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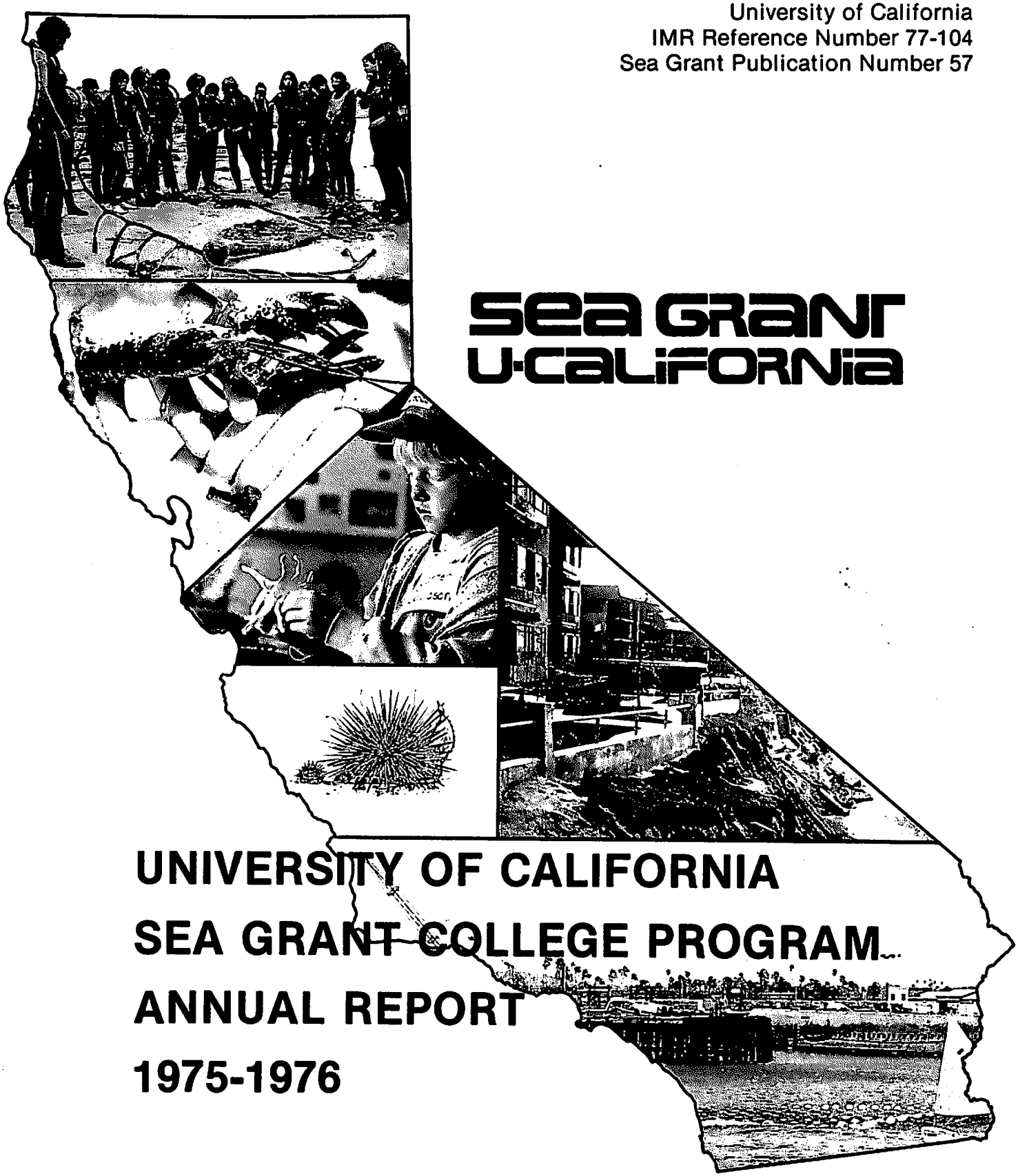

Sea Grant U-California

UNIVERSITY OF CALIFORNIA SEA GRANT COLLEGE PROGRAM

ANNUAL REPORT 1975-1976

A report on the University of California Sea Grant College Program
for September 1, 1975 to August 31, 1976

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INTRODUCTION

In 1966, the Sea Grant Program was created by Public Law 89-688, the National Sea Grant College and Program Act. The purpose of the Act is to accelerate development of marine resources, including their conservation, management, and maximum social and economic utilization. To meet these ends, Sea Grant supports advisory services, education, and research, primarily through a national network of universities that are designated as Sea Grant Institutions or Colleges.

During the brief 10-year history of Sea Grant, the California Sea Grant College Program has systematically grown from a collection of separate projects throughout the state into a coordinated statewide effort to help meet the practical marine-resource needs of its citizens. The Program is administered by the University of California Institute of Marine Resources (IMR). Policy guidance is provided by the IMR Advisory Council appointed by the President of the University of California, which consists of university and non-university members.

Marine and coastal advisory services are provided statewide through the UC Cooperative Extension offices located in each county and the participating campuses. Practical marine-research experience is provided to about 65 graduate students each year in association with Sea Grant supported research projects. These projects reflect the areas we have chosen to emphasize: coastal planning and management; aquaculture; fisheries development, enhancement, and management; energy; and the development of new products from marine sources. Projects in these subject areas are conducted at six UC campuses, San Diego State University, Moss Landing Marine Laboratories, CSU-Northridge, and, beginning this year, Stanford and Humboldt State University.

A refreshing aspect of the Sea Grant Program is that within the broad field of applied work, each Sea Grant College chooses the areas of emphasis that best suit its capabilities and the needs of its local area. Since the University of California is one of a limited number of national research universities, we are responsive to national as well as state needs. This dual approach, we feel, not only allows us to seek broader solutions to identified local needs, but also encourages the generation of fundamental knowledge that can be applied to a wide class of problems. In this way, we believe we best serve all citizens through the interdisciplinary and intercampus Sea Grant approach.

As we move into the next decade, the cooperative links forged among government, industry, universities, and the public need to be further strengthened. The continual interaction among members of these sectors of society enhances the knowledge and wisdom of each, resulting in better understanding of what the real problems are. Thereby, a coordinated, cooperative approach to developing effective solutions can be mounted by those most informed. Accordingly, we will continue to seek out the best talents statewide, to welcome new participants in these endeavors, and we invite you to join with us.

James J. Sullivan
Program Manager

EDUCATION

A major part of Sea Grant's effort lies in the realm of education, to broadcast research findings in the most effective way, and to expedite and facilitate the application of this new knowledge by user groups. Another aspect is Sea Grant's involvement in the training of professional marine scientists. Under its partial sponsorship, the Applied Ocean Science Curriculum since 1968 has enrolled 173 graduate students to date. A total of 29 advanced degrees have been awarded: 18 M.S.'s and 11 Ph.D.'s.

Sea Grant Trainees

James J. Sullivan

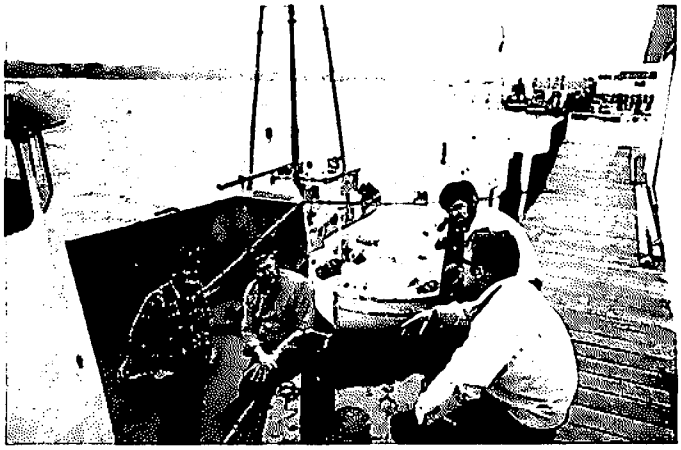
Graduate students are an integral part of most Sea Grant projects and a vital part of the UC Sea Grant College program. Meaningful completion of the projects with which they are associated can be used in partial satisfaction of their degree requirements. Accounts of independent research accomplished by these students during the 1975-76 grant year are reported under the titles of the research projects with which they were associated. Their complete reports are available from the Sea Grant Publications office (see note on inside back cover of this report).

The primary functions of the University of California are education and research. Public service is considered to be an extremely important auxiliary function. The purpose of the Sea Grant Act matches closely the purpose of the University, since it also calls for education and training, research, and public service. A major portion of the research of the University is carried on as an adjunct of the educational process, with graduate students carrying out the actual research under faculty guidance, with the dual purpose of performing a significant research project and satisfying the educational requirement of a Master's or Doctor's thesis. Many UC research projects were initiated by graduate students under the aegis of the faculty member listed as project leader of the research project. Many were initiated by a faculty member to carry out research in the area of his teaching; one or more of his graduate students have become involved in the project, have chosen a portion of it for their own thesis interests, and will carry the major responsibilities for completion. In other cases, students working on a Sea Grant project are acquiring the skills and experience that they will need in subsequent years in order to prepare and carry out their own thesis research. They are, therefore, the heart of the program and are acquiring their education as a primary function while performing research in marine resources as a public benefit.

Thesis project

A Sea Grant Trainee is expected to carry out a program of training and research leading to a recognized graduate degree. The program of work is arranged in consultation with a supervising faculty member and approved by the teaching department in which the student is registered. The program of research must be one that lies within the scope of the University of California Sea Grant College Program in order for a Traineeship to be awarded to the student. This means that, normally, the student will carry out a thesis project within one of the research projects proposed; in all other cases, the project must be approved by the National Office of Sea Grant as lying within its area of interest. A student maintains eligibility for a Traineeship by carrying out research diligently and making good progress toward completion of his thesis.

In 1975-76, there were 60 Sea Grant Trainees assigned to 35 projects on six UC and two State University campuses and at one Private School, funded by the UC program. They functioned in virtually all areas of marine related research.



MARINE ADVISORY SERVICES

The statewide Sea Grant Marine Advisory Program, which is part of the UC Cooperative Extension system, underwent a major expansion last year. Three new local marine advisors were appointed to complement the two already serving the San Diego and the Marin-Mendocino areas. The new advisors are located in the Ventura-San Luis Obispo, Monterey Bay and San Francisco Bay areas. This expansion is in line with the planned growth of the advisory program and reflects the needs identified in the California Marine Advisory Service Plan currently under revision. Coordination of all Sea Grant Marine Advisory Programs in the state has been improved by involving representatives of the U.S.C. and H.S.U. Marine Advisory services in the work of the UC advisory program planning committee. The Aquarium-Museum at the Scripps Institution of Oceanography was visited by over 60,000 students in organized school groups, and members of its staff continued to present the latest information on marine ecology, emphasizing such Sea Grant objectives as conservation and wise utilization of marine resources.

Marine Advisory Programs

Maynard W. Cummings

Marine Advisory Programs make results of Sea Grant Research available to fishermen, seafood processors, coastal resources planners and managers, and to the general public. All are large audiences, especially the public category since 80 per cent of California's 22 million people live in the state's 1100 mile long mainland coastal zone. The marine advisory staff produce special publications, hold public meetings, organize workshops and consult with numerous individual groups to achieve the educational objectives of the Sea Grant Program.

The effective nucleus of the Marine Advisory Program is the local extension agent staff. Delivering information relevant to local situations and pertinent to specific problems requires the services of advisors who are attuned to various audience needs and knowledgeable in locating and applying such information. Two more Marine Advisors were stationed in county offices of Cooperative Extension; one in Santa Barbara with an area assignment to Ventura, Santa Barbara and San Luis Obispo Counties, and the other serving the Monterey Bay area in both Monterey and Santa Cruz counties. Another position was filled in San Francisco-San Mateo counties and that Advisor will be on the job early in the next program year.

These additions will bring the UC Area Marine Advisory staff to a total of five. With the help of UC Sea Grant Specialists and cooperation from Sea Grant staff in other institutions, these Advisors still face a huge job in effectively covering California's 1100 mile coastline which is highly diversified and productive. California's coastal zone is a national as well as a state heritage; it is the vacation goal and recreation area for millions of visitors as well as the home or income-producing area for other millions of residents.

To reach their target audiences, Marine Advisory Programs concentrated educational efforts by means of workshops, conferences, special publications and newsletters as well as by direct contact with individuals and industry groups wherever possible. Audiences align themselves into several primary interests including commercial fishing, sport fishing, seafood processing and plant management, consumer education regarding seafood, aquaculture, 4-H and youth program education, coastal zone resources planning and management, and public education in ocean sciences and resources.

About 40 workshops primarily for commercial fishermen were held at major ports from San Diego to Fort Bragg. These as well as other conferences were well attended by other persons with interests in ocean resource management or sport fishing. Discussion topics included underutilized seafood species, seafood consumer education, effects of boat sounds on fishing success, echo sounders and radars, Loran-C, fishing boat maintenance, fishermen's tax and business management instruction, refrigerated seawater systems and handling the catch at sea, fishermen's financial assistance programs, albacore fishing, rockfish resource and fishery, squid resource and fishery, research and the recreational fisherman, commercial salmon fishery, and fish behavior.

Information on seafood

The seafood consumer workshops were organized with the active assistance of the Cooperative Extension consumer science staff and also received full cooperation from seafood suppliers. They invariably drew large audiences interested in learning how to buy, prepare, store and preserve seafoods. A film "Canning and freezing fish at home" and three slide sets "Seafood facts and bargains", "How to eye and buy seafood", and "Handling and storing seafoods" were made for further advisory program use.

Other special workshops such as a food processors' microbiological short course held by the UC-Davis Department of Food Science and Technology and seafood marketing and retail handling workshops planned by the Seafood Technology Specialist were enthusiastically received by the seafood processing and handling industry. That industry reported favorable consumer response to improved seafood products and retail display, as well as increased seafood acceptance.

Sea Grant Advisory Programs as well as research projects profited from meetings with and recommendations by a seafood industry advisory committee and a newly formed aquaculture industry advisory committee. Both committees are coordinated with Sea Grant activities through marine advisory liaison leadership.

California's troubled salmon resources continue to receive considerable attention

from the UC Sea Grant program. The 40,000 silver salmon raised to ½ lb size at Tiburon in San Francisco Bay, the 10,000 at Tomales Bay, and other releases to the ocean in Mendocino County have made a noticeable contribution to fishermen's resources. Early returns on these fish indicate success and the projects here will be continued. Other groups from Monterey Bay to Ventura and farther south are now talking with Marine Advisors about starting projects for their areas.

Special training meetings were held at Bodega Bay and San Diego for approximately 70 UC Cooperative Extension staff to acquaint them with Sea Grant program objectives. There are UC extension offices in all but five California counties.

Determination of temperature fronts by satellite

Three UC Marine Advisors and one from Humboldt State University teamed up with a national environmental satellite service oceanographer to assist albacore and salmon fishermen in locating fish. Ocean fronts, or temperature "edges" as some commercial fishermen call them, are areas where warm oceanic water and cold upwelled water meet. These edges are frequently rich in the "bait" or forage organisms upon which albacore and salmon feed. Thus, the areas of the fronts, which are generally found 20 to 200 miles offshore, may provide good fishing, and many fishermen expend considerable effort seeking them. Although many boats have equipment to sense temperature changes, they have no way of knowing exactly where to look for them. This is where the satellite imagery comes in.

The TIROS polar-orbiting weather satellites can detect water temperature changes as small as 1°F and relay that information to a receiving station of the National Weather Service in Redwood City. From here it is relayed by telecopier in the form of special charts that show these temperature fronts in relation to the coastline. The Marine Advisors receive these at various telecopier facilities in their districts and post the charts on special bulletin boards at boat landings used by local fishermen. The Advisors also make some special chart deliveries to, and do follow-up work with, certain boats to determine the usefulness of the information. This detection system for fishing boat use is still in the experimental stage but appears promising according to fishermen using it. Some fishing fleet elements may install receiving equipment so they can get the chart information directly without returning to port.

Again a marine science workshop for 4-H youth program leaders was held at Monterey Bay. This weekend training meeting included a research vessel cruise, tide pool, dune, and bird observation sessions. Marine science projects and activities were demonstrated by the marine advisory staff and by instructors and students at Moss Landing Marine Laboratories. This was a valuable and successful workshop for about 50 youth project leaders in marine science.

Local supporting data for the workshops on the effects of boat noise on fishing success were obtained in an applied research cooperative project with Oregon State University. An OSU acoustics engineer and UC Marine Advisors recorded sounds emitted by 50 fishing boats in three California ports. A correlation between the sounds and the fishing success logged by these boats supports the concept that sound does affect the catch. Fifteen boats had below-average catches, and 14 of them emitted sounds that generally were higher in frequency than those emitted by the boats with above-average catches.

In other applied research projects, Marine Advisors worked with fishermen in seeking solutions to such problems as theft of lobsters and lobster traps, lobster trap corrosion, location and harvesting of presently underutilized fish species, and continuing need for artificial reef technology and construction.

The advisory program is working closely with the marine aquaculture industry. Salmon and shellfish, primarily abalone, are targets of advisory-research cooperation to make improved production technology available to this growing industry.

Assistance in coastal resources management planning is provided to local government, builders, planners and coastal regulatory commissions. The coastal resources management researcher, of UC-Berkeley, was assigned half time to advisory services. His expertise was directed to local problems through the Marine Advisory staff and he also provided in-staff training to the Advisors.

The advisory services newsletter produced by the Marine Resources and Seafood Technology Specialists and those issued by the Marine Advisors in their local areas reach audiences of over 2000 monthly. A number of publications were produced by the advisory staff to augment the publication coverage already developed. A detailed reference publication, initially developed by the State

Department of Fish and Game for internal staff information, was reproduced. This volume, "Coastal county fish and wildlife resources and their utilization," is a very comprehensive index and valuable planning reference work. Another, even more important Fish and Game Department publication now out of print is being scheduled for republication jointly with that agency.

The UC Advisory Program continued to participate in the Pacific Sea Grant Advisory Program with the PASGAP grant leadership responsibility through 1975.

Moss Landing Marine Laboratories

The Sea Grant Marine Advisory Services program at Moss Landing Marine Laboratories has maintained a high level of cooperation with the University of California Cooperative Extension, and a wide variety of user groups has participated in its offerings. The Moss Landing Marine Laboratory Sea Grant Program Manager, Dr. Thomas W. Thompson, accepted the position of Area Marine Advisor in early 1976.

Three more issues of *Moss Landing Marine Laboratories News* were printed and circulated this year. Another series of workshops for commercial fishermen was completed. This year two workshops were specifically oriented toward recreational fishermen. A Seafood Consumers Workshop was held on April 6, 1976, at the University of California Agricultural Extension Auditorium in Salinas.

The MLML Marine Advisory Program coordinated an open house attended by about 1500 people at the laboratories on April 25, 1976. During the year, program personnel conducted more than 30 tours, presentations, and training sessions for community and school groups.

Biweekly NOAA imagery sea surface thermal front charts were delivered to the fishing ports of Santa Cruz, Moss Landing and Monterey, June through September. During the Spring, Advisory Services personnel supported the albacore acoustic research program being conducted by Oregon State University. Acoustic profiles and data analyses were made available to the skippers.

The UC-Santa Barbara Marine Science Institute Community Education Program offers opportunities for firsthand exposure to many of the plants and animals that spend their lives beneath the sea. During the past year, almost 3000 people have been able to see, touch, and carefully to examine organisms that are typical of the waters of the Santa Barbara Channel. With the help of graduate and undergraduate students, special diving collections have been made, displays created, and instructional tours given in the marine laboratory at UC-Santa Barbara. These tours and displays are open to any interested community group, three times per year, at the end of each academic quarter. During this time, four consecutive days are devoted to community as well as student education on this campus. This has proven to be a popular and successful means of making marine science activities known to the community, and stimulating interest in these activities.

Preparation of a 25-minute slide show, synchronized with music, was completed this year. This presentation, which shows a sampling of marine life from the Santa Barbara Channel, has been enthusiastically received by viewers such as the Audubon Society, visitors from the State Legislative Analyst's Office, and a new students orientation group.

Publications

Marine Briefs No. 10: Storage of dressed salmon in refrigerated sea water
Idem, No. 11: Buying quality seafood
Idem, No. 12: Marine cost sheet—42 foot swordfish boat
Idem, No. 13: Using satellite photos to locate temperature fronts
Marine Advisory Publication Leaflet No. 2727: Characteristics of rope used in the fishing industry
Idem, No. 2272: Major commercial fisheries in California
Idem, No. 2274: Marine mammals
Idem, No. 2784: Marine education bibliography
California seafood recipes (folder for industry)
Coastal county fish and wildlife resources and their utilization
Hryiewiecka, K., Let's cook squid the European way, University of California Sea Grant Advisory Program, 1976.
Moss Landing Marine Laboratories News, Vol. IV, Numbers 1, 2 and 3.
Operations manual for seafood retailers
Venomous fishes of California

Cooperating Organizations

California Department of Fish and Game
Counties of Del Norte, Humboldt, Mendocino, Sonoma, Marin, San Francisco, San Mateo, Santa Cruz, Monterey, San Luis Obispo, Santa Barbara, Ventura, Los Angeles, Orange, San Diego
Humboldt State University, Arcata, California
Moss Landing Marine Laboratories, California
National Environmental Data Service
National Marine Fisheries Service, La Jolla, Terminal Island and Tiburon, California
National Weather Service, Redwood City, California
San Diego State University
University of California Bodega Marine Laboratory
University of California Cooperative Extension
University of California Division of Agricultural Sciences
University of Southern California

Ocean Education for the Public

Donald W. Wilkie

The primary objective of the Aquarium-Museum at Scripps is to increase public understanding of the marine sciences through education programs and exhibits. An expanding education effort offers programs ranging from structured field trips to career training, and involves over 60,000 students annually.

The wealth of knowledge and credibility of Scripps Institution of Oceanography provide a powerful education tool which not only presents the opportunity of offering effective public education programs, but makes it an essential responsibility.

In recognition of this responsibility, it is the primary objective of the Aquarium-Museum to increase public understanding of the marine sciences. "Public," in this case, includes the general public, school students, and their teachers. To meet this objective effectively, education programs are developed around the Aquarium-Museum exhibits and the research programs at Scripps. In addition, the exhibits themselves are planned as coherent units within the education programs. This requires a professional staff and sufficient funds to develop and distribute educational materials and plan exhibits.

Apart from programs that we initiate, demands are made upon Scripps Institution and the Aquarium-Museum as a marine information and materials resource center by the general public, classroom teachers, educators who are developing programs and materials, vocational guidance personnel, zoos, museums, parks, scientists requiring information outside their immediate fields, and other aquaria. These multitudes of expressed needs are all responsibilities that the Education Department of the Aquarium-Museum strives to fulfill.

Education program

During the 1975-76 school year, 61,364 students participated in the study tour program at the Aquarium-Museum. This program, which is conducted by trained volunteer teachers (docents), is designed to augment the classroom study. It features a complete education package which is mailed to each teacher, containing pre-visit and post-visit lessons for use in the classroom, and a guidesheet with questions to be answered from students' observations. This format, which was originated at the Aquarium-Museum 10 years ago, has proved to be so effective that it has been duplicated by other museums, zoos and aquaria.

Outreach program

Monetary and energy restrictions on bus transportation continue to prevent many schools from participating in field trips. "Outreach" docents travel to these schools bringing with them marine specimens and giving slide-illustrated lectures. Some 38 schools and 2000 students partook in this extension of the education service. From this has evolved a new program, in which we actually set up learning centers in a special classroom, and teach over a period of time a unit in marine biology, conservation, etc. Del Mar, Coronado, Chula Vista and Cardiff school districts are participating in these mini-marine biology courses.

San Diego - La Jolla underwater park guides

The Aquarium staff trains and organizes a special group of docents who act as underwater park guides to promote conservation. During the daytime low tide series, the

guides, wearing Scripps jackets, patrol the tide pool areas answering questions and informing visitors of regulations governing park use.

Career experience program

Selected high school students who anticipate a career in marine biology or aquariology are given an academic program which includes field work, laboratory training, and classroom instruction.

Intern trainee apprenticeship program

College and high school students are trained in the practical management of aquaria, such as water quality, feeding practices, disease treatments, and collecting techniques.

Summer courses

Classes in marine ecology are offered during the summer months from the first grade through high school. These classes are self-supporting through fees charged to participants. The curricula are designed by Aquarium staff members and professional teachers who handle the classes.

Junior Oceanographers Corps (J.O.C.)

J.O.C. is a science club for marine enthusiasts from the fourth grade through high school. Monthly lectures by Scripps scientists cover topics in marine biology and oceanography. Field trips include visits to ships, tide pools, marine industrial plants, and an oceanographic cruise.

Senior Oceanographers Corps (S.O.C.)

S.O.C. is for adults interested in the marine environment. This is a combination of lectures, films, and field trips, with the inclusion of a whale-watching cruise.

In-service training for teachers

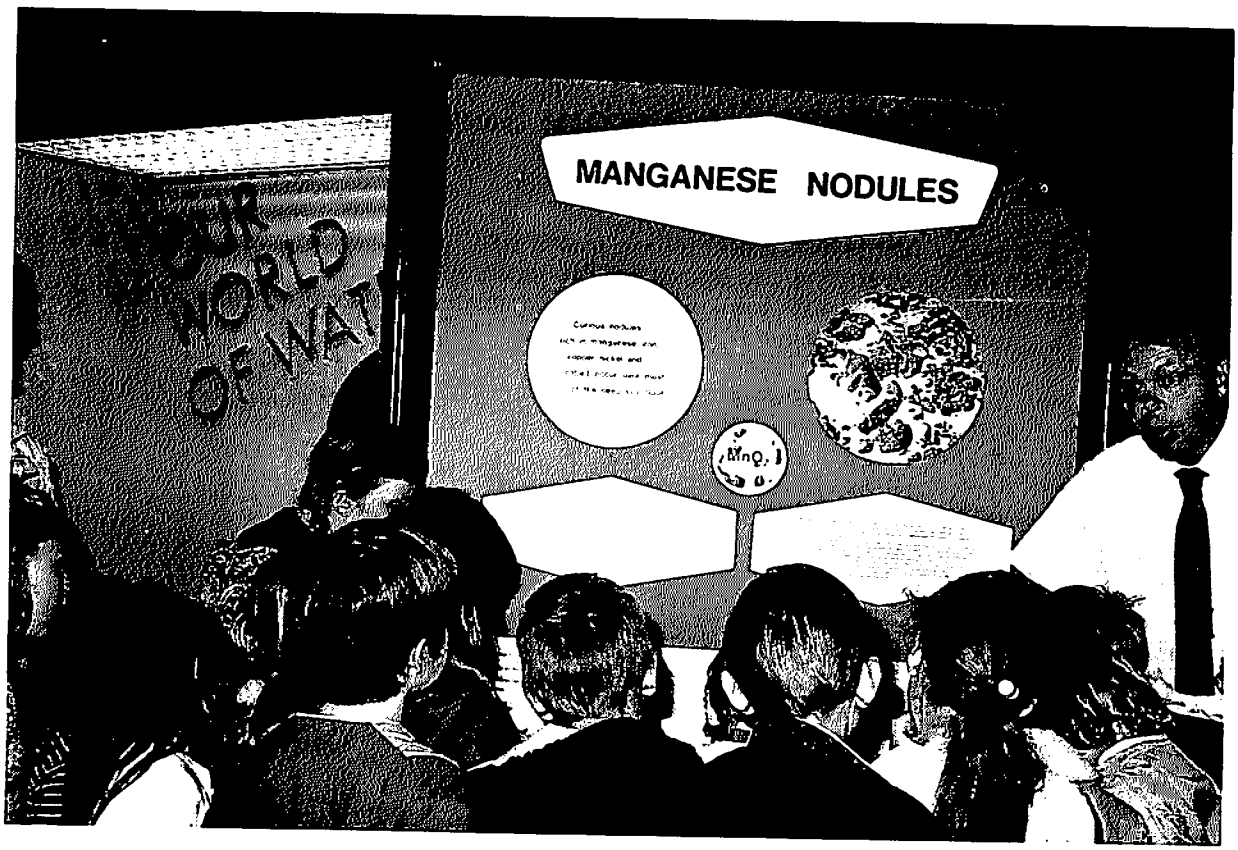
"Kelp and kelp bed communities", our sixth annual symposium for teachers, was attended by over 200 educators. The use and management of the coastal resource comprised the major theme of the symposium.

Docent training program

A yearly lecture series is given each fall to train the new class of docents, and as a refresher class for senior docents. Monthly lectures are held thereafter, including question-and-answer sessions. Special field trips are organized to laboratories, ships, and other institutions.

Advisory services

In addition to supplying information and references in response to inquiries from the



public and students about oceanography, advisory services take a variety of forms.

Teachers and school districts consult us regarding books, slides, films and references for classroom use, and the development of marine education programs.

Aquaria, museums and zoos frequently request advice on the development of education programs. Last year we assisted Sea World and Seattle Marine Aquarium, as well as maintaining a continuing relationship with Waikiki Aquarium and Steinhart Aquarium. Technical assistance in designing seawater systems and maintenance of marine animal facilities is a continuing advisory service.

Spanish language program

Many California school children are Spanish-speaking, particularly in the lower grades, so our education program has been translated into Spanish. We also have Spanish-speaking docents.

Through a San Diego-sponsored program, "Project Amigos", science winners from all the states of Mexico are brought here for a two-week study trip. They learn about Scripps and California-related marine resources through our Spanish-speaking guides.

The university People-to-People organization helps sponsor the library at the Ensenada Oceanographic college (UCM). Scripps docents act as guides and interpreters when the students and faculty visit the Institution's laboratories and the Aquarium-Museum.

Publications

American Association of Museums—Pat Kampmann, panel on education.
American Association of Zoological Parks and Aquaria, Calgary, Canada—Don Wilkie, panel on coloration.
Environmental Symposium for teachers—Kelp and kelp bed communities.
Kampmann, P.A., 1976, Intertidal life, Scripps Aquarium slide presentation.
Revised educational materials at five grade levels.
Scripps Aquarium Newsletter.
Wilkie, D.W., 1976, Sharks, Sea Grant Marine Advisory Publication Leaflet No. 2911.
Idem, The use of anesthetics in capturing and handling marine fishes, NOAA Diving Manual 8.10.5.

Cooperating Organizations

Chula Vista District (including Public Library), California
Marine Advisory Offices, UC-Davis and UC-San Diego, California
San Diego City School District, volunteer office
San Diego County Department of Education, Community Education Resources
Upward Bound and P.I.E. (Primary Inter-racial Education), Federal Programs, Los Angeles, California

Publications and Public Advisory Services

San Diego
A/P-1

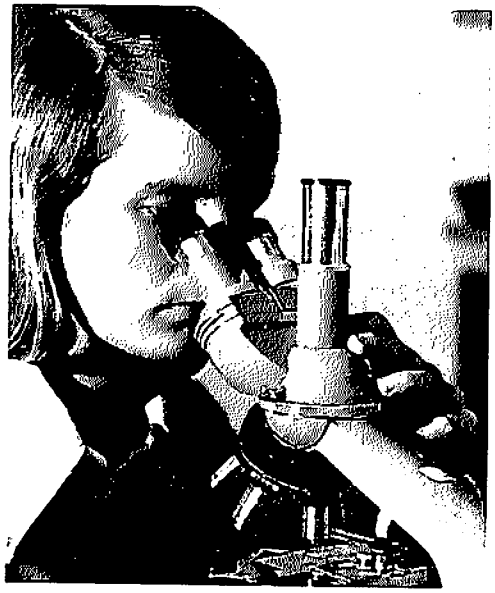
James J. Sullivan

The oceans are a major factor in understanding man's role, position, and accommodation on this planet, and in comprehending the impact of his rapid emergence as a geochemical, geophysical and biological force. Thus, the role of an information center dealing with all aspects of oceanographic science becomes ever more vital.

Although the principal contributions of Sea Grant are the scientific publications of its participants, other routes are also important in contributing to the flow of knowledge.

During the year under review, we distributed information on the UC Sea Grant projects through special reports which included: the 1974-75 Annual Report, the 1975-76 and 1976-77 Program Directories, and the 1976-77 institutional proposal.

We assisted with a number of articles describing the UC Sea Grant research and several news releases, participated in the UC dissemination of research results information program, and laid the groundwork for a general publications plan.



RESEARCH

Although education and public service are vital aspects of the Sea Grant College Program, its basic 'raison d'être' lies in its research function, especially its ability to solve existing problems and anticipate, and so prevent, new problems. Although most of our work is applications oriented, a healthy balance is sought between applied research and basic research, which continues to be a prime University responsibility. California is fortunate in having a high concentration of professional expertise distributed throughout the state on campuses of the University of California system, the State University system and private universities. The research reports that are presented in these pages issue from these diverse sources, although where applicable a high degree of coordination and/or collaboration of research efforts has been effected amongst the different research groups. The 1975-76 University of California Sea Grant research program has been categorized in subject areas dealing with Coastal Resources Issues, Aquaculture (plant and animal), Fisheries, New Marine Products, and Energy Resources. Finally, there is the Rapid Response category, in which projects were established to meet unanticipated needs.

COASTAL RESOURCE ISSUES

Sea Grant sponsored research aims at striking a healthy balance between opposing interests: those forces that value commercial exploitation and 'growth' above all, and those that consider conservation of our natural resources and the ecology as overriding concerns. In recognition of this conflict and the potential for irreversible damage to our coastal lands, a comprehensive coastal plan was delivered to the Legislature on December 31, 1975. Consequently, there have been opportunities this year for Sea Grant to provide independent advice and assistance to the Legislature in its deliberations on this plan. In response to a request for assistance by the leadership of the Legislature, President Saxon has designated the Sea Grant College Program as the vehicle to coordinate the University's efforts in this direction. Liaison with the California Coastal Zone Conservation Commission and other agencies continued as an important program activity.

Methods for the Management of the Cumulative Impacts of Coastal Development

Thomas Dickert

On September 29, 1976, the Governor reaffirmed the citizen initiative creating a permanent coastal zone management authority in California. The Coastal Act of 1976 provides for a state-local partnership in the development and implementation of coastal zone management programs. The research conducted during the year was aimed at developing methods that state agencies and local governments will use in formulating coastal management programs.

For review purposes our work program can be divided into four areas of activity, each intended to provide direct assistance to the California Coastal Zone Conservation Commission (CCZCC) and to develop methods applicable to other states engaged in Coastal Zone Management programs. Our involvement with the CCZCC dates from shortly after the organization of their planning staff in February 1973. We have dealt primarily with the state level commission staff.

Our primary activity has been the development of a process and analytical methods for cumulative impact assessment which could be employed by local units of government to prepare coastal plans based on the policies adopted by the CCZCC. One case study has been used to develop the process—the Half Moon Bay area of San Mateo County. In addition, the Coastal Commission has applied the process in subregional studies conducted in the Big Sur and Irvine areas. Together with previous case histories for Huntington Beach and Marina Del Rey, these studies have served to illustrate further the general applicability of the collaborative planning process.

Cumulative impact assessment

The development of methods for cumulative impact assessment has been focused in five problem areas:

1) Highway, sewage, and water system requirements of coastal land uses in relationship to design capacity and levels of service. Of particular concern is the degree to which traffic congestion generated by residential development may restrict visitor access to the Coast.

2) Estuary sedimentation and pollution generated by land use activities occurring in the estuary watershed. Of particular concern is the effect of sediment and other pollutants on fishery, wildlife, and recreation resources of wetlands.

3) The deterioration in the scenic qualities of coastal communities and landscapes by development activities and physical modification of the environment.

4) The socio-economic mix of coastal communities and associated land uses. Of particular concern is the exclusion of low and middle income groups from residing or recreating within coastal communities.

5) Conversion of coastal dependent and coastal specialty croplands into non-agricultural land uses.

6) The intensity and distribution of public access and recreation. Of particular concern are the effects that coastal land use and access patterns have upon the environmental quality of the recreational site and the quality of the recreational experience.

A second area of activity was testimony and advice to the legislative committees drafting the Coastal Act of 1976. The case studies provided a useful test of the workability of the state-local system proposed in the Coastal Act. Testimony and assistance were provided on several issues, including the content of the local coastal programs, the appropriate inland extent of the coastal zone boundary, and the potential fiscal impacts of the legislation upon local units of government. The extensive data on environmental factors, land use, resources, property ownership, etc. collected for the Half Moon Bay case study area were used to explain the implications of policies proposed in the legislation. Additional input was made through participation in a Coastal Act Task Force organized by the Bay Area Council. Since the Council is an organization representing regional business and industry, the task force provided a broad forum for discussing the implications of the research findings.

A third major activity of the year's research work was the expansion of the coastal zone management library. The library now contains over 2000 documents and is in continual use by state agencies, coastal interest groups, and students.

Because the collection extends back eight years to the origins of the coastal zone management discipline, it is one of the few libraries that can be used for historical trend analysis. In June, the second edition of the "Coastal Zone Bibliography" was published. The publication contains 1701 citations to documents on coastal planning, resources management, and impact assessment.

Establishing contacts and obtaining documents from coastal states with a state-local planning arrangement similar to that adopted by California (under the Coastal Act of 1976), was the fourth major activity during the year. Program documents from Washington state, North Carolina, Oregon, and Maine were collected. Personal interviews were also conducted with various participants in each state. The documents and the interviews plus mail-out questionnaires will form the basis for a critical analysis of the state-local collaborative process. The experience that several coastal states have had with this process should be instructive to California as well as other states considering a similar arrangement.

Publications

Ashbaugh, J., and J. Sorensen, Identifying the public for participation in coastal zone management, *Coastal Zone Management Journal*, 2, 4, (1976).

Bobb, D.C., D. Wormhoudt, and J. Sorensen, Identification and mapping of California's coastal viewshed corridor, Institute of Urban and Regional Development, September, 1975.

Burke, J., Recreation modeling for coastal zone planning: A literature review and critique, working paper, Institute of Urban and Regional Development, August, 1976.

Dickert, T.G., Managing the cumulative impact of coastal development, *Coastal Zone Management Journal*, 3, 4, in press.

Dickert, T.G. and J. Sorensen, State-local collaborative land use planning for the coastal zone, Vol. I Sea Grant Publication, in press.

Idem, State-local collaborative planning for the coastal zone, Vol. II—Half Moon Bay Case Study, Sea Grant Publication, in press.

Hyman, R., California Coastal Plan: Lessons for future environmental planning. Master of City Planning thesis, June, 1976.

Jenks, B., J. Sorensen, and J. Breadon, Coastal zone bibliography: Citations to documents on planning, resources management, and impact assessment, Sea Grant Publication No. 49, IMR 76-8, June, 1976.

Cooperating Organizations

California Coastal Conservation Commissions, Eureka, San Rafael, Santa Cruz, Santa Barbara, Long Beach, and San Diego, California

Governor's Office of Planning and Research, Sacramento, California

Issues of Coastal Governance, with Special Reference to the Seaward Side

Berkeley
R/CZ-27

Eugene Lee and Stanley Scott

This study explored future questions likely to confront decision makers in trying to develop practical policies with respect to the seaward side of California's coast. A variety of topics were examined, with particular attention to governmental jurisdictions and private-sector institutions having responsibilities and interests. The study identified many problems of intergovernmental and interlevel relationships. These will need early attention if prudent future coastal policies are to be formulated and carried out effectively. The questions and issues dealt with may or may not have the importance or validity ascribed to them; nonetheless they are being discussed and viewed as important in many public forums and must be addressed.

A principal finding was that seaward-side issues will probably become an important testing ground for new organizational formulas and intergovernmental relationships needed to achieve the goals of the state and federal coastal legislation. The federal-state-local governmental and private-sector relationships promise to be complex, and the potential for policy conflict substantial. This conclusion emphasizes the need for thoughtful experimentation with new mechanisms for decision making and conflict resolution.

Formal interviews were conducted with approximately 100 respondents, and informal sessions held with others. In addition a literature search was made, and relevant publications analyzed.

