisheries yields of targeted species and gauge the effects of man's fishing activities on reef communities. From multispecies analyses, researchers determined that the deep-sea handline fishery for bottomfish is probably producing close to maximum levels off the main islands. Despite historically heavy fishing pressure, this fishery has remained stable, but researchers concluded that management of bottomfish resources may be required to ensure continued stability.

In addition, researchers estimated that seabirds consume 350 metric tons of fish and other seafood daily. Spiny lobsters found throughout the Hawaiian Archipelago are genetically homogeneous; hence, investigators concluded that they should be managed as a unit stock. Scientists also found that at a point — dubbed the "Darwin Point" — somewhere just north of Kure Atoll, the rate of coral growth is insufficient to prevent islands from "drowning." Were it not for colder water and less intense sunlight at more northerly latitudes, the Hawaiian Archipelago might stretch all the way to Siberia.

Taken as a whole, the data and results of the fisheries investigations comprise an encyclopedia of information on the Hawaiian Archipelago, particularly on the Northwestern Hawaiian Islands.

Both the tripartite program and the Sea Grant program produced an extensive database that was used to develop an ecosystem model (ECOPATH) for French Frigate Shoals. Initially, this ecological model was to be used to predict the effects of fishing as well as environmental anomalies on exploitable stocks.

BENEFITS

A better understanding of complex interdependent tropical island marine ecosystems now exists. Delicate island ecosystems are now under

the protection of a federal national wildlife refuge management plan designed to protect threatened and endangered marine species, including birds.

A marine turtle management plan for the Hawaiian Archipelago was the major benefit of the research on the Hawaiian green sea turtle. A fishery management plan for precious coral in the entire Hawaiian Archipelago was completed and subsequently accepted by the Secretary of Commerce. Fishery management plans for lobsters, bottomfish, and pelagic fishes were developed by the Western Pacific Regional Fishery Management Council. All relied heavily, if not exclusively, on the results of the NWHIFI study.

The annual harvest value of three NWHI fishery resources — lobsters, bottomfish, and pelagic fishes — is about $12 million. These fisheries support about 40 vessels and their crews.

The information base produced by the NWHIFI study will continue to serve as an encyclopedic baseline for management and planning purposes for at least several decades. The tripartite-Sea Grant research agreement and the enormous success of the multiagency program serves in itself as a model of state-federal-university cooperative research for similar programs in the future.

PRECIOUS CORALS

ACTIVITY

Developing an economically viable fishery for precious coral, *Corallium* sp., in Hawaii was the objective of the "Development of a Precious Coral Fishery" project. It began in March 1970, the middle of Sea Grant's second fiscal year. During the first 6-month period, researchers studied the literature, surveyed the existing precious coral industry, and began preliminary field work. Full-scale field work began in fiscal year 1970-71 under a new project title, "Ecology of Precious Corals and Development of Precious Coral Fisheries in Hawaii." The title change reflected the expanded objective of establishing a viable precious coral harvesting, marketing, and manufacturing industry in Hawaii and, to the extent possible, in the then U.S. Trust Territory of the Pacific Islands and Guam.

The threefold research goals were (1) to assess the economic potential of precious coral resources in U.S. and Hawaiian waters (12-mile limit at the time), (2) to develop commercial technology for harvesting precious coral resources, and (3) to develop a management plan for the rational exploitation of precious corals.

The Sea Grant project ended after 4.5 years; however, various aspects of the research have continued to the present. Additionally, Sea Grant funded the "Ecology and Resource Potential of Bottom Fisheries in the Leeward Hawaiian Islands" project. The study, planned for 4 years, ended after the first year, 1977-78. The major emphasis was on precious corals. The following year the "Reef and Precious Coral Resources: Comparative Ecology Within the Hawaiian Archipelago" project was funded. It partially focused on the ecology of precious corals in the Northwestern Hawaiian Islands but was refocused in 1979-80 on nearshore coral reef ecosystem dynamics.

The only other Sea Grant project dealing with some aspect of precious corals was "CORMAR: A Coral Reef Management Program in Hawaii." Data on growth rates and age of reproductive maturity of black and pink corals were studied in 1974-75 for the purpose of making recommendations to proper state and federal agencies for the conservation of commercially valuable species. One year's time of an enforcement officer to help collect data was provided by the state Division of Conservation and Resources Enforcement. This state agency also contributed matching support for the field work by supplying a boat and a vehicle.

RESULTS AND ACHIEVEMENTS

Among Sea Grant's proudest achievements are the development of technology to efficiently harvest precious corals from the sea and the establishment of an industry based on local resources. In 1972, Sea Grant, in cooperation with the state Office of the Marine Affairs Coordinator and Makai Range, Inc., adapted the submersible *Star II* for use as a mechanical harvester. A mechanical arm was attached to the submersible, enabling it to selectively harvest mature coral without damaging the bed.

Project researchers developed a remotely operated deep-water bottom camera and television vehicle to survey potentially productive areas and to determine the abundance patterns of precious corals. Important pink coral beds were located off Makapuu Point, Oahu. Gold coral and bamboo corals — two newly discovered precious coral species — were also found in commercial quantities there. Small beds of pink coral were

discovered off Kaena Point, Necker Bank, Brooks Banks, and Midway Island.

Information on growth and harvest rates of black coral located off Maui indicated that resources there were being depleted. A size limit to regulate harvest was recommended to the state.

In the Trust Territory, large quantities of black coral and smaller quantities of pink coral were also discovered in the southern Marianas.

A precious coral fishery based on local resources of pink coral was established in Hawaii in 1973 and continued until 1980 when global economic conditions changed. A large bed of pink coral discovered by Taiwanese and Japanese fishermen in 1980 resulted in an oversupply, which, in turn, depressed the price of the raw material and removed the economic incentive to harvest coral locally. Since 1980 the industry has relied primarily on imports of both raw and finished pink coral products. Black coral continues to be produced locally although some is imported from the Philippines and Taiwan. Hence, the industry established in Hawaii by the initial research has continued to flourish, even though it is primarily based on imported products rather than local coral resources.

BENEFITS

With the completion of the preliminary research and development, the small precious coral industry, which had an annual retail gross of $2.5 million in 1969, expanded to $11.4 million by 1975 and produced tax revenues then of over $500,000, which is about two times the total federal research and development support that went into its development.

In the early 1970s, most of the coral harvested was purchased by two of the largest coral jewelry firms in Hawaii, Maui Divers of Hawaii, Ltd. and Edward D. Sultan & Company. Approximately 10 jobs were created by Maui Divers.

The precious coral industry in Hawaii today provides about 1,000 jobs for residents of the state. Of these, about 900 were created since the research began. In addition, the industry today generates about $17 million in annual sales of pink, black, and gold corals. Taking into account multiplier effects, the amount generated becomes $40 million.

Fishery management plans have been developed by the state Department of Land and Natural Resources (for black coral) and the Western Pacific Regional Fishery Management Council (for pink, gold, and bamboo corals). These plans have application in principle to the harvesting of precious corals worldwide.

DIVING PHYSIOLOGY

ACTIVITY

The investigative areas of diving physiology have included water immersion, breath holding, thermoregulation and exercise in water, physics of bubble formation and *in-vivo* detection of bubbles, hyperbaric pharmacology, and psychosensory function. Despite this, in the sense application, scientists were and still are most interested in the basic physiology of man in the sea. In some cases, studies in humans have been supplemented with animal experiments since certain techniques are better pursued with animals. The foremost motivation for all research in diving physiology has been and remains improved treatment and, ultimately, the prevention of decompression sickness.

The Department of Physiology has been actively involved in research on the physiology of man in the sea since 1968, the first year the University of Hawaii received an Institutional Support Program grant from the National Sea Grant College Program. Financial support from Sea Grant enabled several faculty members to develop a multidisciplinary research project/program on human performance in the sea. At the time, financial support was also available from the Office of Naval Research and the then Hawaii Office of the Marine Affairs Coordinator to conduct at-sea and laboratory tests. Laboratory tests were conducted in hyperbaric facilities at the J.K.K. Look Laboratory of Oceanographic Engineering and at Makai Range, Inc.

In the early years, the "Human Performance in the Sea" project/program focused on heat regulation functions and on stresses encountered at depths where much work diving and almost all sport diving are done. This project/program was coordinated with the sand recovery project to determine the physiologic limitations of working divers performing such tasks as taking core samples. Other objectives included defining the upper limit of human work capacity as a function of depth, temperature, and other variables that affect that limit; and surveying the heart/lung function of local sport and working divers.

Educational and advisory work were important parts of this project/program. Scientific reports of various test results, graduate courses, lectures, discussion sessions, films, and answers to individual inquiries were some of the means by which special groups — especially the diving community — and the public were reached.

In 1971-72, two of the six projects in the Life in the Sea program area were "Human Performance in the Sea: Physiological and Medical Factors" and "Human Performance in the Sea: Psychological Factors." They shared the joint goals of identifying physiological, psychological, or technical limits to human performance capabilities in the sea and recommending appropriate measures to extend those capabilities. An auxiliary program of instruction and advisory activities was sponsored as part of the projects. A third project, "Improvement and Continued Operation of a Four Atmosphere Hyperbaric Facility," provided the physical facility, a remodeled hyperbaric tank, for the research related to human and animal performance in the sea. This project was merged into the overall human performance program for 1972-73. A fourth project, "Drug Effects Under Hyperbaric Conditions," centered on determining whether the safety and efficacy of drugs are altered in subjects placed in an environment which simulates the hyperbaric conditions of deep-sea diving. Experiments were first conducted with animals and then with human volunteers.

Since it was first funded in 1968, and continuing through mid-1977, the "Human Performance in the Sea" project/program largely centered on

studying methods of avoiding decompression sickness and on developing better ways of dealing with it without long-term disabilities or death. To better understand the physiological effects of diving, the research team studied the effects of high pressure oxygen on the production of surfactant (the coating on lung wall surfaces), the factors affecting thermal balance and heart and lung regulation under immersed and high pressure conditions, and changes in body fluid balance at high pressure.

In the study of decompression sickness, or the bends, gelatin was used to observe bubble formation. The physics and chemistry of bubble nuclei were studied. Researchers noted that bubble formation changed when the surrounding gas was changed. This research began under the broad-based "Human Performance in the Sea" project/program and continued as an independent project, "Exogenous Gas Bubble Disease: Physical Factors in the Etiology, Detection, and Prevention," from 1976-77 to 1980-81. Further work in this area of focus was done under the "Investigation of Methods to Improve the Treatment of Decompression Sickness Based on the Physics of Dissolution of Gas Bubbles in Gelatin" project in 1980-81 and 1981-82. Researchers studied the physical factors which control the rate at which bubbles can be dissolved when they occur in a diver's body following a dive. This was followed by four more years of research under "The Physics of Gas Bubbles: Medical Applications" project. This project involved applying nucleation theory to the study of side effects of ultrasonic radiation and analyzing the physical properties of gas cavitation nuclei to explain the loss of decompression tolerance in vacationing divers and caisson workers.

Another area of focus was the physiological aspect of the effect of the hyperbaric environment on humans. Surrogate experiments were conducted with rats and dogs to detect their thresholds for bubble formation; human studies followed. Efforts centered on determining the factors which control the uptake and elimination of inert gas from the human body during its exposure to increased pressure followed by decompression. This research was conducted under the "Inert Gas Elimination During Decompression" project in 1977-78, the "Inert Gas Elimination and Thresholds for Decompression-Induced Venous Gas Emboli" project in 1978-79, and the "Studies on the Interspecies Conversion of Decompression Tables" project in 1981-82 and 1982-83. The latter effort was also directed at preventing the occurrence of bubbles in the body of a diver following a dive by the development of safer decompression tables. Animal models were used for testing new decompression tables derived theoretically and for improving existing tables, based on interspecies correlations.

Currently, only one project on diving physiology remains. Begun in 1985, the "Influence of Pulmonary Gas Embolism on Cardiopulmonary Functions" project is designed to study quantitative effects of various degrees of pulmonary gas embolism on cardiovascular and respiratory functions and gas exchange, and to elucidate mechanisms involved in various symptomatic expressions of pulmonary embolism. The ultimate goal is to facilitate inert gas elimination during decompression — and hence shorten the decompression time — by means of manipulating cardiovascular and respiratory functions.

RESULTS AND ACHIEVEMENTS

Since 1968, the University of Hawaii Sea Grant College Program has supported research to further understand the effects of high-pressure, or hyperbaric, environments on humans. Physical and physiological data were developed to gain a better understanding of the response of the human body to hyperbaric environments.

The results and achievements of the "Human Performance in the Sea" project/program represent a wide spectra of information on the effects of diving on the human physiology. Briefly, some of

the research results are as follows. Researchers found that lung collapse while breathing oxygen under high pressure in many instances is due to the absence of surfactant. Researchers also found that loss of body fluids is significant when humans are immersed in water. Loss occurs through accelerated urine flow caused by the suppression of the antidiuretic hormone. Divers in a heliox environment during simulated dives in a hyperbaric chamber also exhibited increased urine flow. Fluid imbalance caused by excessive fluid loss could well provoke decompression sickness and affect diver performance. Other research showed that heart and lung functions, even in shallow depths, alter to cope with water pressure. The shifting of blood from the outer parts of the body to the chest cavity was also found to change the lung function.

INTERNATIONAL COOPERATIVE ACTIVITIES

U.S.-Japan Research Cooperative Program. In 1973, Dr. S.K. Hong, then a member of the UH faculty, initiated the U.S.-Japanese cooperative dive research program. One to three UH faculty members participated in most of the Japanese dives from 1973 through 1985. Although the cooperation was between the UH and the Japan Marine Science and Technology Center (JAMSTEC) at Yokosuka, Japan, scientists from Japanese universities were also invited to participate. Cooperative dives are the most cost-effective means of research in hyperbaric physiology and technology. Both countries benefited from these activities.

Seatopia. The U.S.-Japan cooperative dive program started in 1973 when Japan conducted its first saturation dive series, the Seatopia project. This was a series of open-sea saturation dives at relatively shallow depths. The project was concluded in 1975 with a 100-meter saturation dive.

Hana Kai II. In 1975, the University of Hawaii conducted a 17-day saturation dive at 18.6 ATA (580 feet), code named Hana Kai II. Three Japanese scientists, two JAMSTEC personnel, and one UH professor participated in this dive at Makai Testing Range.

Seadragon. The Seadragon dive series (1975-83), consisting of a number of deep-sea (300 meter or 1,000 feet) simulation experiments, was held in the simulator at JAMSTEC. Drs. Smith, Claybough, and Lin participated in various phases of the Seadragon project.

New Seatopia. JAMSTEC has moved into the area of deep open-sea dives with a series of dive codes named New Seatopia, which started in 1983. Drs. Claybough and Lin joined in the experiments in 1983 and 1985.

George F. Bond Underwater Habitat at U.S. Virgin Islands. The United States will host the next cooperative dive at the newly completed U.S. Virgin Island facility in March of 1988. Three Japanese scientists have been invited to participate.

UJNR. The Panel in Diving Physiology and Technology of the U.S.-Japan Cooperative Programs in Natural Resources (UJNR) meets every 2 years, in Japan and the United States alternately, to review the achievements and plans for future joint activities. The current UJNR membership includes Drs. Claybough, Lin, and Malahoff from the University of Hawaii. The UH hosted the 8th joint conference of the panel in 1985, and the 9th meeting was held in Yokosuka, Japan in November 1987.

Over the years, significant advances have been made in revealing the physical laws governing bubble formation in watery fluids. The bubble formation studies indicated that it is possible to control growth or disappearance of bubbles without changing the ambient pressure. Bubble formation changed when the surrounding gas was changed. Hence, researchers found that it may be possible to shorten decompression time with proper gas switching.

The most important accomplishments of the gas bubble research were the development of a physical model — called the nucleation model — to describe bubble formation and the application of the model to the causes, detection, and prevention of decompression sickness.

Researchers used the model to calculate several decompression tables for humans in the mid-1970s. The tables are based on data of bubble formation in gelatin. By 1981, model predictions had been compared with decompression data on salmon, rats, and humans. Later, a new theory of decompression sickness was developed that can be verified without reference to gelatin data. What is important is that the researchers developed diving tables based on physical laws, rather than on ad hoc and often faulty assumptions.

A mathematical theory of bubble dissolution was developed in the project on investigating methods to improve the treatment of decompression sickness. The theory suggests that common treatments for decompression sickness may be only marginally effective and that, in many cases, existing techniques and facilities cannot adequately dissolve the bubbles causing the sickness. The theory and experience also suggest that while common treatments may be successful in relieving pain in cases of simple decompression sickness, they may not be as successful in cases when it afflicts the central nervous system.

The hyperbaric pharmacology research showed that gases such as helium and nitrogen that are inert at sea level become pharmacologically active under high pressure. Oxygen becomes toxic under excessive pressure and/or after prolonged exposure to it. The research also showed that the physiological response to drugs at sea level may differ from that at depth.

In the ongoing study of the influence of pulmonary gas embolism on cardiopulmonary function, researchers have demonstrated that a reversible form of pulmonary embolism can be induced by intravenous infusion of air. Its severity depends on the combination of the rate and duration of infusion. Researchers have also shown that enhanced cardiovascular activity and vasodilation hasten the elimination of inert gases. Recovery from pulmonary gas embolism can be accelerated by increased rate of inert gas elimination.

The results and achievements of the research on diving physiology over the past two decades have been presented through publications, films, lectures, workshops, graduate courses, and various other means. In November 1988, the 2nd International Symposium on Man in the Sea will be held in Honolulu. The planned agenda features a 25-minute presentation on "UH Sea Grant Achievements" by the Sea Grant director.

BENEFITS

Diving physiology research produced nationally relevant information on human hyperbaric physiology, helped guide medical and industrial applications, and provided technical backup for a diver-safety program. In addition, decompression tables were refined. The tables, along with the establishment of decompression chambers in neighbor island counties where diving is an important occupation, are important to the diving community for the prevention or treatment of decompression sickness.

A new in-water treatment of decompression sickness was developed for use by Hawaiian diving fishermen when they are more than one hour's travel time away from a decompression treatment

facility. The treatment involves administering oxygen and then recompressing the victim in water at the 30-foot depth for up to 3 hours. The treatment has been taught to Hawaiian fishermen and is now required for use by University of Hawaii divers. Other groups that have benefited from research in this area include the Undersea Medical Society, the U.S. Navy, and the civilian diving community.

In the project on interspecies convertible decompression table, calculations were made for various species from a universal decompression table. The resulting tables differ only in stage duration, with an identical pressure reduction at each stage. The benefit of this study is that the value for step reduction in pressure can be obtained from species other than humans and still be useful for calculations of tables for human use.

Decompression from great depths takes time and hence is costly to the diving industry. For example, decompression from a 300-meter saturation dive requires 12 days, and that from a 600-meter diver, over 30 days. Each day of operation can cost anywhere from $10,000 to $50,000. Hence, research such as the bubble formation studies is important for finding ways to shorten decompression time. It will not only result in operational economy, but also in possibly saving lives in emergency situations.

SEA GRANT EXTENSION SERVICE

ACTIVITY

The UH Sea Grant Extension Service (SGES) was established in 1970. Initially called the Marine Advisory Program, its purpose was and continues to be to provide an outreach and public information link between the research programs of the Sea Grant College Program and the community. In Hawaii, the goals of both the Sea Grant College Program and the Extension Service closely parallel the marine planning goals of the state as a whole. Consequently, many of the long-term goals of SGES correspond with those found in such state planning documents as *Aquaculture Development for Hawaii, Hawaii Fisheries Development Plan, Hawaii and the Sea: A Plan for State Action, and State Tourism Functional Plan.*

Because of these common aims, SGES works closely with several state of Hawaii agencies. These include the Department of Business and Economic Development (DBED), the Department of Land and Natural Resources, the Department of Transportation, the Department of Education, and the Hawaii Visitors Bureau.

SGES also cooperates with several federal agencies. Among these are the National Marine Fisheries Service, the U.S. Travel and Tourism Administration, and the U.S. Army Corps of Engineers. The cooperation also extends to regional councils such as the Pacific Basin Development Council, the South Region Economic Program, and the South Pacific Region Environmental Organization.

The focus and the specific goals of SGES have shifted periodically over the years to meet the changing needs of the marine community. At each new point SGES works to incorporate the best of past concepts with a vision of the future.

For the first several years, the extension program went through a period of rapid growth. Shortly after the first coordinator of Advisory Services was hired in 1971, a publication staff was recruited to write, edit, and produce publications. By 1973, the program included subject matter specialists to investigate specific problems relating to the use of the sea in Hawaii and the Pacific area. Throughout this period, the program was centralized on the University of Hawaii's Manoa campus.

In 1976, the service was expanded again to provide assistance at the local levels. Marine generalists were placed on the three neighbor islands of Kauai, Maui, and Hawaii. Furthermore, in 1979, outreach services were initiated in Guam, Saipan in the Commonwealth of the Northern Mariana Islands, and Pago Pago in American Samoa. In addition to placing staff in the field, a program was begun which brought trainees from several Pacific island nations to Hawaii for on-the-job training. This program was cooperatively administered by the University of the South Pacific in Fiji and the University of Hawaii. SGES also developed a Pacific-wide communication network to facilitate information sharing and responses to written requests. Information sharing among the islands of the western Pacific was augmented by a seminar program presented via the PEACESAT communication satellite.

Federal budget uncertainties during the early 1980s, however, brought about diminished programming throughout much of the National Sea Grant system. Hawaii Sea Grant dealt with these uncertainties by retrenchment in services offered, reduction in employee hours, and cooperative efforts. For example, when personnel vacancies occurred in the Northern Mariana Islands and on Oahu, they were not filled. Staff positions on Kauai and Maui and those of several communication positions were reduced to part-time status. The

position on Maui became the first jointly funded position at Sea Grant when partial funding was assumed by the University of Hawaii's Cooperative Extension Service. The Guam position reverted to the University of Guam, and the marine economist's position was eliminated.

In 1982, when a new director joined the program, SGES reviewed its past programs and initiated a series of meetings with representatives of Hawaii's ocean community to determine future goals. As a result, SGES concentrated its efforts in four areas: ocean recreation and tourism, aquaculture, commercial and recreational fisheries, and coastal resources management in the American Pacific. This orientation is reflected in the 5-year plan begun in 1985.

Despite continuing fiscal austerity, SGES strives to maintain a flexible and responsive program. A small staff of part-time specialists in the major subject-matter areas is periodically augmented through short-term hire of local specialists or through talent share or exchange programs with other Pacific area Sea Grant programs. Neighbor island staff is maintained only when there is significant need.

SGES continues to strive to develop new initiatives, but funding for these projects is generally short-term. For example, short-term funding for public marine education programs has been made available to local grantees whose proposals have demonstrated innovative promise. Such short-term funding guarantees that projects are more closely geared to local needs and increases the possibility of long-term continuation of meritorious projects after SGES ceases to fund them.

Present Extension Service projects are an outgrowth of Sea Grant research, of interactions with state and county agencies, and of increased ties with private industry. Reflecting its ties with the economic needs of the community, SGES professionals are spending approximately 30 percent of their time on projects concerning ocean recreation and tourism — industries which account for 30 percent of the state's gross revenues and employment. Furthermore, Extension Service professionals are spending 19 percent of their time focusing on the development of a diversified aquaculture industry, and about 19 percent of their time on fisheries enhancement.

RESULTS AND ACHIEVEMENTS

Ocean recreation and tourism

From its earliest years SGES has directed its efforts toward issues of marine recreation in Hawaii and other Pacific islands. Since 1974, for example, marine specialists from Sea Grant have conducted a variety of workshops ranging from diving medicine to criteria for judging surfing competitions. The Extension Service has also published pamphlets on topics as varied as dangerous marine animals in Hawaii and sunburn and skin care. Moreover, the earlier editions of SGES' newsletter, *Kahu o Ke Kai* (Guardian of the Sea), centered on boating and boat fishing interests. Water safety was also the subject of the program's 16-mm film "Roughwater Rescues."

Since 1981, the Sea Grant Extension Service has supported organizations and agencies which foster ocean planning, enjoyment, and safety and emergency services. In 1983, for example, SGES helped form the Big Island Ocean Recreation and Tourism Association, Inc. This nonprofit group of interested citizens and business people seeks to improve ocean recreational opportunities, to diversify the tourism base of the island of Hawaii, and to increase community participation in natural resource management.

With the Ocean Resources Branch of the Hawaii Department of Business and Economic Development, SGES has also assisted another nonprofit group, The Ocean Recreation Council of Hawaii (TORCH), to deal with island-wide

marine recreation concerns. TORCH has sponsored legislation concerning ocean recreation and has representatives working with the Governor's Task Forces on Ocean Resources for Tourism, Sports, and Recreational Motorcraft Management. TORCH has also promoted a mooring buoy system, settled some local access problems, and become active in developing and sponsoring the annual recreation exposition "Nanea Kai."

"Nanea Kai" demonstrates SGES' outreach to small businesses. In 1985, and again in 1987, SGES and DBED cosponsored this exposition designed to spotlight Hawaii's recreation industry. Concurrently with the exposition, SGES sponsored a conference which focused on the needs of the small recreational businesses in Hawaii. The conference also offered Sea Grant researchers an opportunity to present information about ocean recreational management and resources and to meet the community.

SGES also has worked more directly with small businesses in Hawaii. For example, with Destination Hawaii, a nonprofit association of dive shops, SGES sponsored a seminar on development of travel packages to attract more divers to Hawaii. In addition, SGES prepared a dive guide for the state, informing visitors of diving opportunities and concerns throughout the islands.

The Extension Service continues to produce films, printed materials, and radio spots, and conduct workshops for both visitors and residents on water-related sports and safety. Furthermore, a statewide aquatics program is being developed through SGES in cooperation with the state legislature, Hawaii Department of Education, and water safety organizations. This program will promote aquatic employment opportunities, develop lifeguard certification standards, implement an aquatics management option at the University of Hawaii, as well as expand a statewide lifesaver program within the public school system.

Aquaculture

One of the earlier activities of the Sea Grant College Program was its work on the state of Hawaii's aquaculture development plan. Since then, both the Sea Grant College Program and the Extension Service have been active in fostering an environmentally safe aquaculture industry in the state. Activities have included publishing documents and presenting seminars, conferences, and workshops for researchers, business people, and interested citizens and groups.

In 1982, SGES hired an aquaculture specialist to respond to the more immediate needs of the industry. The specialist has worked with prawn farmers to increase their production through improved pond management and with aquaculture engineers to develop more efficient harvesting techniques and equipment. A specialist from the Extension Service was also responsible for the Aquaculture Management Information System. The system was designed to help aquaculturists keep track of critical production factors.

As investigators of projects funded by the Sea Grant College Program have developed research results in the aquaculture area, SGES has sought to bring that information to the producer. The key ingredient of successful aquaculture is up-to-date information. The Extension Service has continued to provide the invaluable link between the researcher and the producer through a series of well-attended workshops. Topics have covered baitfish, channel and Chinese catfish, tilapia, Chinese carp, as well as more efficient production techniques.

Commercial and recreational fisheries

The Sea Grant Extension Service has also worked with commercial and recreational fishing industries within the state. This has been done primarily by reporting the results of Sea Grant work on habitat enhancement through artificial reefs. Both private and public enterprises have used this information to develop commercial ventures in Hawaiian waters. One submarine tour business, for

example, is in the process of deploying three high-tech artificial reefs using designs and methods developed by Extension Service personnel.

The Extension Service has used not only its own publications but also radio, television, and newspapers to inform the public about the state's artificial reef program. SGES personnel have also written and delivered papers on this subject at professional meetings both in the United States and abroad. Furthermore, Extension Service personnel have served on the Steering Committee for the Third International Artificial Reef Conference held in Los Angeles and for the Fourth International Conference held in Miami.

Coastal zone resource management in U.S.-affiliated Pacific islands

Sea Grant Extension Service, in cooperation with several organizations, has developed a number of projects to address the alarming rate of destruction of coastal resources in the Pacific islands and the increasing problem of competing multiple use. These have included funding the production of fisheries conservation posters for the Commonwealth of the Northern Mariana Islands, developing a coastal resource management plan for Pohnpei of the Federated States of Micronesia, and designing and generating a coastal resources inventory for Yap Island Proper.

In October 1987, SGES proposed a coordinated program to develop coastal resource management plans for all major inhabited U.S.-affiliated Micronesian islands. This program will effect coastal resource inventories throughout the area, develop management plans, and assist with the implementation of these management plans. The program also calls for a coastal resource extension specialist for the Federated States of Micronesia, the Marshall Islands, and the Commonwealth of the Northern Mariana Islands to work with local governments on implementing recommendations. This specialist would also train island resource managers in collecting and using the acquired data.

Communication is also an important factor in SGES' Pacific island work. For this reason, since 1984, the Extension Service has presented a series of seminar programs via the PEACESAT satellite system. Pacific SeaLink, as the program is called, was organized as a cooperative effort of the University of the South Pacific's Institute of Marine Resources, the Marine Resources Division of the Federated States of Micronesia, and the Guam/Hawaii Sea Grant Program. SeaLink will facilitate seminars and roundtable discussions to deal with marine resource management problems in the Pacific. With this program, Sea Grant Extension Service is able to disseminate information to areas where access is extremely limited and to provide a forum for cooperative problem solving for marine resources managers throughout the Pacific.

BENEFITS

Sea Grant Extension Service has effectively raised public consciousness about the many uses of the ocean. Public information announcements presented via radio, television, and the press, have informed the public of the economic, recreational, and life-sustaining importance of the ocean that surrounds Hawaii. Moreover, these informational programs have raised the consciousness of planners and citizens on other Pacific islands. This is the first step toward thoughtful, well-planned policies of use and conservation of ocean resources.

Secondly, the Extension Service is sought out by businesses and communities for answers to pressing questions. A prawn farmer who wants information on protecting his crop from disease can call Sea Grant for advice. Likewise, a tourist can find safe, enjoyable activities for a Hawaiian vacation in a Sea Grant pamphlet distributed through hotels and ocean recreation businesses. This information function not only makes for wiser users of the sea but also provides for economic benefits to the community.

Thirdly, the Extension Service has nurtured a close working relationship with county, state, and

federal agencies and with marine-related businesses. Because of this networking approach, its projects now result in cooperative lines with state and county agencies and with private industry and trade associations.

Long-term benefits of SGES are both general and specific. Generally, the information provided by the Extension Service helps guide businesses and other organizations to wisely use the resources of the sea. By working directly with such groups as Destination Hawaii to educate dive shop owners or by sponsoring conferences such as "Nanea Kai," SGES helps interested people learn about new methods and innovative technology to effectively explore marine resources. By providing information and direct assistance, Sea Grant Extension Service has also helped to protect the marine environment from careless exploitation.

To ensure that this protection continues, the Extension Service will remain active in the planning process in both the state of Hawaii and in other Pacific islands. For example, the Extension Service is active in the development of a day-use mooring system to provide protection for both the coral reefs and their users. Active participation in the planning process affords SGES the opportunity to provide programs which will reach a larger public with a greater impact.

Specifically, the program has seven expected outcomes for the 1990s. These include the following:

1. The aquaculture industry will become a major economic force in Hawaii's agricultural diversification program.

2. Ocean recreation and tourism will be recognized by the state as a major contributor to Hawaii's economy, and selected ocean recreation projects will result in a measurable increase in economic activity statewide.

3. Measurably enhanced fish stocks, resulting from the development and deployment of artificial reefs, will benefit recreational and commercial fishermen.

4. There will be a measurable increase in the stability and economic viability of small businesses related to fisheries, aquaculture, and ocean recreation.

5. The island nations of the western Pacific will have regular exposure to current technical information and to planning approaches covering a broad range of ocean-related topics through satellite seminars, staff exchanges, and written materials.

6. Decisionmakers and the general public will have easy access to ocean-related information through widely broadcast radio and TV spots, newspaper columns, county-based ocean centers, and literature.

7. The state of Hawaii will have a clearly defined ocean management policy which will result in improved ocean environments and reduced user-conflicts.

MARINE EDUCATION

ACTIVITY

The goal of the UH Sea Grant College Program marine education component has been to provide residents an understanding of the ocean's importance to life from the perspectives of science, economics, recreation, and culture. The target audiences have included the traditional student in formal educational settings as well as members of the ocean community, representing a broad cross section of users. Educating the latter group has usually been the responsibility of the Sea Grant Extension Service; the former has been served by the Marine Option Program and a variety of principal investigators of shorter-term projects.

The marine education component has encountered various problems over the years. The primary problems derive from the context and orientation of contemporary society in Hawaii which do not support a large ocean constituency. Despite living in the middle of the ocean, most residents maintain a strong terrestrial/plantation/agricultural orientation. This pervades the legislature, city councils, state administration, industry, and university. Many marine education programs fostered by Sea Grant either have failed to "root" or have received grudging acceptance only after inordinate investments of energy and patience. Many of the postsecondary courses existed only as long as the parent faculty members carefully tended them. Few remain. Both the Blue-Water Marine Laboratory and the Marine Option Program have struggled over a decade and a half to find acceptance, funding, and suitable administrative homes for their experiential brand of education. The community college marine technician training program was discontinued. The hallmark of most programs was a short lifespan.

After a few years of mediocre results from postsecondary course development, this type of project was no longer funded. Once the Hawaii Marine Science Studies program had completed its first curriculum draft (at about the same time there was a glut of precollege curriculum production on the mainland), support for this type of development was phased out. The public festival (Makahiki Kai) and the community cultural project (Ho'i Ana Ike Kai) each introduced a few lasting elements in the state's educational programs and in public education programs in the western Pacific, especially through the adoption of the student workbook and teacher manuals. The community cultural project has been incorporated in the education program of elementary schools in the Waianae coast. The marine technician training program soon outproduced graduates for the few existing jobs. Declining enrollment forced the termination of the program in the early 1980s.

As national priorities shifted markedly away from education, few incentives remained for Hawaii initiatives. The programs with enduring elements — those which survive today with little or no Sea Grant funding — include the Marine Option Program, the Blue-Water Marine Laboratory, the High School [nee Hawaii] Marine Science Studies program, the Student Symposium on Marine Affairs, and the Hawaiian Backyard Aquaculture Program. Their common denominator seems to be experiential education, individual attention, and the opportunity to excel by interacting with the ocean outside of the normal formal education framework.

Even though all education projects had university ties, most included strong contributions from the community. The Hawaii Department of Education (DOE) was involved in all precollege curriculum development. Internships and activities for Marine Option Program students typically engage

almost 200 government agencies and private concerns throughout the state each year. The Makahiki Kai and Ho'i Ana Ike Kai programs involved not only DOE, but also a variety of parent and community organizations.

RESULTS AND ACHIEVEMENTS

The goals were high; the funding was not. To reorient society completely from the land to the sea through the formal education system in a span of 20 years was an impossible dream. The patchwork of programs that remain includes some which made and continue to make lasting impressions on the state's understanding of the importance of the sea to all facets of island life. Students fortunate enough to participate in one or more Sea Grant-fostered education programs have had the opportunity to become involved with the ocean and have had the depth of exposure to more accurately glimpse the coming of a time when the ocean will be more fully utilized. However, we have neither a pre- nor a postsecondary education system which contains a significant marine content. Most school children cannot swim. This is sad commentary for an island society.

BENEFITS

The immediate involvement of students provides a consciousness-raising about the ocean — its existence, its origin, its processes, its contents, its potential, and its role in everyday life. This awareness is generally not available from parents, peers, or most institutions in Hawaii's society. In addition, most students are stimulated by ocean studies and retain this momentum for learning in other subjects. The gradual acceptance and expansion of marine education programs have increased employment opportunities for educators. MOP serves as a "one-stop" information center for undergraduate marine education on each campus where it is supported.