Information was sought with special respect to policy issues that might be raised for the state of California, including the Coastal Commission or other appropriate state agencies. The topics so studied included seabed mining, OCS development, fisheries and marine mammals, pollution, ports and offshore terminals, ships and navigation, marine recreation, scientific research, and intergovernmental issues. Tentative conclusions on a number of policy questions and matters meriting future attention are outlined in this report.

With respect to seabed mining, except for some local and offshore materials such as sand—whose depletion along some coastal areas is a major cause of concern—the principal areas of likely development are in far-distant, deep-sea locations. Nevertheless, the land-based processing of manganese nodules seems likely to affect California, which is the most probable location of processing plants based in the continental United States. The adverse pollution effects of such processing could be substantial.

OCS development carries with it environmental hazards and onshore impact problems that are being considered in some depth. Moreover petroleum development involves intense intergovernmental, federal-state struggles, the outcome of which is not yet fully resolved. In any event, California faces many problems of offshore development. Some significant work is being done, including an onshore-impact study under the auspices of the Governor's Office of Planning and Research.

Analogous problems of onshore-impact are faced with respect to the unloading, storing and handling of natural gas in liquid form. California will be the receiving area for much liquefied gas shipped from various points in the Pacific Basin, especially Indonesia. Active intergovernmental efforts are now in progress in this fast-developing field, to review potential environmental and other impacts of LNG port facilities, and to evaluate safeguards.

Effect of legislation on fisheries

With respect to fisheries, a complex of problems are confronted, perhaps the most prominent being difficulties and opportunities inherent in the federal Fishery Conservation and Management Act of 1976. Principal difficulties relate to possible repercussions for California-based fishermen seeking catches in distant waters, especially coastal waters of other nations. They may be injured by reciprocal protection or retaliatory actions. On the other hand, California-based fishermen depending largely on fish caught within the 200 mile limit are hopeful that extended jurisdiction will work to their advantage.

Administration of the new law remains to be worked out, as the multistate regional councils that will develop fishery management plans to guide the Secretary of Commerce have only recently been appoint-

ed. Moreover, the program's administration promises a high degree of intergovernmental complexity, as it involves (1) intra-state interests, (2) interests of neighboring states, and (3) federal jurisdiction, including a strong role by two federal departments with very different objectives and clientele groups, e.g., Commerce and State.

In any event, the new law and related developments could result in better large-scale management of the fisheries, if a consensus can be achieved on what ought to be done, and how to do it.

Problems of pollution and ports

Some of the perceived sources of marine pollution are: oil pollution from either offshore development or tanker or pipeline spills, disposal of municipal and industrial wastes (liquid or solid), disposal of toxic chemicals, thermal discharges, and radioactive wastes. All of these could have significant effects on the onshore and offshore environment. One key issue in pollution regulation is the variety of jurisdictions having some responsibility, including the need for a good interface between federal agencies and theirs, and of both to scientific knowledge.

With respect to ports, a number of problems emerge. Containerization and technological change, plus the obsolescence of some existing port facilities, have brought pressures to expand ports and deepen channels. The coming importation of Alaskan petroleum and LNG from elsewhere is having similar effects. This will give rise to serious conflicts between needs seen by port agencies and the environmental objectives of the coastal plan. Deepwater ports off the coast may provide one partial alternative, but their future remains in doubt.

In any event, California will play a major regional energy role, receiving petroleum through its port facilities, presumably much of it in the Los Angeles-Long Beach area, and shipping it via pipeline to the Midwest. Accordingly California must be prepared to deal with the resulting environmental impacts. As things stand now, coastal planning and regulation seem likely to have a major influence by encouraging redevelopment and more intensive use of existing port facilities, limiting the need for further territorial expansion.

Shipping industry

Although regulation of the shipping industry is considered primarily a responsibility of the federal government, there are also applicable state and sometimes local impacts. For example, state and regional environmental and pollution regulations have produced substantial variations in standards applying to ships in and near ports. The shipping industry finds compliance burdensome, partly because of the differences in standards between one port and another. A related but different problem is the difficult-to-regulate discharge of wastes by ships in and near ports, in state and federal waters, and on the high seas.

Another shipping-industry question relates to terminal-facility location, now principally a responsibility of the competing individual local port authorities. Many observers see a need for more thoughtful state or regional port planning, although the port authorities have been reluctant. CalTrans has recently taken an interest in port-facility location and expansion, and is now studying the matter.

Unlike other maritime states, California has permitted local taxation of incoming cargo and tangible personal property, which the shipping industry believes should be considered "in foreign commerce." The industry hopes that recent legislation and court decisions have successfully resolved the problem.

As suggested earlier, port-access depths are a big problem to the shipping industry, as the new deep-draft ships cannot enter existing U.S. ports. Accommodating these ships poses the question of deepening channels, with many attendant environmental and other impacts, or of establishing off-shore terminals, perhaps beyond state jurisdiction. Future federal-state-local relations and policies with respect to new port facilities remain to be determined.

Finally, the Coast Guard has responsibility for ship safety, which it implements by setting construction standards, providing navigation aids, and engaging in limited traffic control activities. Some California interests consider stronger traffic regulation essential, although the shipping industry believes this has been preempted by federal law. Improved federal traffic-control measures are being experimented with in some areas.

Recreation problems

The management of marine recreation user conflicts appears to have been reasonably successful at the local and county level. But the state needs to provide guidelines for local management to ensure adequate recognition of regional and state needs, and to

guard against adverse effects from concentrated heavy uses in areas of high demand or having sensitive environments.

Related marine recreation problems include obtaining adequate access to desirable recreational sites, while guarding against environmental damage, and providing financial assistance to localities for recreation resource development, maintenance and management. The state could play a direct role in providing some additional access points for water-related uses, and also require private developments to provide such access, as is being done under the coastal plan.

On the other hand, the state needs to monitor marine-recreation activities for possible adverse effects. For this, better baseline information is needed to facilitate early identification of undesirable changes, as well as to guide new conservation measures and remedial actions, if necessary. Accordingly, improved funding seems appropriate to encourage research on coastal marine life and environments.

Finally, it is clear that many governmental levels and agencies are concerned with both the impact of seaward-side developments, and the need for future policies to influence or guide such developments. A substantial number of state and federal agencies share these concerns, as do local governments situated in coastal areas. The California Coastal Commission's responsibilities for the statewide coastal plan signify that it must take continuing account of the seaward-side developments and their potential impact on the coastal zone, although many other agencies may be more directly involved in various functional areas in either a regulatory capacity, or a developmental, facilities-providing capacity.

The extent to which such agencies either respect the coastal plan and work actively for its implementation, or resist, is a matter of great future interest. Presumably Congress intended that the varying and perhaps conflicting intergovernmental interests should be "voluntarily" accommodated to each other in the context of the coastal plans of the individual states, as developed with federal encouragement under the 1972 federal coastal zone management legislation. In any event, implementation of the "federal consistency requirements" in that law will place the state coastal commissions and the various federal agencies in a necessarily close working relationship in trying to accommodate individual agency objectives to the goals of the state coastal plans. Seaward-side issues are likely to provide an important testing ground for these intergovernmental efforts.

Publications

Scott, S., Governing California's coast, Institute of Governmental Studies, University of California, Berkeley, 1975.

Cooperating Organizations

American Institute for Merchant Shipping, Washington, D.C.
Atlantic Richfield Corporation, Los Angeles & Bakersfield, California
Bay Area Council, San Francisco, California
California Academy of Science, San Francisco, California
California Assembly Committee on Resources and Land Use, Sacramento, California
California Assembly Office of Research, Sacramento, California
California Coastal Zone Conservation Commission, San Francisco, California
California Department of Navigation and Ocean Development, Sacramento, California
California Department of Parks & Recreation, Sacramento, California
California Division of Mines & Geology, State Geologist, Sacramento, California
California Marine Parks & Harbor Association, Marina Del Rey, California
California Resources Agency, Department of Fish & Game, Sacramento, California
California Resources Agency, Division of Gas and Oil, Sacramento, California
California State Lands Commission, Sacramento, California
California State Water Resources Control Board, Division of Planning & Research, Sacramento, California
California, University of, Berkeley, Hydraulic & Sanitary Engineering Department, Berkeley, California
California, University of, Berkeley, Zoology Department, Berkeley, California
California, University of, Davis, Extension Marine Resources, Extension Wildlife & Sea Grant, Davis, California
California, University of, Davis, Intitute of Marine Resources, Dept. of Food, Science & Technology, Davis, California
California, University of, San Diego, Scripp's Institution of Oceanography, Institute of Marine Resources, San Diego, California
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Center for Law and Social Policy, Washington, D.C.
Citizens League (Twin Cities area), Minneapolis, Minnesota
Colorado Environmental Affairs and Planning, Denver, Colorado
Colorado Land Use Commission, Denver, Colorado
Colorado Municipal League, Wheat Ridge, Colorado
Colorado, University of, Bureau of Governmental Research and Service, Boulder, Colorado
Conservation Foundation, The, Washington, D.C.
Covington & Burley, Washington, D.C.
Delaware Dept. of Natural Resources and Environmental Control, Dover, Delaware
Delaware Planning Office, Dover, Delaware

Delaware, University of, Coastal Zone Resource Planning, Newark, Delaware
Eureka Fisheries, Eureka, California
Fishermen & Allied Workers Union, Local 33, I.L.U., Terminal Island, California
Florida Atlantic University, Joint Center for Environmental and Urban Problems, Fort Lauderdale, Florida
Florida Coastal Coordinating Council, Tallahassee, Florida
Florida Dept. of Administration, Bureau of Land and Water Management, Tallahassee, Florida
Florida Division of State Planning, Tallahassee, Florida
Hawaii Dept. of Planning and Economic Development, Honolulu, Hawaii
Hawaii Land Use Commission, Honolulu, Hawaii
Johns Hopkins School of Advanced International Studies, Washington, D.C.
Jones & Stokes, Environmental Consultants, Sacramento, California
Kelco Company, San Diego, California
Lazio Fish Company, Eureka, California
Los Angeles County Department of Parks and Recreation, Los Angeles, California
Louisiana State Planning Office, Baton Rouge, Louisiana
Maine Department of Environmental Protection, Augusta, Maine
Maine Natural Resources Council, Augusta, Maine
Maine State Planning Office, Coastal Planning Group, Augusta, Maine
Maine State Planning Office, Land Use Regulation Commission, Augusta, Maine
Maine State Planning Office, Resource Planning Division, Augusta, Maine
Marina Del Rey, Sea Grant Project, Marina Del Rey, California
Maryland Department of Natural Resources, Annapolis, Maryland
Maryland Department of Natural Resources, Coastal Zone Management Program, Annapolis, Maryland
Maryland State Land Use Planning Program, Baltimore, Maryland
Massachusetts, Commonwealth of, Division of Water Resources, Dept. of Environmental Management, Boston, Massachusetts
Massachusetts, Commonwealth of, Executive Office of Environmental Affairs, Boston, Massachusetts
Massachusetts Department of Natural Resources, Wetlands Division, Boston, Massachusetts
Massachusetts, University of, Institute for Man and Environment, Amherst, Massachusetts
Matson Navigation Company, San Francisco, California
Minnesota Coastal Zone Program, State Planning Agency, St. Paul, Minnesota
Minnesota Department of Natural Resources, St. Paul, Minnesota
Minnesota Land Use Planning, State Planning Agency, St. Paul, Minnesota
National Association of Underwater Instructors, Colton, California
National Canners Association, Washington, D.C.
National Marine Fisheries Service, San Francisco & Tiburon, California
New Jersey Dept. of Environmental Protection, Coastal Area Planning, Trenton, New Jersey
New Jersey Dept. of Environmental Protection, Office of Coastal Zone Management, Trenton, New Jersey
New Jersey State and Regional Planning, Department of Community Affairs, Trenton, New Jersey
New York Dept. of Environmental Conservation, Albany, New York
New York Dept. of State Planning, Albany, New York
New York Division of Planning Services, Albany, New York
New York State University, Albany, New York
New York State University, Dept. of Public Administration, Albany, New York
Nossaman, Waters, Krueger, Marsh & Riordan, Los Angeles, California
Oakland, Port of, Oakland, California
Oakland World Trade Club, Oakland, California
Oregon Department of Land Conservation and Development, Salem, Oregon
Oregon, Executive Dept., Local Government Relations Division, Salem, Oregon
Oregon League of Women Voters, North Bend, Oregon
Pacific Coast Fisherman's Organization, Sausalito, California
Pacific Gas & Electric Company, Planning and Research Department, San Francisco, California
Pacific Marine Exchange, San Francisco, California
Pacific Marine Fisheries Commission, Portland, Oregon
Pacific Merchant Shipping Association, San Francisco, California
Resources for the Future, Washington, D.C.
Rhode Island Statewide Planning Program, Providence, Rhode Island
Rhode Island, University of, Coastal Resources Center, Kingston, Rhode Island
Rhode Island, University of, Marine Advisory Service, Kingston, Rhode Island
San Diego, City of, Planning Department, San Diego, California
San Diego Gas & Electric Company, San Diego, California
San Francisco Bay Conservation and Development Commission, San Francisco, California
Save Our Seas, Washington, D.C.
Sierra Club, Minneapolis, Minnesota
1000 Friends of Oregon, Portland, Oregon
Tuna Boat Association, San Diego, California
Tuna Research Foundation, Inc., Terminal Island, California
Twentieth Century Fund, New York, New York
Union Oil Company, Los Angeles, California
U.S. Army Corps of Engineers, Construction Operations Division, San Francisco, California
U.S. Coast Guard, Pacific Area, San Francisco, California
U.S. Department of Commerce, NOAA, Office of Coastal Zone Management, Washington, D.C.
U.S. Environmental Protection Agency, S.F. Office, Facilities Section, San Francisco, California
U.S. Fish & Wildlife Service, San Francisco Bay National Wildlife Refuge Complex, San Francisco, California
U.S. House Ad Hoc Select Committee on OCS, Washington, D.C.
U.S. House Merchant Marine & Fisheries Committee, Washington, D.C.
U.S. Department of Housing & Urban Development, Regional Office, San Francisco, California
U.S. Department of Interior, Washington, D.C.
U.S. Senate Commerce Committee, National Ocean Policy Study, Washington, D.C.
U.S. State Department, Division of Oceans and Fishery Affairs, Washington, D.C.
University of Southern California, Marine Advisory Services, Institute for Marine and Coastal Studies, Wilmington, California
University of Southern California, Political Science Dept., Los Angeles, California
Vermont Environmental Board, Agency of Environmental Conservation, Montpelier, Vermont
Vermont State Planning Office, Montpelier, Vermont
Washington Dept. of Ecology, Office of Land Programs, Olympia, Washington
Washington Dept. of Ecology, Shorelands Division, Olympia, Washington
Washington University, St. Louis, Missouri

Physical Criteria for Coastal Planning

Douglas L. Inman

The principal objective of this project has been to develop instrumentation for accurate and reliable measurements in the nearshore environment and to use these measurements to understand nearshore processes. This objective has been attained with the development and use of the Shelf And Shore (SAS) system during the five-year term of the project. Initial work on the project was primarily concerned with the design and construction of the SAS system, while more recent efforts have emphasized its deployment and data collection. Data obtained as part of the project have been used to gain insight into the physical processes of the nearshore environment and can be translated into practical planning criteria for the coastal zone.

Shelf And Shore (SAS) system

The SAS system has continued to be deployed for the past year to collect additional data from the nearshore environment. Use of the SAS system this year has emphasized the measurement of wave climate, although water temperature and current measurements were also obtained. This measurement technique has now been perfected and provides an accurate and reliable method for measuring ocean wave directional and energy spectra.

During the past four years a shelf station has been deployed off Torrey Pines Beach to measure wave climate. This station is located 900 meters seaward of the beach at a water depth of 10 meters. Three pressure sensors, arranged as a line array on the bottom, parallel to the shoreline, measure the incident wave energy.

Wave climate

Wave frequency and directional spectra are measured four times a day. The data collection project was started in February 1973.

The wave climate in the southern California region is complex, as the area is exposed

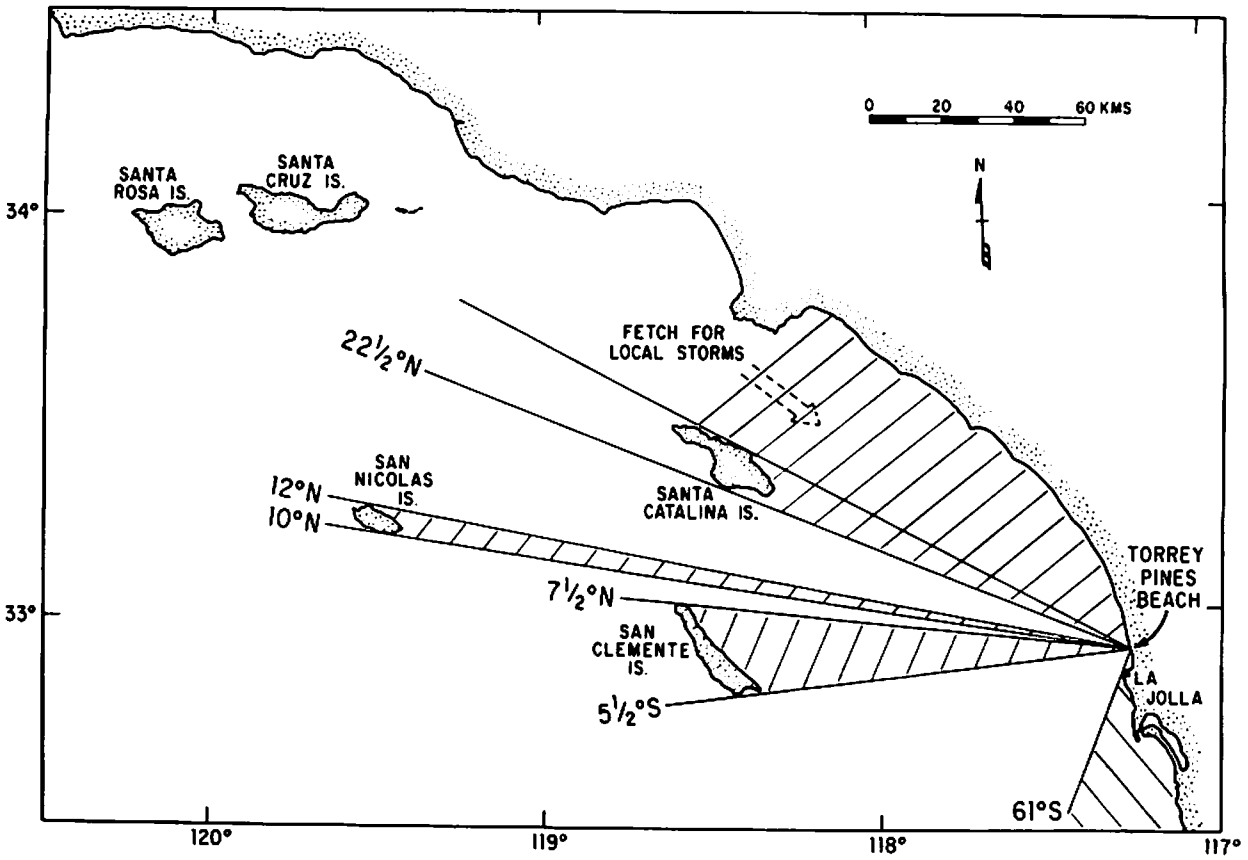


Fig. 1. Southern California borderland region showing the linear shadows of the offshore islands. The northern cut-off (22.5°N) caused by shadowing by both the islands and mainland is a significant factor in protection of this area from energy generated in the northwest region of the North Pacific

to several wave generation regions and there is significant sheltering by offshore islands as shown in Fig. 1. Quite often, more than one of the wave generation regions contribute energy to the local wave field simultaneously. The energy of the wave field associated with each source can be identified as a peak in the frequency spectrum. The significant peaks in the frequency spectra are used to characterize the wave field. Associated with each spectral peak are a peak period, bandwidth and energy (variance). A directional spectrum is then calculated for each peak period. Consideration of the spectra in terms of the significant peaks has aided in the identification of typical wave events that are dominant in the various seasons.

The summer spectra are particularly interesting owing to their characteristic bimodal form. These modes consist of long period (14-18 sec) waves from the southwest and shorter period waves (6-9 sec) from the northwest. Storms in the southern hemisphere and tropical cyclones in the eastern North Pacific, which are active during the summer season, both generate the longer period southern waves. The shorter period waves are due to the stationary high which is located off the California coast in the summer months. The longer and shorter period components both have typical root-mean-square (rms) wave heights of less than 50 cm in water depth of 10 meters.

The fall season is a transitional period during which storms in both the southern and northern hemispheres contribute energy to the region. Consequently, the distribution of energy for long period waves in this season shows strong modes for the directions 8-12° south of west and 8-10° north of west. The waves in the northern quadrant come through the window between San Clemente Island and Santa Rosa-Catalina Islands (see Fig. 1).

Long period waves generated in the regions of extreme storm activity in the North Pacific are evident in the spectra from the late fall through mid-spring. These waves have a typical rms wave height of 80 cm in 10 meters of water, but rms wave heights up to approximately 1.7 meters have been recorded. These waves usually come through the northwest window in the borderland islands. However, at times some of the energy from North Pacific waves is also refracted around the southern tip of San Clemente Island and approaches from directions that are a few degrees south of west.

Local storms which are active in the spring months generate high energy shorter period waves (6-9 sec period) that are one of the most important components of the local wave climate. The locally generated waves have typical directions of 8-14° north of west, but may have directions ranging from 30° south to 30° north depending on the approach path of the storm. These waves are of particular importance when considering beach erosion and the longshore transportation of sand.

Steady streaming around a sphere under linear surface waves

In a previous study (Jenkins and Inman, 1976), the rms horizontal forces resulting from the action of linear, deep and intermediate water, laboratory scale waves, were measured on submerged spheres removed several diameters from the free surface. The study focused on unseparated flow encountered at small values of (d_o/D), where d_o is the orbital diameter and D is the sphere diameter. Under these conditions, the periodic force due to the wave pressure, as represented by the inertia coefficient, was found to be 40 per cent smaller than that predicted by linear potential scattering theory, even though the gross viscous effects associated with separation were avoided. It is now believed that these results can be understood in terms of the mechanics of the flow near the surface of the sphere. Instead of the local flow being strictly periodic in accordance with frictionless scattering models, it is actually found to exhibit steady, time-independent motions, giving rise to a net circulation around the vertical equator of the sphere as shown in Fig. 2. With such a circulation added to the diffracting velocity field, a force proportional to the product of the circulation and the instantaneous far-field velocity ensues and opposes the resultant of the wave pressure at any phase of the incident wave.

Because the wave pressure produces the largest component of the total wave load when $d_o/D<1$ and the circulation streaming significantly diminishes that component, this work has uncovered a practical means for reducing the mooring loads on large submerged structures. Accordingly, our present research is directed towards learning more about the mechanism for generating the circulation.

Nonlinear free-surface effects do not provide a likely explanation for these findings owing to the remoteness of the spheres from the free surface and the small size of the spheres used in the experiments with respect to the incident wavelengths. Furthermore,

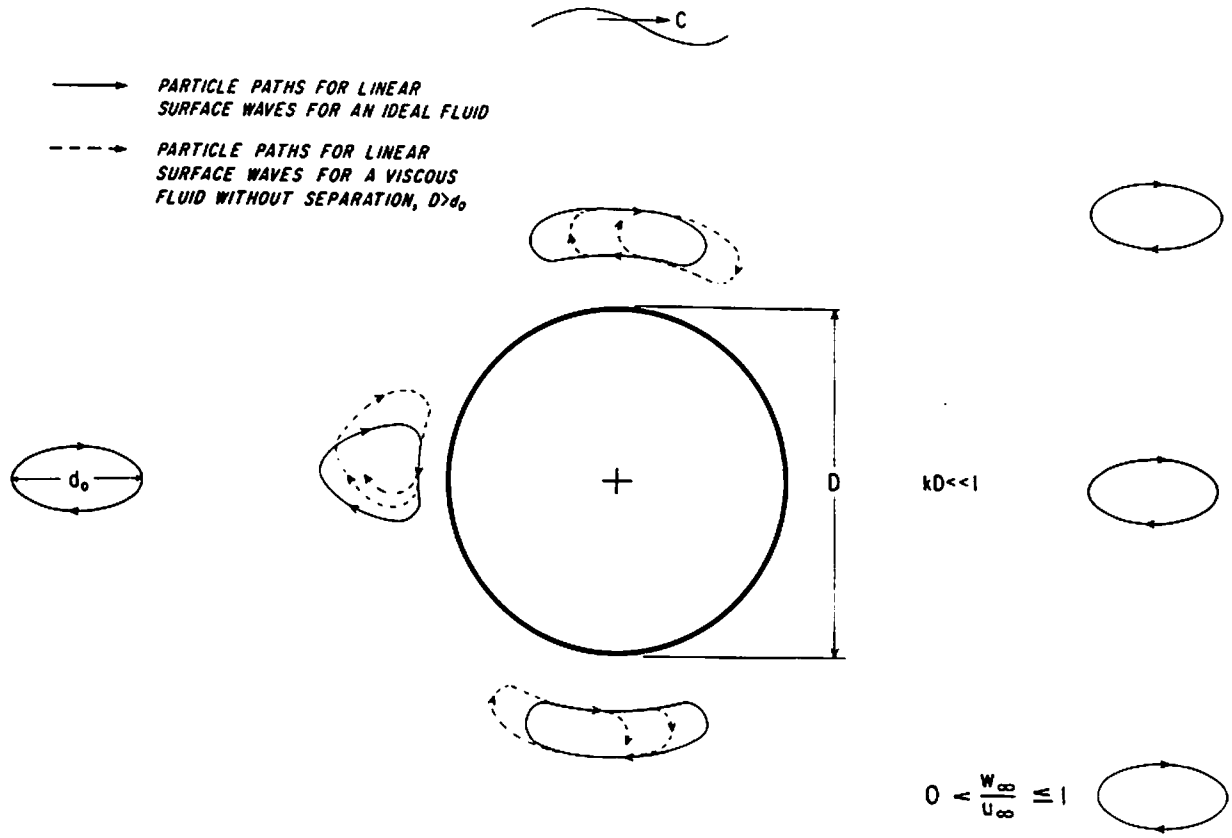


Fig. 2. Circulation streaming around a sphere resulting from retarding influences of the boundary layer being greater for the segments of particle orbits closest to the sphere

the streaming appears most intense near the surface of the sphere. Therefore, boundary layer effects appear to be the most likely mechanism.

Consider, then, in Fig. 2 the solid path lines of deformed, closed orbits in the vicinity of a submerged sphere under linear inviscid, irrotational waves, when the sphere is small in relation to the wavelength. There is negligible decay in the amplitude of the motion vertically over one sphere diameter, and no net time-independent motions result. But, if viscosity and the formation of boundary layers are included, then the orbits can no longer remain closed and a "bottom wind" results around the sphere to give rise to a net circulation that is independent of time. Considerably more vigorous streaming may be realized around a sphere than over a flat bottom, because in diffracting around the sphere the local velocities and the orbital diameters are increased relative to those in an undisturbed wave field. This is revealed in Fig. 3, in which streaming velocities around the vertical equator were measured by following the progress of the leading edge of a dye streak for an integral number of cycles. The circumferential streaming velocity $\langle u_\theta \rangle$

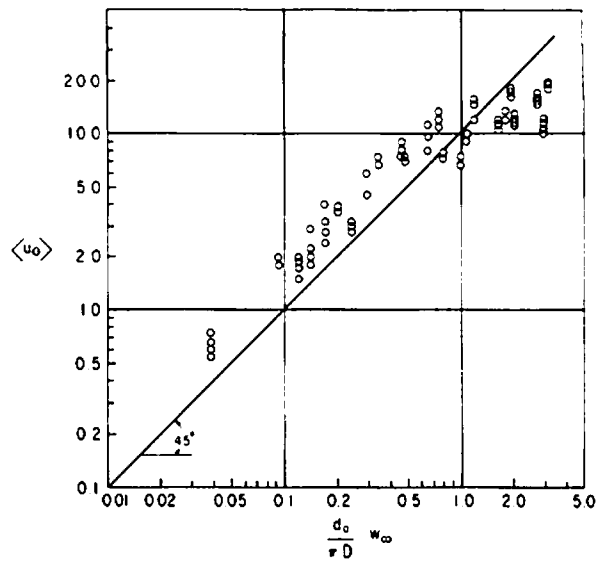


Fig. 3. Streaming velocities, $\langle u_\theta \rangle$ measured around the vertical equator of a sphere against $(d_o w_\infty/\pi D)$, where w_∞ is the maximum value of the vertical particle velocity in the undisturbed wave, d_o is the orbital diameter, and D is the sphere diameter. Velocities are expressed in units of cm/sec

is significant and was found to be almost linear with the parameter $d_0 w_\infty / \pi D$, where w_∞ is the maximum value of the vertical velocity component in the undisturbed wave. However, with the onset of separation, circulation quickly breaks down. These results demonstrate that for a given wave height, the circulation will be most intense for a deep water wave; it will diminish, as the ratio of the vertical to horizontal diameter of the orbital motion decreases with shoaling, and it will cease altogether once the orbital motion is merely back-and-forth.

Dissemination of information

A significant part of this research consisted of the dissemination of project results. This has been accomplished through direct contact with potential users and participation in meetings where there was an exchange of information with people having a mutual interest in the results. Most notable of these meetings was the Sea Grant Conference on Physical Variables in the Coastal Zone, convened at the Scripps Institution of Oceanography, in 1975. This conference was noteworthy for presenting the present state of the art and for indicating the critical gaps in our present understanding. This in turn has led to several other conferences which have had valuable input into concepts for ongoing research on a national level.

In conclusion of this project, a report is to be issued that will document our accomplishments in a user-oriented manner. This report is intended to provide information for coastal engineers and planners to apply project results in solving coastal zone problems.

Publications

Dingler, J.R., and D.L. Inman, Wave-formed ripples in nearshore sands, Proceedings of the 15th International Conference on Coastal Engineering, American Society of Civil Engineers, 1976.

Jenkins, S.A., and D.L. Inman, Forces on a sphere under linear progressive waves, *ibid.*, 1976.

Cooperating Organizations

California Coastal Zone Commission, San Diego Regional Commission

Comprehensive Planning Organization for the San Diego Region, San Diego, California

San Diego County, California

Management of Beach and Dune Vegetation

Michael G. Barbour

Exclosures have been erected in disturbed areas to determine natural revegetation rates. Permanent transects on less disturbed sites show that up to 1 m of sand movement in depth can occur in a six-month period, even where vegetation cover is relatively high. Application of peat moss and slow-release nitrogen fertilizer improves root growth and survival of *Elymus* vegetative plantings. Plantings of other native species from seed have not been successful. Twelve common beach taxa have been ranked in terms of relative tolerance to salt spray and soil salinity, and this information will guide future plantings.

Our objective is to determine which native plants are most suitable for stabilization of upper beach and foredune surfaces, and to develop propagation techniques requiring minimal human effort and expense. We wish to find a substitute for European beach grass (*Ammophila arenaria*), which has been widely planted for erosion control but has the negative traits of crowding out native flora and fauna and grossly altering natural landforms.

Plantings of *Elymus*

We planted the native dune grass (*Elymus mollis*) during the first grant year in small field plots that differed in location, amount of driftwood, amount of algal beach drift (as a natural fertilizer), amount of slow-release fertilizer added to the plot, and density of culms; and some plots were planted to mixtures of *Elymus* and *Ammophila*. These plots continue to be monitored. As shown in Fig. 1, *Elymus* survival is quite low compared to *Ammophila*. This diagram is for a mixed planting at a particular density and fertilizer level, but our data show that the pattern of survival was the same regardless of treatment. The largest effect was from site to site (that is, degree of exposure, which so far we have not been able to quantify): survival ranged from 3 to 55 per cent in the first two months.

In the second year, additional plantings of *Elymus* were made; this time we tried to eliminate site-to-site environmental differences. Subplot variables were: the soaking of the rhizome pieces in rooting hormone (IBA) before planting, the addition of slow-release fertilizer to the sand during planting, and the inclusion of wet peat moss around the rhizome in the planting hole, all with appropriate controls. The rhizomes were enclosed in mesh bags with leader strings left above the surface, so that samples could be periodically exhumed and root growth measured. Peat moss significantly improved survival over a six-month period (29 per cent survival without the moss, 67 per cent survival with the moss), but hormone and fertilizer treatments had no effect. Peat moss also stimulated root growth, as shown in Fig. 2, and there was an interaction with fertilizer level. Hormone application had no statistically significant effect.

Given the mortality rate observed, even in the best conditions, it might be necessary to double or triple our planting density of *Elymus* in order to ultimately remain with a density of established plants that mimics the natural situation. This means a planting density of 25 lengths of rhizome per square meter. Other conclusions are: planting should be done early in winter, during wet weather; peat moss should be added to the drill site; pretreatment of the rhizome with rooting hormone is not necessary (though we have found it induces faster rooting of non-grasses); and the addition of fertilizer may be necessary.

Plantings of other species

We do not propose monoculture plantings, however, and work has continued with other species. A planting of sand-verbena (*Abronia latifolia*) and beach-bur (*Ambrosia chamissonis*) by seed yielded less than 1 per cent establishment, even though 5000 seeds had been sown. We plan to repeat seed planting in the third year, but this time embedding each seed in a gelatinous substance that will retain water and also planting earlier in winter. Particular care will be taken with the *Ambrosia* because growth chamber experiments showed that it was the least tolerant to salt spray and seawater inundation among a dozen common beach species. Beach morning-glory (*Calystegia soldanella*), *Abronia*, and salt bush (*Atriplex leucophylla*) were among the most tolerant, and they may be field planted by seed and by rhizome in the third year.

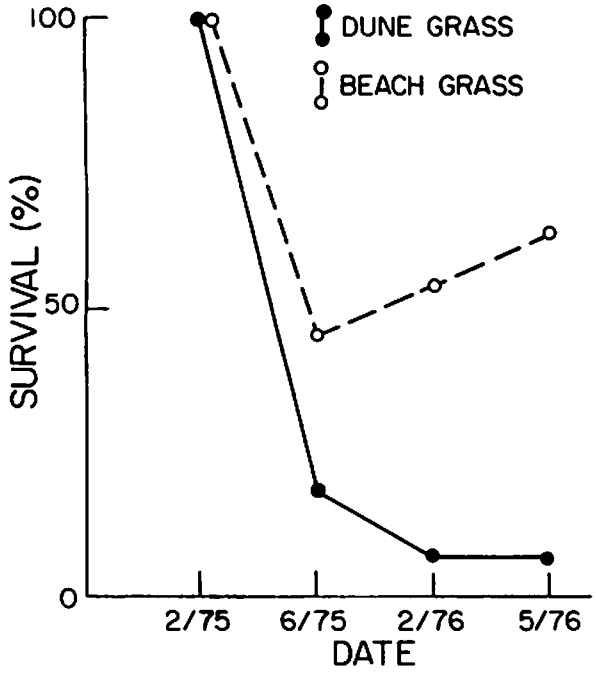


Fig. 1. Long-term survival of native dune grass (*Elymus*) in mixed planting with European beach grass (*Ammophila*) at Point Reyes

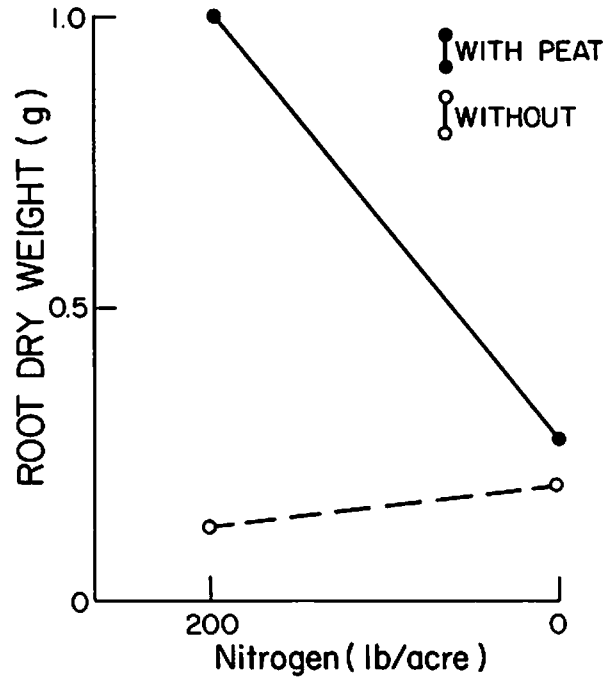


Fig. 2. Effect of peat moss and fertilizer on root growth of *Elymus* two months after planting at Point Reyes. The addition of rooting hormone reduced growth somewhat

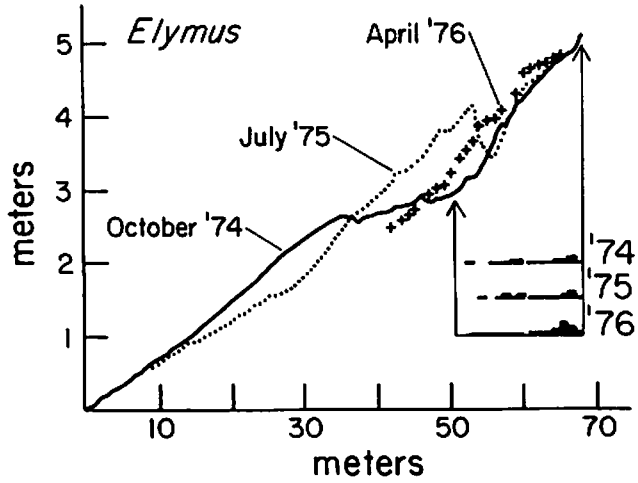


Fig. 3. Beach profile along permanent transects dominated by *Elymus* at Point Reyes; September, 1976 profile not shown

We continued to revisit permanent transects every six months, to measure sand movement and vegetation change along a relatively undisturbed portion of beach and foredune. Figure 3 summarizes, for those transects dominated by *Elymus*, how topography can fluctuate ± 1 m at any one point along the transect, even where vegetation cover is relatively high. The data for September, 1976, do not appear.

Six exclosures, each about 2 x 4 m, were erected; four at heavily visited North Beach, and two at much less visited Kehoe beach. They were established in relatively disturbed places, obviously in the path of most visitors to the beach, and a minimal wire barrier with warning signs was put about each. This barrier should eliminate human and large animal traffic, but will not bar small animals, sand movement, sunlight, or air movement. We plan to record canopy cover of all plants over the next several years to determine if the native vegetation is able to reinvade and reclaim disturbed beach on its own, without benefit, of artificial plantings. The exclosures were erected next to, or containing, some vegetation already, so we are assured that rhizomes or seeds can reach the plots. No data from these plots are yet at hand.

Publications

Barbour, M.G., and R.H. Robichaux, Beach phytomass along the California coast, *Bull. Torrey Bot. Club*, 103, 16-20 (1976).

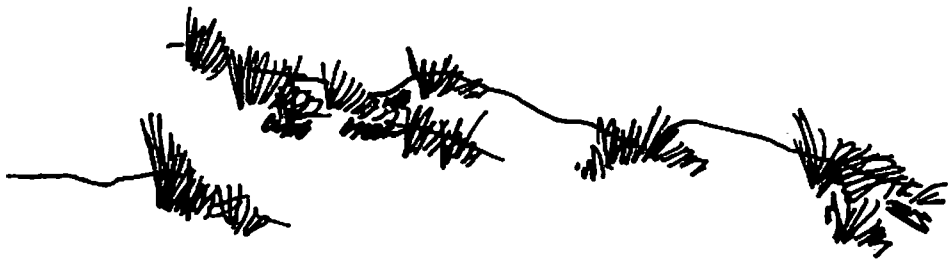
Barbour, M.G., T.M. DeJong, and A.F. Johnson, Synecology of beach vegetation along the Pacific coast of the USA, *J. Biogeog.*, 3, 55-69 (1976).