There are certainly diffusive and contagious effects from the "enlightened" student to peers and parents. The appreciation and understanding of the ocean can be transmitted from those who have been exposed to Sea Grant education programs to those who have not. Ideas about the conservation ethic, the role of plastic debris, the opportunities for wise development of ocean resources, or potential careers can be learned by students at school and shared with others.

The more motivated students who have immersed themselves in the Marine Option Program, the Blue-Water Marine Laboratory, or the Hawaii Marine Science Studies Program have special knowledge about the ocean and Hawaii's ocean community. They can reasonably be expected to ascend to leadership roles guided by wisdom others have not acquired.

Sea Grant-Supported Education

Graduate Level

- Topics in Ocean Engineering Course (UHM, 1969-71)
  - Technical and public lectures presented and published
- Ocean Engineering Course Development
  - 603 Oceanography for Ocean Engineers
  - 651 Instrumentation Seminar
  - 652 Nearshore Marine Survey Techniques
  - 691 Estuaries
- Marine Agronomics (UHM, 1972-74)
  - Course and curriculum
- Seminar Institute HIMB (1983-85)

Undergraduate Level

- Marine Technician Training Program (LCC, 1970-75)
  - A.S. Degree and curriculum
- Instruction in Plant Aquaculture (UHM, 1970-71) Course
- Marine Option Program (UHM, UHH, WCC, LCC, KCC, MCC, HCC, 1970-present)
  - Undergraduate experiential education and certificate program
- Pathology in Marine Animals (UHH, 1970-73)
  - Course, lab, slide sets

Precollege Level

- Blue-Water Marine Laboratory (UHM, 1973-76)
  - Sea-going science and seamanship program

Precollege Level (*continued*)

- Teacher Workshop for K-12 (1974-75)
- Makahiki Kai (1975-79)
  - Traveling exhibit, workbooks
- Hawaii Marine Science Studies Project (1974-present)
  - K-12 curriculum emphasizing observational learning
- Hawaii Nature Studies Series
  - Text: *Reef and Shore Fauna*
- Symposium on Marine Affairs for Secondary Students (1976-83)
- Ho'i Ana Ike Kai
  - Elementary simulation of voyage and fishing and alternative education for alienated students
- Teacher Workshop (1979-80)
  - For Marshallese on HMSS
- National Youth World of Water Awards (1984)
  - Travel awards for local winners
- National CRDG Workshops (1975-79)

Public

- Marine and Freshwater Aquaria (1972-73)
  - Continuing Education course at Waikiki Aquarium
- Docent Handbook (1973-75)
  - Waikiki Aquarium
- Slide and Tape Presentation (1973-75)
  - Waikiki Aquarium
- State Fish Election Campaign

LAW OF THE SEA INSTITUTE

ACTIVITY

In February 1965, the Law of the Sea Institute (LSI) was established at the University of Rhode Island. In 1977, LSI moved to the University of Hawaii and was placed under the leadership of Dr. John P. Craven. With the change in venue, the direction of LSI was broadened and its orientation changed from a focus on domestic scholarship to one that is international. The internationalization of LSI has been further amplified by the holding of its annual conferences under joint sponsorship with academic institutions in Europe and Asia and by having every other conference held outside the United States. Thus, LSI gathers and concentrates the world's intellectual gene pool on ocean law, a process that collapses the long lead time that historically created the basic tenants of customary international laws of the sea.

The international law of the sea predates by many centuries the birth of the modern international system (commonly thought to coincide with the Treaties of Westphalia of 1648). The early ocean technology of the Phoenecians began a long, interactive process of reciprocal growth of organization and function of coastal societies, city-states, and, finally, nation-states whose character was shaped in greater or smaller part by their perceptions and use of the sea. The system of custom and rules which grew from that long experience in the use of the sea is known today as the international law of the sea. Its source is not, therefore, the profession of law, but the sum of mankind's experience at sea, represented in modern parlance by the totality of disciplines which deal with the sea — including science, technology, engineering, economics, politics, business, and law.

This unique multidisciplinary character of the law of the sea is reflected in the composition of LSI's governing body, the Executive Board, as well as its conferences, workshops, and publications. Indeed, it would be impossible to deal with the law of the sea except by a multidisciplinary approach.

Unlike formal governmental forums, in which diplomacy and the exigencies of international politics may necessarily prevail over those of science and policy, this unique intellectual environment encourages participants to put forth new analyses, proposals, and solutions. In a spirit of objectivity and neutrality, remaining open to all relevant disciplines and points of view, students of ocean policy can, in their private capacity, develop ideas which they could not express in their official capacity.

RESULTS AND ACHIEVEMENTS

The Law of the Sea Institute has been in existence long enough to have seen many of its younger participants rise to positions of national and international leadership. Serving on the Executive Board is an interdisciplinary mix of practicing attorneys; professors of law, oceanography, geography, ocean engineering, and political science; directors of leading ocean policy research institutes; consultants in ocean affairs; and business leaders — from North America, South America, Europe, and Asia. The Executive Board can count among its members the United Nations Under-Secretary General for the Law of the Sea, the current Ambassador of Singapore to the United States of America, and a former Chief of the United States delegation to the Third United Nations Conference on the Law of the Sea (UNCLOS-III).

Like the thousands of participants in LSI conferences and workshops, the board members have been exposed to an international, multidisciplinary analysis of ocean policy problems. They contribute their talents in program selection and formal academic labors, and in providing professional contact with a broad set of ocean policy experts throughout the world. Also, as board members, they provide policy guidance, ensuring that LSI performs its mission as an objective and neutral forum of high standards.

One may speculate whether these leaders, and others not elected to board membership, have developed because of their associations with LSI, or whether they have valued their LSI associations because they have developed into senior ocean policy experts. In either case, LSI serves as a nexus of information and skills, where new arrangements, innovative ideas, and sophisticated analyses are exchanged. It provides a unique window on ocean policy — ocean policy which, owing to the physical nature and conformation of the seas, is international in both origin and effect.

Whereas texts on ocean policy can provide knowledge of the topic as it has evolved, only this dynamic forum can show it as it is today and provide the predictive element of how it will develop in the future. The proceedings of LSI conferences and workshops reflect the intellectual process which formed the 1982 Convention on the Law of the Sea. One therefore finds many concepts in that treaty which were analyzed earlier in LSI forums. The ocean science regime, principles for taking and preserving stocks of pelagic and non-pelagic fish, and rules for the delimitation and governance of the special zones of national jurisdiction such as the exclusive economic zone and the continental shelf regime — all can be found in the deliberations.

LSI has contributed to innovative approaches on freedom of navigation. In 1966, at LSI's first conference, a young lieutenant commander in the U.S. Navy presented a paper, entitled "Freedom of Navigation," which contemplated adjustments which might be made to ensure the freedom of international navigation — should a 12-mile territorial sea be generally adopted.

To speculate on such a width for the territorial sea at that time was considered almost heretical by most of his naval colleagues. Indeed, the young officer found it necessary to state, "I should emphasize that I am writing as an individual." He proposed a regime for navigation through international straits which would be closed by a 12-mile territorial sea. He suggested a regime of protected negotiated passageways, open to uninterruptible surface, subsurface, and air navigation. The traditional regime of innocent passage which would otherwise regulate such straits passage allows interruption of surface navigation at the discretion of the coastal state and allows prohibition of air and submarine navigation entirely.

This earliest proposal for protection of passage through the more than 100 straits which would be closed by territorial seas greater than 12 nautical miles was eventually incorporated in the 1982 Convention on the Law of the Sea in Part III, Section 2, paragraphs 1 and 2, which provides for the Transit Passage Regime. The young lieutenant commander who made the proposal is today Rear Admiral Bruce A. Harlow, USN (Ret.).

BENEFITS

The first session of the Third United Nations Conference on the Law of the Sea was still 7 years away when Admiral Harlow made his "heretical" proposal. It would be very difficult to judge how far that proposal went toward setting the agenda for UNCLOS-III and encouraging negotiation on this central problem, which had eluded settlement at the 1958 and 1964 law of the sea negotiations. It is certain that it did have the salutory effect of encouraging consensus and helping to make such negotiation and eventual agreement possible, however.

The range of issues, both seminal and collateral, which have benefited from open, objective analysis in LSI's neutral forum covers the entire scope of ocean law, whether based on treaty law, general principles of law, or customary international law. LSI has been active in aiding analysis and building international consensus throughout its history. It is uniquely capable of bringing considerations of science and technology to bear on international law, a practice which has much significance for the eventual success of law in practice.

Benefits to individuals from LSI's programs have been widespread. To the thousands of ocean policy students who have had the experience of attending a conference or workshop in Asia, Europe, North America, or Latin America must be added the tens of thousands who have been exposed to the current law of the sea through LSI publications. Benefits also extend to those who have never heard of LSI but are protected from pollution of international waters by new principles of law, or to those who have access to newly available stocks of protein and minerals from the sea — the result of principles of law which might have been beyond reach but for this open forum.

There have been widespread national benefits as well. Every nation benefits when international law rather than conflict rules conduct. Every nation can object when an international forum is open to criticism of its national policies, or to ideas and proposals with which it disagrees. Without such discourse and objective analysis, however, agreement and resolution are unlikely.

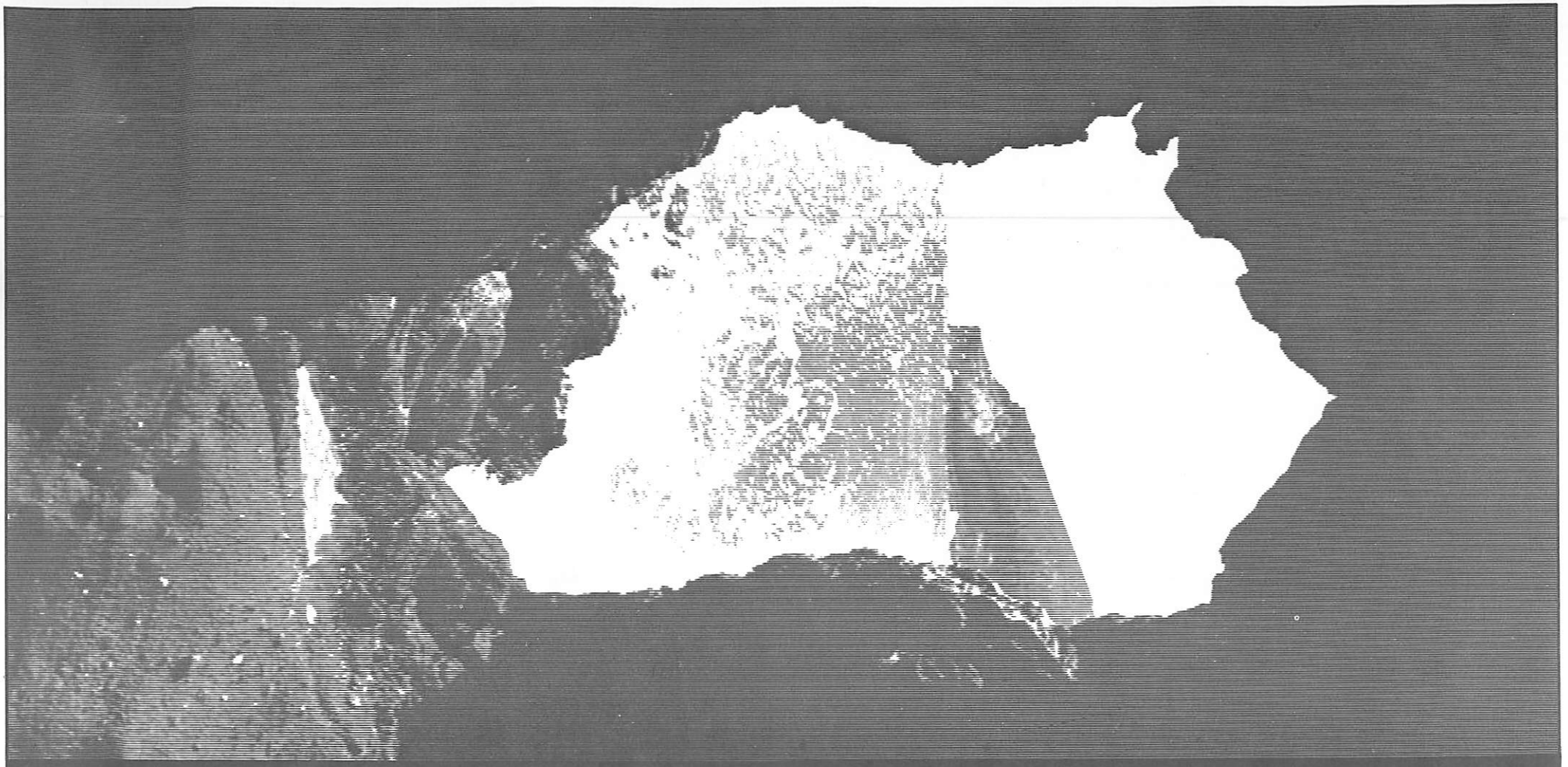
Since the end of UNCLOS-III in 1982, LSI conferences and workshops have been the major multilateral consultative forum for the international ocean policy community. It is especially fortuitous, as events bring us closer to formal international negotiations on issues left unresolved by UNCLOS-III, that this forum includes all relevant disciplines, so that, once again, the central issues to be placed on the agenda in the future can be formulated in the light of science and technology as well as politics and law.

The specific legal form these new negotiations may take is as yet unclear, as is their timing. Some parts of the agenda are emerging nevertheless; they include seabed mining, regional fisheries arrangements, further work on environmental protection, clarification of rules for the ocean science regime and the exclusive economic zone, and claims by some coastal states to rights and zones not sanctioned by the 1982 Convention on the Law of the Sea.

It is clear that this forum will continue and perhaps increase in the future. It is to the credit of the University of Hawaii Sea Grant College Program, as well as early Sea Grant support, from LSI's earliest Rhode Island days to the present, that this essential support has been provided. The LSI program has received broad professional and international validation from the positive evaluations it has received, as evidenced by grants from private foundations and from many governments which have aided their nation's academic institutions in cosponsoring LSI forums within their boundaries.

In its two decades of existence, LSI has held 21 annual conferences and 10 specialized workshops, each accompanied by its book-length proceedings. Each of these conferences and workshops concentrated on the ocean policy problems of the day which were selected as the most critical by the Executive Board. In addition, 36 occasional papers and 6 special publications were produced.

These publications comprise the most complete single collection of intellectual records of the historical development of ocean policy since 1965 in existence. No other organization has gathered in its volumes the work of so many ocean policy specialists or examined ocean policy from so many diverse perspectives. That record has been distributed to major academic libraries and governmental libraries in capitals throughout the world.



LONG-RANGE EFFECTS

ECONOMIC DEVELOPMENT

It would be fair to state that the limited economic "benefits" derived from UHSGCP research reflects the state's only very recent change in policy direction to consider the development of marine industries as a revenue source to fill the vacuum created by the demise of the sugar and pineapple industries and to diffuse the state's dependence on tourism revenues. However, the institutional infrastructure that is needed to promote this changeover to ocean-based industries is not yet in place. The changeover will not be simple because ocean-based industries are not structured around two commodities, but are of great diversity ranging from ocean transport to traditional and cultured fisheries to tourism. Moreover, the basic building block, a citizenry that is highly educated about the ocean and its resources, is not fully in place. Hence, a major UHSGCP contribution has been the "education" of influentials in government, the state's educational systems, and the private sector on the ocean and its resources.

Although there is no clear direction for a concentrated focus on the development of marine industries other than that for aquaculture and skipjack tuna, Sea Grant research efforts were successful in developing the multimillion-dollar coral jewelry manufacturing and sales businesses. The precious coral industry was a UHSGCP-private enterprise joint venture. Besides economic returns to the industry itself and tax revenues and employment to the state, this joint venture included such accomplishments as the mapping of black coral beds in Hawaiian waters; the discovery of bamboo, pink, and gold corals; and the development of a mechanized selective harvesting system attached to a mini-submarine. The jewelry manufacturing factories and sales outlets continue to be a source of revenue for the state and employment for its people.

Economic development was a specific objective of the 10-year prawn aquaculture research. Although state planners envisioned the establishment of large-scale prawn aquaculture enterprises in Hawaii, for a variety of reasons discussed in the "Prawn Aquaculture" section under "Major Programs and Achievements," the projected development did not materialize. Instead of a coherent "industry," current aquaculture activities in Hawaii can be characterized as individual farmers who cultivate crustaceans and/or a diversity of finfish in polyculture or monoculture systems, particularly on the islands of Oahu and Hawaii. It may well be that the more valuable outcome of 10 years of UHSGCP prawn research is the diffusion of the art of aquaculture in the state and elsewhere in the Pacific and Southeast Asia. There are some indications that the ultimate application of the aquaculture technology developed by UHSGCP researchers is yet to come.

PRECIOUS CORAL INDUSTRY

Over the last 20 years the precious coral industry in Hawaii has undergone substantial economic development. In 1966, the industry consisted primarily of products manufactured from black coral harvested off Maui and Kauai. Annual total retail sales amounted to approximately $1 million. In that same year, a bed of pink coral was discovered at a depth near 400 meters off Makapuu, Oahu. This discovery led to research funded by Sea Grant in 1970. The purpose of the research was to make an assessment of the resource, to develop an economically feasible method of harvesting the resource, and to develop management plans in order to conserve the resource. By mid-1970, all three goals had been met and a small fishery for pink coral established by Maui Divers of Hawaii, Ltd.

During the 1970s, the precious coral industry experienced gradual growth, reaching a level of $17 million by 1980. In early 1980, a worldwide recession occurred which depressed coral prices, hindering further growth of the industry. At present, the industry has stabilized near the $20 million level.

Products consist of pink, black, and gold corals. Most of the pink coral sold in Hawaii, however, is actually imported from Taiwan and Japan. Black and gold coral products are manufactured from locally harvested coral. The pink coral harvesting operation by Maui Divers was suspended in 1980 owing to economic constraints associated with high operational costs and the availability of cheaper raw material, primarily from Taiwan. During the last several years, however, prices of raw material have begun to rise again and several domestic companies have recently expressed an interest in harvesting pink coral locally.

At present in Hawaii, approximately 1,000 jobs related to the manufacture or sale of precious corals exist and approximately five local firms manufacture precious corals. In addition, several hundred retail outlets sell both imported and locally manufactured precious coral. Given the availability of the resource from both local and foreign sources, the future of the industry appears to be stable, although somewhat tied to future trends in the state's visitor industry. Local resources are managed under the authority of the Western Pacific Regional Fishery Management Council and the Division of Aquatic Resources of the Hawaii Department of Land and Natural Resources.

THE AQUACULTURE INDUSTRY: CURRENT STATUS

Today's aquaculture industry in Hawaii has its historical roots in freshwater prawn aquaculture. Sea Grant research on the culture and husbandry of prawns during the last two decades has played a significant role in stimulating the creation, development, and growth of water farming of both plant and animal species in Hawaii. Freshwater prawns, marine shrimp, seaweed, trout, and tilapia are among the species now being farmed — at a profit in many cases. Although many challenges face it, the aquaculture industry is today an established part of Hawaii's diversified economy.

A second important outcome of aquaculture research and farming has been the Hawaii's emergence as a major international center for research and development consultation firms. Many of these firms were started by or employ people who gained their expertise through research and farming here. Research, training, and technology transfer conducted here and around the world are significant sources of revenue for Hawaii's economy.

Building on the results of research and knowledge from prior farming experiences, more and more of today's water farmers are moving toward polyculture. Instead of farming just one species, farmers are raising two or more species to increase productivity and profit. Polyculture using cages, tanks, and raceways — as well as conventional ponds — is becoming commonplace on Hawaii's water farms.

The following selected data, collected for 1986, provide a snapshot of aquaculture in Hawaii. The number of farms growing freshwater prawns was 20; tilapia, 12; Chinese catfish, 8; marine shrimp, 5; and channel catfish, 5. An additional 26 farms were growing Chinese carp (4), rainbow trout (4), ornamental fish (4), American bullfrogs (3), mullet (3), microalgae (3), baitfish (2), seaweed (2), and abalone (1). Many of these farms are engaged in polyculture.

In 1986, more than a million pounds of aquacultured plants and animals were harvested. These had an estimated value of more than $3.5 million. In contrast, the 1985 harvest was about 583,000 pounds with an estimated value of nearly $2.8 million. The revenue brought in by research, training, and technology transfers was nearly $9.7 million in 1986, up from $8.7 million in 1985.

BIG ISLAND AQUACULTURE BUSINESSES

During the past 10 years on the island of Hawaii, the Sea Grant Extension Service has assisted 17 commercial aquaculture businesses and 34 backyard aquaculturists in getting started. Prior to the opening of the Extension Service office in Hilo in 1977, only two commercial mullet ventures were in operation — both with limited production. Aquaculture research had been principally conducted on Oahu, with very little technical information flowing to the neighbor islands.

Of the commercial farms that received technical assistance from the Sea Grant extension agent, seven produced rainbow trout; one, microalgae; six, Malaysian prawns; two, tilapia; and one, Chinese catfish. Backyard aquaculturists raised channel catfish, tilapia, grass carp, mullet, silver perch, and ornamental carp. Statewide aquaculture conferences were held in Hilo in 1980, 1981, and 1982 to bring local entrepreneurs up to date on the status of aquaculture in the state. The conferences were cosponsored by Sea Grant, the County of Hawaii, and the Resource Conservation and Development Program.

Recently, with the support of the state government, larger aquaculture ventures have become established in West Hawaii at the Natural Energy Laboratory of Hawaii. One business is marketing abalone; a second is producing microalgae. A third business will be producing *Porphyra* by 1988. Experimental projects have been conducted on Maine lobsters, giant clams, salmon, rainbow trout, oysters, tilapia, and opihi, among other species.

At present, more than 50 people are employed by commercial aquaculture businesses on the Big Island, and this figure is expected to increase in 1988 with the expansion of existing ventures and the starting of new ones. The five

Hawaii County Aquaculture Statistics

	1980	1983	1984	1985	1986*
Aquaculture industries	5	8	12	12	51†
Aquaculture acreage	—	3.4	45	54	43.4
Production (in thousands of pounds)	—	22.9	36.9	33.4	50.5
Value (in thousands of dollars)	—	90.8	126.5	196.5	398.2

Source: *State of Hawaii Databook*, 1986

*1986 data provided by Dr. Leonard Young and Steve Lee, Aquaculture Development Program, State of Hawaii

†Figure given is for number of persons employed instead of number of aquaculture businesses

pilot/demonstration aquaculture projects are not into commercial production yet.

At the University of Hawaii at Hilo, administrators have taken an interest in the future development of commercial aquaculture businesses on the island. An aquaculture course has been added to the College of Agriculture curriculum, and funding to construct an aquaculture training facility at the Panaewa farm has been received. The College of Agriculture is in the process of recruiting an aquaculture faculty member. The Sea Grant extension agent assisted in the planning of the curriculum, course instruction, and training facility design.

The availability of relatively cheap agricultural lands, fresh and salt water, and a climate suitable for raising many species are all factors which continue to capture the interest of local and foreign investors looking for aquaculture sites in the state. At present, Taiwanese businessmen are looking over the possibility of establishing penaeid farms on the island. The Sea Grant extension agent continues to provide entrepreneurs with requested information for getting started in aquaculture.

INSTITUTION BUILDING

It is not surprising that the major contributions made by the UHSGCP over its 20-year history have been the initiation and development and/or the timely support of existing ocean-related organizations, programs, and activities in Hawaii and the Pacific region. Hawaii and other Pacific islands lack the institutional infrastructures that are required to imprint fully an oceanic flavor on their political and cultural templates. It is not possible to imbue a consciousness of the significance of the ocean and its resources without institutional infrastructures that are themselves intrinsically tied to the ocean and marine affairs — it is not enough that the ocean is all around us or that there is a strong tie to the ocean in the indigenous culture.

Because the most sensitive nerve that ultimately can influence the course of a society is its formal and informal educational systems, UHSGCP was a leader in developing programs and institutional infrastructures for channeling marine education to children and the general public. The influence of the three educational centers and the seven marine education programs that are described in this section touched the formal and informal educational programs in the state, the region, and the nation. But more important, they each either support existing marine-related organizations outside of the educational system or are new structures and systems that augment and support the state's educational system. This expanded capacity in the school system and in the three centers will allow each to contribute to the formal and informal education of the youth and people of Hawaii to better understand their ubiquitous oceanic environment and its living and nonliving resources.

The support that UHSGCP provided in the development of the institutional framework for the state's current aquaculture research and development efforts includes completion of the state plan for aquaculture development, the building of the capability for aquaculture research at the University of Hawaii by augmenting the instrumentation in laboratories and in the field, the recruiting and training of scientific personnel in cooperative efforts with state agencies, and the establishing of the Natural Energy Laboratory of Hawaii as the site of deep ocean-water research — a spinoff from the state's ocean thermal energy conversion research program.

The development of both the Big Island Ocean Recreation and Tourism Association and, especially, The Ocean Recreation Council of Hawaii is the watershed in the establishment of the ocean recreation industry in Hawaii as a legitimate tourism-related economic enterprise. Coupled with this, the program on community interpretation was begun by the UHSG Extension Service to provide tour leaders and other tourism-related personnel with a deeper understanding of Hawaii and the spirit of "aloha." This program has now been incorporated into the formal course offering of Kapiolani Community College.

The first wave of programs that supported the marine institutional infrastructures in the Western and South Pacific islands occurred in the 1970s with the development of the Sea Grant program at the University of Guam. During this same period, an outreach program of the Hawaii Institute of Marine Biology (HIMB) at the Micronesian Mariculture Demonstration Center (MMDC) in Palau was funded. This program extended the research capabilities of MMDC and offered HIMB a research site for its scientists. More recently, UHSGCP has been involved in establishing a telecommunications network via PEACESAT in the South Pacific and Micronesia. While that portion of the network that links Hawaii to the South Pacific west of the international dateline and Micronesia is down, this effort confirmed the

feasibility and usefulness of a communication system linked by a satellite.

Finally, as one of the earliest Sea Grant College designees, UHSGCP has contributed to the development of organizational structures and linkages to promote local, regional, and national identities for Sea Grant as a leader in marine research, education, and extension services. This contribution continues in the participation of UHSGCP's administrative staff in such cooperative Sea Grant organizations as the Sea Grant Pacific region consortium, PSGCP, the Sea Grant Association, and the Sea Grant Directors' Council. The most telling evidence of the success of these institutional structures developed over the 20-year life of the National Sea Grant College Program is the establishment of the 29 Sea Grant institutions and the undeniable fact that the program is alive and well.

EDUCATIONAL CENTERS

HAWAII MARITIME CENTER

The Hawaii Maritime Center, a nonprofit ocean resource center, owes much of its success and direction to the support and guidance it has received from Sea Grant, the maritime industry, and the private sector. In 1982, with the assistance of Sea Grant staff, the Hawaii Maritime Center volunteer/docent program was instituted and has over the past 5 years developed into a multifaceted program with volunteer efforts extending to schools, the visitor industry, and maritime research projects. The program has been well received; in 1986, 109,400 residents and visitors had the chance to benefit from this program.

Sea Grant has provided not only support through matched funding for staff, but also the stimulation for development of numerous outreach projects. The community lecture series and the Marine Speakers Bureau have brought an awareness to the community of ongoing and future marine research as well as ocean-related concerns.

The Hawaii Maritime Center newsletter is produced as a cooperative effort with Sea Grant. This newsletter, which contains a current events calendar, is published quarterly. It is a valuable outlet for ocean information, serving a diverse ocean constituency locally, nationally, and internationally.

In the spring of 1988, the Hawaii Maritime Center will open its expanded facility, which is a result of a 3-year $4.5 million fundraising effort. Within this facility will be displays depicting Hawaii's historical tie with the ocean, as well as a reference photo, oral history, and literary library. It will not only serve as a link with the past but also provide a vision of the future.

WAIKIKI AQUARIUM

The mission of the Waikiki Aquarium is "to help people of all ages to understand, to love, and to care for the life of the ocean by providing educational and entertaining experiences involving the oceans and their living systems." The Waikiki Aquarium's goal is to be an interpretive center of the Hawaiian marine environment for the general public. All exhibits of Hawaiian marine life, education programs, publications, films and video productions, research, special events, field trips, and other activities have been developed with this goal in mind.

Sea Grant has helped in this effort during the past 10 years by providing funds for improvements to the exhibit labeling system. High-quality cibachrome transparencies are now in use as part of the interpretive graphics for each exhibit. Sea Grant has also been instrumental in supporting the aquaculture research project on the mahimahi, providing support for personnel and operating expenses.

RICHARDSON OCEAN CENTER

Since 1977, the Richardson Ocean Center, a marine education and recreation facility, has continued to be the first and only site on the island of Hawaii for ongoing marine programs. It was established to familiarize the public with Hawaii's finite marine resources and to enable visitors and residents to enjoy the ocean safely. The center has featured live displays of coastal, pelagic, and freshwater species, as well as maintained a reference collection of local specimens and informative displays of tsunamis, dangerous marine organisms, and whales. An annual docent program for

local and visiting school students continues to be a popular activity. The facility is also the site for the Ocean Fair, a festival spearheaded by the Big Island Ocean Recreation and Tourism Association.

The UH Sea Grant College Program provided seed money for the establishment of Richardson Ocean Center, and the County of Hawaii permitted the setting up of the Extension Office there. In addition, the county government maintains the grounds and pays for the utilities. Sea Grant funds were initially used to set up the displays and to hire a facilities manager to conduct the slide/lecture programs. Employees from social welfare programs were also recruited to assist with special programs.

Today, the County of Hawaii Department of Parks and Recreation has hired a full-time information assistant to run all of the programs at the center. It has also set up its water recreation and safety office at the center and has begun renovating the facility to accommodate new marine educational and recreational programs. The Sea Grant Extension Service agent serves on the center's advisory committee and cosponsors marine programs with the parks and recreation department.

AQUACULTURE

DEVELOPMENT OF INSTITUTIONS

Aquaculture, a topic of high interest in Hawaii since the mid-1960s, was featured in *Hawaii and the Sea: A Plan for State Action* (1969) and *Hawaii and the Sea — 1974*, landmark documents on the state's aspirations on ocean resource development. The state has attempted to promote the development of an economically viable aquaculture industry through a variety of mechanisms since that time.

The UH Sea Grant College Program (UHSGCP) has provided continuous support for the state's goal to promote the development of aquaculture through research and extension programs since 1968. From 1968 to 1974 this support was provided by the National Sea Grant College Program through UHSGCP, with additional direct grants to the Oceanic Institute and the state Anuenue Fisheries Research Center (AFRC). State support and matching for Sea Grant aquaculture projects were provided by the Marine Affairs Coordinator's office and the Department of Land and Natural Resources budget for AFRC. Since 1977, all Sea Grant funding for Hawaii for aquaculture research and extension services has been channelled through the UH Sea Grant.

The cumulative effect of this concentration of funding and effort of multiple sources on the state of the art, and on aquaculture enterprises in the state and beyond, is extremely difficult to measure. Nor are the returns in by any means. On the other hand, the effects on institutions are more apparent. The following are examples of how the Sea Grant aquaculture program has affected existing institutions and promoted new ones and continues to influence developments in the state, region, and nation.

PROGRAMS IN HAWAII

Sea Grant's support for aquaculture development in the state helped set the stage for and led to the development of the state of Hawaii aquaculture plan, *Aquaculture Development for Hawaii*, and led to its successful completion in 1978 and adoption in 1979. As the first state aquaculture plan developed in the United States, it helped set the stage for the subsequent development of a number of state plans, the Sea Grant Aquaculture Plan (1982), and the National Aquaculture Plan (1983).

The Hawaii aquaculture plan set forth the goals and priorities of the state and served as the guiding document for the Aquaculture Development Program (ADP) which was established in 1979 first in the Department of Planning and Economic Development and later transferred to the Department of Land and Natural Resources. Since 1979, ADP and the Sea Grant Aquaculture Program have been closely coordinated around the goals and priorities set forth in the state plan. The synergism resulting from the close coordination between UHSGCP and the state eliminated overlap and concentrated scarce resources to promote aquaculture as a joint effort and enabled the state to provide at least 50 percent of all the matching dollars for the Sea Grant Aquaculture Program.

PROGRAMS AT THE UNIVERSITY OF HAWAII

Sea Grant support of aquaculture at the University of Hawaii played a significant role in the establishment of aquaculture research in the

Hawaii Institute of Marine Biology (HIMB) and the College of Tropical Agriculture and Human Resoruces in augmenting the scientific staff with critically needed talent and in acquiring needed equipment and supplies. At present, aquaculture is recognized as one of the primary missions of HIMB; and HIMB, which now includes the Mariculture Research and Training Center (MRTC), is in turn recognized as one of the leading aquaculture institutions in the country.

Sea Grant support has led to the development of well-established aquaculture programs in the Departments of Agricultural Engineering and Animal Sciences in the College of Tropical Agriculture and Human Resources. Aquaculture is now recognized as an ongoing function of the Department of Agricultural Engineering and departmental support is provided for aquaculture engineering research and extension services. The programs under the Department of Animal Sciences include aquaculture courses and research in domestication of prawns and shrimp, nutrition, pond management, and disease in crustaceans and finfish.

The almost 20 years of Sea Grant support and close cooperation with the state has resulted in the recognition of the capacity of University of Hawaii faculty to respond to state, regional, and national aquaculture research needs. This long-term relationship has led to the recognition of aquaculture as a priority program at the University of Hawaii and has resulted in the establishment of the University of Hawaii Aquaculture Committee and the position of aquaculture coordinator. The Aquaculture Committee is comprised of the directors of the UHSGCP and HIMB, the chairman of the Botany Department, and the director of the Agriculture Experiment Station, with the director of the state Aquaculture Development Program as an ad hoc member. The aquaculture coordinator is responsible for overall coordination of all university aquaculture projects and programs, including Sea Grant-funded research and extension services.

OTEC AQUACULTURE

In some cases the proving up of a new concept may spinoff into its institutionalization and foster the development of new institutions as well as impact traditional ones. Ocean thermal energy conversion (OTEC) aquaculture, a program receiving Sea Grant support early in the present decade, represents such an example. UHSGCP, with its flexibility and rapid response capability, was able to provide initial seed monies and then join in partnership with equally visionary programs of the state of Hawaii to fund two innovative projects that set the stage for a multitude of developments which continue to proliferate in their scope, variety, and revolutionary impact.

Conventional wisdom suggested that the greatest value of deep ocean water was as the cold-water source for the generation of energy through one or more of the OTEC processes. It remained for Sea Grant scientists to postulate that the three characteristics of the deep ocean — its purity, its coldness, and its nutrient content — made it an ideal medium for the aquaculture of marine protein.

Partners in this initial undertaking included the Marine Affairs Coordinator's (MAC) office and its successor agency, the Ocean Resources Branch of the Department of Planning and Economic Development (now the Department of Business and Economic Development). ADP and UHSGCP have continued to support innovative scientists and entrepreneurial efforts to utilize the deep ocean water available through the state's Hawaii Natural Energy Laboratory Program at Keahole Point, Hawaii.

The broad results of the work and investment of OTEC aquaculture investigators and their supporters comprised the "proof of concept" of the feasibility of aquaculture and other extra-energy values of deep ocean water. The results have already manifested themselves in rapidly growing commercially successful aquacultural production

of abalone, algae, salmon, trout, and oysters. In the near future, the commercialization of some, if not all, of the following products is expected: strawberries, alstymaria (an alpine ornamental flower), opihi (a Hawaiian gourmet shellfish), lobster, and an ever-growing number of marine algae species. As a total system for research and development, the cooperative efforts of UHSGCP and the ocean agencies of the state represent a model for innovation that might well be replicated elsewhere.