Holton, B., Jr., and A.F. Johnson, Correlation of soil properties and plant community composition of stabilized dune, Point Reyes, California. Paper presented at the Ecol. Soc. Amer. annual meetings with AIBS at Tulane University, 1976.

Johnson, A.F., B. Holton, and M.G. Barbour, Management of native beach and dune vegetation, Point Reyes, California. Paper presented at the Ecol. Soc. Amer. annual meetings with AIBS, Tulane University, 1976.

Cooperating Organizations

United States Park Service, through Point Reyes National Seashore



San Francisco Bay Project: Reference Collection, Bibliography, Identification Keys and Specimen Repository

California Academy
of Sciences
R/CZ-28

Welton L. Lee

The purpose of this project is to develop a central information source on the invertebrate fauna of San Francisco Bay and the Bay-Delta, and to distribute this information in a series of identification manuals. The manuals represent an entirely new concept in invertebrate taxonomy and provide a common basis for all types of biological studies in the Bay area.

A review by Frederic Nichols in 1973* pointed out the serious shortcomings of nearly all of the various research studies, surveys, and environmental impact reviews which had been made on San Francisco Bay and the Bay-Delta. Various causes were found for these inadequacies, but foremost among them were the failure to retain specimens for checking and future reference, and the great lack of accurate, up-to-date, and easy-to-use identification guides to the various invertebrate groups.

Taxonomic errors have led to other problems. A number of cases of putative environmental damage have actually been the apparent absence of species because of misidentification. With the decline of interest in taxonomic study and collection maintenance at the university level, the Department of Invertebrate Zoology of the California Academy of Sciences determined that it could provide a unique service to the Bay area by developing such services as were needed by the scientific community.

After two years under private funding, during which much of the groundwork and planning were completed, the Department, with the cooperation of San Francisco State University, applied to Sea Grant for funding to move the program into full operation. As a result of this funding, the Department has moved ahead on its four primary objectives:

1. To develop, from department material and newly deposited collections, a fully documented and identified reference collection of all the invertebrates of the Bay and Delta, including large series of typical adult, juvenile, and unusual forms.
2. A complete cross-indexed bibliography of references to all aspects of the life history and taxonomy of the invertebrate organisms, plus various kinds of supplemental information on related topics.
3. A repository for the permanent maintenance and storage of all collections made in the area, for future examination and confirmation.
4. A series of identification manuals to various groups of invertebrates, suitable for use by specialists and non-specialists alike.

The major advance over the past year has been in the development of the identification manual concept, through Sea Grant and a National Science Foundation grant. Our review of the taxonomic and systematic literature has indicated that several different approaches had been used, none having been entirely successful. Some keys were designed by experts for other experts, and thus were so esoteric and detailed that they precluded use by the general biologist or ecologist who required identification of an organism but did not have the time to learn the complexities of such keys. The other keys were very simple and easy to use, but failed to consider the range of variability found in most populations, and so could only be used for "typical, adult, undamaged specimens." Unfortunately, a large number of specimens did not fit that category, and so were identified incorrectly or not at all.

Novel type of manual

The manual concept which we have developed incorporates the best of both types of keys, plus much more. The basic idea has been to provide a suite of distinct, yet complementary keys with full supporting information, so that the identification problem can be approached from different directions. The specialist might find the number of keys somewhat redundant, yet will appreciate the full list of synonymies, detailed descriptions, and complete bibliography. The non-specialist, on the other hand, will find a wealth of accurate yet easily understandable information in the various

* Nichols, F.H., A review of benthic faunal surveys in San Francisco Bay, *U.S. Geological Survey Circular*, 677, 1-20 (1973).

keys and the illustrated glossary with its synonymous terms and French and German equivalents.

At present, manuals for the spionid polychaetes and the acmaeid gastropods (limpets) are in final stages of review and editing, and will be published in the near future, along with a general introductory paper describing the project, its objectives and operations. In addition, keys to the families of polychaetes, gastropods, and sponges are in various stages of preparation, as well as keys to various other groups of species of gastropods, and to the species of sponges from San Francisco Bay. Technical information on range extensions, new species descriptions and other data not appropriate to the manual format are being published in various scientific journals.

Work continues on the other aspects of the program. A cross-referencing outline has been developed for the bibliography, combined with a "location code," so that the location of any reference can be immediately determined.

It is important that various agencies, groups, etc. be made aware of the services which we provide, so that the project and its benefits be utilized to the fullest. Therefore, presentations of the objectives and services of the project have been given to, among others, the Western Society of Naturalists, the Western Society of Malacologists, the Association of Systematics Collections, the National Science Foundation and local colleges and universities, including California State University, Hayward, Diablo Valley Community College and San Jose State University.

In conclusion, the past year has seen significant growth in a project designed to provide assistance to many different types of researchers, formulators and decision-makers, all united by a common need for detailed, accurate, intelligible and readily available information concerning the Bay-Delta System and its invertebrate fauna. We anticipate that the San Francisco Bay Project, its manual series, and the information and storage services it provides, will become the standard method for systematic studies and faunal evaluations for coastal and estuarine areas throughout the country.

Publications

Lee, W.L., The San Francisco Bay project, *Pacific Discovery*, 28(4), 32-33 (1975).

Lee, W.L., W.J. Light and J.E. Sutton, The San Francisco Bay Project. Introduction, overview, and guide to the identification manuals. In preparation.

Light, W.J., The San Francisco Bay Project identification manual series: a new approach to invertebrate keys, *Systematic Zoology*, 25, 236-242 (1976).

Idem, Spionidae (Annelida: Polychaeta) from San Francisco Bay, California: a revised list with nomenclatural changes, new records and comments on related species from the northeastern Pacific Ocean, *Proceedings of the Biological Society of Washington*. In press.

Idem, Invertebrates of San Francisco Bay. Polychaeta. Family Spionidae. In press.

Lindberg, D.R., Artifacts produced by the treatment of radulae with caustic alkalies, *The Veliger*. In press.

Idem, Invertebrates of San Francisco Bay. Mollusca. Family Acmaeidae. In preparation.

Sutton, J.E., CAL-ACAD: The San Francisco Bay Project. *Association of Systematics Collections Newsletter*, 3(5), 5 (1975).

Idem, Partial revision of the genus *Amphiodia* Verrill (Ophiuroidea: Amphiuridae) from the west coast of North America, *Thalassia Jugoslavica*. In press.

Conference Presentations

Association of Systematics Collections; Fourth Annual Meeting; Vicksburg, Virginia, May 13-15, 1976.

Lee, W.L., The San Francisco Bay Project: A new approach to using systematics.

Second International Echinoderms Conference; Rovinj, Croatia, Yugoslavia, Sept. 26-Oct. 1, 1975. 1975.

Sutton, J.E., The taxonomy of the genus *Amphiodia* (Echinodermata: Ophiuroidea) from the Pacific Coast of North America.

Western Society of Naturalists; 56th Annual Meeting; San Francisco, California, Dec. 26-30, 1975. ber 1975.

Lee, W.L., The San Francisco Bay Project - An Overview.

Light, W.J., Identification manual to the Spionidae from San Francisco Bay: A new approach to Polychaeta keys.

Sutton, J.E., Revisions in the genus *Amphiodia* from the west coast of North America (Echinodermata, Ophiuroidea).

Western Society of Malacologists; Tenth Annual Meeting; Asilomar, California, June 23-26, 1976.

Sutton, J.E., The San Francisco Bay Project: a new perspective in taxonomy.

Cooperating Organizations

Allan Hancock Foundation, University of Southern California, Los Angeles, California

California Department of Fish and Game, several branches

California Department of Parks and Beaches

Diablo Valley College, Pleasant Hill, California

Leslie Salt Company, Newark, California

Los Angeles County Museum of Natural History, Los Angeles, California

Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts

National Museum of Natural History, Smithsonian Institution, Washington, D.C.

Regional Water Quality Control Board, Oakland, California

San Francisco Bay Chapter, Oceanic Society, San Francisco, California

San Francisco State University, San Francisco, California

State Water Resources Control Board, Sacramento, California

University of California, Berkeley, California

U.S. Army Corps of Engineers, San Francisco District, San Francisco, California

U.S. Bureau of Reclamation, several branches

U.S. Coast Guard, San Francisco District, San Francisco, California

U.S. Geological Survey, Menlo Park, California

Diving Safety Research Project

Glen H. Egstrom

The Diving Safety Research Project at UCLA focuses upon the identification of objective performance data useful in the promotion of safer and effective diving. Problem areas include the functional performance of scuba equipment, including regulators, gauges, buoyancy compensators, back packs, weight belts, thermal protection and meters; learning patterns for critical skills such as buddy breathing, surf entry and exit, and vest inflation; a comparison of established rules of behavior of different training agencies; and the biomechanical analysis of emergency procedures.

Our studies so far, have revealed a number of important facts which, when considered by the diving community, should result in a modification of training and performance techniques.

In investigating the learning progress during underwater exposure, it was found that plateaus in the learning curves occurred in 17-21 trials on a two-hand coordination task and in 9+ trials while learning buddy breathing.

It has been shown that most scuba students do not practice emergency procedures more than two or three times during the average course. Therefore, a need is indicated for an increased number of successful repetitions in the learning phase of certain of these critical skills for safe diving. These findings are already making an impact upon training programs under study by the National Scuba Training Council. A major finding with regard to diver safety was that buddy pairs who signaled the need to buddy breathe would stop swimming until the mechanics of buddy breathing were established. This in many cases would lead to divers who were negatively buoyant sinking to the bottom of the pool. Later, when comfortable, they would resume swimming. Since this emergency ascent technique requires constant swimming toward the surface, it becomes obvious that *swimming* buddy breathing techniques must be learned by the novice diver if he expects to survive.

Another significant finding resulted from the comparison of the rules of behavior stated in the training materials of the four largest national scuba training agencies. The agencies differ considerably on a number of fundamental emergency procedures and methods of instruction in critical skills. Efforts within the National Scuba Training Council are currently being directed at resolving these differences, with our assistance. A one-day workshop held at UCLA on July 9, 1976, was attended by representatives of 26 agencies. During the workshop, various emergency procedures and training techniques were discussed. It appeared that the differences between organizations are more mechanical than philosophic. Therefore, in the future, it will be possible to arrive at significantly greater similarity in procedures and less confusion than presently exists.

Regulators

The identification of the functional limitations of scuba regulators has progressed significantly. Increasing cooperation from the members of the Diving Equipment Manufacturers Association has speeded the progress of the study. A total of 172 regulators from 11 manufacturers have been tested and are now in the final stages of computer data processing. Increasing acceptance of functional testing of regulators as a method of determining the need for calibration or maintenance has resulted in the development of two inexpensive methods for use by dive shops and divers. The studies have also revealed the necessity for teaching the diver to use low flow rate breathing techniques, especially on deeper dives. The slow, deep inhalation-exhalation cycle results in significantly lower differential pressures in the demand for air. Excessive flow rates cause increased work of breathing and discomfort, which in turn can lead to increased stress on the diver. The mechanical operation of the regulators tested is generally reliable and the changing breathing characteristics are quite predictable. A well-calibrated regulator is a necessity, and semi-annual functional tests can reveal changes in performance that indicate a need for maintenance or recalibration.

Weight belts

A study of weight-belt ditching from varying body attitudes revealed that opening the quick release on weight belts did not result in a spontaneous loss of the belt. If the attitude varied from 10°-20° from the vertical, drops occurred sporadically and at 0°-10° from the vertical the weights released

reliably in the absence of any obstructions. This evidence points to the need for the diver to release the buckle and physically remove the belt from his body. In this way, the belt's tendency to remain in place on a horizontally inclined diver would be overcome.

A measurement technique and instrumentation for the evaluation of the effect of diving equipment on diver mobility has been developed and tested. This program will permit conclusions on the design effectiveness of various items of equipment, including buoyancy compensators, wet suits and tank back packs.

The advisory function of the program has been served through 15 public presentations of the preliminary findings of the study and through an average of 12 phone calls per week relating to specific parts of the research program. Consulting services have been provided to groups such as the Diving Equipment Manufacturers Association, U.S. Navy Coastal Systems Laboratory and Experimental Diving Unit, Undersea Medical Society, Department of Labor, National Institute of Occupational Safety and Health, Naval Medical Research Institute Behavioral Sciences Laboratory and members of the National Scuba Training Council.

Publications

Invited lecture presentations on the Diving Safety Research Project were given to the following organizations:

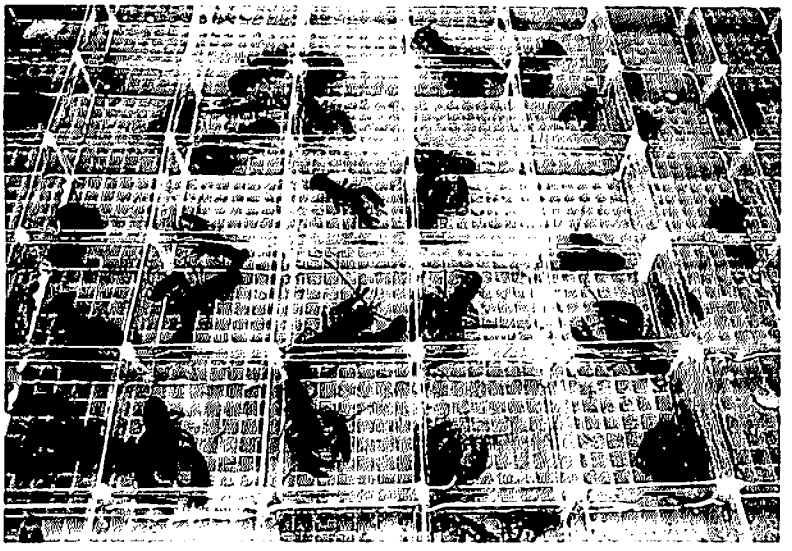
- CDC Diving Safety Workshop, Wilmington, California
- Commercial Diving Center, Wilmington, California
- Commercial Diving OSHA Inspectors, Wilmington, California
- Diving Equipment Manufacturers Association, Long Beach, California
- Diving Medicine Course, San Francisco, California
- Diving Medicine Course, Truk, Micronesia
- Diving Training Program, Kwajalein Atoll, Micronesia
- Instructor Training Course, Honolulu, Hawaii
- LACO Advanced Divers Program, Los Angeles, California
- National Scuba Training Council, Santa Ana, California
- NAUI CANADA, Toronto, Ontario, Canada
- Naval Medical Research Institute, Washington, D.C.
- NMRI, Washington D.C.
- Our World Underwater Conference, Chicago, Illinois
- Statewide Diving Officers Meeting, UCLA, Los Angeles, California

Cooperating Organizations

Diving equipment manufacturers:

- Aqua Craft, San Diego, California
- Dacor Corporation, Chicago, Illinois
- Farallon Industries, Belmont, California
- Healthways, Los Angeles, California
- New England Divers, Los Angeles, California
- O'Neil, Inc., Santa Cruz, California
- Parkway-Poseidon, Perth Amboy, New Jersey
- Scuba Pro, Paramount, California
- Sherwood-Selpac, Santa Ana, California
- Sportsways, Inc., Paramount, California
- Sub Aquatic Systems, Redondo Beach, California
- Techna, Menlo Park, California
- U.S. Divers, Santa Ana, California
- Voit, Santa Ana, California
- White Stag, Inc., Marina del Rey, California

- Diving Equipment Manufacturers Association, Long Beach, California
- Los Angeles County Department of Beaches
- Los Angeles County Department of Parks and Recreation
- National Scuba Training Council: NASDS, NAUI, PADI, SSI and YMCA



AQUACULTURE

The importance of the commercial culture of marine animals and plants for human use has long been recognized, but successful commercial exploitation on a large scale has been infrequently realized. Sea Grant sponsored researchers are dedicated to bring nearer the day that a viable aquaculture industry can be established, to help meet increasing world demands for protein foods. Their main efforts presently are in the development of mass culturing systems using the American lobster as the experimental animal. Knowledge gained in the husbandry of this valuable species could ultimately also lead to practical mass culture of other species, such as the California spot prawn and the Dungeness crab. In recognition of the fact that marine plant resources are becoming increasingly valuable and important, other workers are directing their efforts toward the wise utilization of California's algal resources and their proper management based on ecological data. An unusual line of research, in which crop plants are bred to tolerate irrigation with highly saline water, has so far exceeded expectations in its progress toward the goal of making available the vast resources of the ocean to arid, sandy soils.

Development of Aquaculture Systems

Cadet Hand and Robert Shleser

The Aquaculture Program at the Bodega Marine Laboratory continues to use an interdisciplinary approach in its study of the feasibility of commercial aquaculture of the lobster, *Homarus americanus*. The group also is attempting mass rearing of the Dungeness crab, *Cancer magister*, a valuable California crustacean. Significant progress has been made in rearing crab larvae and in the nutrition, disease control, genetics and broodstock development of lobsters.

Larval biology

The Dungeness crab hatches out into a pinhead-size, delicate larva which looks more like a shrimp than a crab. It spends the first 60-80 days swimming and during this time undergoes six molts, each time becoming more crab-like. After the sixth molt, the crab, which now is a miniature of a mature adult, settles to the bottom and lives there for the rest of its life. During the early swimming period the larvae are vulnerable to all manner of adversities, and maybe, one in one million will survive to the adult stage.

The objective of the larval biology program at Bodega Bay is to develop the technology to culture Dungeness crab larvae through the vulnerable larval period so that the much hardier juvenile crabs may be released back into the ocean or used as potential aquaculture candidates.

The focus of the study is on two major areas: first to define a diet and feeding regime for laboratory-reared Dungeness crab larvae, and second to design a physical system that will successfully keep the animals in a suitable environment until they have completed their larval development. These are the two basic requirements which must be met if crab hatchery technology is to develop.

During the '75-76 crab season, the program tested some six species of phytoplankton, brine shrimp larvae and sea urchin larvae in all possible combinations at several densities as food for the developing larvae.

As favorable trends began to appear in the feeding experiments, some of the emphasis was shifted to the development of culturing systems. Attempts to modify the Hughes lobster culture container were made but proved generally unsuccessful. Experiments in previous years had shown that large aerated tanks such as used in shrimp culture were also unsuccessful.

After long observations of the behavior of the crab larvae and careful consideration of the conditions surrounding them in nature, a rearing system was designed. (*See* Figure)

The rearing system consists of a long, narrow column of water that overflows through a port near the top; the overflow is airlifted up to a higher tube which connects to inflow ports at the bottom of the column. The animals are contained in the mid-portion of the column by an upper and lower screen. The flow creates a slow upwelling current which stimulates the animals to maintain a constant swimming activity. During any non-swimming periods, the animals sink very slowly, and if they do contact the bottom, they are still surrounded by well-aerated gently flowing water.

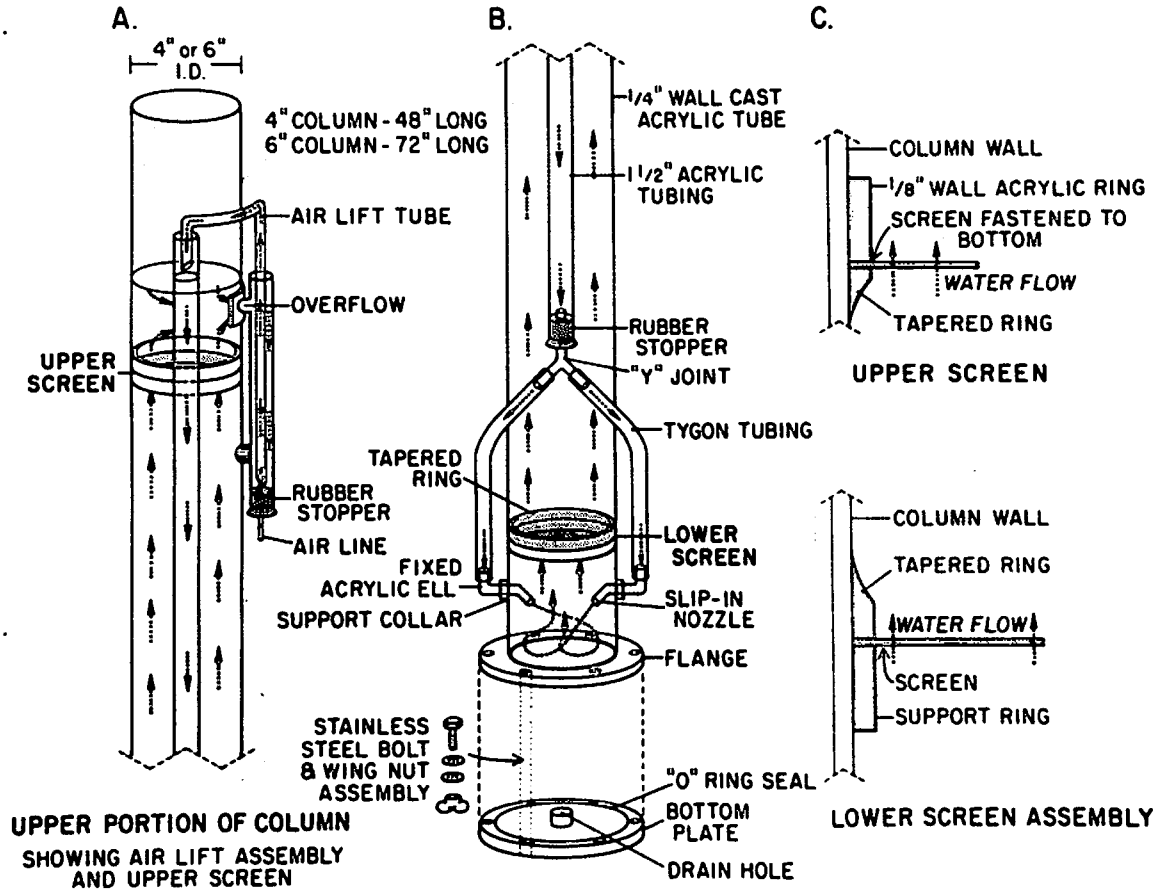
The initial trial of such a system resulted in 65 per cent survival through the fifth stage of 400 crab larvae mass reared in a 4 ft x 4 in column. The animals were fed a combination of planktonic diatoms and *Artemia* nauplii. Similar results were obtained with 200 animals in an identical column.

Nutrition

The long-range goal of the nutritional studies being carried out by the Aquaculture Program at BML is the development of economical rations for crustacean aquaculture. Diets presently available for crustacean cultivation are simply recipes for combining natural foods, by-products, vitamin mixtures, etc. These recipe feeds are unsuitable for intensive commercial aquaculture owing to their relative high cost and lack of reproducibility. It is the present task of the nutrition group to define basic nutritional parameters of the lobster, *Homarus americanus*, so that commercial diets for this animal can be rationally formulated.

Much of our effort this last year has been concerned with defining food consumption by the lobster under different environmental conditions. We have developed a fairly clear picture of the effect of various culturing conditions on lobster food consumption using the brine shrimp control diet. This work will serve as a guideline to evaluate lobster food consumption on artificial diets.

UPWELLING COLUMN FOR CULTURE OF PELAGIC LARVAL CRUSTACEANS



Previous inability to differentiate between qualitative and quantitative growth responses to a particular diet has been pinpointed as the major hindrance limiting further diet work with crustaceans.

Along with this work, we have continued the evaluation of specific diet ingredients. Although live brine shrimp is an established control diet for lobster nutrition studies, alternative forms of this brine shrimp diet—frozen, freeze-dried, and pelletized—have not proved successful when used as a complete diet. Other crustacean meals such as shrimp meal have been useful in supplementing formulated diets, but we have not been successful in ascertaining the reason. We have established that this effect is not due to chitin, which is the main constituent of shrimp meal. Some progress has been made in improving the vitamin mixes used in our formulations. As a general summary, formulated diets appear to give only 75 per cent of the growth of live foods in the case of the lobster. These formulated diets do, however, provide the base from which commercial diets will be ultimately developed.

Microbiology/pathology

Rearing of lobster eggs, larvae, juvenile and adults requires careful monitoring of water quality, both biological and physico-chemical. One of the earliest indicators of conditions less than ideal is an increasing bacterial count. The pathology group continues to monitor all systems for bacterial levels and to inform aquaculturists about the water quality.

Several specific diseases are now recognized by simple routine diagnostic procedures. Etiological agents have been isolated and their identity established. Other agents have been isolated but specificity remains to be established. Prophylactic and therapeutic measures have been found for at least two of the diseases.

A clear relationship has been established between nutritional stress and a disease of the animals. Early diagnosis of poor diets appears certain with gross and histological

observations of the hepatopancreas of the juveniles. Special systems have been constructed for bioassays of larval lobster under sterile conditions to test infectivity of pathogens and effectiveness of treatments for diseased animals.

Experiments have been conducted to determine the ammonia load caused by using live brine shrimp as food for lobster larvae and juveniles.

Water-quality seawater chemistry

In order to carry out research and obtain repeatable results which may be of significance, major water quality parameters must be closely and carefully monitored. The four micro-nutrients, $NH_3 + NH_4^+$, NO_2^-, NO_3^-, as well as $PO_4^{\prime\prime\prime}$, along with carbon, are essential building blocks of the primary trophic levels of the food chain and are, therefore, of importance to aquaculturists in general. Ammonia, which partially ionizes to the less toxic form of NH_4^+ in seawater along with NO_2^- can quickly build up to toxic concentrations under intensive culture conditions. High bacterial populations are also associated with increased nutrient levels. Because of our capacity to analyze a great number of samples, we have been able to take appropriate action when necessary to maintain water purity in all of our systems.

Under new state and federal water quality regulations, the Bodega Marine Laboratory must start a comprehensive water monitoring program to help ensure that the nearby marine environment is not polluted by our discharges. We have been working with the state to set up a water monitoring program according to their guidelines. Because of the high cost of fertilizers and the obvious potential nutrient resource which our aquaculture facilities offer, we are currently working with plant physiologists from UC-Davis who wish to use this untapped resource, wherein waste effluent would be used to water and fertilize salt-resistant strains of food plants they are growing (see the separate section on page 49 of this Report dealing with salt-tolerant plants).

In addition to maintaining the monitoring program, our group has actively participated in research being carried out by the Larval Biology, Nutrition, Broodstock Development (Genetics), and Microbiology Research Groups. Other research has included determining the most reliable method of physically and chemically preserving seawater samples for later analysis of micro-nutrients.

Broodstock development

Our efforts have been directed along two pathways toward the domestication of lobsters and other crustacean candidates for aquaculture. The first is the attempt to bring the reproductive process under control, without which successful culture cannot occur. Toward this end we have begun experiments exploring the use of temperature and photoperiod manipulation to ensure and accelerate the processes of successful egg development, maturation and extrusion upon which both commercial development and genetic improvement depend.

The second pathway involves assessing the genetic potential for domestication to establish the kind of breeding programs that will produce the most rapid results without depleting the available gene pool prematurely. To this end, our growth studies have shown up to 30 per cent heritable variation in American lobster populations, and our biochemical studies of protein variation have pointed up hybridization of American and European lobsters as an important and currently realizable technique. Finally, our biochemical studies in temperate and tropical crustacea are leading to significant generalizations about economically important questions.

Publications

Conklin, D.E., Nutritional studies of lobsters (*Homarus americanus*), Proceedings of the First International Conference on Aquaculture Nutrition, Lewes/Reheboth, Delaware, October 1975.

Idem, Can we afford aquaculture? *The Professional Nutritionist*, Summer 1976, pp. 3-7. A professional service publication of Foremost Foods Company.

Fisher, W.S., E.H. Nilson, L.F. Follet and R.A. Shleser, Hatching and rearing lobster larvae (*Homarus americanus*) in a disease situation, *Aquaculture*, 7(1). 75-80(1976).

Fisher, W.S., E.H. Nilson and R.A. Shleser, Effect of the fungus *Haliphthoros milfordensis* on the juvenile stages of the American lobster, *Homarus americanus*, *Journal of Invertebrate Pathology*, 26, 41-45 (1975).

Idem, Diagnostic procedures for diseases found in egg, larvae, and juvenile cultured American lobsters, Proceedings of the Sixth World Mariculture Society Meeting, 1975, pp. 323-333.

Fisher, W.S., T.R. Rosemark and R.A. Shleser, Toxicity of malachite green to cultured American lobster larvae, *Aquaculture*, 8(2). 151-156(1976).

Fisher, W.S., and D.E. Wickham, Mortalities and epibiotic fouling of eggs of the Dungeness crab (*Cancer magister*), *Fishery Bulletin*, 74(1), 201-207 (1976).

Hedgecock, D., R.A. Shleser and K. Nelson, Applications of biochemical genetics to aquaculture, *J. Fish. Res. Bd. Canada*, 33, 1108-1119 (1976).

Nilson, E.H., W.S. Fisher and R.A. Shleser, Filamentous infestations observed on eggs and larvae of cultured crustaceans, Proceedings of the Sixth World Mariculture Society Meeting, 1975, pp. 367-375.

Idem, A new mycosis of larval lobster (*Homarus americanus*), *Journal of Invertebrate Pathology*, 27, 177-183(1976).

Schuur, A., W.S. Fisher, J.C. Van Olst, J. Carlberg, J.T. Hughes, R.A. Shleser and R.F. Ford, Hatchery methods for the production of *Homarus americanus* juveniles. University of California Sea Grant Publication No. 48 (1976).

Tracey, M.L., K. Nelson, D. Hedgecock, R.A. Shleser and M.L. Pressick, Biochemical genetics of lobsters (*Homarus*). I: Genetic variation and the structure of American lobster populations, *J. Fish. Res. Bd. Canada*, 32, 2091-2101 (1975).

Papers in Press

Fisher, W.S., 1976. Laboratory studies on the relationships of epibiotic fouling and mortalities of the eggs of the Dungeness crab (*Cancer magister*), *J. Fish. Res. Bd. Canada*.

Fisher, W.S., T.R. Rosemark and E.H. Nilson, 1976. The susceptibility of cultured American lobsters to a chitinolytic bacterium, Proceedings of the Seventh Annual Workshop, World Mariculture Society Meeting.

Fisher, W.S., and D.E. Wickham, 1977, Egg mortalities in wild populations of the Dungeness crab in central and northern California, *Fishery Bulletin*.

Gallagher, M.L., D.E. Conklin and W.D. Brown, 1976, The effects of pelletized protein diets on growth, molting and survival of juvenile lobsters, Proceedings of the Seventh Annual Workshop World Mariculture Society.

Hedgecock, D., K. Nelson and R.A. Shleser, 1976, Growth differences among families of the lobster, *Homarus americanus*, Proceedings of the World Mariculture Society.

Hedgecock, D., K. Nelson, J. Simons and R.A. Shleser, 1977, Genic similarity of American and European species of the lobster *Homarus*. Submitted to *Biol. Bull.*

Nelson, K., and D. Hedgecock, 1977, Electrophoretic evidence of multiple paternity in the lobster *Homarus americanus* (Milne-Edwards), *American Naturalist*.

Cooperating Organizations

California Department of Fish and Game, Granite Canyon Lab., California

Department of Land, Air, and Water Resources, University of California, Davis, California

Department of Soils and Plant Nutrition, University of California, Davis, California

Fisheries Research Board of Canada, Nanaimo, British Columbia, Canada

Foremost Research Center, Division of Foremost Foods, Dublin, California

Humboldt State University, Arcata, California

National Marine Fisheries Service, Auke Bay, Alaska

San Diego State University, San Diego, California

San Francisco Bay Brand Brine Shrimp Company, San Francisco, California

State of California Regional Water Quality Control Board, Sacramento, California

Use of Thermal Effluent in Aquaculture

Richard F. Ford and Jon C. Van Olst

The major objectives of this research program are to develop a commercially feasible production system for the American lobster, *Homarus americanus*, and to assess the benefits and problems involved in using thermal effluent as an economical source of heat in this system. During the past year excellent progress has been made toward both of these objectives. It appears that by 1978 a decision can be made regarding the usefulness of initiating a pilot-scale lobster production facility.

The effect of elevated temperatures in accelerating the growth rates of many aquatic organisms is well documented. In aquaculture, increased growth rates can result in decreased total production costs. Low-cost sources of warm seawater for use in mariculture include the naturally occurring warm areas of the tropics, geothermal brine wells, solar energy devices to heat seawater indirectly, and thermal effluent from power plants. Research at San Diego State University has focused on this latter heat source in the culture of the American lobster, *Homarus americanus*.

The research is being conducted at two power plant laboratories, the Encina Power Plant of the San Diego Gas & Electric Company, and the Redondo Beach Generating Station of the Southern California Edison Company. Other related experiments are conducted in the SDSU aquaculture laboratory at the Scripps Institution of Oceanography.

Water quality

One major aspect of our work this past year has been to conduct comparative water quality analyses, lobster tissue analyses, acute toxicity studies, and rearing experiments to assess the benefits and problems in using thermal effluent to culture the American lobster from the egg to market size. Atomic absorption analysis of intake and effluent water samples from three fossil-fuel generating stations indicated that the condenser cooling systems apparently did not affect the concentrations of Cu, Zn, Cd, Co, Cr, Pb, and As in the thermal effluent. The concentrations of these heavy metals in all tissues were well below Food and Drug Adminstration (FDA) limits for these metals in foodstuffs. Lethal limits for these seven metals, as determined by bioassay experiments, were all at least an order of magnitude higher than levels of the chemicals encountered in the generating station effluents. Growth and survival of larval and juvenile lobsters maintained in long-term rearing experiments at constant temperatures were not significantly different in effluent, intake, and Scripps water sources.

More detailed descriptions of results are provided in several recent papers (Dorband, 1975; Ford *et al.*, 1976; Dorband *et al.*, 1976). All of these studies indicate that the thermal effluent from typical fossil fuel generating stations in southern California provides a suitable heated water source for the culture of American lobsters. While these results are encouraging, we are continuing to evaluate related aspects of the water quality problem and to establish specific water quality criteria for lobster aquaculture.

One aspect of this water quality research involves measurement of the chlorinated hydrocarbon compounds, such as DDT, and PCB's, which may be present in seawater at levels high enough to accumulate in lobster tissues and make the animals unsuitable for human consumption. Certain of these chemicals, such as vinyl chlorides and plasticizers, may be introduced into the seawater as they are leached from components used in the culture systems, rather than from the thermal effluent of the power plant.

Samples of seawater from SIO, and intake and discharge water from the power station sites were surveyed for chlorinated hydrocarbons. Preliminary results indicate that several compounds were present in the seawater, but at levels low enough not to impair growth and survival of the animals. Some of the compounds found in the seawater were the pesticides DDT, Lindane and Dieldrin, and the plasticizer Arochlor 1254. In no case did it appear that the power plants were influencing the levels of contaminants in the water, since measurements of intake and discharge water were essentially identical. We have also made preliminary measurements of the levels of hydrocarbons that have accumulated in the edible tissue of lobsters cultured for approximately two years at our SIO laboratory (Fig. 1). In this sample pesticides and plasticizers were also found, but at very low levels. These results are encouraging. In future research we will establish acute lethal

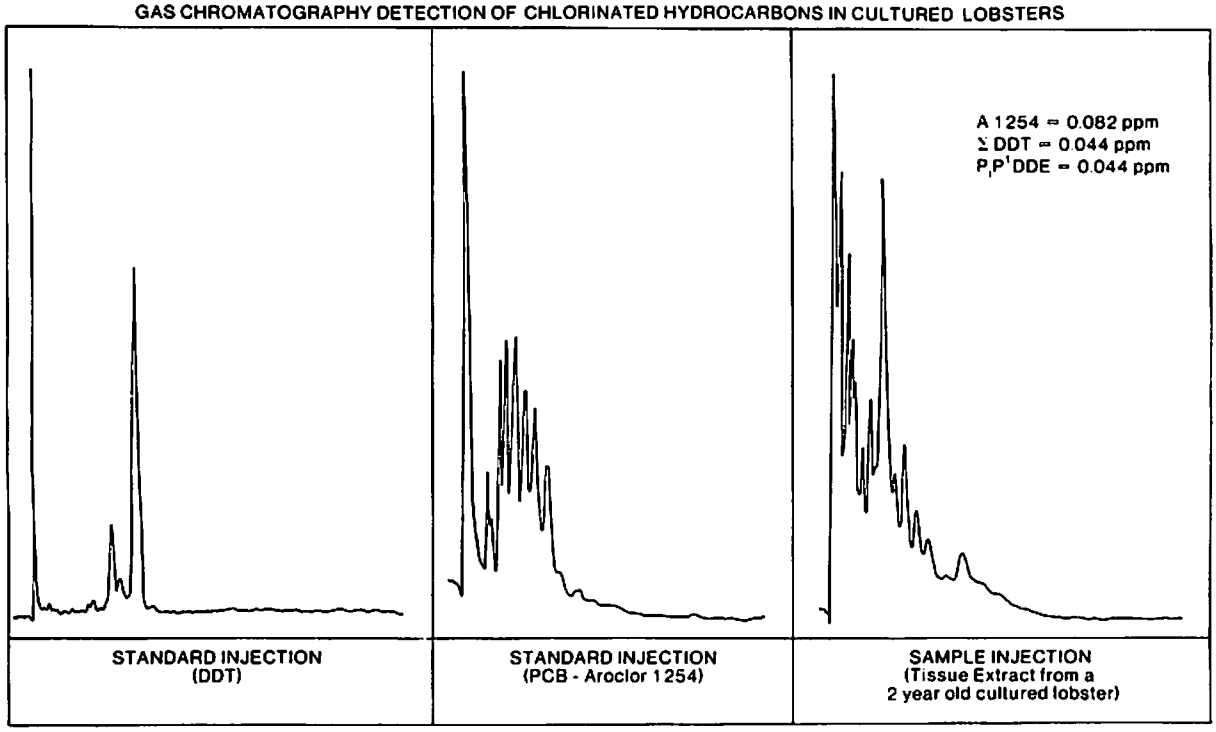


Fig. 1. Gas chromatography curves used to identify chlorinated hydrocarbon compounds found in the tissues of cultured lobsters

limits (LD_{50}'s) and chronic effects for artificially induced levels of those chlorinated hydrocarbons that are found to be present in potentially toxic concentrations. These will include DDT, Arochlor 1254, and vinyl chloride. It is necessary to know what levels of these pollutants would be limiting to growth, survivorship, and acceptability as food.

A second major area of water quality research involves toxicants which are produced by the cultured animals themselves. Ammonia is the primary excretory product of lobsters and is known to be highly toxic to *H. americanus*. Because of this, specific knowledge of tolerances to this compound is essential for proper design of semiclosed culture systems used in rearing species at high densities.

In a series of preliminary experiments, threshold concentration and incipient 50 per cent lethal concentration (LC_{50}) were determined using larval lobsters as the experimental subjects (Fig. 2). Toxicity appeared to be related to the un-ionized NH_3 fraction. This fraction is dependent upon the effects of pH, temperature, and salinity on the NH_3/NH_4^+ equilibrium. Increasing pH caused markedly higher mortalities. Evidence concerning possible effects of both temperature and salinity on ammonia toxicity was less clear (Delistraty *et al.* 1976).

A simplified steady-state model is being developed for predicting optimum carrying capacity of culture systems for juvenile and adult lobsters, as a function of degree of water reuse, ammonia removal efficiency, water flow rate, ammonia excretion rate, and ammonia concentration of the ambient

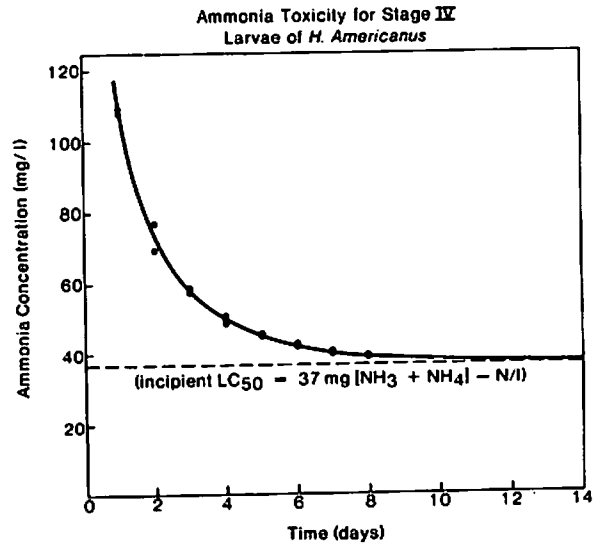


Fig. 2. Graph illustrates the concentrations of ammonia which result in 50 per cent mortality of larval lobsters after exposure to this toxicant for varying lengths of time

source intake water. From these data, a "safe" ammonia tolerance level will be developed.

Effects of elevated temperature

Our previous research has established that the American lobster grows fastest at 21-22°C, all other conditions being equal. We have also demonstrated thermal effluent to be an inexpensive source of warmed seawater for culturing lobsters and other species with high physiological temperature tolerances in temperate geographical zones. As a logical and important extension of this work, experiments are now in progress to assess the influence of fluctuating temperatures on growth and survival.

Constant temperatures are rarely encountered in either the natural or aquaculture environments. We have observed that sudden temperature changes will often induce molting. Lobsters were subjected to several different temperature extremes for varying lengths of time. Some influence of cold temperature shock on inducing molting was evident and proved not detrimental until the thermal limits were approached. It has been suggested that a cold period promotes the physiological events leading to molting, and therefore may result in increased growth rates. Cyclic temperature regimes may be useful in the staging and synchrony of molting. Subjecting juveniles in communal rearing systems to a periodic cold treatment might reduce cannibalism significantly if most animals were in soft post-molt condition simultaneously.

Reproduction and hybridization

In the past, lobster researchers have depended upon a source of egg bearing females captured from the wild. However, in recent years many advancements have been made in the development of techniques for successful year-round reproduction in captivity. This past year we performed 38 controlled matings. Homarid lobsters are generally quite promiscuous and mate immediately following molting of the female. Extrusion of eggs occurred in three to four months when development was accelerated at elevated temperatures of 22°C. In some cases hatching occurred within four months after extrusion, and a second reproductive cycle was initiated after only two months had elapsed. Unfortunately, most females expelled their eggs prematurely and the abortifacient cause is currently being investigated.

We have successfully crossed the American lobster, *H. americanus*, with a closely related European species, *H. gammarus*. Egg development and accurate prediction of hatching were accomplished. Following successful hatching of the hybrid larvae last spring, comparative growth experiments were initiated. Previous comparisons revealed that both species have nearly identical rates of growth. Preliminary results after seven months of growth indicate that the hybrid progeny exhibit growth rates similar to the parent stock.

Development of artificial diets

Several experimental shrimp diets were shown to be nutritionally deficient or imbalanced for lobsters. These rations, when supplemented with pelagic red crab, produced growth rates similar to those achieved for lobsters fed frozen brine shrimp. Ingredient analysis has shown that pelagic red crab has a broad amino acid spectrum, and is high in lipid content and essential carotenoids. In recent feeding trials it was determined that a 10-20 per cent addition of crab meal was sufficient to accomplish this accelerated growth. This level is nearly identical to the concentration determined by fish nutritionists to be necessary for salmonids. These results further demonstrate the value of pelagic red crab meal as aquaculture feed ingredient. The supplemented feed can now be used as a temporary maintenance diet which is less expensive to produce and more conveniently stored and delivered to individual rearing compartments. However, while this diet is superior to other manufactured feeds tested, it is still nutritionally deficient as compared with a live brine shrimp control diet.

Current nutrition research is designed to assess the interaction of the five major dietary components: proteins, saturated and unsaturated fatty acids, vitamins, and carotenoid precursors. This is a cooperative research project by three groups within the UC Sea Grant Program involving diet formulation at the Bodega Marine Laboratory, analysis at Foremost Research Center, and evaluation at the SDSU aquaculture laboratory.

Communal rearing of juvenile lobsters

Communal rearing may have potential for the production of early juvenile stages, since these systems are less complex and are less expensive to operate than individual rearing

systems. However, several experiments have resulted in low survival and yielded individuals of non-uniform size. For example, during six months of communal rearing, dominant individuals achieved a carapace length as large as 44 mm, while their subordinates grew from the same initial size of 5 mm to only 10 mm in length (Fig. 3).

We have identified the major factors controlling the establishment of dominance orders and the degree to which these factors influence cannibalism. Experiments recently completed to optimize environmental culture

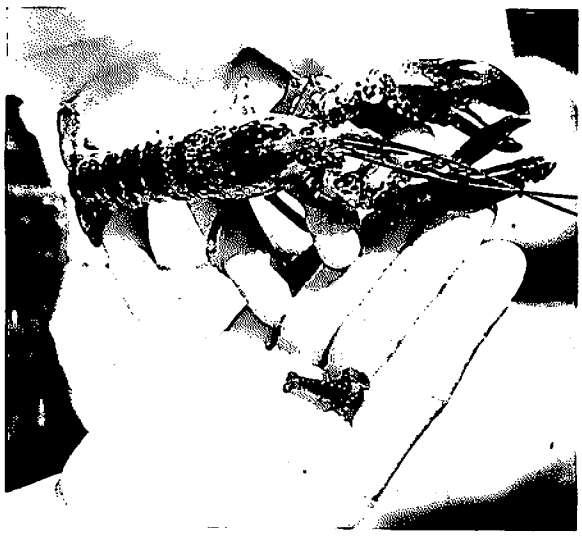


Fig. 3. Sibling lobsters showing the extreme variability in size which may be encountered when lobsters are reared communally. After 6 months the larger animal grew to a carapace length of 44 mm, while the smaller individual grew from the same initial carapace length of 5 mm to only 10 mm in the same period

conditions further, indicate that three-dimensional use of the water column incorporating vertical substrates may be essential in an economical communal rearing program.

Other results show that a stocking density of 100 individuals per square meter will yield juveniles of 20 mm carapace length with 40 per cent survival after six months of culture. Attempts to determine the influence of photoperiod on the nocturnal feeding patterns described in earlier reports indicate that constant dark produces lower survival in communal rearing systems, and that a light cycle between 18 and 24 hours is optimal.

Culture system development

The high rates of cannibalism which have been documented for *H. americanus* reared communally dictate that for most of the culture period the lobsters should be reared individually, in order to eliminate these losses. Several production systems for intensive individual culture have been designed. Working models of three culture systems showing considerable potential were constructed and their performance characteristics are being compared. One system consists of a fiberglass tray from which the water is flushed periodically to remove wastes from lobster holding cells constructed of perforated plastic. A prototype of this unit with rearing compartments to hold 1000 lobsters individually has been constructed (Fig. 4), and dye studies of its flow and flushing characteristics have been completed. The rapid flow resulting from periodic flushing has a scouring effect on the bottom screening and on the bottom of the tray, so that the entire system is almost completely self-cleaning. The flushing tray appears to be outstanding in its ability to hold a large number of animals in a minimal amount of space, deliver oxygenated seawater evenly to each compartment, and remove wastes rapidly and economically. A cooperative effort with the University of Colorado's Department of Architecture is under way to design a full-scale version of this system (Fig. 5).

The space requirements for lobsters under intensive culture conditions represent an important economic consideration in growing the juveniles to market size. We are conducting long-term experiments to determine the minimum space required for rapid growth of lobsters of different life stages in

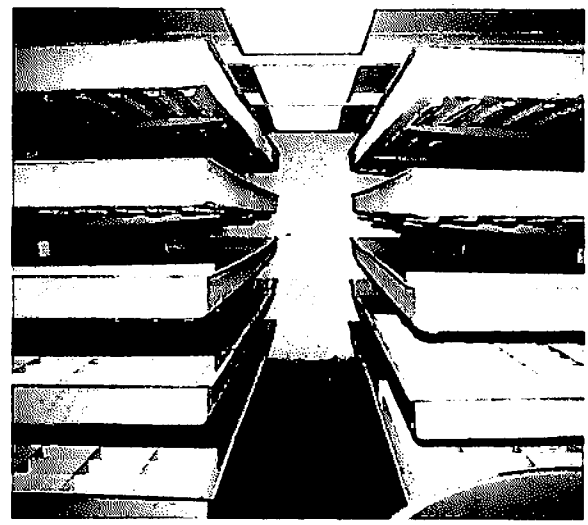


Fig. 4. Prototype of cantilevered flushing tray system, with compartments to hold 1000 lobsters individually. Each tray measures 1.2 x 4.9 cm

individual rectangular compartments. Results after one year of culture suggest that for optimum growth the container width should be greater than the total body length of the lobster. It is possible that some

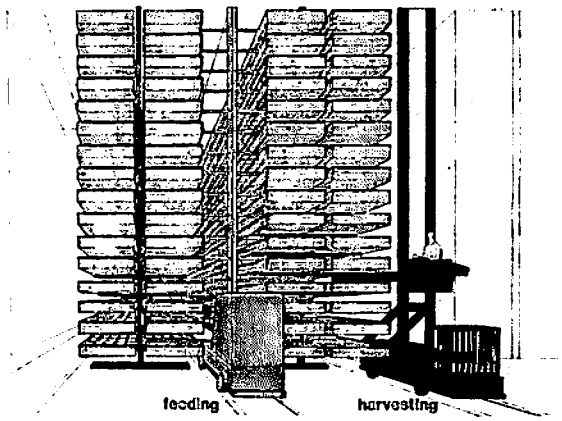


Fig. 5. Artist's conception of full-scale version of the cantilevered tray system, incorporating semi-automated machinery for feeding and harvesting

reduction in growth rate may be tolerable if sufficient savings are realized in the costs of constructing the smaller facility which would be required if smaller culture containers were employed. This concept is being evaluated.

Economics

We have designed and conducted our research program in close cooperation with the cost modeling group at University of California, Davis. The results of the confinement, ammonia tolerance, and communal rearing experiments are being prepared for incorporation into the model. In addition, progress has been made toward the development of a return-on-investment (ROI) analysis, which will be of more direct use to the emerging aquaculture industry.

More information has been obtained to indicate that the use of thermal effluent in aquaculture should result in a significant reduction of production cost. Figure 6 illustrates the potential savings in costs if thermal effluent were used as a cost-free source of heat. In areas where ambient seawater temperatures are about 12°C, production costs are decreased by more than 56 per cent. These computations stress the potential benefits to be derived from the use of thermal effluent in aquaculture.

Cooperative programs

A cooperative program with the Research and Development Program of the Southern California Edison Company (SCE) has been under way for the past three years. SCE has been so much encouraged by the results that the company has agreed to fund the development of a major new aquaculture research site for SDSU at its Ormond Beach Generating Station south of Oxnard, California. This plant is located in a more rural, agricultural area than our current thermal

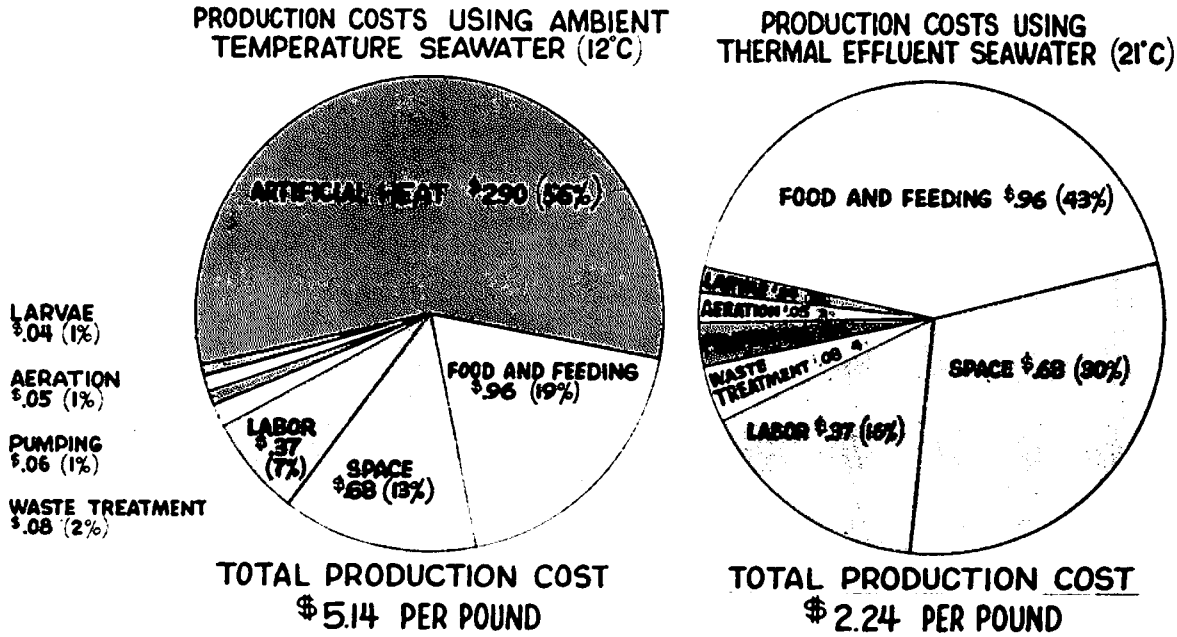


Fig. 6. Estimated lobster production costs with and without the use of thermal effluent as a source of heat (Data from W. Johnston, UCD.)

effects research sites. It has over 100 acres of adjacent land which could be developed for commercial aquaculture, when and if our research indicates commercial feasibility. Several species in addition to lobsters will be studied at this site.

Publications

Carlberg, J.M., and J.C. Van Olst, 1976. Brine shrimp (*Artemia salina*) consumption by the larval stages of the American lobster (*Homarus americanus*) in relation to food density and water temperature. Proceedings of World Mariculture Society's Seventh Annual Meeting, in press.

Carlberg, J.M. 1976. Presentation on use of thermal effluent in aquaculture during Waste Heat Recycling Session of UN/FAO Technical Conference on Aquaculture in Kyoto, Japan.

Delistraty, D.A., J.M. Carlberg, J.C. Van Olst, and R.F. Ford. 1977. Ammonia toxicity in cultured larvae of the American lobster, *Homarus americanus*. Proceedings of World Mariculture Society's Seventh Annual Meeting, in press.

Dorband, W.R., J.C. Van Olst, J.M. Carlberg, and R.F. Ford, 1976. Effects of chemicals in thermal effluent on *Homarus americanus* maintained in aquaculture systems. Proceedings of World Mariculture Society's Seventh Annual Meeting, in press.

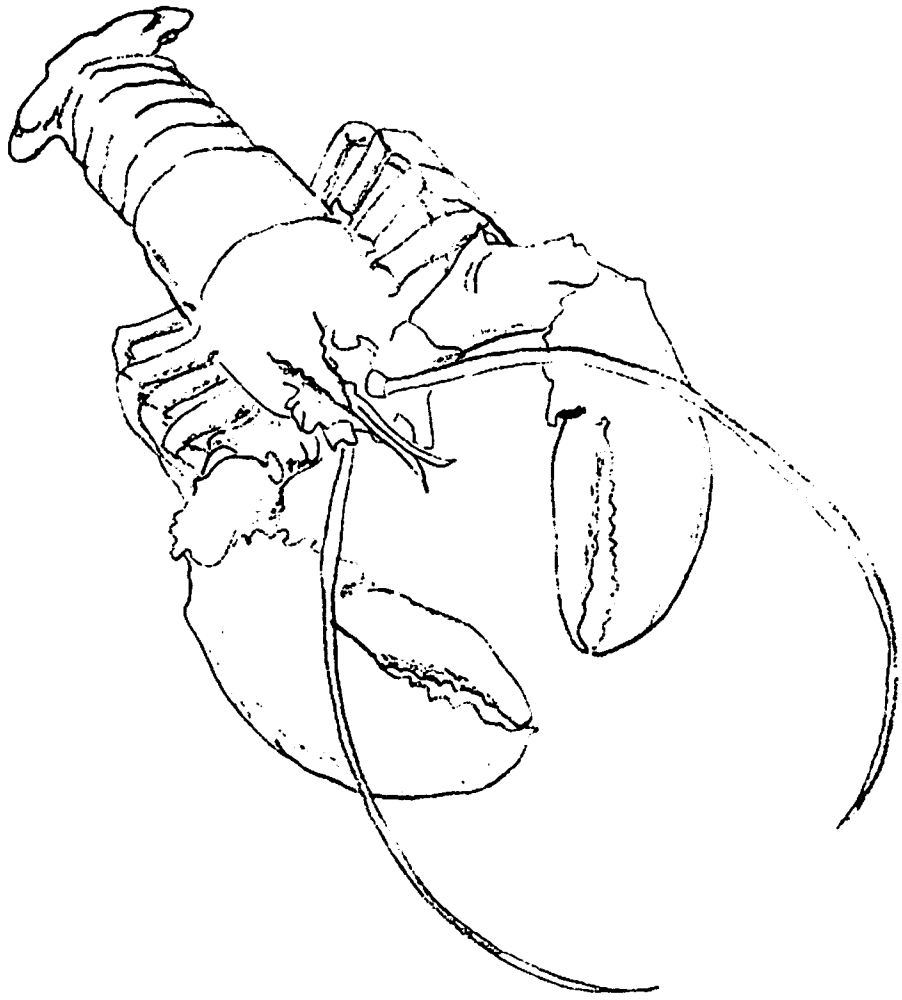
Ford, R.F., J.C. Van Olst, J.M. Carlberg, W.R. Dorband, and R.L. Johnson. 1976. Beneficial use of thermal effluent in lobster culture. Proceedings of World Mariculture Society's Sixth Annual Meeting, pp. 509-515.

Schuur, A., W.S. Fisher, J.C. Van Olst, J.M. Carlberg, J.T. Hughes, R.A. Shleser and R.F. Ford, 1976. Hatchery methods for the production of juvenile lobsters (*Homarus americanus*). University of California Sea Grant Publication #48, Institute of Marine Resources IMR Reference 76-6.

Van Olst, J.C., R.F. Ford, J.M. Carlberg, and W.R. Dorband. 1975. Use of thermal effluent in culturing the American lobster. Power Plant Waste Heat Utilization in Aquaculture-Workshop 1. Published by PSE&G Co. Newark, N.J. pp. 71-100.

Van Olst, J.C., Beneficial use of thermal effluent in aquaculture. Annual Report to Southern California Edison Company, 1975. 277 pp.

Van Olst, J.C., J.M. Carlberg, and R.F. Ford, 1976. Effects of substrate type and other factors on the growth, survival, and cannibalism of juvenile *Homarus americanus* in mass rearing systems. Proceedings of World Mariculture Society's Sixth Annual Meeting, pp. 261-274.



Economics of Aquaculture

W. E. Johnston

A computerized budgeting model for lobster production provides a framework for viewing the technical problems of least-cost production and is useful in determining research priorities in lobster aquaculture. Its degree of generality has been demonstrated by a modification to investigate the same kind of problem in a different species under a different system.

The principal activity in this project during its existence from 1972 to 1976 has been the modeling of an aquaculture system. There were two objectives: an assessment of the economic feasibility of a given technology, and the giving of guidance in the setting of research priorities. The species investigated was the American lobster, *Homarus americanus*. Continued cooperation and support from the Bodega aquaculture group (Sea Grant Project R/FA-4) and California State University at San Diego researchers (Sea Grant Project R/FA-17) were instrumental in the success of this project. Other activity in the project was of broader scope and consisted of preliminary investigations of the demand side and marketing aspects for aquaculture products. These would form the starting point for a follow-up project.

After project initiation, our research effort attacked two problem areas. First, an annotated bibliography of previous economic analyses of selected crustaceans and molluscs was prepared and is available as a Sea Grant publication. Second, model formulation was begun with the drawing of a detailed flow chart for the closed system culture of *Homarus americanus*. This could be regarded as the first model produced by the project. Its main purpose was to facilitate communication between economists, engineers and biologists. An attempt at quantification in a form suitable for computer analysis was also made at this time with a simulation model written DYNAMO. Because of severe data limitations this initial attempt was largely unsuccessful.

The initial modeling effort was followed by an extended period of model development. Computer programs were written in a general purpose language (ALGOL). Converting an engineering flow diagram into a computer program necessitated several substantial restructurings of the program, although the framework at the most aggregate level was maintained. Thus the procedure has always been to compute first biological relations, subsequently physical requirements, and finally costs.

A unique aspect of the computer program is its interactive nature. All assumptions that enter the model are explicitly stated. Parameters and exogenous variable values can be freely altered by the user, thus enabling a person unfamiliar with computer programming to observe immediately the impact of varying the values of different assumptions on final cost. This facility was first demonstrated at a workshop on the American lobster held at Bodega Bay in April 1974 and has been available to University of California researchers ever since. A description of the model and its philosophy was presented to economists in August 1974. Further developments illustrating the ease with which different systems and techniques could be assessed, were given in December 1974.

The model as a guide to research

The underlying philosophy of the modeling exercise has always been integrative. That is, an operating model was created with the assistance of biologists and engineers at the earliest stage possible. Many biological relationships were poorly understood and physical requirements were uncertain. Having a model available early in the life of the project meant that the model itself could be used as a tool to guide research, as the areas of ignorance and relative importance of each were glaringly revealed.

Since the project was also a learning process, model rebuilding was not always performed in the most efficient way. As research progressed, enough was learned to suggest the need for not just a complete documentation of the model but also for the presentation of the philosophy of the modeling exercise and problems encountered. This work, which is being organized in book form collaboratively with Mr. Louis W. Botsford and Mr. Anthonie M. Schuur, is substantially complete but will require some additional effort after project termination. A private publisher is currently interested in acquiring the manuscript.

Other activities that have been completed include an annotated bibliography of recent papers with empirical estimates of demand relationships for fish and shellfish and related studies. It is awaiting publication. A

major effort in the past year has been to describe and show the operation of the latest model development. The table shows part of the output. Cost of production estimates have fluctuated over time. It should be emphasized that the particular values depend on the assumptions employed and hence need care in interpretation. These cautions are fully discussed in a forthcoming paper in *Aquaculture*.

Scope of the modeling approach

There appears to be considerable interest within the aquaculture research community and in industry over the potential of the modeling approach adopted here. Our opinions of the generality and generalizability of the model have broadened over time. The model is specific to *Homarus americanus*, and a range of intensive culture systems can be studied by altering a few assumptions. The framework of the model is generalizable to many other species and systems. As an example, a modification to investigate an integrated clam culture and phytoplankton production plant in St. Croix, Virgin Islands, has already been undertaken. Examination of the fresh water prawn (*Macrobrachium* spp.) has been suggested and would appear to require minimum modification of the lobster model.

Future research should consider three main problem areas. One is the above mentioned modification to explore costs of production of other species. Second is to model directly the level of uncertainty present in empirical, and particularly subjective, estimates. The cost of each component of production then carries with it a measure of its reliability. Third, modeling should accommodate the control theory concepts of altering settings of control variables through time to optimize the objective function (minimizing cost of production in this case). The ability to display performance of the system through simulation should, however, be retained.

BASE-LINE MODEL OUTCOMES, LOBSTER BUDGET MODEL WITH 500 GRAM/ANIMAL TARGET WEIGHT

Cost Summary ($ per unit output):	
Space	$0.75
Heat	3.19
Pumping	0.07
Waste treatment	0.09
Aeration	0.05
Food	1.02
Feeding labor and equipment	0.03
Other labor	0.41
Larvae	0.04
TOTAL COST	$5.65
Other Information (from printout summary):	
Months to output	30.0
Plant output (thousands/month)	80.0
Harvest weight (grams/animal)	502.6
Total capital ($100,000)	31.05
Culture capital	(25.22)
Waste treatment capital	(5.83)
Tank area (1000 m^2)	98.95
Water reuse (% recirculation)	0.00
Intake flow (million liters/day)	43.45
Land area for production facility (hectares)[a]	2.75
Conversion ratio	3.30

[a] Does not include land area for waste treatment facility.

Publications

Allen, P.G., and W.E. Johnston, Research direction and economic feasibility: An example of systems analysis in lobster aquaculture. Forthcoming in *Aquaculture*.

Allen, P.G., A.M. Schuur, L.W. Botsford, and W.E. Johnston, The bioeconomics of aquaculture. Monograph in process. Winter 1976.

Johnston, W.E., and P.G. Allen, Technology assessment and the computerization of future research: Use of computerized budgeting for lobster aquaculture. Paper presented to American Agricultural Economics Association, College Station, Texas, August, 1974.

Johnston, W.E., and D.W. Collinsworth, An annotated bibliography for economic evaluations of the aquaculture of selected crustaceans and molluscs. UC-IMR Reference No. 74-3, Sea Grant Publication No. 2, U.C. Institute of Marine Resources, La Jolla, August, 1973.

Schuur, A.M., P.G. Allen, and L.W. Botsford, An analysis of three facilities for the commercial production of *Homarus americanus*. Paper presented to American Society of Agricultural Engineers, Chicago, Illinois, December, 1974.

Wetzstein, M.E., H.F. Carman, W.E. Johnston, and J.G. Youde, An annotated bibliography of empirical demand studies for fish and shellfish with emphasis on calculated elasticities. Submitted as Sea Grant publication, Fall 1975.

Protective Measures for Shellfish Aquaculture

Harriette C. Schapiro and James F. Steenbergen

Immunization procedures for the American lobster have been confirmed and improved. *In vitro* studies of phagocytosis by lobster hemocytes have shown the immune system to be temperature-sensitive. Serological studies of *Leucothrix* isolates have confirmed the identity of this lobster disease agent. The filamentous isolates from shrimp are apparently unrelated to *Leucothrix*. Other infections have also been investigated.

Both shrimp and lobster mariculturists have observed high mortalities, which have been generally attributed to gill infestation by the filamentous bacterium *Leucothrix mucor*. Studies of the immune system of the American lobster were continued during the past year. The immunization procedure was improved and made more efficacious. On the basis of our previous numerical taxonomy study of both virulent and avirulent strains, we selected other avirulent strains of *Aerococcus viridans* for use in our immunological studies. One of these has proved to be a better immunogen than the strains used in our original studies. Repeated vaccinations over a period of time led to higher resistance to gaffkemia than that observed in animals given single injections, and the observed immunity persisted for a longer period of time.

Our *in vitro* system was used in optimizing the vaccination schedule to provide maximum immunity. Hemocytes were taken from immune and non-immune animals over the course of the vaccinations. These were tested for their phagocytic ability against virulent and avirulent strains of *A. viridans*. Virulent strains were much more effectively phagocytosed by hemocytes from immune lobsters than from non-immune controls. The use of the *in vitro* system for this assessment not only allowed the experiments to be performed with fewer experimental animals, but also enabled us to follow the course of development of resistance to gaffkemia in individual lobsters.

All proposed lobster mariculture systems envision the use of elevated temperatures to enhance the growth rate. Our *in vitro* assay of phagocytosis by lobster hemocytes (Schapiro, Steenbergen and Fitzgerald, 1976) offered an ideal system to measure directly the effect of elevated temperature on the immune system and disease resistance. Our results indicate that phagocytosis becomes inefficient at elevated temperatures, with little or no activity at 24°C. Additional studies will further characterize the temperature dependence of the immune response. The results could be used in selection of the optimum temperature for mariculture operations.

We have established an antigenic schema for *A. viridans* in which one of the surface antigens was highly correlated with virulence for the American lobster (Kimball *et al.*, 1975; Steenbergen *et al.*, 1976). This "virulence antigen" has been shown to be a component of the peptidoglycan cell wall, and is not associated with either the capsule or the teichoic acids. We are currently using gas and column chromatography and antibody-Sepharose columns to purify and chemically characterize this antigenic determinant. Once this is accomplished, the isolated antigen can be radioactively labelled and used to distinguish the "immune" hemocytes from the remainder of the population. Our working hypothesis is that the pathogenic strains of *A. viridans* possess a surface component, a polysaccharide, which is similar or identical to one on the surface of the hemocytes, thereby confusing the "self-nonself" distinction by the hemocytes. We propose to test the isolated virulence antigen as an immunizing agent for lobsters.

Culture medium for *Leucothrix*

We have developed a medium for the isolation of *Leucothrix* from crustaceans, and have used it to isolate this fastidious bacterium from juvenile lobsters (Steenbergen and Schapiro, 1976). We have developed a procedure for studying the antigenic structure of *Leucothrix* by a microcomplement fixation technique, since standard agglutination and precipitin techniques are not practical with filamentous organisms. Our results indicate a high degree of common antigenicity among the lobster strains and the type cultures obtained from the American Type Culture Collection. Strains of presumed *Leucothrix* isolated from shrimp from the Gulf of California, on the other hand, do not cross-react with the other sera. Thus we may conclude that our lobster strains are probably *Leucothrix*,

while the shrimp isolates are not, and may, in fact, be blue green algae. These results may be pertinent in selecting appropriate treatments for gill infestations. *Leucothrix*-specific fluorescent sera will be prepared as soon as the antigenic study is completed, and these antisera will then be used for epidemiological studies of gill disease. We have successfully treated two separate outbreaks of *Leucothrix* in juvenile lobsters with neomycin. The best schedule of treatments and optimal concentrations of the antibiotics will be further refined in future experiments.

A number of strains of gram negative bacteria from moribund lobsters have been isolated. These isolates are usually *Vibrio* sp. or *Pseudomonas* sp. When pure cultures of these isolates are injected into healthy American lobsters, they fail to initiate infections. Therefore, we have concluded that the bacteria that we have isolated are secondary invaders that cause septicemia only in stressed animals. They are seen primarily in lobsters soon after being shipped across country or, in some cases, in those which have been held under less than ideal conditions. The infections can be controlled by treatment with tetracycline antibiotics in lobsters not intended for consumption, such as mariculture brood stock. While these diseases do not now represent a threat to lobster mariculture, they could possibly become a problem under commercial conditions in which crowding, to conserve space, and elevated temperatures, to achieve faster growth, are imposed.

A number of tumors and exoskeleton lesions have been observed in our autopsies of moribund lobsters. These miscellaneous infections may be primary or secondary infections, and either kill the animal or produce unsightly lesions which depreciate the market value. We have isolates of bacteria from these lesions and preserved tissues from the tumors. Further study will attempt to determine the etiology in question, thereby allowing us to develop appropriate treatments.

Utilization of results

Autopsies have been routinely performed on animals received from other groups, including the Environmental Research Laboratory at Tucson (shrimp), Aquaculture Enterprises at Monterey (lobsters), Jerry Roberson at Encinitas (*Macrobrachium*), and the Ford/Van Olst group at San Diego State University (trout and lobsters). Our lobster autopsy procedure includes a macroscopic check for gross lesions and a microscopic examination of gill tissue for *Leucothrix, Laginidium*, and other infections. Hemolymph samples are withdrawn from the ventral sinus and plated on a variety of bacteriological media to check for systemic infections. Isolates are identified and added to our stock culture collection, and are tested for pathogenicity for the American lobster.

Publications

Kimball, H.S., J.F. Steenbergen, H.C. Schapiro and L.N. Phelps, Serological grouping of *Pediococcus homari* and *Aerococcus viridans*, *Bacteriol. Proc.*, I-154 (1975).

Schapiro, H.C., J.F. Steenbergen and Z. Fitzgerald, Hemocytes and phagocytosis in the American lobster, *Homarus americanus*, *Comparative Pathobiology*, Vol. 3, in press.

Steenbergen, J.F., H.S. Kimball, D.A. Low, H.C. Schapiro and L.N. Phelps. Serological grouping of virulent and avirulent strains of the lobster pathogen *Aerococcus viridans*, *J. Gen Microbiol.*, in press.

Steenbergen, J.F., and H.C. Schapiro, Filamentous bacterial infestations of lobster and shrimp gills, *Amer. Zoologist*, 15(3), 816 (1976).

Cooperating Organizations

Aquaculture Enterprises, Monterey, California
Environmental Research Laboratory, Tucson, Arizona

Salt-Tolerant Plants: Problems and Potentials

Emanuel Epstein

Large strides have been made in a program of research and development to create crop plants suited to seawater culture. Barley has been grown in this way in a coastal area, and work with tomatoes and wheat along similar lines is progressing well. Success in this project would make the enormous resources of water and mineral nutrients of the sea available for crop production.

This project was started with the aim of using seawater and coastal areas for a novel purpose: the production of edible crops that would be raised with seawater as the source of both water and mineral nutrients. This aim was and is considered to be in line with the Congressional mandate to use marine resources (in this instance, water and nutrients) as a "far-reaching...asset of immense potential significance to the United States" and to tap "new sources of food."

The fundamental biological fact upon which the project is based is the following. Virtually all crop plants are sensitive to salt, but there are many kinds of wild plants, the "halophytes," which grow in very saline environments like the oceans, along the seashores, in salt marshes, deltas, and estuaries, and on saline desert soils. From this it follows that plant life is not necessarily incompatible with salinity, and it may well be possible, we reasoned, to combine within the same plant the economic utility of a crop with the salt tolerance that plant life is evidently capable of possessing.

To achieve the aim decided upon, two lines of endeavor have been pursued in this project: 1) study of the factors that enable salt-tolerant plants to thrive in saline environments fatal to salt-sensitive plants, and 2) development of strains or varieties of crop plants much more salt-tolerant than the existing ones, in the hope of ultimately making it possible to raise crops irrigated with seawater, or cultured in systems of seawater hydroponics.

Characteristics of salt-sensitive and salt-tolerant plants

We have compared the responses of two species of the tomato to saline conditions: *Lycopersicon esculentum*, the ordinary, commercial tomato, not very salt-tolerant, and *Lycopersicon cheesmanii*, a wild species from the Galapagos Islands where it grows just a few yards above high tide. In experiments with salinized nutrient solutions we indeed found the latter species to be quite salt-tolerant; it survived even at a salinity equivalent to that of seawater. (The conventional tomato died at half that salinity.) Commercially, the Galapagos tomato is useless, bearing tomatoes about ¼ inch in diameter. It is, however, so closely related to the conventional, commercial tomato that the two can be readily crossed.

Despite their close genetic relationship, the two responded to saline conditions in contrasting fashion. Solution cultures were salinized progressively, using a salt mix closely approaching the proportions of salts in seawater. At increasing salinities (0 - 0.7 seawater salinity) the salt-tolerant Galapagos tomato absorbed ever larger amounts of sodium, up to nearly 6 per cent sodium on a dry weight basis. The salt-sensitive commercial kind absorbed much less sodium, up to 0.5 seawater salinity. At higher salinity there was an abrupt breakthrough of sodium into the plant (6 per cent sodium on a dry weight basis—as much as the salt-tolerant kind) and the plants died. In this and still other characteristics the two species of the tomato, despite their close relationship, acted like typical salt-tolerant and salt-sensitive plants, respectively. The mechanism of salt toleration in the Galapagos species is being investigated further. A paper on the work accomplished so far has been published.

Development of salt-tolerant crops

We have chosen barley, wheat, and tomatoes as the initial crops to work on for the following reasons. Barley is more salt-tolerant than most crops; it is an important grain; much is known about its mineral nutrition, salt relations, and genetics; and we had available on the Davis campus seed of a "composite cross" representing a reservoir of genetic variability derived from thousands of strains from all over the world. Wheat, while reputedly less salt-tolerant than barley, is the world's premier food grain. Tomatoes can be grown profitably on relatively small areas, so that the engineering problems of seawater irrigation or seawater hydroponics would be

minimal. Also, tomatoes are dicotyledons, so that their inclusion broadens the botanical base of the project, both barley and wheat being monocotyledons (grasses).

Barley. We have made unexpectedly large strides in the development of barley that can be irrigated with seawater, which furnishes not only water but mineral nutrients as well. Strains initially selected in salinized solution cultures on the Davis campus have been field tested at Bodega Marine Laboratory north of San Francisco. The water came from the Pacific Ocean. Our best selections grew, matured and produced grain that is normal by every test we have applied, including the conventional "proximate analysis" (measure of feed quality). While for several reasons no firm estimates of yield were obtained, tentative extrapolations (believed to be conservative) are on the order of half a ton per acre. This we believe to be promising, especially in view of the resources used—sandy dune land most farmers would not even consider, and seawater which, where it intrudes into agricultural water supplies, is considered a serious menace. The success of this feasibility study on seawater culture of a grain crop has aroused world-wide interest. A paper has been prepared for publication.

Tomato. We did not find much genetic variability in salt tolerance among varieties of the commercial tomato, *Lycopersicon esculentum*. None of the varieties had high salt tolerance. We therefore crossed the commercial tomato with a salt-tolerant wild species from the Galapagos Islands, *Lycopersicon cheesmanii* (see "Characteristics of salt-sensitive and salt-tolerant plants," above). Progeny of this cross has been field tested on the experimental site at Bodega Marine Laboratory at salinities up to 4/10 that of seawater. It grew well and produced profusely.

Wheat. Work on wheat is in the early stage of selection for salt tolerance. Seed from the world collection has been planted over nutrient solutions salinized to about 90 per cent seawater salinity. This eliminates the great majority of the entries but at the same time, surprising numbers of the genetic lines have some seeds that germinate and establish seedlings.

To sum up, we believe that we have moved what only a few years ago was considered a rather far-out scheme much closer to the realm of reality: the creation of crops by means of seawater culture. Ultimate success would mean that the vast resources of water and mineral nutrients of the sea could be put to use in crop production on sandy, otherwise unproductive land.

Publications

Epstein, E., Salt tolerant crops? Proceedings of the 1974 California Plant and Soil Conference, pp. 59-60.

Fredrickson, D.L., and E. Epstein, Genetically controlled differences in salt tolerance of two species of the tomato. *Plant Physiology* Supplement to Vol. 56(2), 4 (1975).

Norlyn, J.D., and E. Epstein, Salt stress during the life cycle of barley cultivars, *ibid*.

Rush, D.W., and E. Epstein, Effects of salinity on *Lycopersicon esculentum* and *L. cheesmanii*, *ibid*.

Idem, Genotypic responses to salinity: differences between salt-sensitive and salt-tolerant genotypes of the tomato, *Plant Physiology*, 57, 162 (1976).

Cooperating Organizations

A.L. Castle, Inc., Morgan Hill, California

Bodega Marine Laboratory, Bodega Bay, California

Cooperative Extension Laboratory, UC-Davis, California

Department of Agronomy and Range Science, UC-Davis, California

Department of Vegetable Crops, UC-Davis, California

U.S. Department of Agriculture, Beltsville, Maryland

Kelp Bed Mariculture and Resource Management

M. Neushul and David Coon

The kelp beds of California, are submerged "forests" extending from the intertidal zone out to depths of 80 to 100 feet. In the northern hemisphere, these are unique to the Pacific Coast of North America. The kelp beds are an important economic and recreational resource, yielding a variety of finfish, abalone, crab, lobster and sea urchins to both the commercial and sport fisherman. Also the kelp itself is harvested, with nearly 200,000 wet tons being cut from the beds yearly.

The rational use and conservation of the marine resources of California are a major concern of the people of the state. This concern is reflected in the actions of agencies of the State Government, the California Department of Fish and Game, and those private firms (Stauffer, Merck Chemical, and American Agar) whose raw materials now come from publicly owned kelp forest, which are leased from the state.

The kelp beds of California are highly productive and unique ecosystems, which as mentioned above are used extensively as a source for alginates, fish, and shellfish. However, the primary producers in these forests, the marine plants (kelps, agar weeds, and nori) are still uncultivated, "wild" plants. Efforts are being made in the reforestation of harvested southern California beds, by the California Department of Fish and Game and Merck. While these "hand-planting" efforts are proving to be effective, we are searching for less labor-intensive methods.

Enhancement of reproductive processes

It has long been our contention that with a basic understanding of the functioning of these plants in the sea, it will be possible to enhance their reproductive processes in specific ways. Also, we could select more effectively for high-yielding, or temperature-resistant strains. Unfortunately, there are two major "roadblocks" that have impeded progress in this area. The first is that there have been no easily operated methods for storing "seedstock" and making controlled crosses of these plants at will. The second is one that Dr. W.J. North has confronted, and this is the so-called "seeding" problem. Once kelps of a specific type have been obtained in dishes it is exceedingly difficult to rear these *specific* plants to a mature stage and plant them in the sea, so that subsequent generations can be studied, and further genetically defined features identified and selected for.