REGIONAL AQUACULTURE

UHSGCP support for aquaculture in the tropical insular Pacific areas has been directly responsible for an increased recognition of aquacultural research capacity at the University of Guam Marine Laboratory and indirectly for the establishment of the Marine Mariculture Development Center (MMDC) at Palau. A cooperative UHSGCP-Office of Technical Assistance (U.S. Department of Interior) program is currently in process to provide support for MMDC and to extend aquaculture research and extension services to other American flag and affiliated Pacific insular communities.

Sea Grant has contributed both indirectly and directly to the establishment of the regional Center for Tropical and Subtropical Aquaculture (CTSA). Through its continuous support for research, education, and extension services, described above, Sea Grant set the stage for the center's development. Sea Grant efforts have provided the critical mass of information and accomplishments, established an awareness of needs and opportunities, and developed the required expertise among university faculty and other resource people involved in aquaculture in the region. More directly, the director of UHSGCP participated in the planning for CTSA as a member of a special ad hoc committee set up for this purpose and serves as a member of the CTSA Board of Directors.

COMMERCIAL OCEAN RECREATION

COMMUNITY INTERPRETATION TRAINING PROGRAM

The community interpretation training program evolved from UH Sea Grant Extension Service's earlier involvement with the Big Island Ocean Recreation and Tourism project. In an effort to expand and improve ocean recreation opportunities on the Big Island, Dr. Gabriel Cherem from Michigan was invited to present seminars on "community interpretation." More than 100 individuals participated, representing a broad spectrum of agencies, organizations, and businesses which interpret, or present, Hawaii's cultural and natural heritage to visitors and residents. The seminars were conducted in cooperation with the Hawaii Museums Association, Hawaii Visitors Bureau, and UH continuing education program in west Hawaii.

As a result of the seminars, a task force of interested participants was formed to further develop the concept for Hawaii. John Brizdle of E Noa Tours emerged as the chairman, with Sea Grant Extension Service providing staff support. The task force aimed to (1) improve the quality of interpretation presented to visitors, (2) increase resident awareness and appreciation of Hawaii's rich natural and cultural heritage, (3) stimulate agencies and organizations to cooperate and network in improving interpretive programs throughout the state, and (4) facilitate visitor access to special experiences available to the public.

In 1986, the project, which earlier was primarily supported by UH Sea Grant Extension Service, became independent and self-sufficient when Kapiolani Community College's Office of Community Services obtained a special grant from the University of Hawaii's Chancellor for Community Colleges to develop Interpret Hawaii, an interpretive training program for the visitor industry.

Many people in the visitor industry now perceive interpretation as an important element in overall tourism development. Also, the University of Hawaii now recognizes that vocational training for people in the visitor industry will help ensure a higher-quality experience for tourists. Individuals who took Interpret Hawaii's Visitor Industry Personnel (VIP) 40-hour course gained not only new knowledge about Hawaii's heritage and interpretive techniques, but also pride in their job and their island home. The various programs sponsored by Sea Grant and Kapiolani Community College have helped to bring together individuals from many agencies and organizations in a volunteer, cooperative effort to improve the quality of interpretation in Hawaii, especially as presented to visitors. Also, the programs have helped to form networks of people with common interests and concerns. Finally, at informal sessions such as Interpret Hawaii's monthly coffee hours, individuals with diverse affiliations have had unique opportunities to explore areas of mutual concern and interest.

BIORTA

A countywide effort, initiated by the University of Hawaii Sea Grant Extension Service (SGES) in 1983, resulted in the recent formation of a nonprofit group, the Big Island Ocean Recreation and Tourism Association, Inc. (BIORTA). The intent of the original community-based project was the development and improvement of ocean recreation opportunities to diversify the tourist base in an economically depressed region and, also, to increase community participation in natural and cultural resources management.

The new association continues to blend long-range planning, economic and conservation concerns, and community and business development in a comprehensive countywide effort. Among the projects initiated or completed to date with Sea Grant funds are upgrading of local lifeguard expertise, ocean visitor center programs, islandwide ocean fairs to demonstrate the linkage between the ocean and everyday and cultural life, informational signs and booklets, and work with the state legislature and governmental agencies. Current and future endeavors include pushing for better control on nonpoint pollution sources, solid waste recovery/recycling centers, and a mooring buoy system, as well as assisting the local ocean recreation industry in promotional efforts and cooperative ventures.

By the end of 1984 several demonstration projects were completed: a 24-page color brochure which introduces visitors to ocean recreation on the Big Island (reprinted in 1986); an informational display at the island's most popular snorkeling site; and program development for the Richardson Ocean Center in Hilo.

BIORTA attracted the attention of the Hawaii Legislature which passed supportive resolutions in 1983 and appropriated project funds totaling nearly $200,000 between 1984 and 1985. SGES submitted a 5-year plan for the BIORTA program to the legislature in 1985.

In March 1985, BIORTA and the Royal Lifesaving Society, Canada, a nonprofit organization which promotes lifesaving professionalism and training, sponsored a training course for 12 county and resort hotel lifeguards. Additionally, during the 1985 and 1986 legislative sessions, $36,000 was appropriated to BIORTA to train school children and additional local instructors. By summer 1986 approximately 1,000 children in the Kona district had been trained to recognize and take steps against dangerous swimming situations. The Hawaii Department of Education has expressed interest in similar training programs for its system, and in 1987 the state legislature appropriated funds for a full-time position and $50,000 in programmatic and staff funds for a statewide aquatics program.

Another BIORTA-initiated community activity is the annual Big Island Ocean Fair. Each year, over a 3-month period, nine sites become the focus of a celebration of life associated with the ocean. Civic groups and local businesses are pulled together by BIORTA to demonstrate a variety of different relationships with the sea, including recreational, cultural, historical, artistic, and scientific aspects. Each celebration is unique and draws scores more participants each year.

TORCH

The Sea Grant Extension Service (SGES) recognizes the vital role of small ocean recreation businesses in providing attractions and services for Hawaii's visitors and residents.

As a result of discussions at the first statewide conference on ocean recreation and tourism, cosponsored by the UH Sea Grant College Program and the Hawaii Department of Business and Economic Development (DBED) on how to best further the interests of the ocean recreation community, a nonprofit group was formed "to perpetuate and enhance the state of Hawaii's marine resources through the cooperative management of ocean recreation. The key word is "cooperative." In the past, ocean recreation in Hawaii suffered from competitive distrust and fragmentation. However, the "industry" recognized the need to resolve user conflicts and safety and to address the issue of inadequate access. It was made very clear at the conference that changes or progress could not be effected by any one group or individual but rather through cooperative and united action.

The Ocean Recreation Council of Hawaii (TORCH), with the aid of SGES and DBED, has in its first 2 years already sponsored a number of pieces of legislation and settled some local access

problems. Its members have been asked to sit on a number of important task forces and committees. Of greatest importance are the Governor's Task Force on Ocean Resources for Tourism and the state's ad hoc committees on Ocean Recreational Motorcraft Management Areas. The former addresses the need to protect and enhance resources used for tourism and the latter concerns the development of guidelines for recreational motorcraft management. Sea Grant Extension Service will continue as necessary and appropriate to provide technical and coordination assistance to TORCH in these ventures.

A significant program being sponsored by TORCH and given technical assistance by Sea Grant is the statewide buoy mooring system. This system will provide safe, temporary moorings as well as maximum protection to coral from anchor damage. The basic technology has been adapted for Hawaiian basaltic substrates by researchers from the UH Department of Ocean Engineering and the Hawaii Institute of Geophysics. They adapted it from one developed for the limestone substrates of Key Largo National Marine Sanctuary in Florida.

EDUCATION PROJECTS

Over the past two decades, the UH Sea Grant College Program has sponsored a variety of marine education programs and projects, which range from elementary to graduate levels, in formal to nontraditional formats. At the graduate level, support was provided for the development of new courses for the Ocean Engineering, Botany, and Zoology departments; the Hawaii Institute of Marine Biology; and the College of Tropical Agriculture and Human Resources. At the undergraduate level, support has been provided for experiential education on all campuses of the UH system through the Marine Option Program, marine technician training at Leeward Community College, and backyard aquaculture skills development at Windward Community College. Undergraduate course development was also supported in the following areas: marine pathology at UH-Hilo and marine sciences and aquaculture at UH-Manoa. The precollege level programs and projects supported include curriculum development under the "Hawaii Marine Science Studies" project; an annual student marine affairs symposium; a sea-going science education program called the Blue-Water Marine Laboratory; a traveling display and activities "festival of the sea"; a nontraditional, culture-based activities program to instill pride in and reduce the dropout rate of Hawaiian students; a glass-bottom boat harbor tour program; and several teacher workshops in Hawaii and the southwestern Pacific islands. The Waikiki Aquarium has benefited from Sea Grant support for courses and materials used for public and docent education.

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MARINE OPTION PROGRAM

The Marine Option Program (MOP) is an experiential ocean education program for undergraduates. It is designed to provide an interdisciplinary complement to the traditional classroom by promoting learning through first-hand experiences, thus better preparing students for marine-related employment or further specialized training. Its primary goal is to become the principal source for undergraduates in all fields of study at the University of Hawaii to develop their marine-related interests and talents. MOP provides counseling to students; places them in jobs and internships; serves as a marine information clearinghouse; and sponsors field trips, courses and workshops with a practical orientation, community service projects, and field research studies. Since the program's inception, 352 students have earned a certificate by completing a core of ocean-related courses in addition to an internship or independent study project. Annual systemwide enrollment currently runs between 300 and 400 students.

The Marine Option Program was initiated as a Sea Grant project at the UH-Manoa campus in 1971. Initially, support was provided for both administrative and operational costs (such as stipends, supplies, and travel expenses for student projects). The program expanded to other UH campuses, encompassing at one time UH-Hilo, Windward Community College, Maui Community College, Honolulu Community College, Leeward Community College, and Kauai Community College. Budget cuts in the early 1980s combined with a shift in UH administration priorities to more traditional forms of education, resulted in the program being dropped at the latter three campuses. As MOP evolved, its funding base expanded to include state agencies such as the Office

of the Marine Affairs Coordinator, Department of Business and Economic Development, Aquaculture Development Program, and Division of Aquatic Resources; federal agencies such as the National Science Foundation, National Marine Fisheries Service, Naval Ocean Systems Center, and Army Corps of Engineers; and private concerns such as The Lanai Group, Maui Land and Pineapple Co., and Castle and Cooke. At present, funding is principally provided by the University of Hawaii, with all personnel and administrative costs covered in the budget of each campus. Sea Grant continues support at a modest level for individual student projects.

Sea Grant continues to provide an administrative home for MOP at the Manoa campus.

BLUE-WATER MARINE LABORATORY

The Blue-Water Marine Laboratory (BML) is a statewide sea-going science education program designed primarily for students in grades 7 to 12. During the academic year students are taken out for a 3-hour cruise aboard a research vessel on which they participate in a variety of hands-on activities, including sampling and sample analyses, techniques of navigation and positioning, and water safety practices. At the same time, they are taught basic oceanographic principles and maritime history, and they learn about issues of coastal zone management. High school students who graduate from BML's Summer Ocean Studies Program and who continue training during the year — by participating in weekend workshops and by preparing marine projects for the annual science fair or marine symposium — serve as cruise instructors under the supervision of undergraduate teaching assistants from the Marine Option Program (MOP). The student instructors earn high school science credits.

BML was designed after the Orange County (California) Floating Lab. Originally intended for college students, it was initiated with UH Sea Grant support in 1972 by a MOP student as the marine skill project required for his MOP certificate. Substantial Sea Grant funding ended after 3 years as support was secured from a private foundation and then, in succession, the state Office of the Marine Affairs Coordinator and state Department of Education. Until 1986, BML and MOP were administered by the same personnel under Sea Grant. Funding problems in the state legislature resulted in suspension of sea-going activities in 1983-84, but an active beach trip program, which maintained the foundation of peer education, was substituted. The following year, line-item funding was restored with program responsibility transferred from MOP to the university's Waikiki Aquarium, which is also administered by Sea Grant.

Since its inception, BML has taken out nearly 35,000 students on cruises and trained some 350 high school and 45 college student instructors. Both a teacher's guide and the curriculum for the summer study program were developed. This project exemplifies how Sea Grant seed money can effectively initiate an education program to meet local needs.

SYMPOSIUM FOR YOUNG MARINE SCIENTISTS

On May 21, 1976, the first Annual Student Symposium on Marine Affairs, under the sponsorship of the UH Sea Grant College Program, convened at the Hilton Hawaiian Village Hotel in Waikiki. Twenty high school students presented 12 papers at panel sessions on Hawaii's skipjack tuna fishery, law of the sea, coastal zone management, and aquaculture.

The sponsorship of the symposium was taken over by the Hawaiian Academy of Science in 1980. Currently the academy cosponsors the event,

which is entering its 13th year, with the Hawaii Science Teachers Association.

The symposium provides an opportunity for high school students to present research and literature review papers on marine topics in a forum much the same as a professional symposium in which scientists and other professionals participate. It also creates opportunities for teachers to exercise their students in reading, writing, speaking, and research skills and to acquaint them with scientific and academic styles of presentation.

Since 1976, the symposium has grown in the reach of its influence. Today, the islands of Hawaii and Kauai hold "divisional symposiums" that feed into the "big" symposium. American Samoa's participation has grown steadily since 1982, and, in 1988, they will hold a divisional symposium as well. In 1985, the Extension Service of the University of Alaska at Sitka decided to emulate the Hawaii model and has since held an Alaska Marine Symposium.

In the early years, only a few original research papers were submitted. Now, the symposium receives 15 to 20 bonafide papers on laboratory and field experiments, most of which, according to scientific reviewers, are of college-level quality. Nonresearch papers continue to be valued but are a less important part of today's symposium.

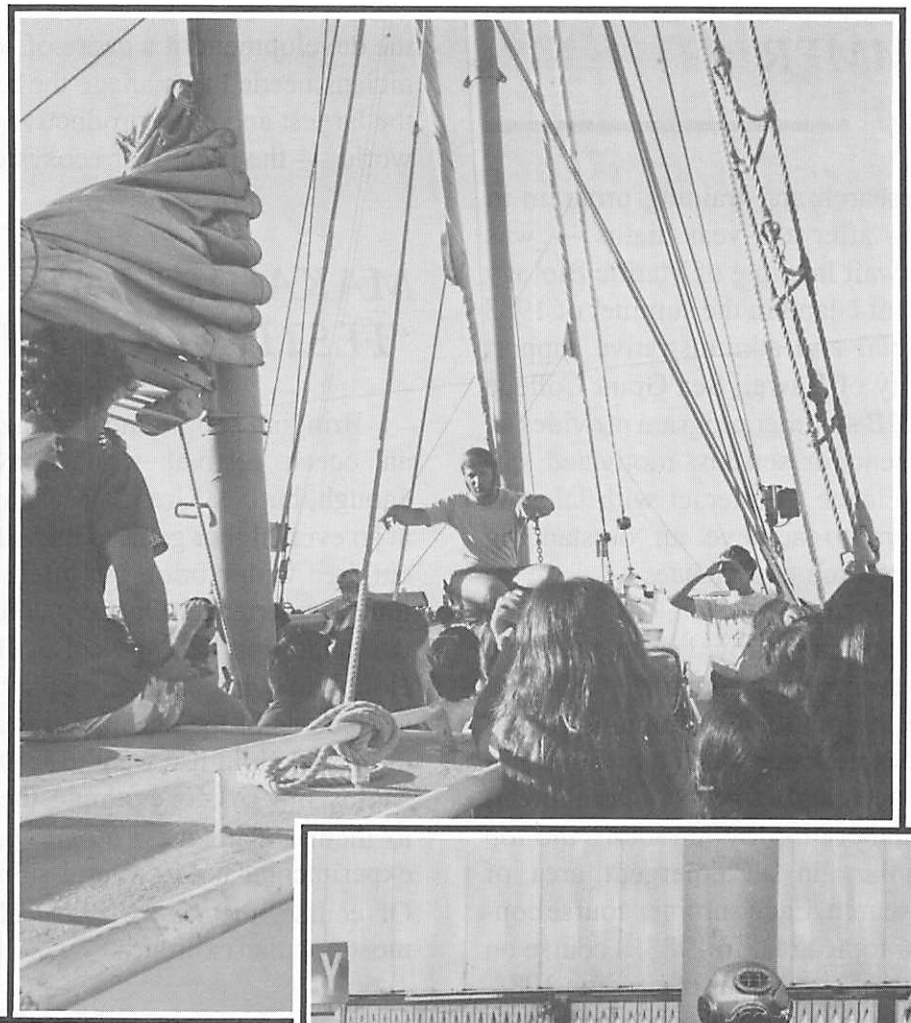
Annual evaluations of the symposium consistently indicate that what students like most is listening to the presentations of other students and reporting their work to adults who listen and ask questions "as if they consider our work worth talking about." Teachers report that the symposium has a significant positive effect on the academic attitudes of participating students.

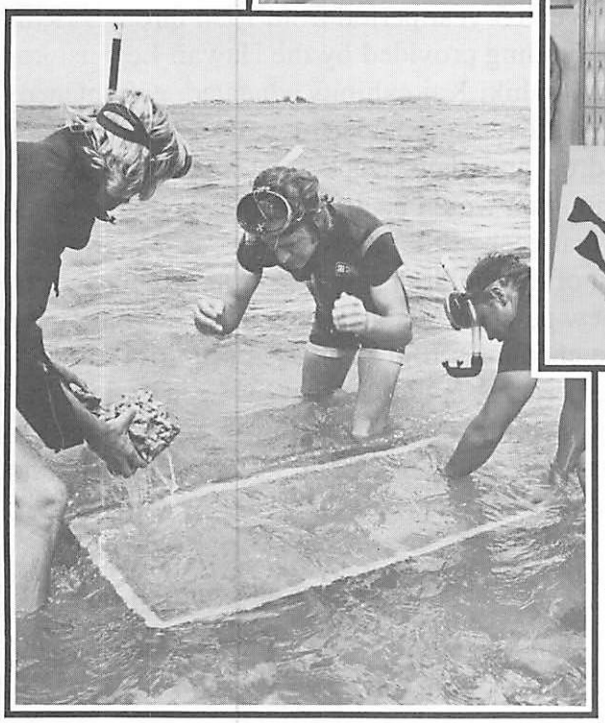
HIGH SCHOOL MARINE SCIENCE STUDIES PROGRAM

Engaging high school students in hands-on investigations of oceanic phenomena using basic concepts of science and technology is the goal of the High School Marine Science Studies (HMSS) program. HMSS is a multidisciplinary science course set in a marine context. Although developed for students of all abilities in grades 9 through 12, HMSS materials have been used successfully in postsecondary and nonformal settings as well.