The seeding problem is one that we have approached by experimentally manipulating "segments" of the sea floor. This meant that a new research strategy had to be developed and shown to work. Also we had to measure environmental conditions in the "planting" area. This was done using fouling plates and a telemetry system developed with Sea Grant support. The effort has been successful and a major paper has been accepted, entitled "An *in situ* study of recruitment, growth, and survival of subtidal marine algae; techniques and preliminary results." This paper will appear in the December 1976 issue of the *American Journal of Phycology*. The abstract of the paper follows:

> Fouling plates (Plexiglas squares and concrete blocks) were bolted in a horizontal position to racks on the ocean floor at a depth of 12 m. Some of these were periodically taken from the sea, subjected to non-destructive microscopic survey in the laboratory, and then replaced in the sea. Others were: a) left undisturbed as controls; b) variously caged to exclude larger predatory animals; or, c) had sediment removed from them at intervals. Populations that developed on the periodically surveyed plates were similar to populations that developed on undisturbed plates. Populations on undisturbed plates were significantly different from those on partially caged plates. The exclusion of large predators by complete caging resulted in highly significantly different communities from those on partially caged plates. Completely caged communities were composed mainly of worms, barnacles and bryozoans. Plates installed in summer supported significantly different populations at the end of the experimental period (12 months) from those supported by plates installed in winter. Plant growth rates were slow, not exceeding 2 cm per month, and the mortality rates were often high. A few

species had high rates of recruitment and survival each month. Most had high recruitment only in the most favorable growth periods and high loss rates. Physical conditions on the sea floor were measured. The methods developed during this study make it possible to quantitatively describe the growth and reproduction of populations of benthic marine algae in the sea.

The problem of developing a reasonable genetics program for kelps has as far as we are aware, not been solved by any group. The Japanese rather surprisingly have put little effort into marine plant genetics. This is due, in part, to the difficulties in rearing genetically defined plants to reproductive condition, such rearing for the most part has to be done in the sea where mortality rates are exceedingly high. Our marine greenhouse provides a solution to this problem, since there we can rear plants up to a size where they are not subject to the extremely high mortality rates encountered in the sea. It was the utilization of this facility by Mr. Y. Sanbonsuga, during his year in Santa Barbara, that made the kelp hybridization work possible. This has been completed, and submitted for publication. Part of the introduction to this paper is reproduced fully here:

> The possibility of applying genetic improvement techniques, like those that have been so successful with land plants, for marine kelps, has been discussed for many years (Lewin, 1958). But the development of such programs has been slowed by difficulties in isolating gametophytes, controlling gamete release, and rearing the progeny of crosses to a size in the laboratory where their characteristics become evident.
>
> Hybridization of brown algae has been attempted by several workers. Working with members of the order Fucales, interspecific crosses have been obtained....Williams (1899) produced an intergeneric hybrid between *Fucus* and *Ascophyllum*. The hybrid seemed stunted and did not grow well. Interspecific crosses in the order *Laminariales* seemed possible because of the similarity of the gametophytic phases of these plants, and led Schreiber (1930) to attempt them, in *Laminaria,* without success. As far as we are aware, no one has attemped to hybridize any of the float-bearing kelps. However, successful hybridization has been achieved more recently by several marine botanists working with *Laminaria*....The feasibility of such crosses has raised questions about the validity of specific differences within the genus *Laminaria*. Other kelps have also been successfully hybridized. *Agarum* species have been crossed by Nakahara and Yamada (1974) who found interform fertility....[Some] have observed interform and interspecies fertility in *Undaria*. In all of these studies, except [one]....the gametophytes used for the crosses were isolated from mixed male-female cultures. They were described as being either an "early stage" or having reached a size of about 10 cells or more. When large gametophytes are isolated, there is a greater chance that they could carry with them very small gametophytes of the opposite sex...Thus, in such cases there is a possibility of cross-contamination. Also,....[three] have been able to rear their hybrids to reproductive condition, which was done by outplanting in the sea.

Plants of unknown affinity, found within natural populations in the sea, have been considered to be chimerae or hybrids. Tokida, Ohmi, and Imashima (1958) suggested that the unusual plant they found might be a chimaera of *Laminaria* and *Alaria*. Neushul (1971) has suggested that a very distinctive, float-bearing plant, of which three specimens were found in 1957, was a naturally occurring intergeneric hybrid of *Macrocystis* and *Pelagophycus*.

In this study we have used newly developed crossing and rearing techniques to produce intergeneric hybrids between *Macrocystis* and *Pelagophycus*, and between *Macrocystis* and *Nereocystis* in the laboratory. Tank cultivation techniques were used to raise the *Macrocystis* x *Pelagophycus* hybrids to a stage where they were morphologically distinctive and could be compared with similar plants that had been found in the sea.

Cooperating Organizations
California Department of Fish and Game, Sacramento, California
Marine Colloids, Rockland, Maine
Merck Chemical, San Diego, California
Stauffer Chemical, Port Hueneme, California

Kelp Bed Mariculture: *Iridaea* Population Dynamics and Cultivation

Santa Cruz
R/A-16B

William Doyle and Judith Hansen

Coordinated field and laboratory studies are being carried out on the seaweed *Iridaea cordata*, a red alga of potential economic importance because its cell wall contains carrageenan, a compound of important industrial uses. In this study our objectives are to provide basic information on the reproductive biology and growth dynamics of this plant in the field and laboratory in order to: 1) assess the feasibility of developing a harvest program of natural populations of this plant, and 2) develop data necessary for the management of a mariculture program. Study of the natural populations in the central California coastal area has been nearly completed. A pilot mariculture program is under way.

The carrageenophyte, *Iridaea cordata*, rims the Pacific basin from Japan to Mexico with major populations from central California to southern Oregon. Carrageenan has numerous industrial uses (e.g., food, biomedical, pharmaceutical, brewing, textile) and is currently being imported to meet our domestic needs. The quality and quantity of *Iridaea* carrageenan are comparable to those of east coast *Chondrus crispus*, presently our only developed domestic resource.

With Sea Grant support we have studied resource availability, population biology (Hansen and Doyle, 1976; Hansen, in press), biochemistry (McCandless *et al.*, 1975), and aspects of physiological ecology (Hansen, 1976) of central California *I. cordata* (Fig. 1).

Resource availability - Natural populations

Standing crops of *I. cordata* in the areas studied are larger than those in the Pacific Northwest and are similar to those of *C. crispus* now harvested on the east coast. Crops are seasonal with peaks during summer and lows in winter (Fig. 2). The populations are dominated by the diploid stage which produces lambda carrageenan (viscous type). However, the male and female stages which produce kappa carrageenan (gelling type) reach a peak in spring-summer and could be selectively harvested at that time.

The plant has a basal, perennial crust that initiates juvenile blades predominantly during the winter. The blades undergo a spectacular 18-22 fold increase in growth rate during spring, mature during summer-autumn (at which time harvesting would produce the greatest return), and die back in winter (Fig. 3). The majority of biomass is produced by vegetative means. Harvesting down to the basal crust, but not damaging it, during late summer-autumn is not detrimental to the subsequent crop (Fig. 4, 5).

Iridaea grows best on rocky platforms and headlands of the exposed coast which make access and hand harvesting difficult.

Laboratory studies

The male and female stages of *Iridaea* produce the type of carrageenan most highly prized by industry.

The photosynthetic rate, the basic metabolic rate for determining production rates, is light limited at the low levels recorded for winter, indicating greater crops can be stimulated by manipulating irradiance levels.

Iridaea prefers ammonium over nitrate as a nitrogen source, and maximum uptake rates occur at ammonium concentrations greater than local ambient seawater levels. This

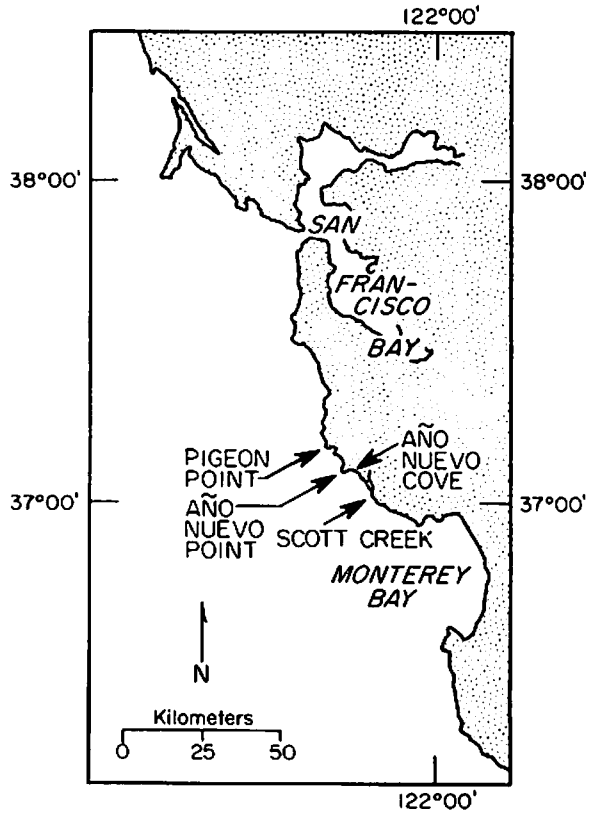


Fig. 1. *Iridaea* study sites

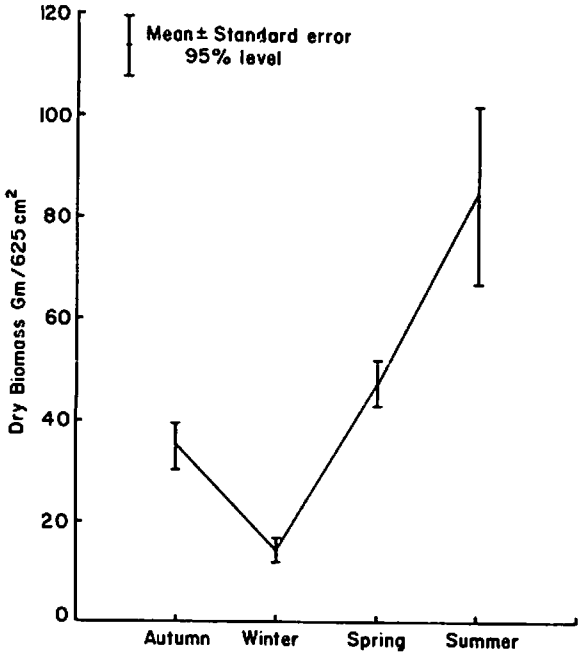


Fig. 2. *Iridaea cordata* standing crops 1972-1973

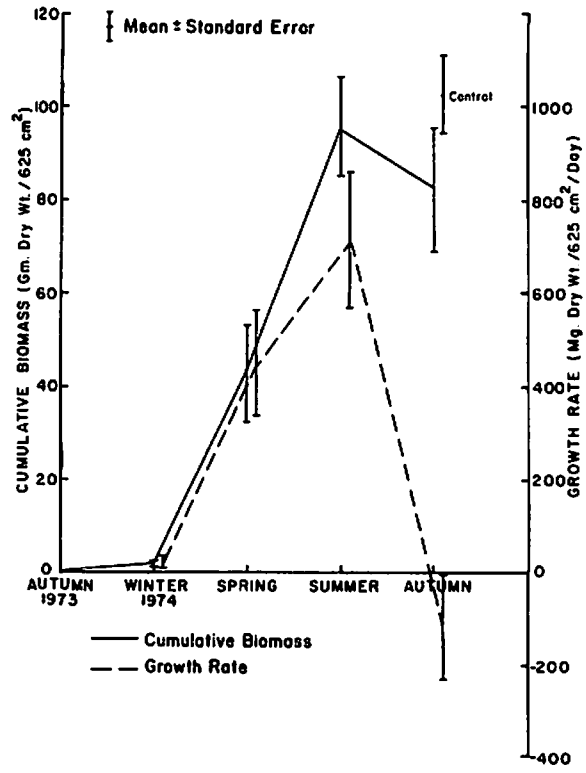


Fig. 3. Regrowth of harvested *Iridaea* populations

indicates either that *Iridaea* utilizes other nitrogen sources to a significant degree, or that greater growth could be obtained by a fertilization program.

Pilot mariculture program

It is extremely difficult to manipulate natural plant populations to achieve maximum growth potential. Additionally, *in situ* populations produce predominantly lambda carrageenan. However, selective harvest could produce a largely kappa carrageenan-producing crop. Further, growing *Iridaea* on nets (a method originating in Japan) has demonstrated that crops four (in California) to 25 (in the Pacific Northwest) times that of natural populations can be grown on nets in Washington (C. Kemp and T. Mumford, personal communication). Therefore, a pilot net mariculture study was designed using our previously determined results.

A net system was built using PVC frames, nylon seine netting and an adjustable mooring system to manipulate the depth fcr optimum irradiance regimes. The experimental nets will be selectively "seeded" to grow male and female stages resulting in a high quality kappa-carrageenan-producing crop.

Additionally, we will continue in our advisory capacity with the Washington Department of Natural Resources regarding in-progress studies of aquaculture of carrageenophytes.

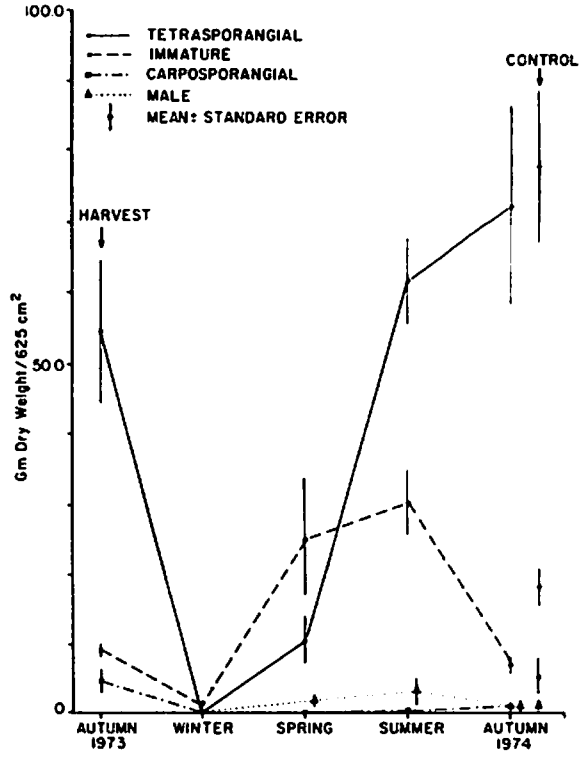


Fig. 4. *Iridaea* regrowth—Biomass

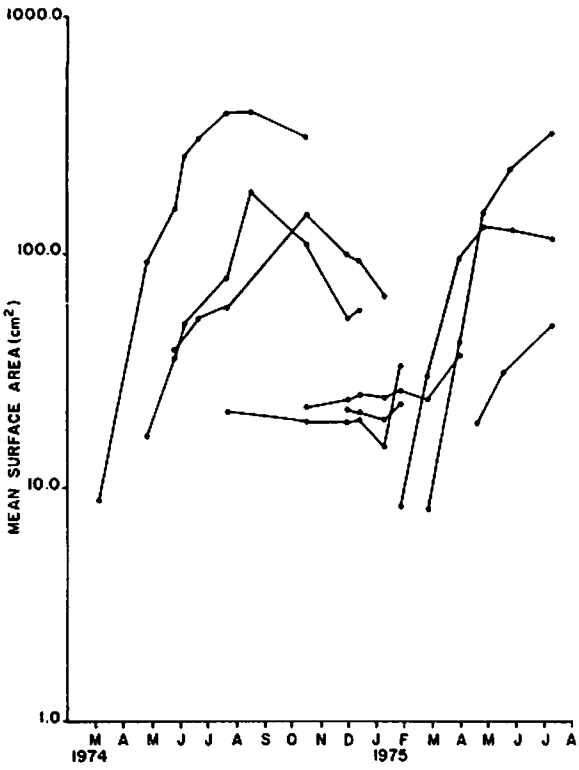


Fig. 5. Mean growth of tagged *Iridaea cordata* thalli

Publications

Hansen, J.E., Population biology of *Iridaea cordata* (Rhodophyta, Gigartinaceae). University of California, Ph.D. Thesis, 1976.

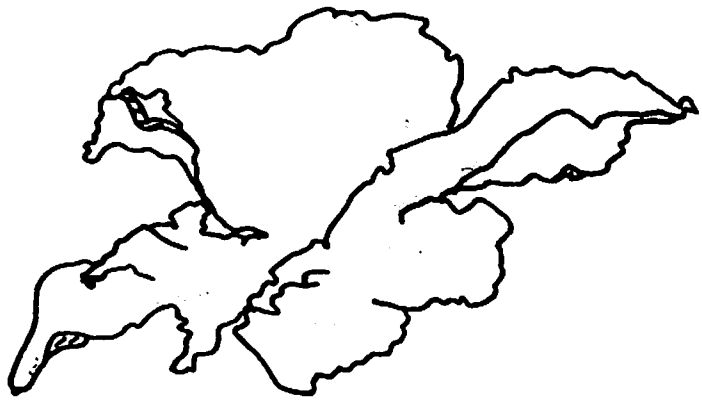
Idem, Studies on the population dynamics of *Iridaea cordata* (Gigartinaceae, Rhodophyta), Proc. Int. Seaweed Symp. VIII, 1974. In press.

Hansen, J.E., and W.T. Doyle, Ecology and natural history of *Iridaea cordata* (Rhodophyta: Gigartinaceae), population structure. *J. Phycol.*, **12**, 273-278 (1976).

McCandless, E.L., J.S. Craigie, and J.E. Hansen, Carrageenans of gametangial and tetrasporangial stages of *Iridaea cordata* (Gigartinaceae), *Can. J. Bot.*, **53**, 2315-2318 (1975).

Cooperating Organizations

Soil Control Lab, Watsonville, California



Kelp Forest Ecology of the Central California Coast

Santa Cruz
R/A-16C

John S. Pearse and Anson H. Hines

Kelp forests are complex and highly productive coastal ecosystems. This project is examining energy flow and interactions among the species within central California kelp forests, including giant kelp and pea kelp plants, the major primary producers, snails, abalones, spider crabs, sea urchins and batstars, the major herbivores, and corals, sea stars, rockfishes and sea otters, the major predators. Information gained can be applied to sound management and utilization of this rich resource.

In our overall goal of understanding "how a kelp forest works," we are emphasizing a community approach to developing, managing, and protecting kelp forest resources along the central California coast in cooperation with Dr. Michael Neushul and David Coon's group at UC-Santa Barbara. This involves a study of the standing crops, energy flow and ecological interactions of the major primary producers, herbivores, filter feeders, and predators in the community. These studies provide essential quantitative information on the important, but little known, aspects of seasonal and annual changes in the populations which have central roles in the productivity and trophic interactions of kelp forests.

Hopkins Marine Life Refuge: A kelp forest inhabited by sea otters

Our major study area is in the kelp forest of the Hopkins Marine Life Refuge off Pacific Grove, California. This forest is within the established range of sea otters, which are particularly important predators regulating herbivore densities. Growing out of previous work funded by Sea Grant since 1972, our studies during the first year of our present three-year project have concentrated on estimating productivity in three major trophic levels of the kelp forest: 1) the quantification of seasonal changes in standing crops and production of attached and drift algae; 2) measurement of feeding rates and seasonal changes in the population densities, size structures and standing crops of the major herbivores in the system (sea urchins, abalones, crabs, turban snails, and bat stars); and 3) measurements of the diets and densities of certain major predators (sea stars, rockfish, and sea otters) which regulate the herbivore populations and/or are of commercial and sport use.

The completion of a 2½ year study by trainee Val Gerard on the major primary producer, giant kelp (*Macrocystis pyrifera*), in the system shows that while *Macrocystis* frond size has a seasonal cycle, plant size and density have not (Fig. 1). Variations in these aspects of kelp standing crops correlate mainly with fluctuations in water movement (waves) and storms. In cooperation with Mr. Dan Miller of the California Department of Fish and Game, we are using aerial photography to monitor long-term fluctuations in the kelp canopy.

The greater part of the total annual net production of *Macrocystis* forms drift kelp, mainly during the first storms in the fall when whole fronds and plants are torn loose. Export of this drift kelp from the forest also correlates with water movement intensity and is greatest in the fall and winter.

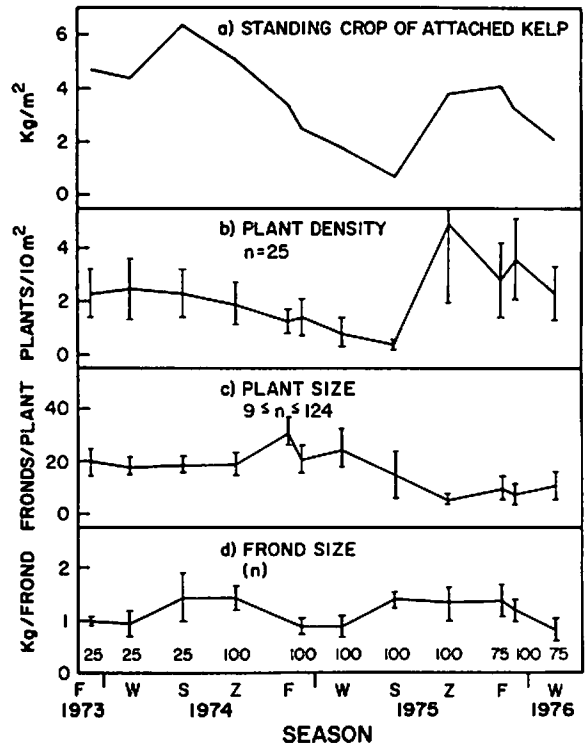


Fig. 1. Standing crop and population parameters (± 95 per cent confidence limits) measured seasonally for the giant kelp, *Macrocystis pyrifera*, in the Hopkins Marine Life Refuge study area

Consequently, during the season of highest drift production, most of the drift is exported. During the spring and summer, when production of drift kelp is relatively low, export is also low so the standing crop of drift kelp on the forest floor increases. Much of this accumulated drift kelp is also swept from the forest floor during the fall and winter. Therefore, the supply of drift kelp to other communities is probably very seasonal, with a peak in the fall.

Completion of a year's measurement of the pea kelp (*Cystoseira osmundacea*) shows that, while the production of the canopy-forming reproductive fronds is highly seasonal, the population of the vegetative plants is very steady through time. Seasonal sampling of bottom algae (primarily foliose red and coralline algae, indicates that standing crops of these producers are constant.

Completion of one year's study of the densities and standing crops of the major herbivores in the kelp forest shows that some, such as abalones and bat stars are constant through time; others, such as turban snails and spider crabs, show long-period, non-seasonal fluctuations; and some, such as sea urchins, show large erratic fluctuations owing to variable recruitment success. Sea urchins, which have a high potential for kelp overgrazing and are important in the diet of sea otters, are of particular interest because they underwent a 500 per cent increase in density (to a present density of about five per square meter) as a result of a large settlement of purple urchins in the summer and fall of 1975. It will be extremely interesting to follow the growth of this large recruitment of sea urchins during the next year. Although turban snails and some kelp crabs are grazing directly on attached kelp, most of the herbivores are feeding on drift algae, effectively cycling this resource within the food web of the kelp forest.

It is apparent from our initial studies that sea otters, fish, sea stars, and predatory anthozoans, as well as other predators, have a broad and diverse food base on the major herbivores in the Hopkins Marine Life Refuge. These predators are important in regulating the populations of herbivores, thus minimizing overgrazing. Continuation and expansion of our studies at this trophic level will be our major emphasis during the coming (1976-77) year, with the doctoral research of Sea Grant Trainees Christopher Harrold and Yusef Fadlallah on sea stars and corals respectively.

In a preliminary attempt to integrate our findings into a cohesive model of the energy flow and material cycling in the kelp forest at the Hopkins Marine Life Refuge, we are working with a flow chart relating the density and standing crop data to the major trophic pathways of the community (Fig. 2). This tentative model provides us with a simplified working framework quantifying the relative importance of these pathways. It also serves as a basis for more detailed studies of the dynamics of the system and for the design of relevant manipulative experiments, isolating mechanisms of competitive and structural regulation of the kelp forest.

Santa Cruz Point: A kelp forest outside the current range of sea otters

Monitoring of four permanently marked stations in the kelp forest off Santa Cruz Point, Santa Cruz County, is continuing. Sizes and densities of populations of kelps, sea urchins, abalones, rock crabs, and sea stars have been sampled seasonally since the summer of 1974. Up until the winter of 1975-76 the seaward portion of this forest contained large numbers of sea urchins and sea stars, and was relatively barren of algae. Aerial photographs indicated that the forest boundaries were quite stable for the previous five years. During the spring of 1976 a major, though localized, die-off of red sea urchins virtually wiped out the population of these grazers in all but a narrow band along the edge of the kelp forest (Fig. 3). This die-off was apparently the result of an unknown sea

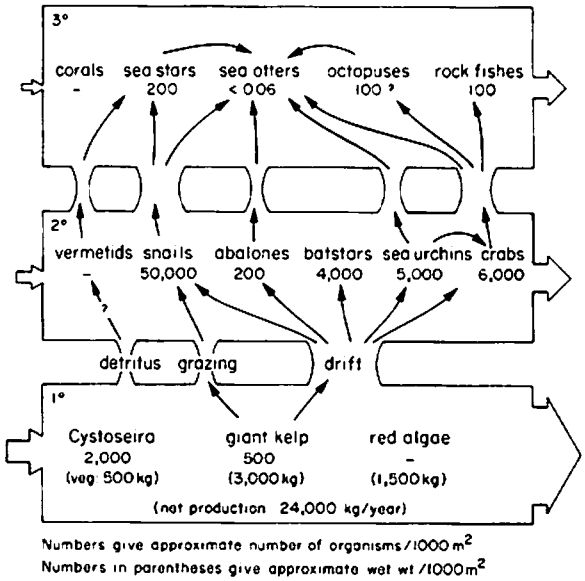


Fig. 2. A tentative diagram showing the standing crops of the major primary, secondary and tertiary producers within the kelp forest in the Hopkins Marine Life Refuge, and their interrelations with respect to energy flow

urchin disease which caused the loss of large patches of spines (Fig. 4) and killed some 20,000 sea urchins in our study areas. During the summer following the die-off, large numbers of kelp plants (approximately 250,000 plants and 750,000 stipes of *Macrocystis* and 10,000 *Nereocystis* plants in our study area of 10,000 m^2) grew up in the area previously dominated by the sea urchins (see Fig. 3), and aerial photographs show that the width of the canopy had nearly doubled by September, 1976.

In addition to providing valuable comparative data on a kelp forest in a different area from our principal study area in the Hopkins Marine Life Refuge, these studies provide a base line for the study of the impact of sea otters on a kelp forest with their imminent arrival in the area. The observed urchin die-off provides independent documentation that removal of large numbers of these grazers has dramatic effects on the structure and production of kelp forests in central California, and we will continue to follow the consequences of these changes in the coming year.

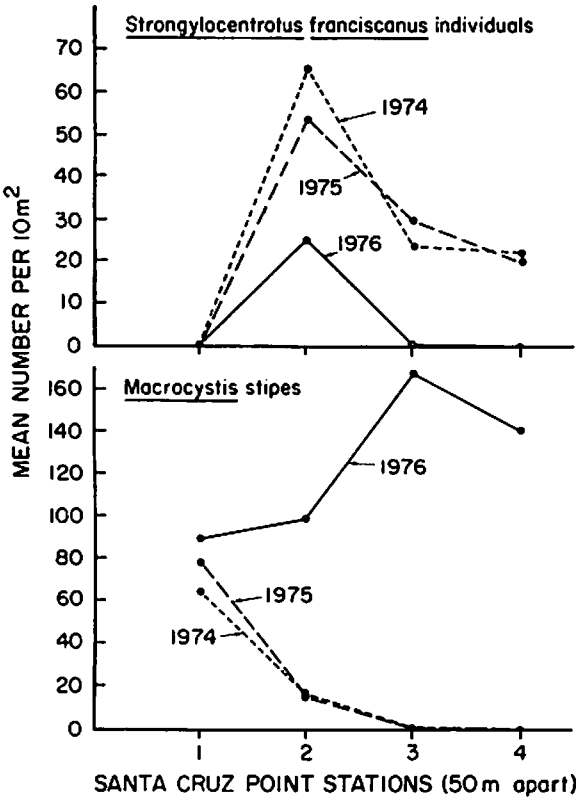


Fig. 3. Changes in the mean densities of red sea urchins (above) and stipes of giant kelp (below) at four permanent sampling stations transecting the kelp forest off Santa Cruz Point in September of 1974, 1975 and 1976. A major die-off of sea urchins occurred in the spring of 1976, followed by a dramatic growth of kelp in the seaward stations (station 3 and 4).

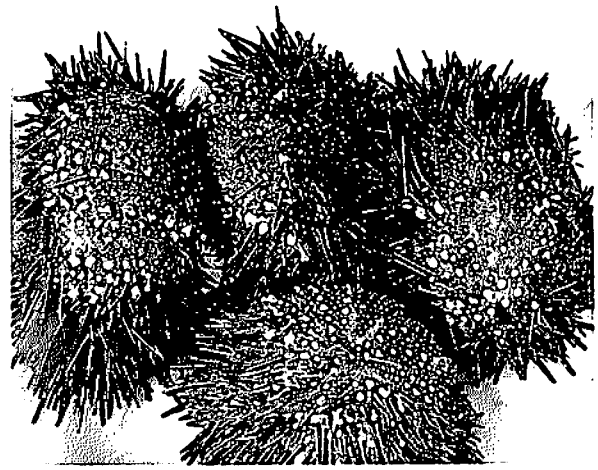


Fig. 4. Diseased red sea urchins showing the loss of spines over large portions of the body. Collected from a population undergoing a localized die-off at Año Nuevo Island in July, 1976, similar to that seen at Santa Cruz Point in early June, 1976

Publications

Cooper, J., M. Wieland, and A. Hines, Subtidal abalone populations in an area inhabited by sea otters. *Veliger*, in press.

Gerard, V.A., The role of drift algae in the flow of energy through a Monterey kelp forest. Kelp and kelp bed communities. Symposium for teachers, co-sponsored by the Scripps Aquarium and the County Department of Education under the auspices of Sea Grant, 2-3 April 1976.

Idem, Some aspects of material dynamics and energy flow in a kelp forest in Monterey Bay, California. Ph.D. thesis, University of California, Santa Cruz, 1976.

Pearse, J.S., The habitat of the California sea otter. Conference on the biology and conservation of marine mammals, University of California, Santa Cruz, 4-7 December 1975.

Cooperating Organizations

California Department of Fish and Game, Monterey, California
Hopkins Marine Station of Stanford University, Pacific Grove, California
Kelp Habitat Improvement Project, California Institute of Technology, Pasadena, California
Kinnetics Laboratory, Inc., Santa Cruz, California
O'Neill's Dive Shop, Santa Cruz, California
Seven Seas Dive Shop, Monterey, California
U.S. Fish and Wildlife Service, Monterey, California
U.S. Marine Mammal Commission, Washington, D.C.

A Genetic Program for Improvement of Carrageenan Production in the Red Alga *Gigartina*

John West

Experimental laboratory crossing experiments were begun on field collected plants selected for high carrageenan yields and growth rates. The F 1 generation is now under study in the laboratory to determine if improvement of production can be achieved through genetic selection and manipulation.

I. Field studies

Beginning in October, 1975, field observations were undertaken at four northern California sites (Rockaway, Duxbury Reef, Bodega Marine Lab, and Shell Beach). Each site has a large vigorous population of the two perennial species under investigation (*Gigartina agardhii* and *G. papillata*). Thirteen male and female plants of *G. agardhii*, 81 male and female plants of *G. papillata* and 15 of *Petrocelis* (the crustose alternate stage of *Gigartina*) were labeled with permanent concrete and stainless steel markers. Each was photographed, measured, sampled for culture and carrageenan analyses. Data on reproductive condition and regeneration were also taken. This procedure was repeated every month or every two months for the one-year period.

There was a significant seasonal loss of *Gigartina papillata* plants. After one year 37 per cent of the females (16 of 43) and 56 per cent of the males (15 of 26) were lost. There was no mortality of either *G. agardhii* or the *Petrocelis* stage.

Growth rates are being assessed in order to select those parent plants with the greatest potential for productivity. Because *Gigartina* has an extensively divided blade, we chose to use length rather than surface area as a parameter for growth. Although data are still being analyzed, it is apparent that a wide range of growth rates occur even in plants within a limited area. For example, *G. agardhii* plants in the length range from 2 to 20 cm, have growth of 1.0 to 6.0 cm/month. *G. papillata* plants of the same size class show rates of 0.5 to 5.5 cm/month. Those with maximum percentage increases per month during peak growing periods are being selected for the breeding stock. In general, male and female plants have nearly equal growth rates, although asexually produced (apomictic) females grow somewhat faster than sexual plants. Growth rates of the crustose *Petrocelis* tetrasporophyte stage are not yet tabulated.

Regeneration of new blades from the perennial base and from the blades of field plants is also being investigated as this will be a useful attribute for rapid asexual propagation of plants for commercial production. Although this characteristic is less easily quantified, we are selecting those with the best regeneration rates for our crossing studies in the laboratory.

Carrageenan analyses are currently in progress. Percentage yield, percentage sulfate ester and percentage of 3,6-anhydrogalactose are the three criteria used to select the breeding stocks. Each plant has been sampled monthly or bimonthly to determine if seasonal variations occurs in these characteristics. Overall, the yields range from 40-68 per cent carrageenan on a dry weight basis. Generally, apomictic females of *G. papillata* have lower yields (41-55 per cent) than sexual females and males (52-68 per cent). *G. agardhii* has somewhat lower yields (47-59 per cent) than *G. papillata* sexual plants. Sulfate and anhydrogalactose levels are now being determined. At present we are unable to determine the degree to which environmental factors play a role in controlling the above-mentioned features.

II. Lab culture studies

Each of the marked plants in the field is sampled for culture, in order to determine if they are sexual or apomictic and to isolate sexual males and females for breeding stocks. Cultures are started from each plant after each field sampling period (1-2 month intervals) to determine if their reproduction patterns are constant or variable. Carpospores (which are diploid spores produced after fertilization and which germinate to yield free-living plants—the tetrasporophytes) are started. Blade tips are excised from each female (only blade tips are isolated from males). Carpospores from sexual plants develop into the tetrasporophyte stage (*Petrocelis*) and those from

apomictic plants develop into new *Gigartina* blades.

G. papillata exhibits a high frequency of apomictic plants from all localities. Thirty nine of 51 female blades are apomictic. The eight sexual plants will be used for breeding stocks. Four plants appear to have produced a combination of both sexual and apomictic progeny. The reason for this is unknown, but is being investigated. All breeding stocks are maintained in unialgal culture in defined laboratory conditions.

Conclusions

The sexual plants isolated into culture from tagged plants in the field have all been crossed in various combinations to determine their interfertility. The following conclusions can be drawn from these experiments:

All *G. agardhii* sexual plants are interfertile. The isolates from our four localities in California also cross with *G. agardhii* plants from Oregon, Washington and British Columbia.

None of the *G. agardhii* plants are interfertile with *G. papillata* plants, indicating that they are genetically isolated species.

G. papillata sexual isolates from our four localities are interfertile (in part) and form about three distinct non-interbreeding groups. Within each group, all strains are interfertile but no group-to-group interfertility has been achieved, indicating that genetically and morphologically distinct forms exist within this species.

The isolates of *G. papillata* cross with male and female plants derived from tetraspores of *Petrocelis* crusts, but those of *G. agardhii* do not. This indicates that the alternate tetrasporophyte stage for *G. agardhii* is as yet unknown.

The crustose *Petrocelis* stage derived from *G. papillata* crosses have been induced to sporulate in the laboratory under short day (8L:16D) conditions at 10 and 15°C.

We are now selecting a series of *G. papillata* sexual plants for further crossing experiments. These plants are selected for their carrageenan production, growth rates and regeneration. For example, 15 D male (63 per cent carrageenan, good regeneration and 5.0 cm/month growth rate) X 25 A female (65 per cent carrageenan, poor regeneration and 2.0 cm/month growth rate) are being crossed to see if the progeny will maintain high levels of carrageenan coupled with fast growth and good regeneration in field out-plants.

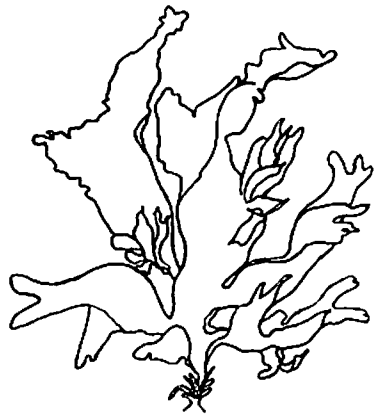
Publications

Polanshek, A., and J. West, Culture and hybridization studies on *Petrocelis* (Rhodophyta) from Alaska and California, *J. Phycol.*, 11, 434-439 (1975).

West, J., and A. Polanshek, Genetic affinities among eastern Pacific populations of *Petrocelis* and *Gigartina* subgenus *Mastocarpus*. A paper presented at the U.S. Japan Cooperative Science Program Seminar, Kobe University, Kobe, Japan, 30 November - 5 December 1975.

Cooperating Organizations

Marine Colloids, Inc., Rockland, Maine



Effects of Public Regulation on California's Aquaculture Industry

Gerald Bowden

Aquaculture, like every infant industry, is finding it increasingly difficult to wedge its way through the legal labyrinth which our lawmakers have constructed over the past half century. Commercial aquaculturists must cope with a proliferating array of permit and licensing requirements administered by a growing number of local, state, and federal agencies. The purpose of this study has been to assess the effect of these regulations on the aquaculture industry in California.

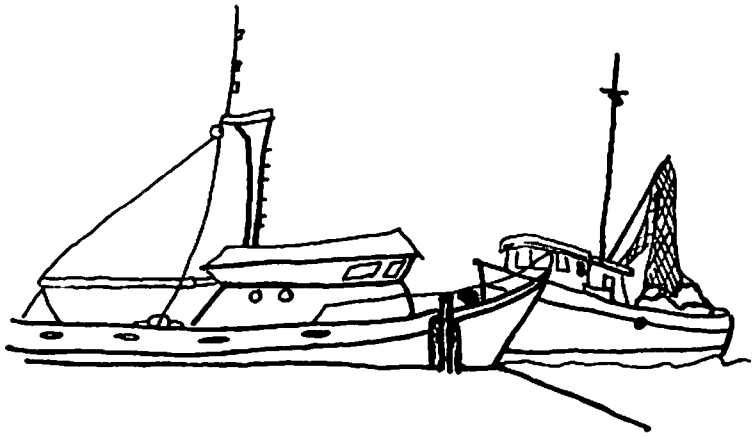
Work on this project during the past year consisted of legal research, writing, and discussions with representatives of the aquaculture industry and the public agencies who regulate it. The legal research component of this project has been demanding and often tedious: mounds of primary legal material, predominantly statutes and administrative regulations, had to be sifted and digested in an effort to understand how the law treats the aquaculture industry. This is often difficult to determine, because aquaculture is a relatively new industry and the laws regulating it often predate its birth. For this reason, many important statutes contain no explicit reference to aquaculture. One must discover, through consultation and minute statutory analysis, how old laws apply to this new industry.

Complexities of regulating aquaculture

An astounding array of agencies are involved in regulating aquaculture, and similarly surprising are the extent and complexity of the law administered by these agencies. Because there are so many agencies applying so much law, it is difficult to grasp the impact of regulation on the industry. Adding to this difficulty is the fact that the aquaculture industry is itself very heterogeneous. Different sectors of the industry confront their own sets of legal problems. Land-based closed-system generators seem to encounter the largest number of legal constraints. To understand these constraints it is necessary to master the regulations promulgated by the Occupational Safety and Health Administration (OSHA), the Food and Drug Administration, the Drug Enforcement Administration, the Bureau of Alcohol, Firearms and Tobacco, the Army Corps of Engineers (discharge lines), Agriculture (importation of breeding stock), the Environmental Protection Agency (water discharge) as well as a host of state agencies including Fish and Game, Coastal Commission and the State Lands Commission, to name only a few. The law governing each of these agencies is elaborate and overlaps the law administered by other agencies. To make matters even more complicated, the same laws often apply differently to different kinds of aquaculture. An anadromous fish operation, for example, would encounter few of the legal problems faced by a closed-system shellfish operation but would also face a different set of regulations. And there is a significant difference between marine and freshwater aquaculture, since the federal government is heavily involved in controlling uses of seawater whereas state agencies predominate in controlling fresh water. Neat lines are, however, impossible to draw.

A complete exposition of this problem would take a team of lawyers several years to complete. Learning the dimensions of the problem is, however, an important step toward resolving it. If this project had done nothing more than describe the problem accurately, it would have made an important contribution. The project, however, has been more fruitful than that. The draft legal summaries written during the past year will be useful in evaluating the competing public policies that will decide the future of the aquaculture industry.

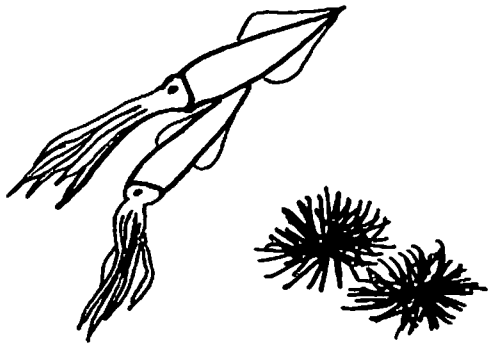
It is hoped that the end product of this research will be a better understanding of the impact that specific regulatory programs have on specific aquaculture enterprises. It is not enough to generalize about the cumulative effect of all regulatory programs when the nature of these programs is diverse. What is needed is a fine-grained disaggregated understanding of individual regulatory programs. Without such understanding it will be impossible to demonstrate how the law can be changed to meet the needs of public protection without unnecessarily retarding the growth of the aquaculture industry. This is, therefore, the direction proposed for developing our research program over the next few years.



FISHERIES

The California Current populations are marked by a number of valuable species that are underutilized. As a result of exploratory fishing cruises, further data were accumulated on an apparently underutilized food resource, *Loligo opalescens*, a species of squid common to Monterey Bay.

An intercampus study continued to investigate the sea urchin, with a view to determining its population parameters necessary for managing its fishery in a sustained-yield manner consistent with the optimal use of kelp community resources. In view of the fact that this country and an increasing number of other countries are in the process of establishing 200-mile fisheries zones along their shores, social scientists explore the social, political and economic consequences of this and other management innovations on fisheries, in particular the abalone industry. A further group of projects are concerned with improving the preservation, appearance and palatibility of processed fish.



The California Market Squid Fishery

Moss Landing
Marine Laboratories
R/F-15

Conrad W. Recksiek

The second year of this three-year research program on the biology of market squid has been devoted toward accumulating data on reproductive and population biology, age-growth dynamics, predator-prey relations, spatial-temporal distribution, life history and fishery oceanography of these molluscs.
The goal of this research effort is to provide basic biological information for sound management of the resource and to develop management alternatives and fishery methods which could be applied to increase the present harvest.

Introduction

This report is divided into six parts. These are the accounts of the original five interdisciplinary research teams, dealing, respectively, with squid productivity in the California Current system; the population biology of *Loligo opalescens*; the animal's reproductive biology; chemical and physical oceanography as related to squid spawning; and an analysis of the major squid predators; and that of one additional research group, activated this year, which investigated the impact of squid as predators upon other marine resources.

(1) Squid Productivity

Project Leaders: C.W. Recksiek and H.W. Frey; Associate: J.R.R. Ally

The principal goals of the squid productivity studies are to investigate methods whereby population sizes could be estimated, and to explore different fishing methods and fishing grounds.

A three-week exploratory cruise aboard the California Department of Fish and Game's R/V *Alaska* from the Mexican border to Monterey Bay during June was devoted to this effort. Samples for population, reproduction and squid prey studies were collected through jig fishing under lights and midwater trawling. Squid samples were collected by guest squid researchers aboard National Marine Fisheries research vessels in Monterey Bay during July. Samples were also accumulated through September incidentally on other vessels.

Acoustic studies have revealed that squid schools can be located with high (200kHz) and low (38kHz) frequency echo sounders. Verification of squid traces on echograms was accomplished by midwater trawling, jig fishing under lights and visual observation. The greater part of this work was accomplished aboard *Alaska* during June. Low and high frequency machines were operated simultaneously.

Two radically different behavior patterns are represented by the echograms: 1) continuous bottom-associated traces which can be resolved over a substantial frequency range; 2) midwater plume-like traces which may be effectively resolved at higher frequencies. The use of echosounders seems practical in determining spatial and temporal distribution of squid.

Squid schools of both general types have been observed in the shallow traditional fishing grounds of the Santa Barbara Channel Islands and in southern Monterey Bay, but preliminary data indicate that large non-spawning (continuous trace) schools occur near the bottom in deep waters.

Fig. 1. Sorting a juvenile squid sample at sea

During June an attempt was made to collect larval squid. Oblique tows with a large Tucker trawl were conducted at stations from San Diego to Monterey Bay but proved ineffective in capturing large numbers. It was concluded that young squid may occur in association with the bottom. To that end a plankton net sled was designed and fished July through September on the spawning grounds of Monterey Bay. To date the results are encouraging since high catches have been experienced with the gear. The implication is that larval squid may maintain position through bottom-related behavior patterns. Another implication is that spawning success may be analyzable through this technique.

(2) Population Structure

Project Leaders: J.R.R. Ally, J.P. Christoferson and C.W. Recksiek

To manage a fishery properly, it is important to establish whether the population is composed of a single homogenous unit or is made up of several subpopulations.

To determine whether or not there exist separate breeding populations of *L. opalescens*, it is necessary to have a phenotypic variation to analyze. Proteins were chosen because they are the indirect product of the gene and they are relatively easily resolved from one another. Twenty three enzymes and plasma hemocyanins were separated by starch-gel electrophoresis and appropriately stained. However, only digestive gland esterases, mantle muscle phosphoglucomutase, and plasma hemocyanins show any significant polymorphism.

Phosphoglucomutase (PGM) in the mantle muscle tissue was found to consist of five allozymes (electrophoretic variants of an enzyme from one locus). Of the 15 possible phenotypes which can be produced by the five PGM alleles, eight were observed.

The sample of squid with which all other samples were compared consisted of 2000 specimens captured off Santa Catalina Island. The other samples consisted of 200 specimens from six locations south and two locations north of Point Conception. Some locations were sampled more than once and at different intervals. One sample was composed entirely of juveniles. All other samples were of spawning or about-to-spawn animals.

The sample of juvenile *L. opalescens* was analyzed for digestive gland esterases. The esterase patterns are similar to that of the mature squid, but contain several more bands. A comparison between 13 samples of mature squid (from seven locations) utilizing esterases and hemocyanins suggests that there are some significant differences. These variations occur among locations and among dates of capture, suggesting the probability of subpopulations of *L. opalescens*.

Analyses of data for electrophoretic studies are still in progress.

The beaks of more than 70 southern California and 140 Monterey Bay squid have been extracted. Four beak parameters on the lower beak and on the upper beak respectively have been measured. Regressions between beak parameters and dorsal mantle length will be prepared to understand areal differences in the beak morphology which may, in turn, be attributable to population differences. The regression analyses will be of value to the squid predator studies, since dorsal mantle lengths would be inferred from the relatively digestion-resistant beaks in predator stomachs.

Samples from the whole range of *Loligo opalescens* are now being assembled so that variation in morphometric and meristic characters can be understood better. To date we have accumulated adequate samples from Mexican waters through Monterey Bay.

(3) Reproduction and age determination

Project Leaders: R.D. Beeman and J.D. Spratt

Spermatogenesis in the spawning population of the squid, *Loligo opalescens*, has been studied by means of light and electron microscopy. During the course of this study, the testicular tissue of 22 animals was examined in order to follow the gametogenic process. Only cells representing the late stages of spermatogenesis were found within the testes of each of these specimens; no germinal cells or spermatogonia were found within the seminiferous tubules of the testes. The development of the male gametes appeared to proceed in a synchronous fashion, and the seminiferous tubules of some animals examined contained only a few relict spermatozoa. The lack of any sign of a renewed gametogenic cycle, the degenerative condition of the seminiferous epithelia, and the emaciated condition of the "spent" animals led to the conclusion that males spawn only once and subsequently die.

Electron microscopy has been employed in order to elucidate the maturation of the spermatids. Nuclear condensation and elongation, flagellar growth, morphogenesis of the mitochondria, microtubular assembly, and acrosome formation have been described in detail.

Oogenesis has been studied in the squid utilizing both light and electron microscopy. Using these techniques, the 10 stages of oocyte maturation have been revealed with respect to their structure and sequential relationship.

Detailed microscopic examination of females from 20mm to 160mm has shown that in 20 animals all oocytes are in a similar primary stage of maturation. Squid 60 mm and larger appear to be mature and have oocytes which appear in all stages of maturation. In mature, obviously spent *Loligo*, where the oviduct is empty or nearly so, there still exist within the ovary, all stages of oocyte maturation. It is doubtful, however, that the numbers of oocytes are such that the squid could carry out further spawning. The formation of primary oogonium from germ cells and their subsequent development to oocytes are still under study.

Techniques for preparing statoliths have been developed and growth rings have been counted in about 100 statoliths. Two types of growth rings have been found. Small uniform rings correlate best with daily growth in juveniles, and large irregularly spaced rings correlate best with the lunar cycle in adults. About 150 daily rings can be counted and up to 19 lunar rings. (*See* Fig. 2)

Mean length at age reveals that market squid may mature in about 1 year and that most will spawn when 14 to 22 lunar months of age at about 100-145 mm dorsal mantle length. These findings are supported by rearing experiments by Dr. Ann Hurley (1976) and by agreement with monthly modal length progressions collected during the study.

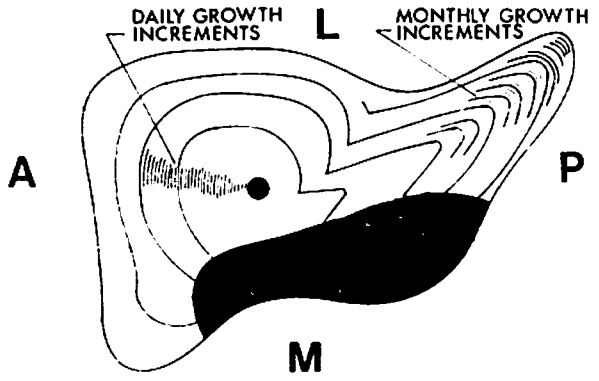


Fig. 2. Ventral view of hypothetical statolith from an adult squid, as it appears under transmitted light. Anterior (A), posterior (P), median (M), and lateral (L) surfaces are labeled. Areas where daily and monthly growth increments are best viewed are indicated

(4) Oceanography

Project Leader: W.W. Broenkow

Oceanographic studies in the southern Monterey Bay squid spawning grounds were continued during the past year. These studies included the biweekly CalCOFI hydrographic cruises (Broenkow, *et al.*, 1976), and three intensive week-long cruises using a conductivity-temperature-depth (CTD) profiler (Broenkow, *et al.*, in press) and surface profiling instrumentation. In addition, a time series study was made in March 1976 over Monterey Submarine Canyon. The latter was decided upon because during the past year we have found there may be a relationship between the occurrence of squid near the rim of the Canyon and the abundance of euphausiids there. The euphausiid abundance may, in turn, be related to the presence of the internal tide and divergence of water containing deep scattering layer organisms.

Preliminary results of these observations have shown: 1) the spring and summer of 1976 were anomalous oceanographically, warm offshore California Current waters having entered the Bay early in the summer; 2) temperature, salinity, chlorophyll and chemical parameters indicate the predominantly northerly flow of waters into Monterey Bay from Carmel Bay; 3) the internal tide was observed in central Monterey Bay with cooler deep waters spreading out over the Canyon rim; and 4) a weak thermal front was observed near the traditional squid spawning grounds. There may be a correlation between the presence of cool waters as found in submarine canyons, the availability of a nearby suitable spawning substrate and the occurrence of concentrations of spawning squid.

Hydrographic and chemical data in Monterey Bay have been used to estimate the residence time of near surface waters in the northern and southern bights (Broenkow and Smethie, submitted). The replacement of surface waters takes about six days (two to 12-day range) and flow is predominantly northward inside the Bay. These results offer a possible explanation for the occurrence of spawning squid in the south Bay: the south Bay waters being closest to the Canyon, they are least affected by accumulations of domestic sewage, and are generally cooler than waters in north Bay.

A cross-correlation analysis of squid catch in Monterey Bay versus climatic variables (wind, water temperature, thermal gradients, and rainfall) has been completed. Squid catch shows strong yearly periodicity

suggesting hydrographic control. Lag correlations between squid catch per unit effort and temperature anomalies at 10 m both over the Canyon and spawning grounds show significant correlations ($p<0.01$) at a lag of 18 months. Thus lowest squid catches are associated with the presence of anomalously cool waters in the Bay 18 months previously. This is consistent with McGowan's (1954) and McMahon and Summer's (1971) observations that the developmental time of squid is slowed by low temperatures, thus allowing greater mortality. This result also suggests that squid spawn at an age of about 18 months. (*See* Fig. 3)

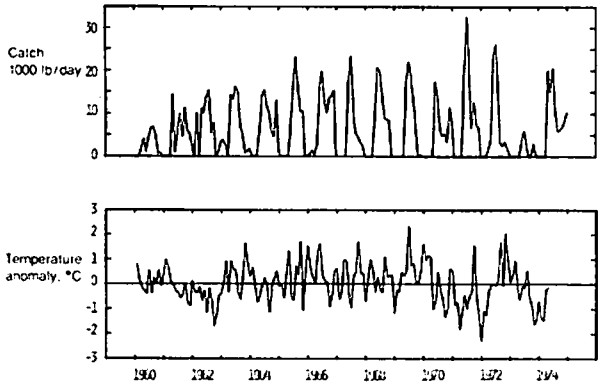


Fig. 3. Squid catch at Monterey, California and 10 m temperature anomaly in central Monterey Bay from 1960 through 1974

(5) Food Chains: Predators

Project Leader G.V. Morejohn

The vertebrate predators of squid (*Loligo opalescens*) were largely identified during the first year's collection effort. Our second year's effort was concentrated on collection of more specimens of those species that were considered to be major squid predators.

The two species of salmon, king (*Oncorhynchus tshawyscha*) and silver (*O. kisutch*) were sampled extensively throughout the year. The king salmon preferred anchovies (*Engraulis mordax*) and juvenile rockfish (*Sebastes* spp.) over commercial squid (*Loligo*). In contrast, the silver salmon largely preferred crustacean krill* (*Thysannoessa spinifera*) over commercial squid followed by herring (*Clupea harengus*) and juvenile rockfish, then crab megalops larvae.

The blue shark (*Prionace glauca*) was also taken in large numbers, and it was found to consume a great variety of prey species. An important discovery was predation by blue sharks on most of the prey species preferred by both species of salmon, i.e. anchovies, herring, juvenile rockfish, commercial squid, and krill. Interestingly, the prey items most preferred are anchovies and krill, the major foods of both salmon species.

Increased sampling of these major avian predators further documented our earlier studies. From feeding bird aggregations over the Monterey Canyon, several bird species were collected monthly from November to April. One species, the rhinocerus auklet (*Cerorhinca monocerata*), was found to feed on juvenile *Loligo* exclusive of other cephalopods throughout its stay in Monterey Bay. During some months this avian species may number in excess of 50,000 individuals per day. Approximately 80 per cent of their diet consists of juvenile *Loligo*. This is significant and supports our contention of large *Loligo* populations in Monterey Bay.

We have identified fishes of many species and 12 species of cephalopods from the stomachs or droppings of five seal species, four porpoise species, and two small whale species. From the sea otter we have identified only *Loligo* and many species of invertebrates. Marine mammal species studied fed upon 10 species of cephalopods. The greatest cephalopod species diversity and highest consumption were found in stomachs of Dall's porpoise (*Phocoenides dalli*) and the pigmy sperm whale (*Kogia breviceps*). All marine mammal species studied, except harbor seals, fed on *Loligo* either seasonally or throughout the year.

In summary, our significant discoveries thus far concerned with the food web involving *Loligo opalescens* are as follows:

1) King salmon feed extensively on *Engraulis*; silver salmon extensively on *Thysannoessa*; both feed highly on *Loligo*.
2) Food ranked in order of greatest preference for blue sharks are *Engraulis* and *Thysannoessa*; of lower preference (tentatively at sixth place) is *Loligo*.
3) Consumption of post-hatching and juvenile squid (dorsal mantle length ≦ 80 mm) by several flatfish genera (*Pleuronectidae, Bothidae*) occurs on the spawning grounds off Cannery Row, Monterey.
4) The heaviest avian consumer of juvenile *Loligo* is the rhinocerus auklet.
5) Dall's porpoise feeds on *Loligo* during its northward and southward migration 11 months of the year.
6) Three of the important marine resources in Monterey Bay—anchovy, salmon, and commercial squid—are all intimately

*euphausiids.

associated in a food web based largely on crustaceans such as *Euchausia*, *Thysannoessa*, and crab megalops. These are prey of salmon, anchovies, commercial squid, blue sharks, shearwaters and the large whales.

(6) Food chains: squid prey and competitors
Project Leader: G.M. Cailliet

Since September 1975 over 2000 individuals of *Loligo opalescens* have been taken from large midwater trawls, commercial anchovy haul subsamples, and from spawning ground catches with 350 of these used for analysis of prey composition and shipboard and laboratory digestion rate experiments. In addition, 700 individuals have been utilized to assess feeding chronology. Subsamples from anchovy boats and midwater trawling cruises have allowed us to study pelagic assemblages in Monterey Bay, especially those associated with non-spawning squid.

Loligo opalescens has been found to consume a variety of prey items that differ depending upon where the animals were taken. Offshore, in deeper water, euphausiids played a prominent role, while more inshore, on the spawning grounds, other crustaceans and juvenile gastropods were more important. A comprehensive list of prey items found in squid stomachs is in preparation, and these results will be compared by size, sex, and location.

Field experiments on digestion rates indicate that squid have an extremely rapid digestion rate, comparable, or even more rapid, than estimates for other fast-swimming pelagic predators. Our preliminary laboratory experiments generally support this conclusion.

Estimated fullness and state of digestion and weight of prey per body weight of squid at intervals of several hours over 24-hour periods indicate that squid feed more intensely during daylight, peaking during midday, and to a much lesser extent at night. The chronology evident from these estimates suggests that squid have a rapid rate of digestion, requiring only five or six hours for completion, corroborating the high rate found in the digestion rate experiments.

From catches of large midwater trawls and commercial anchovy purse seine hauls recurrent assemblages of pelagic organisms in Monterey Bay were dominated by *Loligo opalescens* and *Engraulis mordax*, but the list of other frequently occurring organisms includes *Sebastes* spp., *Merluccius productus*, scyphomedusae, *Torpedo californica*, *Citharichthys sordidus*, *Porichthys notatus*, *Genyonemus lineatus*, *Peprilus simillimus*, *Clupea harengus pallasii*, and euphausiids.

Publications

Broenkow, W.W., W. Abrahams, and R.R. McInnis, A CTD data acquisition system for coastal application, Proc. of 4th STD conference, San Diego, California, in press.

Broenkow, W.W., S.R. Lasley, and G.C. Schrader, California cooperative oceanic fisheries investigation hydrographic data report, Monterey Bay, January to December 1975. MLML Tech. Publ. 76-1.

Broenkow, W.W., and W.M. Smethie, Jr., Surface circulation and replacement of water in Monterey Bay, *Estuarine and Coastal Mar. Sci.*, submitted.

Hurley, A., Personal communication, 1976.

McGowan, J.A., Observations on the sexual behavior and spawning of the squid, *Loligo opalescens*, at La Jolla, California, *Calif. Fish and Game*, 40(1), 47-54(1954).

McMahon, J.J., and W.C. Summers, Temperature effect on the development rate of squid (*Loligo pealei*) embryos, *Bull. Mar. Biol. Lab. Woods Hole*, 141(3), 561-567(1971).

Cooperating Organizations

California Department of Fish and Game, Long Beach and Monterey, California
California Marine Research Committee
Northwest Fisheries Center, Seattle, Washington
Southwest Regional Calibration Center, San Diego, California

Studies Toward the Optimal Management and Environmental Effects of Sea Urchin Fisheries

Paul K. Dayton, Mia J. Tegner and Joseph H. Connell

This project is an attempt to examine some of the ecological consequences of the red sea urchin fishery in southern California. In 1975, this fishery removed 7.3 million red urchins from kelp bed habitats, primarily from the northern Santa Barbara Channel Islands. The consequences can be placed into two major categories: 1) effects of the fishery on the population dynamics of red urchins, and 2) effects of the fishery on the kelp bed community in general. Tegner and Dayton at UC-San Diego, are seeking answers to the first question; Connell at UC-Santa Barbara is seeking answers to the second question.

Effects of fishery on population dynamics

Our major efforts during the past year have been devoted to understanding the patterns of recruitment of sea urchin larvae to benthic life, a process of fundamental importance to sea urchin population dynamics. We have been studying the settlement and survival of post-metamorphic urchins of the two major west coast species, the commercially exploited red urchin, *Strongylocentrotus franciscanus*, and the smaller purple urchin, *S. purpuratus*, in order to determine the effects of harvesting on local populations. Our results indicate that the two species show very different recruitment behavior patterns and that the commercial fishery is affecting nursery grounds as well as the reproductive potential of red urchins.

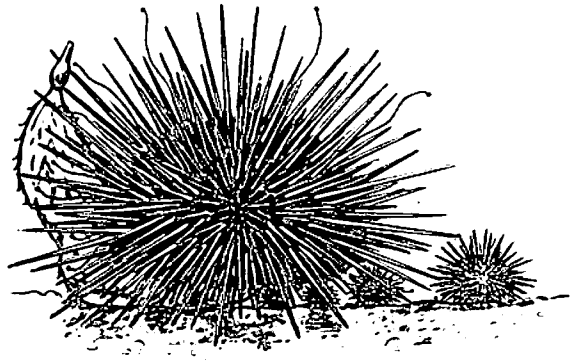
Small purple urchins, quite flexible in their recruitment behavior, are found in a variety of microhabitats: in kelp holdfasts, in coralline algae, in cobble, under rocks, and under adult urchins. Small red urchins are far less versatile in their recruitment behavior; they are found almost exclusively under the spine canopy of conspecific adults. These different recruitment patterns suggest that the two urchin species have very different colonizing abilities.

The tests of adult red urchins are situated 1-2 cm above the bottom, resting on the short spines of the oral surface; small urchins are located among these spines (see Figure). Field and laboratory observations suggested that juvenile red urchins seek out the adults of their own species. For example, a small reef was cleared of all red urchins in August of 1975; 208 purple urchins remained. Four months later, after substantial recruitment had taken place in the general area, nine of the 10 juvenile red urchins found on this reef were under the single adult red urchin which had immigrated onto the reef. The 10th was associated with the spine canopy of a purple urchin. Furthermore, recently collected small red urchins rapidly cluster under larger conspecifics in aquaria.

Investigation of recruitment

We conducted experiments in the Point Loma kelp bed which demonstrated that the recruitment of juvenile red urchins is not random with respect to the presence or absence of adults and that recruitment is not equal in equal areas. To further test the hypothesis that settlement, and/or survival, of juvenile red urchins depends upon the presence of adults, we carried out small-scale fishing experiments designed to simulate commercial fishing practices. The number of juvenile red urchins was significantly lowered by fishing as compared to controls. The variable factors that could alleviate this effect on recruitment are the number of adults and subadults left behind after an area has been harvested, and immigration of other urchins into fished areas. We are now working with commercial fishermen in San Diego to determine the importance of these variables on a larger scale.

This nursery association offers two advantages to the juvenile red urchins: a food source and protection from predators. The small urchins share the drift kelp snared and anchored by the larger urchin. However, the potential refuge from predators offered by the spine canopy may be the most important aspect of this association for the small urchins, juvenile abalone, and other motile species found under adult red urchins. Small urchins are very susceptible to fish predation, and sheephead often follow fishermen to feed on small urchins as the adults are harvested. Juvenile red urchins move towards the periphery of the spine



Courtesy of Science magazine

Juvenile red sea urchins cluster under and around the spine canopy of adult red urchins. This nursery association offers the small urchins protection from predation and a chance to share the drift kelp which the adult has snared and anchored

canopy as they grow, still clustering close to the adult when they no longer fit under the spine canopy (see Figure). The population size structure of red urchins in unfished areas suggests that juveniles are protected from predation until they reach a size of 30-40 mm, when they begin to move away from the adults. Juveniles then face intensive predation pressure until they achieve a partial refuge in size. Purple urchins, which do not rely on a nursery association for recruitment, show a very different population size structure.

We are continuing to monitor other population parameters necessary to determine what sort of management scheme should be placed on the red sea urchin fishery to ensure optimum sustainable yield. This work is being carried out at our permanent study areas in the Point Loma kelp bed and on local fishing grounds as well. Parameters under study include age structure, growth rates, gonad index, fecundity and natural mortality. Growth rates are being studied with the use of cohort analysis, tetracycline labeling, growth ring analysis, and laboratory studies. We have conducted experimental manipulations of density and food supply in the field and laboratory to study the effects of these parameters on fecundity. We will continue these observations through the final year of this project, but the data thus far are available for inspection.

Effects of fishing on the kelp bed community

We have hypothesized that the red and purple urchins are competing species, and that the urchin fishery, by removing reds, will reduce competitive pressure on purples and lead to an increase in the latter's abundance. During the first year of our grant, we designed field experiments to test whether red and purple urchins were competing. These experiments were conducted in a shallow subtidal boulder field on Santa Cruz Island. They showed that once the reds had been removed, purple urchins quickly moved into "favorable" microhabitats vacated by reds. No such movement of purples occurred in controls where reds were counted and replaced in the "favorable" microhabitats. During the second year of our grant, we showed, by the use of subtidal enclosures, that red urchins depressed both the growth and gonadal development of purple urchins. In addition to demonstrating competition in the field, we were able to provide a description of the mechanism of competition (Schroeter, in preparation).

Although these findings are theoretically interesting, they do not tell us directly whether removing reds increases the abundance of purples. We began two series of experiments to find this out. The first series was begun between one and one and a half years ago in several low intertidal pools on the west end of Santa Cruz Island. We removed red urchins from some pools and counted and replaced them (as controls) in others. Subsequently we have sampled these pools at varying intervals. Seven months after the first set of pools was manipulated, we detected significantly more settlement of purple urchins in the removal pool when compared to the control, but no difference in the settlement of red urchins between the removal and control pools was found. We began a second series of experiments at a shallow subtidal reef near UC-Santa Barbara. There are a number of isolated troughs at the top of the reef that are dominated by red urchins. We chose pairs of troughs and removed the red urchins from one of each pair of troughs. As at Santa Cruz Island, we counted and replaced the red urchins in the other member of each pair as controls. We have not yet resampled these troughs.

The results at Santa Cruz Island suggested the following question: How will a new urchin guild, with fewer reds and more purples, affect the kelp community algal species? Leighton (1966) documented the destruction of a kelp stand near Palos Verdes by mixed aggregations of red and purple urchins. This and other studies (North and Pearse, 1970) led to the prediction that the fishery will result in more extensive kelp beds by reducing abnormally high urchin densities and their harmful overgrazing effects (Kato, 1975). In order to see if this is

likely, we first need to find out how important sea urchin grazing is to southern California kelp beds in general.

Lowe (1975) observed that red urchins tend to recruit to the benthic population underneath adults of the same species. Work by us, and Tegner and Dayton (in press), has verified this, and has shown that in contrast, purple urchins settle from the plankton into a much wider range of microhabitats. Urchins of both species settle into kelp holdfasts, but presumably because of their more eclectic settling behavior, purple urchins should occur more frequently and at higher densities in *Macrocystis* sp. holdfasts than reds. During the past year, David Coon (a research associate of Dr. Neushul's) and I dissected 162 washed-up and 14 attached kelp holdfasts. Purples comprised 91 per cent of all the urchins we found in both sets of holdfasts. If urchins, by burrowing into holdfasts, cause significant kelp mortality, our sampling shows that purples are much more important than reds in this regard.

To see whether adult red and purple urchins affected *Macrocystis* holdfasts differently, Coon and I placed equal weights of red or purple urchins of average size on holdfasts of isolated kelp plants around their primary dichotomies. We made observations every one to two weeks for two months. Within a week, purple urchins burrowed into the holdfasts around the primary dichotomies. In contrast to the purples, all the red urchins moved down from the primary dichotomies and remained around the periphery of the holdfasts where they attached to the bottom without burrowing into them.

The information from these two studies is not sufficient to build a model describing the effects of urchins on a kelp population. However, together with the results of the red urchin removals on Santa Cruz Island, they do allow us to predict the following likely consequences of the fishery: 1) purple urchin abundance will increase in heavily fished areas; 2) if the red urchins removed by the fishery are eventually replaced by an equal biomass of purples, kelp mortality might well increase. Our experiment of placing urchins on holdfasts shows that replacing a given weight of red urchins with an equal weight of purples causes more direct damage to the holdfast. It could also increase mortality indirectly by causing bits of holdfasts to break away and become drifting plants. These "drifters" have been shown to be a major cause of kelp mortality, because they tangle otherwise healthy plants and increase the probability of the latter being ripped up in storms (Rosenthal *et al.*, 1974). More purple urchins in the subtidal will increase the supply of purple urchin larvae. This could result in a greater number of *Macrocystis* holdfasts being colonized by juvenile purple urchins, and being weakened by their burrowing activities. Loss by either mode of attack (borrowing of young or adult grazing) will increase the number of drifting plants in local beds.

Conclusions

To summarize, our study has yielded the following results:

1) We have demonstrated interspecific competition in field populations of motile animals, and have described its mechanism.
2) We have also demonstrated the phenomenon of competitive release, where the abundance of one species increases in the absence of its competitor.
3) We have described differences in the settling and grazing behavior of red and purple urchins.

The data gained from these studies support our initial prediction that the red urchin fishery will exacerbate any existing negative effects that urchins have on kelp. These results are being made available to Susumu Kato, a biologist with the National Marine Fisheries Service. It was through Mr. Kato's efforts that the fishing was begun. Because of his knowledge of the fishery, he is in the best position to suggest practical applications of our findings and to disseminate this information to harvesters and processors.

Publications

Tegner, M.J., Kelp, herbivores, and sea otters. Talk given at an environmental symposium for teachers: Kelp and kelp bed communities. Scripps Institution of Oceanography, April 3, 1976.

Cooperating Organizations

California Department of Fish and Game, Long Beach, Monterey and San Diego, California
Kelco Company, San Diego, California
Local fishermen
National Marine Fisheries Service, La Jolla and Tiburon, California

Studies of Fish Muscle Proteins and Fresh and Frozen Seafood Technology

W. D. Brown

Preliminary studies indicate that atmospheres containing elevated levels (e.g. 50 per cent) of carbon dioxide effectively inhibit microbial growth on fish surfaces, resulting in improved quality following refrigerated storage of products so treated. The inclusion of low levels (1 per cent) of carbon monoxide may improve color in fish subjected to such atmospheres. A method for determining the amount of carbon monoxide bound to myoglobin, as well as the amounts of other myoglobin derivatives present, has been developed.

Controlled atmosphere storage of fish

This work has been done in cooperation with TransFresh Corporation, a company that provides modified atmospheres for ship, rail and truck transport of a number of fruits and vegetables. The primary objectives to date have been (1) to ascertain the efficiency with which carbon dioxide inhibits microbial growth on the surface of fish, thus reducing the rate of deterioration and extending shelf life or providing a more effective transport system, and (2) to evaluate whether the inclusion of low levels of carbon monoxide in such mixtures would result in color improvement. The main reason for interest in the latter topic is that red meats stored under elevated levels of carbon dioxide do discolor. Less information is available about fish, but discoloration could be a problem, particularly in more heavily pigmented species.

The initial trials with fish involved rex sole and red snapper obtained fresh at the docks in Monterey. Fish fillets were held at refrigerated temperatures in atmospheres containing carbon monoxide (3 per cent), carbon dioxide (50 per cent), oxygen (10 per cent) and nitrogen (37 per cent). Controls were stored in air. Samples were removed at varying time intervals and examined for development of off-odors and/or colors. Microbial examinations were performed on each sample. It was found that atmospheres containing carbon dioxide were effective in inhibiting microbial growth and in preventing the development of off-odors. The presence of carbon monoxide had, however, little effect on color. A significant post-treatment effect was obtained after samples were removed from the CO_2-enriched atmospheres and held in air.

These promising findings led to a more detailed study, done this time with salmon and red snapper obtained through Ocean Beauty Seafoods in Sacramento. Samples were stored in two levels of carbon dioxide, 20 per cent and 40 per cent, and in the presence or absence of 1 per cent carbon monoxide. Again air controls were included. This investigation is still in progress. A number of chemical assays are included: peroxide values and thiobarbituric acid assays for lipid oxidation; determination of hypoxanthine levels, a test sometimes used for freshness; trimethylamine, for freshness or fishiness; and ammonia levels for similar purposes. Each sample is also examined for microbial load (cooperating here is Silliker Laboratories), as well as for color and odor using a suitably constituted panel of observers and appropriate statistical analysis. The results are encouraging, generally indicating that deterioration is slowed in the presence of carbon dioxide; that carbon monoxide improves color of red snapper held in such atmospheres; and that the treatments do yield a better product in the eyes (and noses) of the panel.

Myoglobin analysis

In the course of the work just summarized it became necessary to develop a procedure for the analyses of various myoglobin derivatives in order to determine the extent to which carbon monoxide was reacting with the fish myoglobins. A general method was developed which determines relative and absolute pigment concentrations of myoglobin derivatives in fish (and meats), both untreated and treated with atmospheres containing carbon monoxide. Carboxymyoglobin, metmyoglobin, and deoxymyoglobin plus oxymyoglobin can be determined using simple extraction and absorption spectrophotometry. The method does not permit independent measurement of deoxymyoglobin.

Enzymatic reduction of myoglobin

The oxidized form of the myoglobin pigment, so-called metmyoglobin, is brown and its presence results in an undesirable surface appearance in fish in which the oxidation has taken place. It also contributes to discoloration problems in canned fish, including tuna. Thus there is interest in systems reversing or preventing the oxida-

tion. Enzyme systems are known to do this in some animals; little work has been done with fish. These enzyme systems were, therefore, studied in two species of fish, mackerel and bluefin tuna. Work has included determining areas within the fish in which the enzyme is most active together with various features of its biochemical properties, such as optimal pH and temperature. We have also examined the effects of anaerobic versus aerobic conditions on enzymatic activity and the effect of certain inhibitors. More recently, the enzyme from bluefin tuna has been purified by ammonium sulfate fractionation and a combination of gel filtration techniques. A 940-fold purification has been achieved. The enzyme has been shown to be activated by ferric and iodide ions and, particularly, by manganese. On the other hand, copper and chloride ions were inhibitory.

Lipids of skipjack tuna

We have previously reported that lipid oxidation was in part responsible for a browning problem encountered when precooked tuna loins were frozen and stored. The literature revealed no detailed information about the lipids of skipjack tuna, the species in question. Thus, one of the trainees on this project has studied this problem. Because the practical problem was encountered on the surface only, we have studied skin lipids, subcutaneous, and interior muscle lipids independently. In broad terms, there are no marked differences in composition among lipids from these three sources. Thus, the more pronounced oxidation on the surface is apparently due to the increased concentration of lipids found there and the exposure to air. In a different study we have recently found that surfaces of "good" precooked loins had peroxide values (a measure of lipid oxidation) of 90 contrasted to values of about 15 in the interior of the same loins. Vacuum packing in a moisture and air-impermeable film appears to be the method of choice for handling precooked loins to be frozen for storage. This suggestion has been made to the industry, and it apparently works.

Edible coatings for fish products

Only a preliminary study has been completed in this area. Future work is contemplated. One product, "Flavor-Tex", was utilized for coating red snapper fillets which were stored along with uncoated controls. Subsequently, samples were cooked in a variety of ways, and evaluated by a panel of observers. The panel could not detect differences between coated fillets and controls. Thus, the material does not impart any off-odor or flavor, at least under the conditions tested to date.

Histamine review

The Principal Investigator on this project was asked by the Editors of *Advances in Food Research* to do a review article dealing with so-called histamine toxicity from fish (scombroid poisoning). With the able assistance of a Trainee, Sally Hudson Arnold, from project R/F-22, the review has been completed and submitted to the Editors. It is too lengthy to lend itself to summary here. Hopefully it provides a useful statement of the nature of the problem at present and, perhaps, a basis for future work in this area.

Publications

Fosmire, G.J., and W.D. Brown, Yellowfin tuna (*Thunnus albacares*) myoglobin: Characterization and relative stability, *Comparative Biochemistry and Physiology*, **55B**, 293-299 (1976).

Takeoka, G., The lipids of skipjack tuna. M.S. Thesis, 1976.

Williams, J.D., Jr., and W.D. Brown, Characterization of myoglobin from Atlantic and Pacific green sea turtles, *ibid.*, **54B**, 258-259 (1976).

Reports and/or papers presented at conferences

Meeting of the Research Committee of the California Seafood Institute, Sacramento, October 1975. Report given on work done in this project.

Tuna Research Foundation-Food and Drug Administration Tuna Workshop held at the National Canners Association, Berkeley, February 1976. Paper given on "Tuna Pigments".

National meeting of the Institute of Food Technologists in Anaheim, June, 1976. Paper given on "Preservation of refrigerated fish with controlled atmospheres". This paper will be published.

Cooperating Organizations

California Seafood Institute, Research Committee, Sacramento, California

D. H. McKee, Inc. ("Flavor-Tex"), Tampa, Florida

Silliker Laboratories, Vernon, California.

Transfresh Corporation, Salinas, California

Tuna Research Foundation, Terminal Island, California

Histamine Toxicity from Fish Products

H.S. Olcott, R.J. Price, W.D. Brown, and Leonard Bjeldanes

In this intercampus project, Olcott, Price, and Brown at UC-Davis have investigated the causes of occasional illness from consuming scombroid fish (tuna, mackerel); and Bjeldanes at UC-Berkeley has developed a rapid, low-cost, thin-layer chromatographic method for histamine in fish products. The latter worker also found that certain diamines present in toxic tuna greatly enhance the biological activity of orally administered histamine in laboratory animals.

SCOMBROID FISH POISONING

A continuing study of the literature on this subject has resulted in a bibliography of 250 titles, and in a review of the present status by S. H. Arnold and W. D. Brown which will appear in a forthcoming volume of *Advances in Food Research*. Without exception, reported cases of poisoning occurred shortly after eating a meal in which a fish component contained relatively high levels of histamine, the resultant of enzymatic decarboxylation of the naturally occurring non-toxic histidine. Both the literature and self-experimentation have indicated that taking histamine by mouth in the human does not by itself cause the syndrome characteristic of so-called "Scombroid" poisoning.

One objective was to develop new, accurate and rapid methods for histamine analysis since this constituent may be utilized by Government authorities as a compound indicative of spoilage, regardless of whether it is or is not the sole agent responsible for illness. The Berkeley group, reported separately (see below), and the Davis group have worked out methods which should be satisfactory for this purpose. The Davis procedure depends upon thin-layer chromatography of a methanol extract of tuna meat.