Materials include two companion textbooks, *Fluid Earth* and *Living Ocean*, accompanying workbooks, and teacher guides. *Fluid Earth* explores the physics, chemistry, and geology of the oceans and their applications in ocean engineering and related technologies. *Living Ocean* explores the biology and ecology of the oceans and other aquatic environments and their applications in aquaculture and related technologies. Units are modular in design, allowing use of the materials as a one-semester or one-year course. Modules may also be used as marine segments in other science or technology courses.

Begun with Sea Grant funding in 1975, the materials have undergone continuous classroom testing, revision, and updating. (The fourth edition will be published in hardback in 1988). Revisions are based on feedback from more than 400 teachers and review by more than 50 scientists, assuring both the pedagogical soundness and the scientific validity of the instructional strategies and materials. HMSS is being used by 90 percent of the high schools on Oahu and by some teachers on all other islands in Hawaii. It has also been successfully adopted by schools in Massachusetts, California, North Carolina, Virginia, Maryland, Alaska, Kosrae, and Samoa. In 1982, HMSS was selected as an "Exemplary Program in Science" by the National Science Teachers Association in its first nationwide "Search for Excellence."





HIMB SUMMER PROGRAM

A graduate research and training program in marine science — after a 5-year hiatus — was resumed at the Hawaii Institute of Marine Biology (HIMB) on Coconut Island in the summer of 1983 with major financial and administrative support from the University of Hawaii Sea Grant College Program. The HIMB summer program provides an optimal environment for serious, motivated students in marine science to interact with talented teachers/researchers to achieve an outstanding educational and research experience.

The summer program provides an intensive educational experience for graduate students selected from the international community based on their academic excellence and interest in tropical marine science and fosters international exchange and collaboration by attracting the top international scholars in an emergent area of marine science research. Each summer course concentrates on a new topic area. In 1983, a course on population biology of corals was offered; in 1984, a course on solar radiation in the sea. A course on marine shrimp is planned for the summer of 1988.

The 1983 session resulted in 57 papers, most of which were published in an edited collected volume. It also resulted in a number of associations and collaborative relationships among faculty and students, some of which have persisted to the present. Perhaps the most important achievement was the establishment of a credible, quality program in the eyes of the trustees of the Edwin W. Pauley Foundation. This could not have been accomplished without the 2-year participation of the UH Sea Grant College Program. Evidence of this is seen in the total support of this program by the Pauley Foundation for the past 4 years.

Program participants are exposed to the best scientists in the field of coral biology, the latest ideas and research methods, and some of the most challenging hypotheses to test. This has enhanced the development of a cadre of scientists and technicians needed to manage the resources of one of the largest and most productive ecosystems in the world — the coral reef ecosystem.

MAKAHIKI KAI — "FESTIVAL OF THE SEA"

Bringing people and organizations together for an ocean festival would have been purpose enough, but Sea Grant's Makahiki Kai was aimed at an even higher goal: to provide Hawaii's school children with a brief, but intensive marine educational experience. On Oahu, Makahiki Kai filled the exhibition hall at Neal S. Blaisdell Center in Honolulu with booths, displays, exhibits, films, and people of the ocean. For neighbor island children, Makahiki Kai went to sea and arrived at their shores. In 1976, for example, the festival was taken to them aboard the *Kaimalino*, the U.S. Navy's experimental and first semi-submersible platform. Of course, the *Kaimalino* itself was one of the most popular exhibits.

Over a 5-year period from 1974 through 1978, with funding provided by the Hawaii Legislature, the Makahiki Kai exhibits educated, enlightened, and, yes, even entertained more than 50,000 school children and their teachers throughout Hawaii. Although it would be difficult to specify the benefits that each child received, it is safe to say that most of the children saw the ocean from a variety of new perspectives that they might not otherwise have encountered in the classroom. More important, perhaps, is that teachers were introduced to the possibility of incorporating elements of the sea into their lesson plans for these children and for the children of Hawaii's future.

HO'I ANA IKE KAI — "RETURN TO THE SEA"

Using the ocean as an educational tool was the strategy of an experimental educational program for secondary and elementary students from the Waianae coast of Oahu. The program, Ho'i Ana ike Kai, was designed to motivate those students for whom traditional classroom learning lacked relevancy.

Two courses were developed for the program and were used at Waianae High School and Maile Elementary School in the spring of 1978. In the "Fishing in Hawaii" course the ocean was presented to high school students as a valuable resource from which they could potentially earn a living. A Leeward Community College instructor with years of commercial fishing experience taught nearly three dozen students a variety of skills needed for commercial fishing. The course included fishing "field trips" aboard sportfishing boats.

In the "Hawaii Reef Food" course, students in grades 4 to 6 learned about the reef plant and animal life that can be eaten as food. They also learned about ancient Hawaiian lore and food preparation techniques related to these resources. The instructional strategy employed, which included reef walks, was "hands-on" learning. The culmination of this course was a simulation of a trip on an ancient voyaging canoe.

This Sea Grant-supported project demonstrated the efficacy of ocean-oriented alternative educational approaches to motivate secondary-level students otherwise not performing well in school.

TROPICAL PACIFIC PROGRAMS

UNIVERSITY OF HAWAII/ UNIVERSITY OF GUAM SEA GRANT PROGRAM

The formal association which led to the formation of the University of Hawaii/University of Guam Sea Grant Program began in 1979 with the placement of a University of Hawaii Sea Grant extension agent at the University of Guam's Marine Laboratory. The first UH/UG research projects were proposed in 1980 and initiated the following year by faculty of the University of Guam Marine Laboratory.

Challenges facing the program include coastal pollution, introduction of alien species, overharvesting, and destructive harvesting practices by a gleaning society. Additionally, ocean-related conflicts are often a result of the differing opinions by Guam's multiethnic population about the use of marine resources.

The program has met these challenges by focusing on fisheries and coastal resource issues unique to Guam and the western Pacific. For example, recruitment rates and resource assessments on the stocks of herbivorous reef fishes at different depths, latitudes, and habitats were made in conjunction with research on historical and current fishing methods in Guam. The stock assessments provide a basis for reasonable prediction of the effects on benthic communities of overfishing of these fish populations. Correspondingly, the study of fishing methods resulted in a guidebook which documented traditional and alternative harvesting methods and encouraged appropriate fishery development. It now serves as a guide for coastal resource managers.

Furthermore, the extension agent has instituted a fishery training program for Guam teenagers to foster greater understanding of the value of fishery resources and to increase responsible participation in reef fisheries. Emphasis was placed on basic biological interrelationships of mangroves, coral reefs, and the open ocean and the damage caused by destructive fishing methods, pollution, and overharvesting. Additionally, elderly fishermen presented information on traditional fishing methods.

The Guam program has also included studies of alternative fisheries such as the culture of the seaweed *Gracilaria* and the farming of sea cucumbers. Studies on the effectiveness of various coral transplant methods and the role of seagrass communities in the biology of coral reef fishes have also been carried out to provide resource managers with additional knowledge.

USP-UH INTERNATIONAL PROGRAM

The International Sea Grant Program (ISGP) was begun in 1979 as a cooperative effort between the University of Hawaii (UH) and the University of the South Pacific (USP). Its intent was to extend the expertise available through the National Sea Grant College Program to the South Pacific via USP. The goal was to foster the wise development and use of marine resources of the region to benefit local populations. In an effort to achieve this, cooperative extension programs and research projects, special training exercises, academic interchange between the staffs and faculties of the two institutions, and satellite seminars involving participants from 12 Pacific islands and rim countries were initiated.

By the conclusion of the program in 1984, 7 USP faculty members and 6 UH faculty or staff members had spent time at each other's institution on an exchange basis; 5 conferences/workshops had been planned or cosponsored; 8 USP graduates had received additional specialized training at the University of Hawaii; 5 joint research projects were undertaken; and 72 one-hour satellite sessions were conducted, including 9 seminars on marine conservation, aquaculture, and related topics.

These numbers serve as an indicator of a successful cooperative effort. The real success, however, is not reflected in numbers, but in the enhanced skill of the participants. As the program evolved the participants became acquainted with each other's problems, styles, special skills, and needs. As a result, the program matured to a point where special-topic seminars, joint research projects, and collaborative efforts made a significant contribution to the training and problem-solving skills of the people involved.

The long-range benefits of the program are difficult to assess at present because the impact of increased skills takes a longer time than has passed to be fully realized. As the participants from Fiji, Western Samoa, Kiribati, the Solomon Islands, and Tonga move toward positions of leadership in their respective departments of fisheries and natural resources, the results of the program will become more apparent.

MMDC AT PALAU

In 1975, a 2-year cooperative aquaculture project was initiated between the Micronesian Mariculture Demonstration Center (MMDC), with its natural potential as an aquaculture site, and the Hawaii Institute of Marine Biology (HIMB), with its well-established laboratory and University of Hawaii backing. This liaison was advantageous to both in that it afforded UH faculty and students the opportunity to undertake applied research at a site in the equatorial Pacific and facilitated aquacultural development in Palau by drawing upon outside expertise.

MMDC, which was established by the government of the then Trust Territory of the Pacific Islands, is committed to developing hatchery and production techniques to make commercially viable aquaculture possible in Micronesia. The major subprojects involving Sea Grant funding were siganid and *Macrobrachium* culture. Peace Corps volunteers carried out work on other species, and much of the pond technology work was supported with matching funds provided under the Manpower Development and Training Act.

In 1986, Sea Grant renewed its support for the MMDC aquaculture program by providing two consultants and special procurement of equipment and supplies for *Macrobrachium* culture in an integrated aquaculture-agriculture extension-demonstration project. That work was continued into 1987-88 and was expanded to provide principal management and technical staff for MMDC, specific support for giant clam (*Tridacna* sp.) culture, and additional support to upgrade the extension-demonstration project, for travel and communications, for procurement of equipment and supplies, and for other items.

The need for training young Micronesians to participate in the development of marine resource-related industries is important for Palau and other former Trust Territory communities to shift from a predominantly subsistence economy to one of an increasingly commercial character. Sea Grant continues to support the education and training services of MMDC.

On a larger scale, Sea Grant is promoting the development of aquaculture among all American-affiliated island communities in the Pacific by supporting the establishment of a Pacific aquaculture association and a Pacific aquaculture development plan.

the National Sea Grant College Program has been

(1982)

- International Symposium on Salmon and Trout Reproduction (1983)

- Workshop on the Impact and Fate of Marine Debris (1984); major cooperators PSGCP, NMFS, FWS

- Gordon Research Conference of Marine Natural Products (1986 and 1988)

Important products include better-trained extension personnel, coordination of research and extension efforts and information transfer, and publication of workshop and conference proceedings which provide state-of-the-art information and recommendations. Examples of publications include:

- *Proceedings of the Workshop on the Fate and Impact of Marine Debris*, 27-29 November 1984, Honolulu, HI

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By the conclusion of the program in 1984, 7 USP faculty members and 6 UH faculty or staff members had spent time at each other's institution on an exchange basis; 5 conferences/workshops had been planned or cosponsored; 8 USP graduates had received additional specialized training at the University of Hawaii; 5 joint research projects were undertaken; and 72 one-hour satellite sessions were conducted, including 9 seminars on marine conservation, aquaculture, and related topics.

These numbers serve as an indicator of a successful cooperative effort. The real success, however, is not reflected in numbers, but in the enhanced skill of the participants. As the program evolved the participants became acquainted with each other's problems, styles, special skills, and needs. As a result, the program matured to a point where special-topic seminars, joint research projects, and collaborative efforts made a significant contribution to the training and problem-solving skills of the people involved.

The long-range benefits of the program are difficult to assess at present because the impact of increased skills takes a longer time than has passed to be fully realized. As the participants from Fiji, Western Samoa, Kiribati, the Solomon Islands, and Tonga move toward positions of leadership in their respective departments of fisheries and natural resources, the results of the program will become more apparent.

MMDC AT PALAU

In 1975, a 2-year cooperative aquaculture project was initiated between the Micronesian Mariculture Demonstration Center (MMDC), with its natural potential as an aquaculture site, and the Hawaii Institute of Marine Biology (HIMB), with its well-established laboratory and University of Hawaii backing. This liaison was advantageous to both in that it afforded UH faculty and students the opportunity to undertake applied research at a site in the equatorial Pacific and facilitated aquacultural development in Palau by drawing upon outside expertise.

MMDC, which was established by the government of the then Trust Territory of the Pacific Islands, is committed to developing hatchery and production techniques to make commercially viable aquaculture possible in Micronesia. The major subprojects involving Sea Grant funding were siganid and *Macrobrachium* culture. Peace Corps volunteers carried out work on other species, and much of the pond technology work was supported with matching funds provided under the Manpower Development and Training Act.

In 1986, Sea Grant renewed its support for the MMDC aquaculture program by providing two consultants and special procurement of equipment and supplies for *Macrobrachium* culture in an integrated aquaculture-agriculture extension-demonstration project. That work was continued into 1987-88 and was expanded to provide principal management and technical staff for MMDC, specific support for giant clam (*Tridacna* sp.) culture, and additional support to upgrade the extension-demonstration project, for travel and communications, for procurement of equipment and supplies, and for other items.

The need for training young Micronesians to participate in the development of marine resource-related industries is important for Palau and other former Trust Territory communities to shift from a predominantly subsistence economy to one of an increasingly commercial character. Sea Grant continues to support the education and training services of MMDC.

On a larger scale, Sea Grant is promoting the development of aquaculture among all American-affiliated island communities in the Pacific by supporting the establishment of a Pacific aquaculture association and a Pacific aquaculture development plan.

COASTAL RESOURCES MANAGEMENT PLANNING FOR MICRONESIA

In response to increased economic and population pressures, many western pacific Island leaders are accelerating the pace of development. In most cases this means development of coastal resources because they are the most abundant and easily exploitable. The use of these resources has led to economic gains and expanded living space, but it has also caused unintended environmental damage. Adverse effects can be avoided by careful planning and implementation of environmentally sensitive alternative development strategies.

The University of Hawaii Sea Grant Extension Service (SGES), assisted by the U.S. Army Corps of Engineers, has developed a coastal zone program to assist U.S.-affiliated island governments.This program is designed to provide local coastal resource managers with ready access to technical information and planning expertise as well as help island planners to create and implement sound resource management plans.

To date, coastal resource atlases and inventories have been completed for Pohnpei and Yap in the Federated States of Micronesia (FSM). Similar products are currently being developed for Kwajalein Atoll in the Republic of the Marshall Islands. Coastal resource management plans have also been completed or nearly completed for Pohnpei, Yap, and Kosrae (FSM). In addition, with the South Pacific Regional Environmental Program, SGES cosponsored a workshop in Pohnpei on the process of coastal zone management planning on tropical islands.

Where the coastal resource management plan *is being* implemented, for example in Guam and FSM, resident extension agents work with local authorities to ensure that the provisions of the plan are carried out and to provide educational programs. These agents are part of a Pacific-wide network of coastal resource managers. The network will use satellite communications to provide the means for discussing common problems and areas of concern, as well as possible solutions.

PEACESAT

Since early 1980 the UH Sea Grant College Program has used the PEACESAT (Pan-Pacific Education and Communication Experiments by Satellite) communication network to organize and carry out joint marine research and extension programs. The PEACESAT project, initiated by the University of Hawaii, was begun in 1971 "to demonstrate the benefits of currently available telecommunications technology when applied specifically to the needs of sparsely populated, less industrialized areas." PEACESAT utilizes the National Aeronautic and Space Administration's (NASA) Application Technology Satellite (ATS-3) as the medium for conducting long-range communication in the Pacific.

The UH Sea Grant College Program has utilized the PEACESAT network to maintain communication with a number of marine-oriented professionals in the Pacific, ranging from fisheries officers to aquaculturists. PEACESAT was also used in two important Pacific programs: the Cooperative UH Sea Grant/University of the South Pacific (USP) International Sea Grant Program (explained in detail in a previous section); and the Pacific SeaLink Program, an outgrowth of the UH Sea Grant/USP program.

Pacific SeaLink's purpose is to broadcast seminars dealing with issues and problems in marine resource management in the Pacific. Seminars are organized by one of the several island area participants and broadcast to other participants at a regularly scheduled time. The program, begun in 1984, was temporarily suspended beginning in August 1985 owing to satellite problems. It resumed in late 1987 and will continue until December 1988, at which time an evaluation of its effectiveness will be made. Continuance is likely.

REGIONAL AND NATIONAL ROLES AND IMPACTS

PACIFIC SEA GRANT COLLEGE PROGRAM

The University of Hawaii Sea Grant College Program (UHSGCP) is a founding and continuing sponsor of the first regional Sea Grant program, the Pacific Area Sea Grant Advisory Program (PASGAP), which was established in 1969. Cooperating programs included the University of Alaska, the University of California, the University of Hawaii, Oregon State University, the University of Southern California, the University of Washington, and the University of British Columbia. The early PASGAP focus was on the development of high-quality Sea Grant Advisory Services throughout the region through cooperative training and talent sharing. The cooperative agreement was later expanded to encompass the research and education dimensions of the Sea Grant mission. In April 1979, the first national-regional conference on marine education was held in Honolulu under the sponsorship of PASGAP. UHSGCP took the leadership in this unique conference-within-a-conference that focused on developing a plan of action in marine education in the PASGAP states. A follow-up workshop was held in June 1980 in Fairbanks, Alaska to evaluate the progress of the work done in implementing the state plans. The coordinator of the marine education program for the California Sea Grant College Program has credited this planning effort in the success she had in establishing linkages within the school system.