Search for identification of spoilage bacteria

Considerable effort has been expended on determining the nature of the spoilage bacteria in two fresh skipjack which had been obtained from Hawaii by air and allowed to spoil in the laboratory. Numerous isolations and identifications of the individual organisms were made, and the ability of each to decarboxylate histidine was determined. This work is being prepared for publication.

A bioassay was not found for the toxic substance or substances in the canned product known to cause human illness. "Toxic" tuna has been offered to and consumed by dogs and cats without observing usable results. Similarly, pigs did not show a reaction. Quail are killed when fed toxic tuna and Daphnia are killed by exposure to toxic tuna, but histamine itself gives the same results so the reactions do not parallel the human experience.

ROLE AND DETERMINATION OF HISTAMINE—Research at Berkeley

The original major objectives of the project were: first, to determine whether histamine alone could account for the sporadic toxicity of certain scombroid fish, and secondly, to develop analytical methods for the toxin or toxins implicated in fish poisoning. Various secondary objectives were envisioned, which were to provide data for evaluation of the primary goals. These secondary objectives include determination of the effect of bacterial metabolism on certain tuna components, conditions for histamine production in tuna, and development of assay methods for known tuna components.

Several significant developments have occurred during the past year of work on this project. It became clear that histamine was involved as an important factor in the toxicity of scombroid fish. Thus, a rapid, cheap analytical method for histamine in tuna was required in our studies. Such a method was also seen as useful for screening of tuna on a commercial scale. A very simple, semiquantitative, chromatographic method was developed, which satisfied our needs and, we feel, will be of considerable use to the tuna industry. The method simply requires thin-layer chromatography of fish extracts or chunks of meat. Interfering substances are eliminated by choice of eluting solvent and visualizing agent.

While it has been established that histamine is involved in scombroid poisoning, it also became apparent that histamine is not the only toxin involved. Thus, the toxicology of other substances that are known to occur in toxic fish in addition to histamine, was studied. A series of experiments involving oral administration of various substances to rats, mice and guinea pigs has led us to the conclusion that the activity of histamine is greatly increased by certain diamines, most notably putrescine

and cadaverine. We feel that these compounds in addition to histamine may account for the toxicity of scombroid fish.

With the realization that diamines play an important role in fish poisoning, analytical methods for these substances became necessary. We have explored several thin-layer and gas chromatographic methods for diamines in fish material, and some of these methods look promising. With certain modifications we expect to determine several diamines, including histamine, in a single analytical procedure. The methods appear highly promising and their development is near completion.

We are most encouraged by the results of our first year's studies. We expect to obtain further answers to major questions concerning cause and prevention of scombroid fish poisoning by our continued efforts in this area.

Publications

Arnold, S.H., The histidine decarboxylase activity of selected microorganisms isolated from skipjack tuna, M.S. Thesis, 1976.

Lin, J.S., J.D. Baranowski, and H.S. Olcott, Rapid thin-layer chromatography—Densitometry determination of histamine in tuna. *J. Chromatography*, in press.

Schutz, D.E., G.W. Chang, and L.F. Bjeldanes, Rapid thin-layer chromatographic method for histamine in fish products, *J.A.O.A.C.*, in press.

Cooperating Organizations

The Star Kist Tuna Company, Terminal Island, California

Methods for Quality Assessment in Fishery Products

Berkeley
R/F-23

George W. Chang

Trimethylamine (TMA) is one of the major components of the smell of spoiled marine fish. An increased TMA level is so characteristic of spoilage that the TMA levels have been used as an objective index of fish quality. A specific electrode was developed in order to simplify the measurement of TMA. This electrode is suitable for the measurement of TMA in aqueous solutions and in homogenates of fish muscle.

Introduction

The trimethylamine (TMA) level in fish is an important factor in the subjective evaluation of fish quality because of its close association with fish spoilage and its low odor detection threshold. Measurement of the TMA level provides an objective measurement of fish spoilage.

A simpler method of TMA determination is needed for use in fish quality control. The widely used colorimetric method involves several steps, including an extraction of TMA with toluene (Dyer, 1945). The method is tedious and the toluene is toxic and expensive. Recently, gas chromatography has been used (Keay and Hardy, 1972; Ritskes, 1975). The chromatographic method is rapid and accurate, but the preliminary sample handling is tedious and the equipment requires a high initial investment, constant maintenance, and a cumbersome gas supply.

Ion-specific electrodes have greatly simplified many analytical problems. These electrodes have the advantages of being rapid, accurate, and simple to use. Many of them can be used with an ordinary pH meter. Therefore, a TMA-specific electrode was developed for use in fish quality control.

The starting point for the design of a TMA-specific electrode was a commercial gas-sensing ammonia electrode (Orion Research Inc., Cambridge, Mass.). This electrode consists of a glass (pH) electrode and an AgCl reference electrode bathed in an internal filling solution of NH_4Cl, neutral salt(s), and a dye. The internal solution is separated from the sample by a gas-permeable, ion-impermeable membrane. Dissolved ammonia from the alkalinized sample solution diffuses through the membrane and raises the pH of the internal solution. At equilibrium, the pH of the internal solution is an accurate reflection of the ammonia concentration of the sample.

TMA-specific electrode

The inner filling solution of the Orion ammonia electrode was replaced by a solution containing 0.01M TMA hydrochloride and 0.04M KCl. The electrode was connected to a Beckman Expandomatic pH meter model SS-2. The electrode was mounted 20° from the vertical to prevent trapping bubbles of air between the sample and the gas-permeable membrane.

TMA was measured by adding either 0.5 ml of fish extract or a small amount of a standard TMA solution to about 8 ml of water in a 10-ml volumetric flask. This was followed by 0.05 ml of 37 per cent formaldehyde and 0.10 ml of 10M NaOH. Water was added to bring the volume to 10.0 ml. After mixing and shaking, the stoppered flask was left at room temperature to allow the formaldehyde to complex with ammonia in the sample. After 30 min, the contents of the flask were poured into a 7 dram (25 x 50 mm) shell vial. Then the electrode was inserted and the sample was stirred with a magnetic stirrer. The electrode potential was measured after it had stopped drifting and translated into TMA concentration with a standard curve.

Preparation of fish extracts

Fresh fish were purchased at local markets. 100g of fish were homogenized with 200 ml of deionized water and 3.5 ml of 37 per cent formaldehyde in a Waring Blendor. The homogenized fish was then vacuum filtered through filter paper and the filtrate was used for TMA analysis. Filtration was unnecessary for the electrode analyses, but was important for the picric acid procedure.

Colorimetric determination of TMA

The picric acid procedure was adopted for use with the equipment in our laboratory. A sample of fish extract or standard TMA solution was added to a 20 ml scintillation vial, and enough water was added to bring

the total volume to 2.0 ml. One-half ml of 3.7 per cent formaldehyde was added, followed by 5 ml of toluene and 1.5 ml of 5M KOH. After shaking and separation of aqueous and organic phases, about 4 ml of the organic phase was then transferred into another scintillation vial which contained about ⅓g of anhydrous Na_2SO_4. After shaking and letting the Na_2SO_4 settle out, 2 ml of the toluene solution was added to a test tube containing 2 ml of 0.02 per cent picric acid in toluene. After mixing, the 410 nm absorbance of the solution was read.

Formaldehyde was added to the sample solution to reduce the response of the electrode to ammonia. Without formaldehyde, the Orion electrode responds equally well to ammonia and TMA. The concentration of formaldehyde chosen was sufficient to prevent interference from ammonia but low enough not to release irritating fumes.

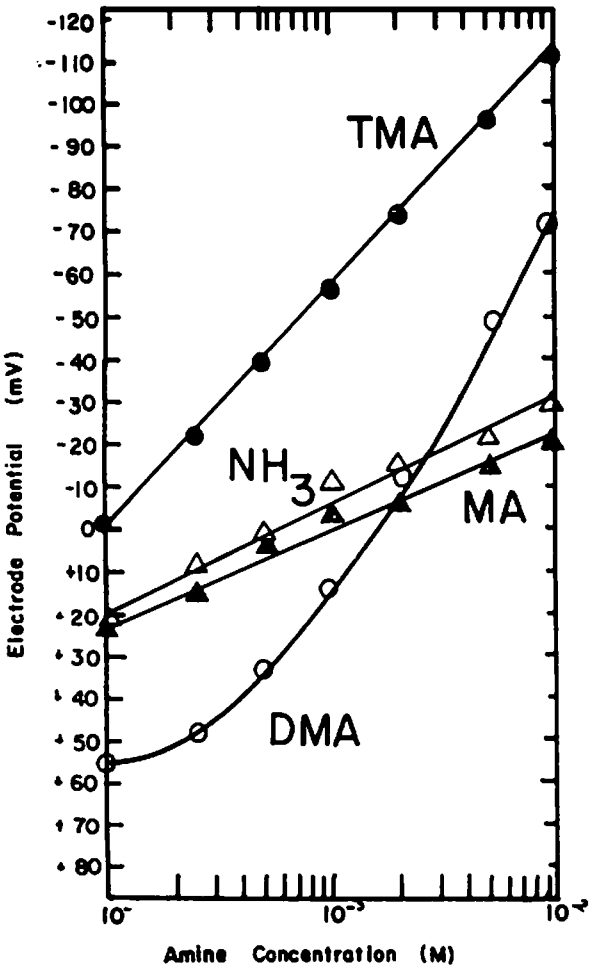


Fig. 1. Response of the TMA electrode to trimethylamine (TMA), dimethylamine (DMA), methylamine (MA) and ammonia

Once formaldehyde was added to sample solutions, it became necessary to modify the internal filling solution. The electrode potentials obtained with the standard Orion internal filling solution were erratic and not reproducible. The internal filling solution described in the experimental section was found to be suitable for samples containing 0.10-10 mM TMA, the range of concentrations expected in fish.

The response and selectivity of the TMA electrode were first tested in aqueous solutions of amines. The results are summarized in Fig. 1.

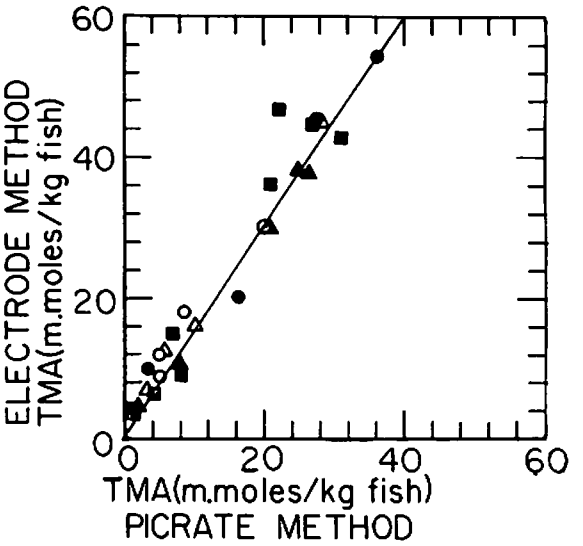


Fig. 2. Measurement of TMA in extracts of fish after storage for various times at 5°C. Correlation between determinations made with the electrode and those made with picric acid method. The fish used were the West Coast varieties of English sole (*Parophrys vertulus*, ○), ocean perch (*Sebastodes alutus*, ●), ling cod (*Ophiodon elongatus*, ▲), sand dab (*Citharichthys stigmaeus*, △), and red snapper (*Sebastodes miniatus*, ■)

TMA measurements made on aqueous solutions by the electrode agreed very well with those made by the picric acid procedure. When, however, the electrode and the picric acid methods were compared using fish extracts, the agreement was somewhat poorer (Fig. 2). The data were fitted by the line TMA (by electrode) = 1.452 TMA (by picric acid) + 1.107 mmoles/kg fish flesh. The correlation coefficient was 0.971. The poorer agreement is probably attributable to the fact that the electrode is not quite as selective for TMA over ammonia as the picric acid method is. Whereas the electrode has selectivity factors ranging from 10-500, the picric acid method consistently had selectivities of about 100.

Despite its modest selectivity, the electrode offers many advantages for fish quality control. It is fast, accurate, and economical to use. TMA determinations can be done with only a fraction of the materials, apparatus, sample handling, and time required for the conventional picric acid procedure. The electrode is much simpler and demands much less laboratory skill than the conventional method. The electrode's small size, simple operation, and simple instrumentation requirements recommend it for field work.

Publications

Chang, G.W., TMA electrode for fish quality control. Paper presented at the meeting of the Pacific Fisheries Technologists, Orcas Island, Washington, February 1976.

Idem, The genetics and bacteriology of TMA production. Seminar in the Department of Bacteriology, UC-Davis, May 1976.

Chang, G.W., W.L. Chang, and K.B.K. Lew, Trimethylamine-specific electrode for fish quality control, *Journal of Food Science*, 41, 723 (1976).

Cooperating Organizations

California Agricultural Experimental Station, Berkeley, California

Limited Entry: An Assessment for California Fisheries

Santa Barbara
R/F-24A

Alan J. Wyner, Biliana Cicin-Sain and John E. Moore

Two phenomena, increasing demand and dwindling stocks, characterize many California fishery resources. New management initiatives seem imperative. Limited entry has recently been enacted for the California abalone fishery and is a consideration for other fisheries in California and elsewhere. What are the political and economic consequences of this and other possible fishery management innovations?

Management approaches for marine fisheries: The case of California abalone

The world's fishery resources are not limitless and the growing recognition of this fact has been the impetus behind a new surge in this country and elsewhere toward a more active governmental management of fishery resources. A management technique known as "limited entry" has attracted worldwide attention and undergone actual implementation during the past few years. Essentially, limited entry refers to any one of several ways in which government controls the number of fishermen who are legally eligible to take a fish species (usually for commercial purposes). Experience with limited entry programs is too recent for a thorough evaluation. It is clear, however, that every limited entry program should be designed to fit the specific needs and conditions of each particular situation; i.e., universal rules will not work in all cases. Furthermore, limited entry programs in any one fishery may have impact on other fisheries and these consequences must be carefully considered. There are, in addition, serious administrative problems.

Probably the single most important generalization to be made about the abalone resource, and especially its commercial use, is that this decade has seen a drastic decline in its availability. Major reasons for this are the exhaustion of accumulated (virgin) stocks, the frequent picking of immediate sublegal size abalone and the resulting high mortality rate from bar-cutting, sea otter foraging, and the large number of divers. The combined impact of these forces, coupled with such things as the continued closure of the north coast, has resulted in a serious decrease in the abalone harvest. Indeed, many formerly rich ocean beds are now barren.

It became apparent to many that some action was required if the resource were to be preserved in the area between Point Lobos and the Mexican border. Those engaged in the policy-making process had three basic management plans to consider: limited entry, limited access, and resource augmentation. While there is no reason why each of these basic types must be implemented separately, the interaction of the species' biological requirements with political and administrative constraints and realities dictated an abalone policy approach that leaned heavily upon limited entry for the commercial fishery.

The development of any abalone management plan, and especially its successful implementation, depends upon the interaction of resource managers, affected interest groups and whatever public sector groups define abalone resource issues as relevant to their goals. To better understand the way these different parties define the issues and express their preferences for problem solutions, we conducted extensive interviews with all segments of the industry, recreational users, resource managers and relevant public sector groups. The resulting data reveal that there is a fairly high degree of consensus on problem definition, but, as to be expected, there are differences when management preferences are stated. Reflecting the process of compromise that produced AB2224, a law limiting the number of commercial abalone divers (for more specifics, *See* under "Conclusion"), we found considerable support for the limited entry thrust of that recently passed law. It also appears that resource augmentation is something of a motherhood issue. Everyone wants to increase the supply of abalones; however, finding the money and scientific knowledge for a successful resource augmentation program may be a very different matter.

By the time the new legislation (AB2224) was heard by relevant legislative committees, the process of compromise had managed to include only those features in the bill that would not receive strong opposition. Indeed, there was no visible opposition at all. With respect to future abalone management policy, there are some

very clear areas of agreement and disagreement between the interested parties as well as some mixed reactions on a few possible policies. For those subjects of agreement—such as the widely shared desire for resource augmentation—the political process "simply" requires a coordinated campaign to secure the necessary money and talent. However, where there is disagreement over future policy—such as the use of area rotation or containment of the sea otter—the end result is determined by the relative political effectiveness of the affected parties. The role adopted by the California Department of Fish and Game (DFG) in those policy areas where disagreement exists will be crucial. DFG is affected by its clientele, and in turn the Department has an important impact on its clientele. It is often very hard to know the net impact of DFG as a result of this two-way interactive process, but it is obvious that DFG's policy position will play a very important role in legislative considerations and the deliberations of the Fish and Game Commission. DFG is moving into a relatively new role as it becomes a more active, aggressive marine resource manager.

Conclusion

To conclude this brief summary, it may be helpful to recount the current (as of January 1, 1977) status of abalone management of California. Although there is no need to repeat the details of AB2224, some of its major provisions and intended effects should be remembered. The new law limits the number of commercial abalone divers by granting renewed diving permits only to those who currently hold a permit and additionally to a very small number of new divers. Limiting the number of "permanent" commercial divers, and presumably making it difficult for part-time divers to satisfy minimum landing requirements, the anticipated decrease in picking pressure and bar-cutting mortality from inexperienced divers are all expected to stabilize the declining resource base. In the sport sector, the open season has been reduced as has the daily bag limit. The north coast, the sea otter, area rotation and quotas are among the major issues with the abalone resource left unresolved.

Another unresolved question is posed by legislative provisions for adjusting the total number of commercial diving permits to the capacity of the resource. AB2224 and AB2880 provide a mechanism for limiting the number of commercial divers. The Fish and Game Commission has been delegated the responsibility for establishing the number of commercial permits to be issued at such time as the (then) current permits are reduced to 200, or in any event, no later than January 1, 1981. If the number of then current commercial permits is either greater or less than the number justified by the status of the resource, as determined by DFG, a drawing will be held to determine who actually get the permits. If the number of existing commercial permits is less than the resource can support, new commercial divers will be admitted through a drawing of qualified applicants. On the other hand, if the number of existing permits is greater than the resource can support, all commercial divers must take their chances in a drawing of qualified applicants, with qualification to be determined by either prior experience or the passing of a proficiency test.

What is clear from the above described situation is the possibility of controversy and conflict at such time as the Commission establishes the total number of diving permits to be issued. The then current commercial divers will not take lightly any rules which put them on equal footing with new entrants to the fishery. The delicate balancing of interests that produced AB2224 may slip into heated discussion.

Publications

Cicin-Sain, B., J.E. Moore, and A.J. Wyner, Management approaches for marine fisheries: The case of California abalone. In preparation.

Idem, Limiting entry to fisheries: Some worldwide comparisons. In preparation.

Idem, Decision-making for the management of fishery resources: Evaluative criteria, data needs and research problems. In preparation.

Idem, Managing the California abalone fishery. In preparation.

Idem, Public regulation of fishery resources: Changing expectations. In preparation.

Cooperating Organizations

Alaska Commercial Fisheries Entry Commission, Juneau, Alaska
California Abalone Association, Santa Barbara, California
California Department of Fish and Game, Sacramento, California
Canada Department of the Environment, Vancouver, British Columbia
Commercial processors for abalone, tuna and salmon
Environmental groups
Fishermen's unions
NOAA, Office of Sea Grant, Washington, D.C.
Sport and commercial fishermen's associations
Sport diving clubs

NEW MARINE PRODUCTS

Originally, this research was directed primarily at obtaining new drugs from the sea, but the program has recently been expanded to emphasize the search for chemical products of marine derivation that can find application in industry and agriculture. Thus, at Scripps new substances are sought useful as anti-fouling agents and as antimicrobial agents for shrimp disease control in mariculture.

Also, new halogen-containing and biodegradable compounds from marine organisms are being tested for application as agricultural chemicals. In another related project at Scripps, four new halogenated monoterpenes derived from algae have been isolated and identified, and three of these have been submitted for screening as insect-control agents. Some compounds that were isolated from marine algae as part of a search for antibiotics have been shown to be toxic to larval crustaceans potentially valuable to control barnacle settlement.

At UC-Berkeley, efforts are under way to assay for the presence of antiviral activity in marine algae collected from local habitats. Thus, it is hoped to develop therapeutic agents active against viral infections such as herpes simplex in humans.

Seaweed Products: Applications in Algae Control, Mariculture and Agriculture

William H. Fenical

Chemical substances produced by marine organisms may provide new products for use in a variety of commercial applications. This project is designed to explore the application of these compounds in algae control, aquaculture disease problem control, and as insecticides and herbicides.

Antialgal compounds from marine organisms

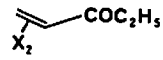
In an attempt to assess the potential of marine organisms to provide a natural algicide, a bioassay was perfected to detect algal growth inhibition using the marine diatom *Skeletonema costatum*. Extracts for assay were prepared from marine organisms collected in the Gulf of California while onboard R/V *Dolphin*. Lipid and aqueous extracts were made, and a number of 10 mg samples were each diluted to 2 ml. A series of further dilutions was then examined, to elucidate minimal levels of activity.

The results of over 50 extracts were obtained and the total picture can be exemplified by the behavior of four representative aqueous extracts, as shown in Fig. 1 (a)-(d). Graph (a) was obtained from the red seaweed *Lomentaria* sp., (b) from the brown alga *Dictyota*, (c) from a red sponge, and (d) from the tunicate *Aplidium* sp. All graphs show, in general, that concentrated extracts exhibit initial growth inhibitory effects. The seaweed extracts were most active, perhaps indicating the action of chemicals that reduce diatom epiphyte settling phenomena under natural conditions. While one would expect filter-feeding organisms to require chemical methods for prevention of fouling, the sponge and tunicate extracts showed poor toxicity [Graphs (c) and (d)]. On the contrary, at high dilution most extracts showed growth stimulation effects.

Antimicrobial agents for shrimp disease control in mariculture

Extracts of the red seaweeds *Bonnemaisonia nootkana* and *Asparagopsis taxiformis* showed strong antibacterial activity, and hence these seaweeds may have medicinal value in controlling the shrimp pathogen *Vibrio*. Thus, it became important to isolate and identify these antibacterials. Employing chromatography and mass spectrometry, the "active" components of *A. taxiformis* were identified as halomethanes, haloacetones, and haloacetic and acrylic acids (organic compounds containing a halogen—usually chlorine, bromine or both). The following specific compounds were identified, many of which are active against *Vibrio:*

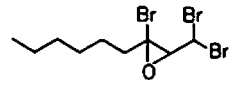
* CH_3I
CH_2ClI
* $CHCl_3$
* CCl_4
$CHBrCl_2$
$CHBr_2Cl$
$CHBr_3$
CBr_4
$CHBr_2I$

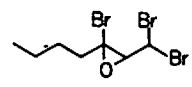


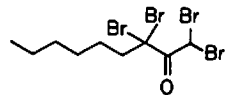
$CHX_2COC_2H_5$

It should be pointed out that we have identified methyliodide*, chloroform*, and carbon tetrachloride*, as natural products. These substances have been, in recent discussions, referred to as entirely "man-made" pollutants.

The antibacterials from *B. nootkana* have also been isolated and elucidated. Two sets of homologous ketones and epoxides, 1 and 2, appear responsible for the antibacterial activity of the extracts of this alga. We are currently synthesizing these substances as proof of structure and also so that proper testing can be completed.







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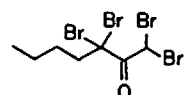

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The antibacterials we have isolated have been provided for *in vivo* testing with shrimp. While the reasons are not yet clear, shrimp appear to be less plagued by bacterial pathogens when culture tanks are engulfed

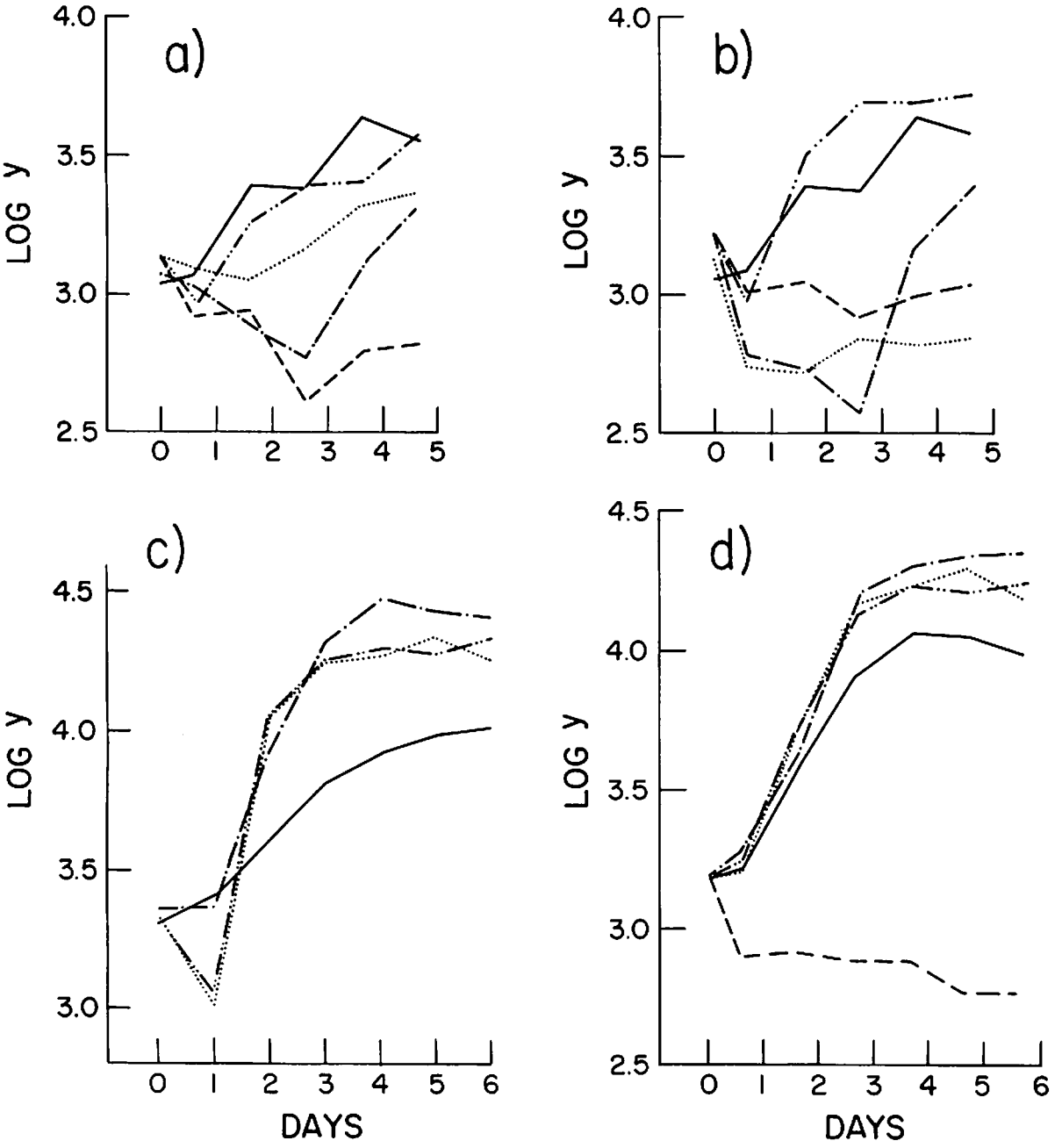


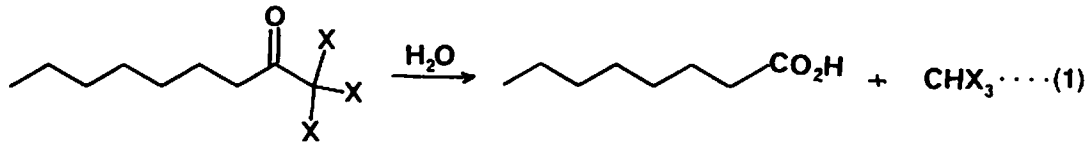
Fig. 1. Growth curves of the microalga *Skeletonema costatum* as a function of added aqueous extract of four marine organisms: (a) *Lomentaria* (red alga), (b) *Dictyota* (brown alga), (c) red sponge #52, and (d) black tunicate #54. The solid line represents a control or unhindered growth in each case. Dotted lines represent growth at various addend dilutions: ---- straight extract (~1.0 mg/ml), ----- 1/10 dilution, - - - - - 1/100 dilution, and · · · · 1/1000 dilution. y = Number of cells/ml, as measured by Coulter counter

with algal growth. We have not yet studied these particular species, but they may contain bacteriostatic substances.

New halogenated compounds for agricultural applications

Considerable progress has been made this year in the application of naturally halogenated compounds as agricultural chemicals. In all, 12 substances have been tested at Stauffer Chemical Company; nine of these evinced promising activity. The data have not yet been made available to us, so that a thorough discussion could not be presented here. However, certain chamigrene derivatives from the red alga *Laurencia* showed high levels of insect control, and we are applying for a use patent to cover this application.

The chemistry of *Bonnemaisonia* spp. has suggested the investigation of haloketones as new agricultural chemicals. In *Bonnemaisonia*, 1,1,1-trihalo-2-heptanone is produced by enzymatic halogenation reactions. When this compound is exuded into the surrounding seawater, a facile haloform reaction occurs, liberating the more mobile C_1 fragment, haloform (Eqn. 1). Since haloforms are clearly biocidal, the alga obtains an advantage against predators. This natural system may be copied to generate a useful biocide or fumigant which is readily controlled. A series of perhaloketones is now being synthesized, and the rates of haloform chemistry in soil will be measured. We hope to find a compound which is relatively non-toxic but decomposes controllably in soil, yielding a volatile biocide.



(1)

Publications

Fenical, W., J. Finer and J. Clardy, Sphaerococcenol A: A rearranged bromo diterpene from the red alga *Sphaerococcus coronopifolius*, *Tetrahedron Letters*, 10, 731 (1976).

McConnell, O., and W. Fenical, Halogen chemistry in the red alga *Asparagopsis*, *Phytochemistry*, in press.

Cooperating Organizations

Environmental Research Laboratories, Puerto Penasco, Sonora, Mexico

Kelco, Division of Merck and Co. Inc., San Diego, California

G.D. Searle and Company, Chicago, Illinois

Stauffer Agricultural and Chemical Company, Mountain View, California

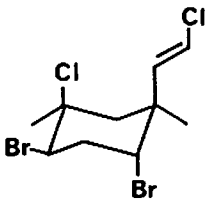
Marine Natural Products Chemistry of Fouling Organisms

San Diego
R/MP-10

D. J. Faulkner

"Antibiotics" from some red algae also possess larvicidal activity against crustacean larvae. Comparison of metabolites from English *Plocamium cartilagineum* with local samples revealed a totally different array of halogenated metabolites, whose structures are under investigation.

During the period July-December 1975, the author was on sabbatical leave in Cambridge, U. K. As a result, the new project did not begin until January 1976 and the reporting period is therefore eight months. However, such is the nature of our research that we have never really abandoned the investigations initiated several years ago by Dr. J.S. Mynderse, a Sea Grant Trainee. Dr. Mynderse had studied the halogenated monoterpenes from *Plocamium cartilagineum* and *Plocamium violaceum*. Two companies had requested samples of the halogenated monoterpenes for screening as insect control agents. I therefore collected samples of *P. cartilagineum* from the English and Welsh coasts. Examination of these samples revealed that the North Atlantic samples contained some compounds which were different from those found in California



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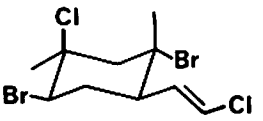

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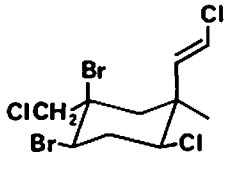
in that they contained a higher bromine to chlorine ratio. The major compound 1 of the U. K. sample was of additional academic interest, since it was a postulated biosynthetic intermediate for the interconversion of two unusual monoterpene carbon skeletons, Five new compounds have been isolated, and four of these have been identified. There is sufficient material of two of these, compounds 1 and 3, to allow extensive biological screening.



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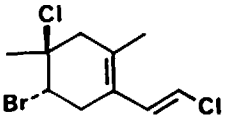

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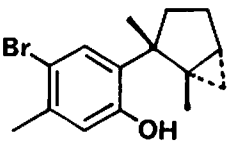
One of the more intriguing aspects of the chemistry of fouling is the question of why some algae (and other organisms) become covered in fouling organisms while others remain clean. Are the fouling organisms attracted to the correct substrate or repelled by others? We had noticed that marine algae which produced antibiotics were generally rather clean of epiphytes. It is therefore possible that the antibiotics are general toxins which may have evolved as antifouling agents. We tested a number of marine natural products as antilarval compounds, using *Tisbe furcata* larvae as test organisms. (This will be repeated using barnacle larvae.) We found that the two most effective "antibiotics," laurenol 5 and the sulphone 6, were also the most effective toxins (LD~0.25 ppm) towards third stage copepidae. We did not observe any unusual larval development.



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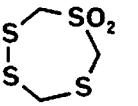

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Cooperating Organizations
Abbott Laboratories, N. Chicago, Illinois
Shell Development Laboratories, Modesto, California
Zoecon Corporation, Palo Alto, California

Antiviral Compounds from Algae as a Potential Marine Resource

Neylan A. Vedros

In the course of making a survey of local marine algae for antiviral substances, we were primarily interested in the chemical characterization and purification of a substance discovered in *Cryptosiphonia woodii* and *Farlowia mollis* which interfered with the *in vitro* replication of herpes simplex viruses. As this work proceeded it was anticipated that the antiviral material would be evaluated for activity in animals.

During this first year of Sea Grant funding, work initiated by the Office of Naval Research to survey local marine algae for antiviral substances was continued. Assistance in collection and identification of algae was obtained from Dr. John A. West, Dr. Paul Silva, Arthur Nonomura, Thomas DeCew and Richard Moe, all of the Department of Botany, The University of California, Berkeley. The algae were then tested for antiviral activity against a large group of mammalian viruses. Results are in press and will appear shortly in the *Journal of Phycology*. These data identify other algae containing specific activity against herpes simplex viruses.

Active material was shown to precipitate in the presence of ethyl alcohol and this provided a useful first step in purification. Preliminary evidence was obtained that the antiviral agent is a large polysaccharide molecule which is relatively non-toxic to cells and acts by blocking some early step in the attachment of virus to host cells. Current work, with the assistance of chemists from Marine Colloids, Inc., Rockland, Maine, should lead to additional information on chemical composition. Since the polysaccharide composition of these algae is rather complex, such information is essential if separation of the active material from the non-active polysaccharide fraction is to be achieved.

Herpes simplex virus, when injected into newborn mice, produces a rapidly ascending fatal encephalitis. Algal material, active against the virus *in vitro*, significantly protected infant mice from developing encephalitis but only if given prior to the virus. This demonstrated a prophylactic *in vivo* potential for the antiviral substance against both type 1 and type 2 herpes simplex. In adult mice the development of encephalitis is variable depending on virus and mouse strains used, virus dose, site of inoculation, and other factors. Therefore, we have spent some months in establishing a reproducible herpes-induced skin lesion model in adult mice with minimal encephalitis sequelae. This model has now been established and will shortly be used in therapeutic testing of antiviral material. In addition, collaborative assistance was secured from the National Institutes of Health, Bethesda, Maryland, to carry out an evaluation of such material for efficacy in treating herpes infection in animals and, if this is promising, then in humans.

Publications

Ehresmann, D.W., E.F. Deig, M.T. Hatch, and D.J. Riedlinger, Characterization of the anti-herpes virus activity in extracts of marine algae. Paper presented at the Annual Meeting, American Society for Microbiology, May 2-7, 1975.

A film entitled "Drugs from seaweed" was made with the assistance of the Public Information Office, UC-Berkeley. It is available from the producers, Gordon News Films, 1557 Pine Street, San Francisco, California 94109. Price of the film is $25; length is 1 min 18 sec.

Cooperating Organizations

Marine Colloids, Inc., Rockland, Maine
National Institutes of Health, Bethesda, Maryland

ENERGY RESOURCE RESEARCH AND DEVELOPMENT

The main thrust of projects in the energy research section of the program continues to be the development of useful information and innovative techniques to resolve the exploration, transportation, distribution, and storage problems associated with the extraction and utilization of energy resources in the marine environment.

The original Scripps wave climate modification project was completed this year in cooperation with the U.S. Navy and the California Department of Navigation and Ocean Development. The concept of using the drag of rapidly oscillating floats to dissipate wave energy, first proposed by Prof. Isaacs in 1970, has now evolved into the installation of a functional tethered float breakwater in San Diego Bay; and the design and installation of a full-scale ocean breakwater experiment have begun.

Two complementary studies at UC-Berkeley and UC-Santa Barbara, concerned with the effects of thermal effluent from coastal power plants on marine life, were completed last year. Valuable data were obtained on the reproduction of mussels and anemones, and on fish parasitism, as affected by this effluent.

A new project at UC-Berkeley investigated prestressed concrete structural elements, used increasingly in coastal and offshore structures, for the extent of accelerated deterioration to which they are subject in the presence of stray electrical currents such as are typically associated with cathodic protection of adjacent installations.

Wave Climate Modification and Monitoring

John D. Isaacs

This project, initiated in 1972, has been principally concerned with the development of a transportable floating breakwater. The concept of using the drag of rapidly oscillating floats to dissipate wave energy was first proposed by Professor Isaacs in 1970. After an initial successful laboratory demonstration of feasibility funded by the Foundation for Ocean Research, a program of analytical investigations and laboratory and field experiments was undertaken by Richard Seymour, a former Sea Grant Trainee. This work led to Seymour's Ph.D. dissertation and to the establishment of a federal/state cooperative demonstration project. The latter evolved into the installation of a functional tethered float breakwater in San Diego Bay, and the design and installation of a full-scale ocean breakwater experiment have been begun. Dr. Seymour has been an active participant in the continuing phases of this research.

The tethered float breakwater concept is very simple. A large number of very buoyant spherical floats are held nearly or shallowly submerged by long tether cables. When these floats are driven by the oscillatory motion of the water in surface waves, they oscillate somewhat like inverted pendulums. If the tether is selected with an appropriate length, the float will amplify the water motion (move further than the water particles do) and also be out of phase (move offshore while the water moves onshore). This keeps the relative velocity of the float with respect to the water very high—as much as six to 10 times as high as it would be if the float were stationary. Since the power dissipated by each float is proportional to the cube of the relative velocity, the moving float is from 100 to 1000 times as effective as a stationary one in taking energy out of the wave (and thereby reducing its height and its destructive potential).

Dr. Seymour's dissertation, entitled "The resistance of spheres in oscillatory flows," was concerned with determining the power dissipated by such a system and developing a mathematical model for predicting it under any combination of float/tether geometry and wave conditions. This mathematical model was tested by measuring the resistance of floats oscillated in water in the laboratory and also by measuring the actual motions of a float tethered to the ocean bottom and comparing these measurements to the predictions from theory.

Once it was shown that the drag power of a single float could be predicted, it was possible to develop a computer simulation of a breakwater containing hundreds or thousands of floats. A simulation was developed in which any breakwater design could be selected and exposed to any wave climate. As the wave train was passed through the first row of floats, the computer program determined how much energy was removed at each frequency and then the program modified the wave climate seen by the next row by this amount. This process was repeated until the final transmitted wave was calculated as it exited the last row. In spite of the accumulation of errors in such a scheme, the computer simulation is remarkably successful. It predicts the transmitted wave energy spectrum to within a few per cent.

During this project, more than 400 laboratory experiments were conducted in the wave channel. In these experiments, various configurations of model breakwaters (about 1/10 ocean scale) were subjected to simulated ocean waves, and measurements were obtained of the effects of the breakwater on these waves and of the resulting loads on and motions of the breakwater. The function of the breakwater is to reduce the height of the waves passing through it. To evaluate this height reduction capability, the wave heights in front of and behind the model breakwaters were recorded under a wide range of wave climates, under simulated deep and shallow water conditions, and employing floats of various densities. In these experiments, the measured transmitted wave heights were compared with those predicted by the computer simulation of the same conditions, and the agreement was excellent in all cases. Certain other experiments were conducted to measure the structural loads caused by waves. These data were then used to verify a computer simulation model of the major structural loads such as mooring line tension and tether tension. A 1/50 scale model of Avalon Harbor on Catalina Island was constructed to evaluate the wave height reduction performance of a scaled TFB at the harbor mouth.