The broader cooperative program, renamed the Pacific Sea Grant College Programs (PSGCP), has served as a model to other regions of the U.S. and led the Sea Grant Association to take the following position:

> One of the most promising areas of development for the National Sea Grant College Program has been the emergence of regional networks covering most of the Pacific, Gulf, Atlantic and Great Lakes coasts. These regional networks appear to be the most promising means of coordinated interaction with NOAA, the regional fishery management councils, other agencies and private interests on important national and regional questions . . . . (Sea Grant Association Task Force, FY84 Request, June 1, 1984)

The present Pacific regional Sea Grant network provides a mechanism for cooperation to attack a variety of mutual problems regarding the wise use and development of the Pacific region's marine resource wealth. PSGCP has sponsored and continues to sponsor workshops and symposiums; regional training for advisory, education, and communication personnel; publication of symposium and workshop proceedings; and regional talent sharing.

Some of the PSGCP cooperative events in which UHSGCP has participated in recent years include:

- International Workshop on the Taxonomy of Economically Important Seaweeds, Guam (1984)
- Pacific Island Marine Education and Teacher Training Workshops, Ponape/ Kosrae (1978), Palau (1979 & 1980), Ponape (1981), Marshall Islands (1982), Truk (1983), Yap (1984)
- Extension Training (alternate years)
- Cooperative whale research, workshops, and publications with the University of Alaska (1980-1987)
- International Symposium on Recent Innovations in Cultivation of Pacific Molluscs (1982)

- International Symposium on Salmon and Trout Reproduction (1983)

- Workshop on the Impact and Fate of Marine Debris (1984); major cooperators PSGCP, NMFS, FWS

- Gordon Research Conference of Marine Natural Products (1986 and 1988)

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survey, 1971-72, Charles Black Mardella Corp.

2. Participated in developing the National Academy of Science-National Research Council, Committee on Aquaculture report, *Aquaculture in the United States Constraints and Opportunities* (1978)

3. Helped develop the *Sea Grant Aquaculture Plan* (1982)

4. Participated in the general planning conference for the *National Aquaculture Plan* (1983)

5. Helped initiate the Marine Shrimp Genetics workshop, La Jolla, California, Jan. 24 and 25, 1986

6. Participated in the JSA National Aquaculture Forum, Davis, California, Nov. 4-6, 1987

SEA GRANT NETWORK INITIATIVES

Marine Shrimp Initiative

The University of Hawaii, University of California, Texas A&M, South Carolina Sea Grant College Programs have defined an informal initiative to facilitate the development of U.S. marine shrimp farming through Sea Grant research and extension. To date this initiative includes talent sharing; a conference on marine shrimp genetics, La Jolla, 1986 (proceedings to be published in 1988); a meeting of marine shrimp research experts from these programs and other interested Sea Grant institutions, May 3-4, 1987. This latter group discussed marine shrimp research needs and recommended Sea Grant sponsorship of a national workshop on shrimp research. This workshop will be held June 23-24, 1988, in Washington, D.C. It will bring together the scientific research community, the science funding community, the science policy community, and industry.

Pacific and Caribbean Initiative

The University of Hawaii Sea Grant College Program, together with the University of Puerto Rico Sea Grant Program (UPRSGP), took leadership in developing a Sea Grant network initiative to address the potential Sea Grant contribution to marine-related opportunities and problems of the U.S. flag, affiliated and neighboring Pacific and Caribbean communities. This resulted in a Conference on Development of Marine Resources in Tropical Areas, June 19, 1987, in the House Longworth Building in Washington, D.C. This conference brought representatives of the Sea Grant network, congressional staffers, and representatives of federal agencies together to discuss needs, opportunities, and problems associated with developing viable programs to meet U.S. interests in these areas. The directors of UHSGCP and UPRSGP provided testimony before the U.S. House of Representatives, Subcommittee on Insular and International Affairs on September 29, 1987, on the Office of Technology Assessment Report, *Integrated Renewable Resource Management for United States Insular Areas.*

This initiative has had the effect to date of increasing the interest of the Congress and appeared to have increased the attention of several federal agencies in the Pacific and Caribbean areas. It appears to have had at least an indirect effect on the initiation of some new projects in these regions. The effort to find ways and means to utilize the potential of the Sea Grant network in these regions will continue.

IMPACTS ON UH ACADEMIC COMMUNITY AND PROGRAMS

One of the unique features and strengths of the University of Hawaii marine programs is their multidisciplinary nature, with recognized expertise in the social sciences, education, and law, as well as the natural sciences. The UH Sea Grant College Program has been and continues to be a major factor in enhancing the excellence of marine programs on the campuses of the University of Hawaii system. This is accomplished by providing funds, planning, and management support services to conduct research and education projects in seven colleges and schools of the University of Hawaii — education, arts and sciences, agriculture, law, engineering, medicine, and business — and in three University research institutes — Hawaii Institute of Marine Biology (HIMB), Hawaii Institute of Geophysics (HIG), and Water Resources Research Center (WRRC).

In a typical year the Sea Grant research program involves 12 campus departments, most of the marine-oriented research institutes, the two on-campus federal research units, and the University of Guam Marine Laboratory. The program provides support for 110 faculty, postdoctoral fellows, and professional staff, as well as 8 technicians. The program also provides support for 20 graduate students working on Sea Grant projects as part of their thesis work.

Sea Grant-sponsored research enabled the College of Education to develop a secondary school-level curriculum on marine sciences which attracted national attention. Faculty in several departments within the College of Arts and Sciences, including oceanography, biology, chemistry, zoology, political science, sociology, geography, and economics, were able to study ocean-related problems because of Sea Grant funding. A significant number of graduate degrees with a marine focus awarded by the College of Tropical Agriculture and Human Resources resulted from Sea Grant-funded research.

Since 1977, the Sea Grant-supported Law of the Sea Institute's annual international conferences on various issues related to the law of the sea have provided a global forum for the work of several members of the UH law faculty. Additionally, UHSGCP-funded research has established several of the law faculty as marine law and policy experts. Research projects have involved many of the students in the School of Law. For example, in 8.5 years of Sea Grant involvement, Professor Jon Van Dyke has utilized approximately 30 law students as interns in marine law and policy or for specific research assignments. Because of their involvement in these Sea Grant-funded activities, each of these students starts his/her profession with a marine orientation.

Conceptual feasibility studies in the engineered design of floating platforms and their various applications and in the design of sea-kindly hulls, pre-buckled acrylic aquarium, and submarine hulls; the investigation on the effects of tsunami runoff; studies in marine corrosion; and the study of beach erosion and natural submarine sediment stabilizing structures — all are among the Sea Grant-funded research which helped the College of Engineering establish a national marine engineering reputation. As a result, the college is now considered a serious contender for a National Science Foundation Engineering Research Center. Several of the results of the above Sea Grant engineering developments, although widely disseminated in the United States, ironically, have been implemented by other nations, e.g., Japan's adoption of the floating city and sea-kindly hull concepts and the North Sea application of floating platforms in drilling offshore oil.

The international reputation of researchers in the Department of Physiology in the School of Medicine has been firmly established as a result of two decades of Sea Grant study on human performance under hyperbaric conditions. Their findings have led to the recomputing of dive tables to permit safer decompression. More recently, clinical applications of the results of the immersion studies have shown exciting promise as an alternative to drug therapy for diuretics. This provides an opportunity for the University of Hawaii to move to the forefront of medical research in these areas.

Pioneering research into bubble formation under hyperbaric conditions has led to significant basic research in the physics of bubble formation. In tests conducted in the late 1970s, researchers in the Department of Physics in the College of Arts and Sciences introduced the varying-permeability (VP) model to explain the existence of stable gas nuclei.

The benefits derived from this research are aptly captured in the statement read during the presentation of the prestigious Stover-Link Award by the Undersea and Hyperbaric Medical Society to Dr. David Yount, principal investigator of the Sea Grant project. In part, the commendation states:

> We honor him today, . . . for seminal contributions which have led the diving community to better understanding of the fundamental physical nature of cavitation and bubble growth and have stimulated new approaches to decompression table development (emphasis added).

A major multidisciplinary Sea Grant project — "Quality of Coastal Waters" — was initiated in 1971. Drawing on faculty from 14 disciplines in the university and coordinated by the director of WRRC, the studies firmly established the University of Hawaii as the source of definitive information and expertise for water quality information for Hawaii and the insular Pacific.

The Hawaii Institute of Marine Biology has achieved an international reputation as a leading institute for aquacultural research funded in large part by Sea Grant. In addition, Sea Grant funding of coral reef research, and the subsequent development of a summer institute, has helped establish HIMB as a major international center for research and education on tropical coral reef ecosystems. Recent pioneering work with sensory systems of fish and with acoustical tracking of pelagic fish is rapidly establishing a reputation for HIMB and its scientists in this area of research.

Although initiated only in 1987, it is evident that the Ocean Minerals Program will place Sea Grant-Hawaii Institute of Geophysics and Department of Oceanography scientists at the cutting edge of research and development of ocean minerals on seamounts.

In summary, UHSGCP provides the university administration with a powerful tool to develop a broad-based marine faculty — a resource that is critical to the achievement of the university's strategic goal of becoming "the research, training, and cultural center of the Pacific Basin." Over the 20-year history of UHSGCP, hundreds of faculty and graduates got their start or enhanced their scientific reputations and expertise in marine fields as a result of their involvement with Sea Grant. Since many have gone on to careers in other universities in the United States and abroad, the total effect is much more extensive. (A listing of researchers is provided in the data section of this recertification briefing document.) The University of Hawaii is, of course, only one of 29 Sea Grant institutions in the United States. Hence, if the contribution of Sea Grant to the University of Hawaii is extrapolated throughout the Sea Grant network, the following statement of British analysts Horsfeld and Stone (1981) appears prophetic:

> If the sea grant programme goes on to fulfill its objectives, America will soon have the most awesome capability in marine activities. The momentum provided by such a solidly based labour force will be irresistible and, if there is wealth in the oceans, then the United States will get it. (*The Great Ocean Business*)

PEOPLE BUILDING

Numbers, statistics, results and achievements, benefits — all of these are important elements in evaluating past performance and in establishing future directions. In Sea Grant, as in other organizations, they are used to generate high-level abstractions, concentrated distillations of organizational performance. As valuable and essential as such performance data are for planning and decisionmaking, they do not adequately account for Sea Grant's performance in human terms.

Sea Grant is quintessentially a people program. Implicit in our mission is the use of information on marine coastal resources to improve the lives and well being of the public. Within the University of Hawaii Sea Grant College Program this is described as "People Working with People."

Documenting the impact that the UH Sea Grant has made on the lives of people in Hawaii, the Pacific, and the nation is not an easy task. Instead of numbers and statistics, representative vignettes of individuals who were touched in very different ways by the program are presented here. Each is a leader in his professional field who can advance marine research and development in Hawaii in significant ways. Sea Grant provided each with an opportunity to accomplish key objectives in his life. In turn, each has influenced the objectives of the Sea Grant Program in Hawaii.

PETER APO AND SEA GRANT: A LASTING RELATIONSHIP

Peter Apo and the University of Hawaii Sea Grant College Program go back a long way together. From the days when he taught at Waianae High School on Oahu to his present position as State House Majority Floor Leader, Apo and Sea Grant have worked together on ocean concerns.

"My first encounter with Sea Grant was back around 1975 when I was teaching at Waianae High School," says Apo. He was seeking funds to develop social studies materials about the ocean because most ocean-related curriculum materials were in science.

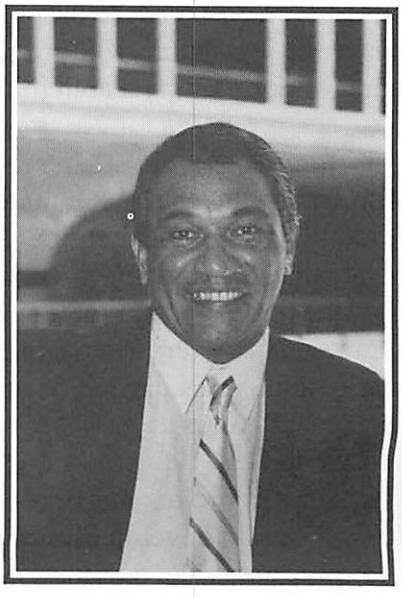
"Sea Grant provided the funds," explains Apo, "and we did get a marine social studies curricular package developed in conjunction with UH's Curriculum Research and Development Group." The educational program, titled Ho'i Ana ike Kai (Return to the Sea), adapted the university's materials for use with marine subjects, including such science skills as mapping, graphing, and hypothesis formulation. Many of the activities were approached from Polynesian and ancient Hawaiian perspectives of the oceanic environment. This first interaction with Sea Grant has had a lasting effect on Apo.

"My experience with that one marine education project took me far beyond just marine education," says Apo. The experience of developing and implementing the project gave him an inside look at the Hawaii Department of Education and insights to its operations and effects on classroom learning.

Today, both as legislator and citizen, Apo traces his deep concern for education in Hawaii in part to his participation in Ho'i Ana ike Kai. He sees education as a vital key to the welfare of the state. Also because of that experience, Apo has made it a point over the years to keep abreast of Sea Grant programs and progress.

"When I became a legislator in 1982, I was very aware of the important role Sea Grant could play in ocean resources development," says Apo. During his second term in office, Apo was selected chairman of the House Ocean and Marine Resources Committee. Not surprisingly, one of the first people he made a point of contacting was Sea Grant Director Jack Davidson.

Because of the nature of the legislative district that he serves, Apo has a broader understanding, perhaps than do many of his colleagues, of ocean issues and concerns. The 49th House District includes the Waianae coast of Oahu and the north shore of Kauai. His constituents' ocean-related concerns reflect the extremes of Hawaii's economy and society. The north shore, says Apo, is relatively affluent with both thriving agricultural and tourist industries. The impact on the community of tour boat operations from Hanalei to the Na Pali Coast is the major issue. Residents are concerned about their semi-rural community becoming overwhelmed by the number of tourists entering their community each day to take ocean sightseeing excursions.



The Waianae coast is much different, according to Apo. In an area that is economically characterized by welfare and

unemployment, the people are concerned largely about fishing especially subsistence fishing. A major issue now is the state's plan to establish a system of conservation districts that would be opened and closed on a rotating basis. Fishermen are unsure as to how this system, if implemented, will affect them.

As a legislator, Apo needs to deal with these local problems. But, he also needs to address large statewide issues. With the presidential declaration of the 200-mile exclusive economic zone, ocean resource development has taken on new importance for Hawaii. Much research and data collection must be done, however, before development decisions can be made. In Apo's view, this is a kind of situation in which Sea Grant has played and will continue to play a vital role.

"Getting research money for locally beneficial projects from the federal government unless they also serve the national interest is very difficult," says Apo. "Sea Grant has really been a blessing in this area. Were it not for Sea Grant, we'd be way behind in exploring and developing our ocean resources."

The research, design, and development of artificial reefs are one example Apo uses to illustrate a major Sea Grant contribution. Sea Grant researchers have been studying high-tech artificial reefs based on Japanese designs in the field. Apo hopes the legislature will provide funding to continue work on this research initiated by Sea Grant.

Citing economic studies as another example, Apo points out that Sea Grant has often been at the leading edge of developing information that is invaluable for making good decisions about the use and management of ocean and coastal resources. Apo refers to several economic studies of marine industries carried out by Sea Grant in the last several years.

"Sea Grant was the first organization, to my knowledge, to develop economic information, for example, about the commercial tour boats, which we now know is a $100-million-a-year industry," says Apo.

As he looks back over his years as an educator and a legislator, Apo describes the personal impact that Sea Grant has had on him in terms of the unique contributions it has made to Hawaii.

"I've developed a deep appreciation of the role that Sea Grant plays in filling a lot of gaps and holes in information, in research, and in education," explains Apo.

Looking toward the future, Apo would like to see more state support for Sea Grant and for further formalizing of relationships between Sea Grant and other state departments and agencies for cooperative research.

"My disappointment is that neither the legislative nor the executive branch through the university has provided the kind of matching funds that I think Sea Grant deserves," says Apo.

"What I like about Sea Grant," Apo sums up, "is its semi-autonomous nature within the university structure. This allows it to move quickly. That to me is really important — to be able to respond rapidly when a challenge or opportunity arises to take advantage of."

JEREMY HARRIS: SEA GRANT ALUMNUS

Today he administers an annual budget of $.75 billion and manages the operations of the City and County of Honolulu. A scant decade ago, he was leading school children on reef walks, conducting workshops for commercial fishermen, and keeping the community of Kauai County informed on marine issues through newspapers, radio, and television.

The progress of the professional life of Jeremy Harris at first seems remarkable. But in actuality, the strides that Harris has taken in his professional life have been normal — for him.

The dramatic turns in Harris' political career have not been merely accidental; rather, they have been the result of tremendous drive, purpose, and effort. He is quick to point out that his days as the agent for Kauai County with the Sea Grant Extension Service (then known as the Marine Advisory Program) for Kauai County played an important role in his career.

"Working for Sea Grant was a broadening, enriching experience — one that I wouldn't have missed for the world," says Harris.

In late 1974 when the advisory agent position on Kauai was established, Harris was teaching oceanography and biology at Kauai Community College. He was immediately attracted by the prospect of working for Sea Grant.

"[For me] the advisory agent job was perfect. It allowed me to do the three things that I really love: to work with things marine, work with the community, and teach — because I come from a teaching background," explains Harris. "I was very excited; I saw great possibilities with the Sea Grant Extension Service. I thought we had a really big opportunity for playing a key role in expanding marine industries [in Hawaii]."

During his first 10 months on the job, Harris produced a television show called "Sea" for cable television community programming. Eventually, the show aired on KHET, the Honolulu affiliate of the Public Broadcasting System. In addition, Harris had a biweekly radio program and a local newspaper column on Kauai. In that time he also formed the first marine advisory council in the state.

In October 1975, Harris began a 2-year stint as the acting coordinator for the Sea Grant Extension Service. He was 24 years old and at the time was the youngest advisory coordinator in the national Sea Grant network. In this capacity, Harris gained management and leadership experience that would later prove valuable in his political career.

Around the same time, Harris served as co-principal investigator of the International Sea Grant program with Dr. Philip Helfrich, director of the Hawaii Institute of Marine Biology. The program supported several marine projects being carried out by an 11-nation consortium that formed the marine program at the University of the South Pacific in Suva, Fiji. Eventually, the program diminished in the early 1980s as federal funding for Sea Grant tightened up.

In 1978, Harris made his first forays into politics. He served as a delegate from Kauai to the state's first constitutional convention and ran unsuccessfully for the State House of Representatives. Besides an admitted activist bent, Harris says that his work as an advisory agent lead him into politics.

"The community work I had been doing with Sea Grant. . .really motivated me to get involved politically," says Harris. "I soon realized that all the hard work and good intentions were not going to accomplish anything unless political solutions were achieved and decisionmakers were moving with us."

Harris' political career began in earnest when he was elected to the Kauai County Council in 1980. The other council members selected Harris as their chairperson. Since the council job was a part-time one, Harris continued to work half-time with Sea Grant. In late 1981, at about the time Harris was filing to run for council again, the University of Hawaii Board of Regents changed its policy to prohibit university employees from running for and holding political offices. With that, Harris' tenure at Sea Grant ended.

Choosing between Sea Grant and politics was tough, Harris recalls. "At that stage, I really had too much invested in my political career. It was a difficult decision because my chosen career was obviously marine biology and to have to give it up completely in order to continue in politics was tough," he says.

He was re-elected to the council and served for 2 more years. In 1984, he ran for mayor of Kauai and lost, although polls had shown him with a big lead in the weeks just before election day. As Harris was losing, underdog Frank Fasi was winning the mayoral election in Honolulu. These ironical events soon brought Harris and Fasi together.

Instead of serving as mayor of Kauai, Harris became Fasi's executive assistant in January 1985. He was appointed city deputy managing director in January 1986 and succeeded gubernatorial candidate Andy Anderson as city managing director in July 1986.

As the city managing director, Harris is still in the thick of "things marine." Some of his work involves beach park expansion and acquisition, dealing with erosion and coastal problems, and working out problems with the state, for example, to provide lifeguard services at beaches not under the county's jurisdiction. He says that he still calls on university researchers he worked with during his Sea Grant days when he needs expert information concerning ocean-related matters.

In looking back over his successful political career, Harris acknowledges his debt to Sea Grant. "The Sea Grant work really prepared me well for politics. . . . [It] was heavily involved with communication, and communication is probably the most important component of politics."

CRAIG MacDONALD: FROM SEA GRANT RESEARCHER TO PUBLIC ADMINISTRATOR

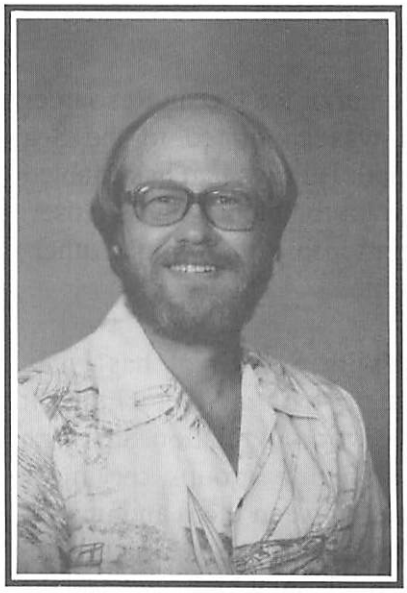
The movies and other media often portray scientific researchers as lone figures in their search for knowledge. Modern researchers are, however, far different from this stereotype. They often head up projects involving teams of individuals carrying out research. To be sure that research goals are fulfilled they must devote a large amount of time carrying out project management responsibilities. Dr. Craig MacDonald is a typical modern researcher.

In large part because of the management experiences he gained as a Sea Grant researcher, MacDonald has successfully made the transition to the management arena. Now, he is the chief of the Ocean Resources Branch (formerly, the Ocean Resources Office) in the Hawaii Department of Business and Economic Development.

With a professional staff of seven and a budget of about $1 million in state and federal funds, MacDonald directs and manages the state's Ocean Resources Development Program. The program involves a wide range of activities including the development of plans for the assessment and use of Hawaii's ocean resources, support and technical help for the development of new ocean-related industries, coordination of multiagency marine activities, funding of ocean-related research with economic potential, promotion of ocean-related economic development activities, and distribution of information to the public.

"I'm not as much a researcher as I used to be although I'm still a research associate with the Hawaii Institute of Marine Biology," says MacDonald. "How I really see myself now is as a public administrator."

As a research associate with the Hawaii Institute of Marine Biology, MacDonald is continuing to analyze and report the results of Sea Grant supported research that began in 1979. The research, for which MacDonald served as the principal investigator, was part of the Northwestern Hawaiian Islands Fisheries Investigations. MacDonald's research focused on the spiny and slipper lobsters of the Hawaiian Archipelago. The results of this and other research by MacDonald were essential in guiding state and federal efforts to develop and manage the commercial lobster fishery in Hawaii.



In carrying out this research, MacDonald obtained and managed $336,000 in state and federal funds and hired and supervised a research staff of 20. In addition to managerial experiences, MacDonald gained a great deal of knowledge about the workings of a number of organizations.

"Essentially, the nature of the Sea Grant lobster research required that I coordinate [activities] with several federal and state agencies, the U.S. Navy, and the U.S. Coast Guard,"says MacDonald. "I developed quite a network of working relationships just to support the project, which took place over the length of the Hawaiian Archipelago."

When the lobster research ended in 1982, MacDonald began working as a marine program specialist with the Ocean Resources Branch (formerly, the Ocean Resources Office). Among his responsibilities were identifying and coordinating activities required for the implementation of marine programs. The network proved invaluable.

"That network was extremely useful to me in the work that I was doing here — coordinating projects, lining up program elements, and coordinating our office relative to what other groups were doing," says MacDonald.

After he became chief of the Ocean Resources Branch, MacDonald was appointed to the Sea Grant Advisory Council. He says that has enabled the branch and Sea Grant to "blend" into a closer, more cooperative relationship than might otherwise have been possible.

Working closely with Sea Grant has given MacDonald an intimate look at Sea Grant. It strives for cooperative working relationships with other agencies and community groups, serving as an information vehicle between them and university researchers. He believes that Sea Grant represents an excellent model on which to base the research and development work of the Ocean Resources Branch.

MacDonald says that working with Sea Grant has helped him grow as an administrator.

"It has been very useful to see the way that the Sea Grant and UH administrations work relative to the way the state administration works," says MacDonald. "This has broadened my views on administration."

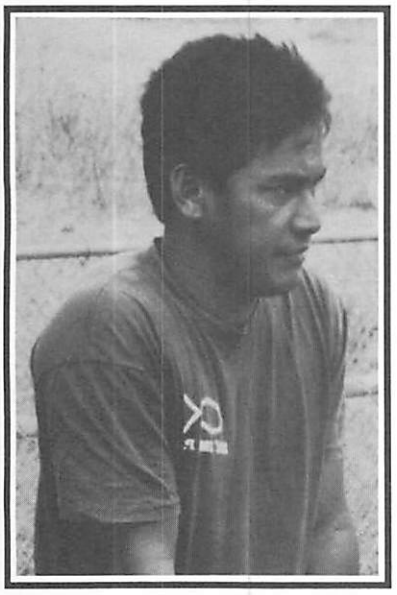
As for the future, MacDonald expects the good working relationship between the Ocean Resources Branch and Sea Grant to continue.

HENRY PELEKAI: FISHERMAN-BUSINESSMAN

Henry Pelekai of Nanakuli considers himself to be a very lucky fisherman. Others might consider him to be a very good fisherman because he is an astute businessman.

Fishing, as Pelekai tells it, has been a lifelong activity. Several years ago he wanted to buy a larger boat for fishing, but he could not obtain a loan.

"The places I approached all told me the same thing: 'We need some background, some idea of your potential. You tell us you're a commercial fisherman, but there's nothing on paper,' " explains Pelekai. This experience showed him that if he were to succeed in the business of fishing, he would have to treat fishing as a business.



So, as Pelekai describes it, he decided to go "legal," that is, to keep records and run his fishing operation as a bonafide business. He also decided to retain the services of a bookkeeper.

He solved the boat problem by building his own, thinking this would be the cheapest route. It turned out to be the most expensive alternative.

His first day of fishing was a disaster. He and his crew were hauling in a net that they had laid around a school of *akule* (mackerel scad). At the same time, threatening waves started to build up. As the last length of net was being hauled in, a large wave broke. The crew jumped off the boat for safety. Pelekai saved the boat, but lost all the nets.

"People laughed at me when I came back with no nets," says Pelekai. "They teased, 'You laying your nets overnight?' " That night he went out and bought nets from anyone who had them. The next morning, Pelekai was out fishing again.

"From then on I caught fish," he says.

After a few years of good akule fishing, catch rates began to fall rapidly. Pelekai knew he had to move into another fishery, so he began to research the *aku* (skipjack tuna) fishery. One of his first moves was to see Sea Grant Extension Service agent Mark Suiso about the availability of baitfish since the traditional baitfish, *nehu* (Hawaiian anchovy), was scarce. At about the same time a Sea Grant-sponsored sea fair, which Suiso had coordinated, was being held in Waianae, Oahu. It was at the fair that Pelekai made the decision to enter the aku fishery.

In a session on baitfish at the fair, Sea Grant researcher Dr. Wayne Baldwin showed a film on baitfish trials using Mexican topminnows. As he watched the film, Pelekai recalls saying to himself, "I can do it. I can fish just like the big boats."

Later, Baldwin gave Pelekai a dozen or so of his limited supply of Mexican topminnows to rear. Unfortunately, cats made a meal of the small fish. Over the last 4 years that Pelekai has been aku fishing, obtaining enough baitfish — let alone finding a steady supply — has been a continual challenge. He bought baitfish from Maui County when their baitfish aquaculture project (in which Sea Grant staff were involved) was operating, and he

has caught baitfish in streams. Now he is buying Cuban topminnows from farmers on Oahu's north shore.

Pelekai has had a lot of help from Sea Grant with his baitfish operations. Suiso helped him with ideas for building a baitfish holding and rearing tank at his home. Another Sea Grant Extension Service agent helped him with filtration systems for the tank. Suiso also helped Pelekai develop an airstone that has resulted in big savings on oxygen. He uses oxygen to aerate containers to reduce stress on baitfish during transport to his home.

"I was blowing 2,000 pounds of oxygen during a one-and-a-half-hour trip," says Pelekai. With the new airstone, a tank of oxygen lasts several times longer.

Pelekai says that one important way that Sea Grant helped him was to give him business information related to fishing. He uses the example of crew shares to show how information from a Sea Grant publication helped to put his business in the profit column.

"When I first started, it used to be like old style — we split the share evenly: one share for the boat, one for each of the crew, and one for the captain," says Pelekai. "But at the end of the year nobody came back to give me money to repair the boat. So the first year, I lost money fishing."

Then, Suiso gave Pelekai a booklet from a West Coast Sea Grant program on fishing operations. Using the information in the booklet, Pelekai analyzed his operation and developed a new share structure, which includes what he calls an "opportunity share." This share is used, among other purposes, for boat repairs and equipment purchases.

"Then fishing became a business that shows a little profit," says Pelekai. "The crew is happy because they get paid very well. I'm happy because I'm getting paid. The boat is happy because its got its share to keep it going."

Although all his problems are not yet solved, Pelekai considers his move into the aku fishery as a small-boat fisherman to be successful thus far. As the sampan fleet dies out, innovators like Pelekai are leading the way for a new generation of small-boat fishermen into the aku fishery. His successes with nontraditional baitfish are not going unnoticed.

"People are starting to recognize that the bait is working," says Pelekai.

Has Sea Grant made a difference in the life of fisherman-businessman Henry Pelekai? He thinks so.

RICK SPENCER: THE SEA SPROUT KING

Rick Spencer went to a cocktail party and became involved in seaweed research. From this unusual beginning, Spencer has gone on to become a partner in one of the most successful seaweed farms in Hawaii.

In the late 1970s when he was finishing his doctoral work in invertebrate physiology at the University of Hawaii, Spencer met the environmental division chief from Hawaiian Electric Company at a cocktail party. In conversation with him, Spencer learned that the electric company was seeking ways of using water being discharged from its Kahe Point power plant. According to the chief, the company had rejected the idea of growing animals. Spencer asked, "How about plants?"

As a result, the electric company funded a project to carry out basket culture of *Gracilaria* (*ogo*) and other seaweeds. To carry out the project while completing his doctorate, Spencer enlisted the aid of Fred Mencher. Together they formed a consulting firm, Aquaculture Associates.

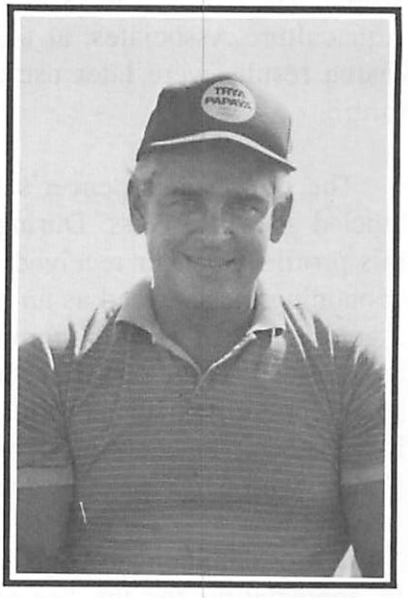
The partners' next venture was a large contract to review a gas industry project on growing kelp in California. They "got good marks" for the review work, in which they involved several experts from the University of Hawaii. This is how Spencer met John Craven, an ocean engineer at the university, and how he and Mencher became involved in a Sea Grant research project.

At the time, Craven was leading the effort to redeploy the Mini-OTEC (ocean thermal energy conversion) platform for further energy research. Their interactions with Craven led to their submitting an aquaculture research proposal to Sea Grant and the state in 1980. The Mini-OTEC redeployment, however, was not carried out. Instead, they carried out their research at the Natural Energy Laboratory of Hawaii at Keahole Point on the island of Hawaii. Because their research was peripheral to the other OTEC engineering research, they chose to study nori, an edible seaweed popular in Japan.

"It occurred to us that if we're going to do this project, we had better pick a species that is pretty well known," says Spencer. "The Japanese have worked nori into a billion-dollar-a-year industry."

Using nori obtained from the Japanese, Spencer and Mencher set out to demonstrate the use of tumble culture for raising nori. Tumble culture at the time was a new method that had been developed in Florida. In Japan, nori is grown attached to nets and harvested by "mowing" it.

"We demonstrated that you can grow nori unattached," says Spencer. "To be profitable in the U.S. it had to be grown with a lot less labor than is used in Japan. What's important about tumble culture is that you can concentrate a large number of plants in a small area."



What is more important, however, is that Spencer and Mencher's research, together with the salmon culture work done by Sea Grant researcher Arlo Fast, demonstrated that OTEC deep, cold water could be used for aquaculture. Largely as a result of their work, Keahole Point has become

a commercial, high-technology center for tropical deep, cold-water aquaculture.

In 1983, consulting work began to dry up, says Spencer, so the partners decided to try farming ogo. They set up a one-acre farm in Kahuku on Oahu's north shore. A year later, they were almost broke. They advertised in local newspapers and found a Canadian willing to invest in the farm. To keep the consulting and farming businesses separate they formed Hawaiian Marine Enterprises. Aquaculture Associates sold its interest in the farm to the new company.

Although the seaweed farm had to weather a difficult first year, it has been doing well and the future looks bright. It has grown from 6 to 32 tanks in which ogo is tumble cultured. Spencer says that they hope to double the number of tanks to 64 in 1988.

Sea Grant funding provided an important opportunity, says Spencer, for him and Mencher to become involved in the OTEC aquaculture research. The research work helped their company, Aquaculture Associates, at the time, and the research results were later useful in running their farm.

The ogo from Spencer's farm can truly be labeled as world class. During the interview for this profile, Spencer received word that a recipe containing his seaweed as an ingredient had won a gold medal in a chefs' competition in Geneva, Switzerland. This came about because Spencer has been supplying a man in Florida with ogo. The man introduced it to chefs at Disney World's Epcot Center, who participated in the cookoff.

In Florida, Spencer's ogo is called sea sprouts. In appreciation for the "emergency shipments" that Spencer has sent, his Florida contact has dubbed him the "King of Sea Sprouts."

After completing a course on entrepreneurship in 1987, Spencer says he realized that supplying the local market was not the only market for ogo. In Hawaii, Spencer estimates that his farm has about 60 to 70 percent of the local edible seaweed market.

"I pulled my head out of the sand and realized that just by a simple name change — calling it a vegetable instead of a seafood, we could open the mainland market to our seaweed," says Spencer. "People are going crazy over varieties of vegetables. They want more and more variety."

Looking toward the future, he sees other markets for seaweed as well. He already is selling seaweed to mainland biomedical researchers who use extracts from it in DNA research. A fellow from the Midwest investigated the possibility of using ogo to make seaweed "potato chips." The health food market is another potential market, one that Spencer describes as a high-end market. Still another market is in cosmetics. Spencer has already had discussions with a cosmetics manufacturer in Beverly Hills, California. Spencer sees his Hawaiian seaweed being used as a promotional ingredient for cosmetic products in much the same way as kelp, for example, has been used.

Since he and Mensch have been farming, Sea Grant Extension Service agents and specialists such as Mark Brooks, Mark Suiso, and Peter Rappa have been helpful in obtaining information and identifying resource people.

"Mark Brooks, for example, recently was instrumental in setting us up with two university researchers who are now working on projects that will help us grow better ogo faster," says Spencer.

"I guess it's a more less weekly or monthly event that there is something coming to our office from Sea Grant — updates, newsletters, workshop announcements, and other information," he says.

As for Sea Grant itself, Spencer says that he "has seen Sea Grant come of age. It's become more mature and more directed than it used to be."

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