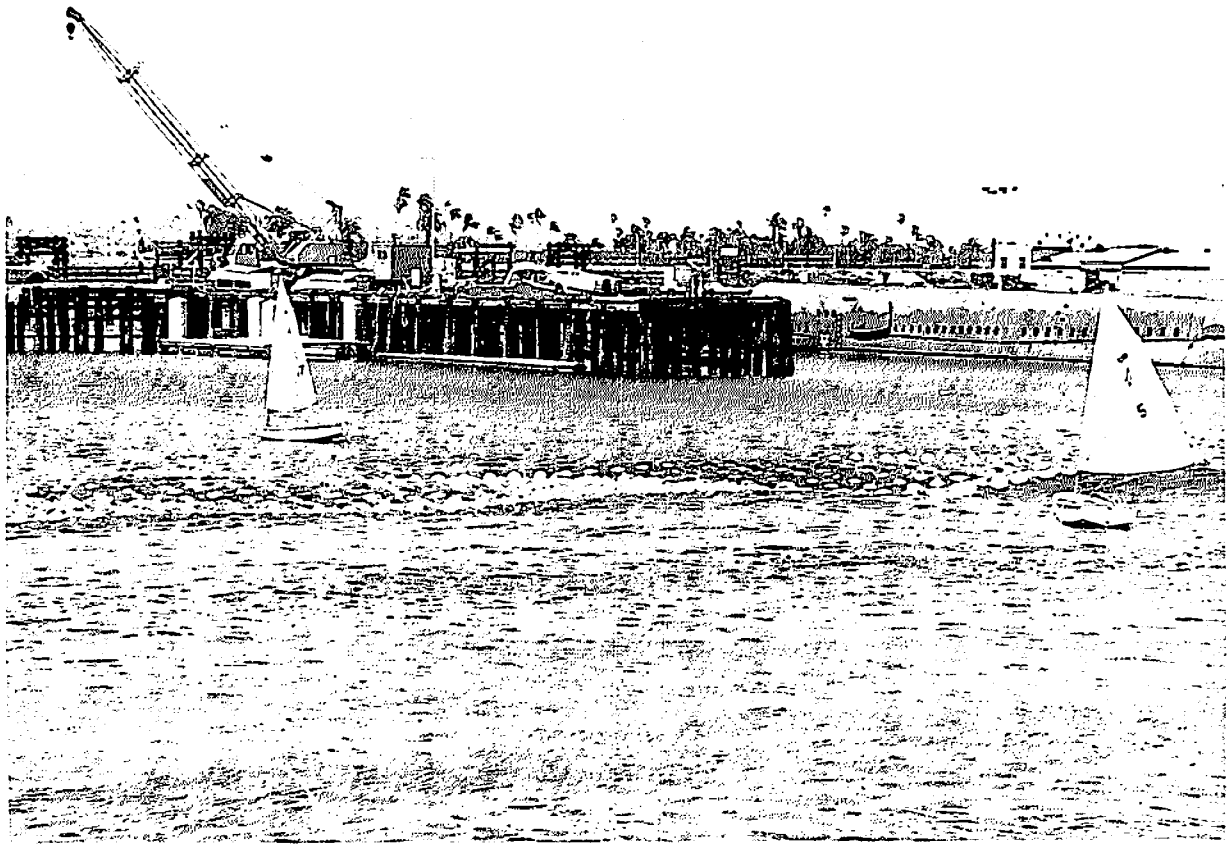
The initial breakwater design configuration had each float and tether secured to the

bottom by an individual anchor. This posed some severe installation problems, limited the range of applicability, reduced performance at high tide, and precluded temporary installation or simple transportability. A new concept was developed in which hundreds of floats were tethered to a semi-rigid frame that was suspended by the floats and clear of the bottom. By selecting properly the weight of this frame, the floats would have sufficient freeboard to float the whole system. The frame is then moored by long lines to anchors that keep it at the desired location. The whole breakwater now goes up and down with the tide (or with storm surge), so that its efficiency is not impaired. Since the drag of the array to a constant current is very low, it not only impedes the tides negligibly but also is readily towed from the manufacturing point to the site, or to a new location in the case of a temporary installation. This concept was tested successfully in the laboratory; subsequently a large subscale test was made in cooperation with the Navy at San Clemente Island in which a simulated breakwater section was installed in deep water and then retrieved.

The computer model was improved in stages to increase its usefulness. An iteration scheme was developed that allowed for an automatic search of float diameters, tether lengths, water depths and other design parameters to find the optimum configuration for a given wave reduction requirement. The capability was added to estimate the structural loads on various breakwater components including the mooring loads for free-floating systems. These load predictions were verified by laboratory measurements in model breakwaters. As component designs for ocean breakwaters were evolved, the program was modified to estimate costs for these components and for a complete breakwater so that a first order economic comparison could be made between different designs.

DNOD/Navy breakwater project in San Diego Bay

Substantial matching funds were provided throughout the life of this Sea Grant project by the California Department of Navigation and Ocean Development (DNOD). DNOD provided, in addition, funding towards the



Wind wave attenuation in San Diego Bay field experiment

federal/state project which eventually included the Navy, the Army Corps of Engineers, and the Maritime Administration as sponsors. This parallel project, which will be called the DNOD/Navy project, undertook the design and installation of an experimental breakwater in San Diego Bay. This breakwater, using 1 ft diameter floats, was designed for short period wind waves and boat wakes typical of a semi-protected harbor environment. The functional design of the system and its performance analysis were done by the Sea Grant/DNOD project. Since storms of the proper intensity and direction were rare and unpredictable in this location, it was necessary to install an automatic data gathering system developed under this project. A dedicated minicomputer was connected to wave gages at the breakwater site by means of leased telephone lines. It automatically sampled the wave intensity several times an hour and if the waves were of an interesting size, was programmed to record data continuously until they died down again. In this manner, two storms were recorded. The wave climate changed as the storms built and decayed so that a wide range of operational data was obtained. In all, 26 experiments from these storms were analyzed and compared with the predictions of the computer simulator. The excellent agreement between predicted and measured wave energy transmission in these field and laboratory experiments is shown above. The design of this breakwater, which is suitable for marina protection and other wave abatement requirements in sheltered waters, has been made public and several installations are now being planned.

Upon the completion of the field experiment, the breakwater was donated by the DNOD/Navy project to the San Diego Unified Port District and towed to a new site near the Market Street Pier, where it is now in use for protection from boat and ship wakes. This is the first functional installation of the tethered float breakwater (TFB).

Papers describing the breakwater have been presented at a number of technical meetings and symposia (see publications list) to help publicize the potential of this innovative system. As a result of this exposure, several companies are now actively considering entering the business of supplying ocean scale TFB's. One firm is already prepared to supply and install marina scale breakwaters. The Maritime Administration has funded a study, independent of the breakwater development project, to evaluate the economics of a number of potential breakwater applications including protection

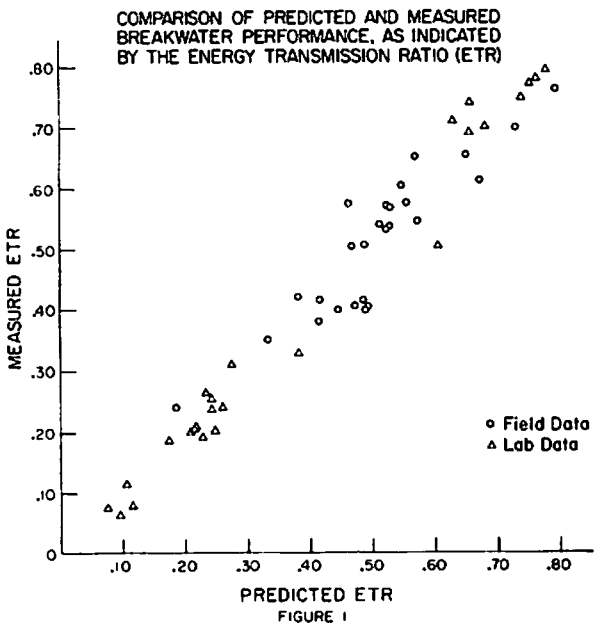


FIGURE 1

of offshore dredging, ocean pipelaying, installation of ocean outfalls and discharge of containerized cargoes where no deep water port facilities are available.

The laboratory modeling program, conducted under this project, produced valuable design criteria that are presently being employed by the engineers in the DNOD/Navy project to design the components for an ocean scale experimental breakwater which will be installed next year off San Diego. Among the information gained from these studies are: estimates of maximum structural loads, flexural duty cycle estimates (how many times joints must bend during the life of the TFB), optimum freeboard for floats, limitations on ballast geometry, acceptable limits on float density, optimum float diameter range (about 5 ft) and the probable number of rows required to meet standard wave abatement requirements (about 30). Using these data, candidate component designs were developed by the DNOD/Navy project team and these were installed in the ocean off Imperial Beach, California. To properly evaluate the performance of these components, it was necessary to characterize the wave climate to which they had been subjected. The wave measurement job was quite different from that required by the breakwater experiment in San Diego Bay. Rather than measure a few severe events, it was necessary to sample the wave climate at regular intervals for durations of at least a year, and perhaps much longer. Using the same general equipment and technology as for the breakwater performance analysis, the Sea Grant/DNOD project undertook the development of an automatic wave climate

sampling system in which the central computer dials a telephone number that connects it to a wave sensing station at a remote site. Wave climate samples have been collected at the Imperial Beach site every 10 hours since December, 1975.

DNOD recognized the potential of this wave statistics gathering system for establishing much needed data on the coastal wave climate to support rational planning for shoreline erosion protection and other coastal management activities. Therefore, additional matching funds were provided and the wave measurement system was expanded to include three more stations at Ocean Beach (San Diego), Scripps Institution of Oceanography, and Oceanside, California. The success of this demonstration has resulted in a new Sea Grant project, with matching funds from DNOD, for the 1976-77 program year for the continued development of the Coastal Engineering Data Network.

The end product of this project, now in final draft, is a design manual for marina scale breakwaters, which will provide the engineering data on performance, component design, mooring and installation to allow a competent engineer to undertake the construction of such a system. In four years the project has taken a laboratory curiosity and developed it into a commercially feasible product, which appears to provide an economical answer to the needs for wave protection in sheltered waters. The results achieved so far have lent technical and scientific support to a major government program that is expected to demonstrate the same level of feasibility for ocean breakwaters within the next two years.

Publications

Essoglou, M.E., R.J. Seymour, and J.B. Berkley, TFB: A transportable open ocean breakwater, Proc. 11th Annual Conference of the Marine Technology Society, San Diego, September 1975.

Hanes, D.M., and R.J. Seymour, Design limits on critical float emergence in a tethered float breakwater, Institute of Marine Resources, University of California, IMR Ref. 76-2. Sea Grant Pub. No. 44 (1976).

Isaacs, J.D., R.J. Seymour, and S.L. Costa, Exploiting highly nonlinear interactions in ocean processes, presented at Joint Oceanographic Assembly, Edinburgh, Scotland, September 13-24, 1976.

Seymour, R.J., Resistance of spheres in oscillatory flows, 1974 Ph.D. dissertation.

Idem, Wave induced loads on multi-element structures. Proc. Symposium on modeling techniques for waterways, harbors and coastal engineering, San Francisco, September 1975.

Idem, Tethered float breakwater: a temporary wave protection system for open ocean construction, OTC 2545, Proc. Eighth Annual Offshore Tech. Conf., Houston, Texas, May 1976.

Idem, Performance of tethered float breakwaters in deep ocean waves, Institute of Marine Resources, University of California, IMR Ref. 76-4. Sea Grant Pub. No. 46 (1976).

Idem, Estimating wave generation on restricted fetches. *Journ. Waterways, Harbors and Coastal Engr.*, in press.

Seymour, R.J., and D.M. Hanes, Investigation of the effects of bio-fouling on the performance of a tethered float breakwater, Institute of Marine Resources, University of California, IMR Ref. 76-3. Sea Grant Pub. No. 45 (1976).

Idem, Performance analysis of a tethered float breakwater, in press, IMR/Sea Grant publication, in press.

Seymour, R.J., and J.D. Isaacs, Tethered float breakwaters, Proc. Floating Breakwaters Conference, Marine Technical Rept. Ser. No. 24, Univ. Rhode Island, pp. 56-72 (1974).

Seymour, R.J., and M.H. Sessions, A regional network for coastal engineering data, Proc., Fifteenth Conf. on Coastal Engineering, Honolulu, Hawaii, July 1976.

Seymour, R.J., M.H. Sessions, S.L. Wald, and A.E. Woods, Coastal engineering data network first semi-annual report, December 1975 to June 1976. Institute of Marine Resources, University of California, IMR Ref. 76-11. Sea Grant Pub. No. 50 (1976).

Cooperating Organizations

City of Imperial Beach, California
City of Oceanside, California
City of San Diego, California
Department of Navigation and Ocean Development, State of California, Sacramento, California
Foundation for Ocean Research, San Diego, California
Maritime Administration, Washington, D.C.
U.S. Navy (Facilities Engineering Command, Washington, D.C., Naval Undersea Center, San Diego, California, and Civil Engineering Lab., Port Hueneme, California)
U.S. Army Corps of Engineers (Headquarters, Washington, D.C., Los Angeles District, Los Angeles, California, and Coastal Engineering Research Center, Ft. Belvoir, Virginia)

Biological Effects of Waste-Heat Effluents of Coastal Power Plants

Ralph I. Smith and Cadet Hand

What are the effects of increased temperature upon attached marine organisms living in the warm-water discharge canals of coastal power plants? So-called "waste-heat" results from the use of seawater in the cooling system of such plants, whether employing nuclear or conventional fuels. There is need for more and better data on the precise effects of this heated effluent, so that local environmental damage may be minimized. This research has contributed valuable information on representatives of three important groups of attached, intertidal, marine animals.

The project began with work of Trainee Anson H. Hines on the growth and reproduction of mussels and barnacles in the discharge canal of the Pacific Gas and Electric Company's power plant at Morro Bay. This was supported in 1972-1974 by NSF Grant GI-34932 to Profs. G.J. Trezek and V.E. Shrock, College of Engineering, UC-Berkeley. In 1974-75 Mr. Hines received Sea Grant Support under project R/E-10 and completed his doctoral research.

A second aspect of this research concerned a study of the energetics of two species of mussels, *Mytilus californianus* and *M. edulis*, in response to food, temperature, salinity and water currents, by Trainee Bruce R. Hargreaves. The main emphasis of the project has been on an assessment of the effects of temperature upon growth and metabolism of mussels within the Morro Bay heated outfall and in nearby control areas. Both the growth of mussels and their nutritional condition were markedly affected by temperature, although the animals are capable of considerable metabolic adaptations (respiration was comparable in outfall and control sites once the animals were temperature-adapted). The effects of heated water were deleterious when average temperatures exceeded 26-27°C. This is clearly valuable information for those concerned with setting upper limits on the temperatures allowable in coastal power plant effluents, or in cultivating this potentially economically-important food animal. Of the two mussels, only *Mytilus edulis* is abundant subtidally within the heated effluent canal, where, it may be noted, predatory starfish seem to be completely excluded.

A third aspect of the project has been a study of the clonal sea anemone *Anthopleura elegantissima*, a common intertidal animal, by Trainee Brian L. Jennison. Mr. Jennison has been supported under this project since 1974-75. He, like Hargreaves, is currently working on a six-month extension of his 1975-76 year of Sea Grant support, and is completing his histological and biochemical studies. Jennison is working up data on the timing of, and energy reserves available for, reproduction of *A. elegantissima* under the warm conditions of the Morro Bay outfall as compared to nearby, cooler, control areas. He has found that sea anemones living in the heated effluent canal do not show an alteration in the timing of gametogenesis and spawning, as had been shown in certain barnacle species by Trainee Hines. They do, however, show significantly lower lipid reserves than sea anemones in cooler, control areas. It would appear that the higher temperatures of the warmed effluent water impose greater metabolic demands upon sea anemones subjected to them.

Summary of findings to date

Hines, by his studies on barnacle growth, reproduction, recruitment, and mortality, has shown that the effects of "waste-heat" are not simple. Among the three major species in the outfall, the reproduction of one was hastened, that of another delayed and repressed, and that of a third was little affected. The coast mussel (*Mytilus californianus*) reproduced better in the outfall; the bay mussel (*M. edulis*) reproduced more poorly than controls. Jennison has shown that, of the two common species of the sea anemone *Anthopleura, A. xanthogrammica* is nearly excluded by heat from the outfall, while *A. elegantissima* is able to live and reproduce year-round, although with a lowered lipid reserve. Hargreaves has shown that the edible mussel, *Mytilus edulis*, grows well in the outfall, unless mean temperatures exceed 25°C. An interesting and unexpected beneficial effect of the heated effluent is that *M. edulis* can thrive at temperatures high enough to exclude its major predator, the starfish *Pisaster ochraceus*. Since *M. edulis* is a species of great potentiality as a food resource, these findings may have an immediate importance in mariculture. In gener-

al the studies increase the body of information upon which to base the solution of engineering problems with minimal or at least predictable environmental consequences.

Publications

Hargreaves, B.R., Laboratory feeding rates of *Mytilus californianus* with automatic dosing and recording apparatus, *Amer. Zool.*, 15, 816 (1975) (Abstract of a paper presented at the Amer. Soc. Zoologists national meeting at Corvallis, Oregon, August 1975.)

Hines, A.H., Barnacle reproductive ecology, *ibid.*, 14, 1266 (1974). (Abstract of a paper presented at Amer. Soc. Zoologists national meeting at Tucson, Arizona, December 1974.)

Idem, Effects of a thermal outfall on reproduction in mussels and barnacles, *ibid.*, 15, 788 (1975). (Abstract of a paper presented at a meeting of the American Institute of Biological Sciences at Corvallis, Oregon, August 1975.)

Idem, Effects of a thermal discharge on reproductive cycles in the mussels *Mytilis edulis* and *M. californianus* (Mollusca Bivalva). In manuscript, to be submitted for publication.

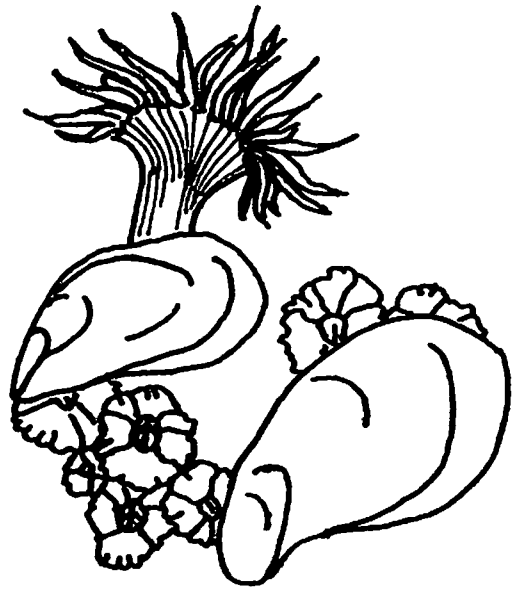
Idem, Ph.D. thesis in zoology: Comparative reproductive ecology of three species of intertidal barnacles. University of California, Berkeley; Ph.D. awarded June, 1976.

Hines, T. (=A.H. Hines), The effects of thermal effluents on reproduction in mussels and barnacles. NSF Waste Heat Management, Report No. WHM-15, NSF Grant GI-34932, College of Engineering, University of California, Berkeley, July 1974.

Jennison, B.L., The effect of increased temperature on reproduction in the sea anemone *Anthopleura elegantissima*, *Amer. Zool.*, 15, 787 (1975).

Cooperating Organizations

Pacific Gas and Electric Company, Department of Engineering Research, San Ramon, California, and Morro Bay Power Plant, California



Stress-Induced Fish Parasitism: Effects of Waste-Heat Effluent from the Diablo Cove Plant

Elmer R. Noble

An atomic energy plant is to become operational at Diablo Cove in the near future. This work aims at establishing a base line of information on parasites in fishes living in the test and control areas in Diablo Cove and adjacent coves before the plant begins operations with its resultant thermal pollution of the Cove.

We made monthly samples of four species of fish collected from Diablo Cove: pile surfperch (*Damalichthys vacca*), striped surfperch (*Embiotoca lateralis*), olive rockfish (*Sebastes serranoides*), and blue rockfish (*S. mystinus*). These fish were selected because of their abundance and their sport and commercial importance. The fishes were fully autopsied and both protozoan and helminth parasites were identified.

The trainee, Mike Moser, made many trips to Diablo Cove to collect the fishes, and did almost all of the autopsies, with some help from Milton Love, a graduate student in ichthyology, who had already collected some of the fishes that we expected to use. Mike made measurements of the hosts and recorded all of the collection data as well as the descriptive data of the parasites. He searched the literature to aid in the identification of the parasites, made microscopic studies, slide preparations, photographs, and tabulations. He also made preparations to begin a study of live fishes in artificial ponds on our campus.

During the first three months (September, October, November, 1975), we worked on preserved fishes collected during September, October, and November of 1974, but we were unable to collect live fishes at Diablo Cove during the fall of 1976 because of severe weather conditions. Therefore, Mike will make at least three collecting trips during the fall of 1976 to Diablo Cove.

We have autopsied approximately 800 fishes to date (from Diablo Cove) and expect to add 200 or 300 more before the end of 1976. The work this fall is being done after our grant has terminated, but is desirable in order to complete the original objectives relating to a survey of parasitism in Diablo Cove before the plant begins operation.

Publications

Love, M., and M. Moser, Parasites of California marine and estuarine fish, Marine Science Institute, 1976.

Idem, *Davisia reginae* sp. n. (Protozoa, Myxosporida) from four California marine fish, *J. Parasitol.*, in press.

Moser, M., *Ceratomyxa anoplopoma* sp. n. (Protozoa, Myxosporida) from the sablefish *Anoplopoma fimbria*, *Can. J. Zool.*, **54**, 1405 (1976).

Idem, Effects of *Cardiodectes medusaeus* on *Stenobrachius leucopsarus* and a case of hypercastration by *Hydrichthys*. Paper presented at the 51st Annual Meeting of the Amer. Soc. of Parasitologists, August 22-26, 1976, San Antonio, Texas.

Idem, Myxosporida (Protozoa) as biological tags in a deep-sea macrourid fish, *Coryphaenoides acrolepis*. Paper presented at the Joint Oceanographic Assembly, September 13-24, Edinburgh, Scotland.

Idem, Inter-species association of Myxosporida (Protozoa) in macrourid fishes, *Zeitschrift für Parasitenkunde*, in press.

Idem, *Sarcotaces* (Copepoda) in *Physiculus rastrelliger*, *Can. J. Zool.*, in press.

Moser, M., and L. Haldorson, *Zschokkella embiotocidis* sp. n. (Protozoa, Myxosporida) from California pile perch, *Damalichthys vacca* and striped perch, *Embiotoca lateralis*, *ibid.*, **54**, 1403 (1976).

Moser, M., M.S. Love, and L.A. Jensen, Myxosporidae (Protozoa) in California rockfish Sebastes spp., *J. Parasitol.*, in press.

Moser, M., and E.R. Noble, The genus *Ceratomyxa* (Protozoa, Myxosporida) in macrourid fishes, *Can. J. Zool.*, **54**, 1535 (1976).

Idem, Three genera of Myxosporida (Protozoa) in macrourid fishes, *Int. J. Parasitol.*, in press.

Idem, *Zschokkella* (Protozoa, Myxosporida) in macrourid fishes, *ibid.*, in press.

Idem, The genus *Leptotheca* (Protozoa, Myxosporida) in macrourid fishes and sablefish, *Anoploma fimbria*, *J. Protozool.*, in press.

Idem, Myxosporidan genera *Auerbachia*, *Sphaerospora*, *Davisia* and *Chloromyxum* in macrourid fishes and the sablefish, *Anoploma fimbria*, *Zeitschrift für Parasitenkunde*, in press.

Moser, M., E.R. Noble, and R. Lee, The genus *Myxidium* (Protozoa, Myxosporida) in macrourid fishes, *J. Parasitol.*, in press.

Cooperating Organizations

California Department of Fish and Game, San Francisco, California

Stray Electrical Current Hazards to Prestressed Concrete Construction in Seawater

Israel Cornet

Prestressed concrete structural elements, used increasingly in coastal structures, offshore terminals, etc., are subject to accelerated deterioration, and even risks of disastrous failure, in the presence of stray electrical currents. Such stray currents are typically associated with cathodic protection of adjacent structures. In this research, prestressed concrete beams were immersed in seawater, subjected to electrical currents such as exist in some areas, and tested to evaluate the extent of the deterioration.

Steel in prestressed concrete, unlike that in ordinary reinforced concrete, is critically weakened by any corrosion or chemical damage. Electrochemical corrosion weakening may occur in steel through interaction with electrical potential fields set up by adjacent cathodically protected structures, or by high voltage direct current transmission grounding. Whatever the origin of the potential field, current flow in the prestressing steel results in corrosion of steel at the point of current discharge. If this discharge is highly localized, failure of the wire could be the result; on the other hand, if the discharge is evenly distributed over the surface of the wire, the overall strength reduction may be small. The resulting corrosion products, when exposed to sufficient free oxygen, form the familiar red rust, $Fe(OH)_3$. The corrosion products, which have a greater specific volume than the steel, cause cracks to form in the concrete cover when resulting internal pressures exceed the tensile strength of the concrete.

In this project, impressed current corrosion tests were performed on 12 prestressed concrete 2.5 x 2.5 x 48 in specimens submerged in seawater. Two constant currents, 20 and 60 milliamperes per square foot of surface of the steel, were used with two cathode designs. One cathode was designed to distribute the current discharge evenly over the entire prestressing wire surface, while the second cathode configuration was designed to concentrate the current discharge within a very small section of the prestressing wire. In addition to the electrified specimens, several control beams were placed in seawater and in tap water but without impressed current.

During the seawater exposure period, electrical potential was monitored and visual inspections were made on a weekly basis to observe the presence of surface rust stains and cracks. Surface rust stains appeared on the beams after eight to 15 weeks. Surface cracks generally followed these stains by one or two weeks. Total exposures ranged from 12 to 20 weeks, after which the prestressing wires were tested to failure in tension to determine the strength reduction due to corrosion.

The reduction in strength ranged from 21 to 48 per cent, with seemingly no relation to the corresponding cathode configuration. Following testing, the beams were disassembled to inspect visually the areas of corrosion along the wires. From the test results and the lack of definite corrosion patterns corresponding to the cathode design, it appears that the relative cathode-anode geometry had little effect on the results. In general, the potential and resistance exhibited sharp drops within a week prior to surface cracks becoming visible. This was probably due to the crack propagating outward from the corroding wire. None of the control beams, in seawater or in tapwater, showed any signs of corrosion.

RAPID RESPONSE

Because commitment must be made to the regular planned research program almost a year in advance of beginning investigations, provision has been made for starting a limited number of projects within a short time frame. Projects which qualify for this kind of support fall within three general classes:

1. **Research needed to address a problem of public importance and urgency.**
2. **Exploration of a potentially important new research idea to determine whether or not it should be included in future plans for the regular research program (basically a feasibility study).**
3. **A project included for funding in the regular research program which for various reasons should be initiated in advance of the starting date for regular projects.**

Model Course in Marine Planning

Dudley J. Burton

The objectives of this new course were: first, to provide UC-Santa Cruz students, especially graduate students in marine sciences, a detailed introduction to specific policy problems of marine environments; and second, to provide more contact between UC-Santa Cruz and local groups carrying out and evaluating marine coastal policy.

Introduction

The purpose of this project was to support the research and teaching efforts on marine problems already under way at UC-Santa Cruz. We had an active faculty in Marine Science, another group interested in questions of environmental policy and planning, and an interested group of students. But we had very little established curriculum to treat specifically the economic, political, social, and administrative aspects of marine resource questions.

The course provided 32 undergraduate and one graduate students the opportunity to synthesize their work (mostly in biology and planning) through a systematic presentation of marine-resource issues, models, and decision strategies. It provided faculty members the opportunity to present latest research results, as well as to suggest and criticize ideas for campus program development in marine planning. In addition to the substantive material covered in the course, students learned how to make a case for their interests and to support the establishment of a "marine environment" program track through the Environmental Studies Board.

Contents of the course

The 10-week course covered the following topics, with as much depth as possible, depending upon the students' backgrounds and time available for discussion:

I. Economics and ecology
The section covered the discontinuities between economic and ecological modes of analysis. The economic framework of investment, profit, prices, and demand is not necessarily consistent with analyses of populations, reproduction rates, nutrient cycles, etc.

II. Models and modeling
The geologic, chemical, physical, and biological "systems" of importance in the oceans are not well understood. This section discussed problems in data, modeling techniques, and objectives in modeling studies.

III. General theory of resources
Some questions on resource economics involving pricing, optional use over time, conservation, and the economic justifications for market intervention were discussed. The readings indicated clearly the necessity for precise and carefully developed mathematical models; the class discussion focused on limitations and criticisms of such models.

IV. Common property resources
On the boundary between economics and politics, common property models obviously apply to many marine resource problems. For some, these characteristics (basically, multiple users subject to a shared constraint) may be eliminated but, for others, elaborate governance mechanisms are necessary. This section covered the general theory and strategies necessary to deal with such problems.

V. Living resources
This section went into more detail about the ecological conditions influencing the exploitation of biological resources, developed use analyses of the tuna and whaling industries, and raised questions about the possibilities of controlled production (mariculture).

VI. Mineral resources
The questions here are how extensive, how significant, and costly oil, gas, and other mineral resources in the oceans are likely to be. The tensions between the theoretical plausibility of common project models and the desires of powerful political groups in the establishment of exploitation patterns were considered in some detail.

VII. Marine science and technology
This section covered the issues of "scientific freedom" with respect to geographical boundaries in the seas, the questions of rights to scientific knowledge and technology relevant to resource exploitation, and the relations between resource questions and other sensitive matters, such as defense and cultural invasion.

VIII. U.S. ocean politics
The problems of domestic fishing industries that use international waters,

the issues surrounding the establishment of a 200-mile economic zone, and the difficulties of a national oceans policy provided the basic content for issue-oriented discussion. Structural implications of comprehensive marine policy with respect to these issues were suggested but not pursued.

IX. Law of the Sea
The ambiguities of national politics in an international arena; the tensions between "development," especially on the part of the Third World, and the desire of present powers to maintain political stability; and the questions of "rights and access to the benefits of marine resource exploitation provided the background for discussing the Law-of-the-Sea debates.

X. Role of international organizations
The necessity for international regulation and management for good biological and economic reasons, yet the difficulties of Law-of-the-Sea expectations, suggests the appropriateness of interim and temporary strategies for species and regional management. The relationship among short-term, incremental, and more comprehensive "constitutional" questions was considered in terms of what general conditions should be sought and how they might be approached.

Faulting and Related Sea-Cliff Erosion San Dieguito River to Carlsbad, San Diego County, California

Francis P. Shepard and Gerald G. Kuhn

This study's objective was to provide base-line geological data relating to sea-cliff stability and coastal erosion in northern San Diego County.

The central focus of this project during the previous year has been the investigation, geological mapping, and stability analysis of the sea cliffs along the coastal communities of Solana Beach, Cardiff-by-the-Sea, Encinitas, and Leucadia, San Diego County, California. Specifically we have mapped the hazardous areas and monitored the rate of sea-cliff retreat. Solana Beach and Encinitas were mapped on a 1:2400 scale with all hazards, present and potential, being noted. We have observed that the sea-cliff erosion is the result of many factors: rain, wind, waves, biological activity, geological conditions, and especially man's intervention. We have found that severe erosion will occur particularly where unconsolidated sedimentary units are exposed to wave erosion and where ground water accelerates material removal along faults, joints, and sea caves.

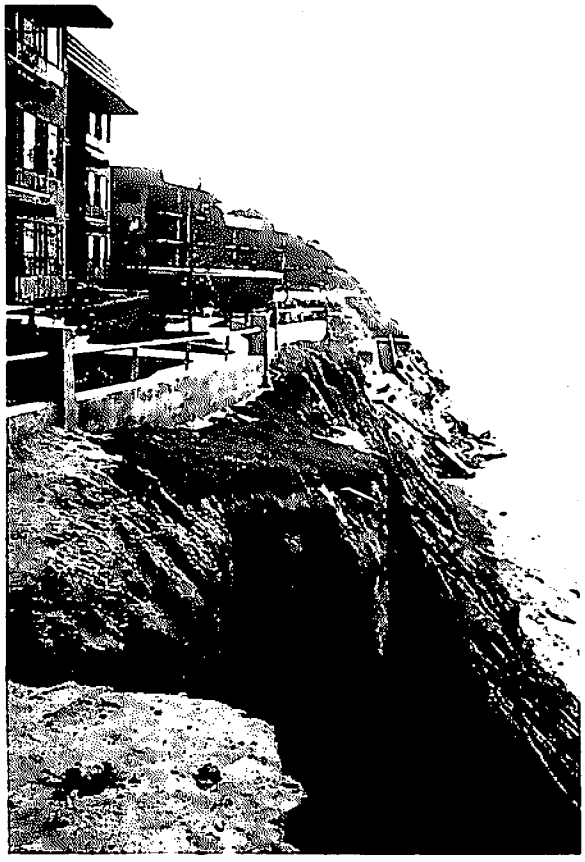


Fig. 1. Severe gullying of the sea cliff due to uncontrolled water runoff

In a recent study of sea-cliff erosion along Solana Beach and Leucadia, Lee, Pinckney, and Bemis concluded that the rate of sea-cliff retreat ranged from 0 to 3.4 in per year with an adjusted yearly average of 0.5 in. However, our recent studies in the same area indicate that it is unrealistic to attempt to average rates of sea-cliff retreat because each specific site must be considered independently. For example, between 1973 and 1976, 15 large sections of the cliff fell to the beach in Encinitas. These blockfalls varied in dimensions from 3 to 6 ft thick (measuring from the face of the slope landward), 15 to 60 ft in length, and a maximum of 32 ft in height. To average these localized, instantaneous cliff retreats is not practical, especially where development of the bluffs is contemplated.

Comparison of the 1976 shoreline area with the 1883 plat map of Encinitas and information from the San Diego County tax records indicates that approximately 20 acres of real estate have disappeared in 93 years amounting to as much as 800 ft of retreat at "B" Street. The most significant retreat has occurred following the severe wet years before the turn of the century. The year 1884 was the wettest on record in San Diego County; the rainy period lasted from February to July.

The episodic severity of sea storms cannot be overlooked. In 1938 and 1939 large storms inundated sections of the California coastline. Between December 24, 1940, and January 7, 1941, northern San Diego County was particularly hard hit by a storm which produced 30 ft sea swells, stripped away the beach along the cliffs north of Scripps Institution of Oceanography, removed the talus at the foot of one of the canyons which previously allowed access to that canyon, undermined the cliffs in Del Mar causing a train to fall to the beach, washed houses out to sea, and caused the Self-Realization Fellowship temple to fall off the cliff in Encinitas (see Fig. 1-5).

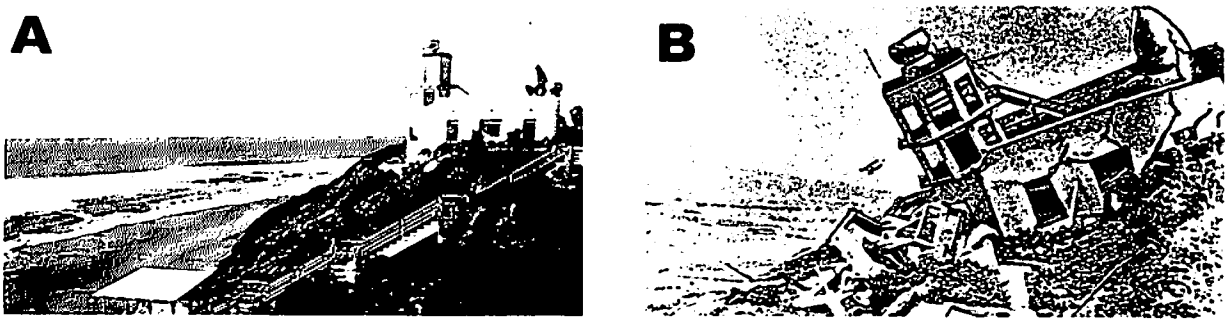


Fig. 2. Self-Realization Fellowship temple, Encinitas, California, A. 1938, B. 1941. The temple collapsed primarily due to a severe sea storm which ravaged the California coastline in January, 1941

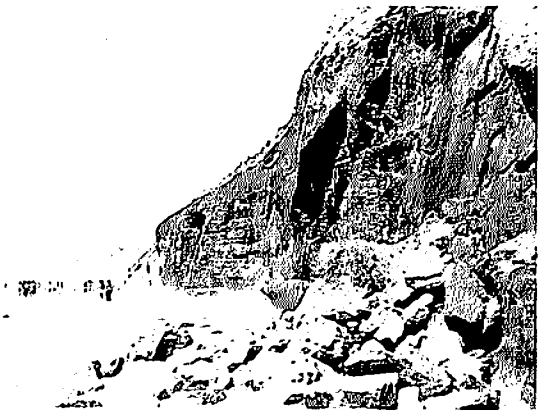


Fig. 3. Bedrock failure due to ground water seeping out along fractures in the sea cliff

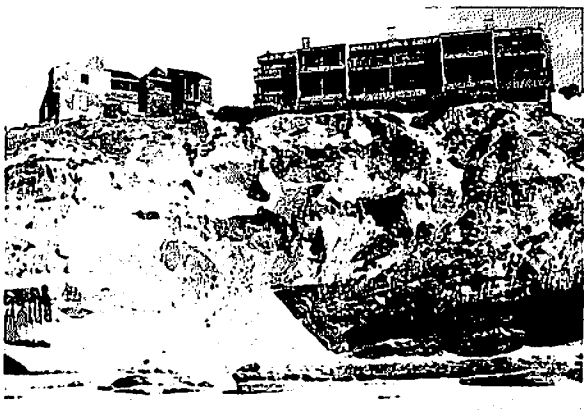


Fig. 4. Sea cave collapse and bluff failure in south Solana Beach

The urgent need for this site specific information is best indicated by the fact that some 33 groups—including businesses, local, state, and federal agencies, newspapers, all three major television networks, and numerous private citizens and citizen groups—have contacted our research group over a period of five months.

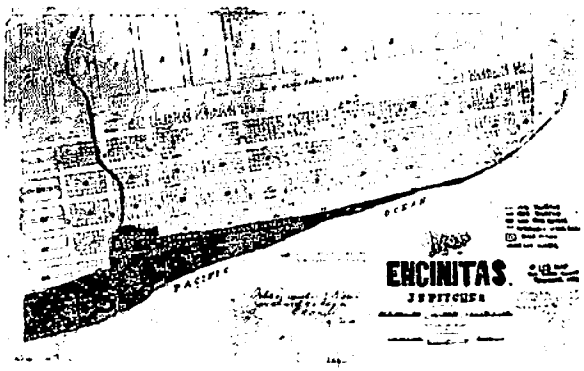


Fig. 5. 1883 plat map of Encinitas, California; shading indicates area that has since eroded

Publications

Berger, W.H. (with contributions by G.Kuhn), Walk along the ocean, Border-Mountain Press, Alhambra, California, 1976.

Kuhn, G.G., Sea-cliff erosion: Solana Beach and Encinitas, San Diego County, California, *California Geology*, in press.

Cooperating Organizations

Department of Sanitation and Flood Control, San Diego County, California

U.S. Geological Survey, Environmental Division, Menlo Park, California

The Potential Environmental Impact of the Japanese Alga, *Sargassum muticum*

Paul K. Dayton and Lawrence Deysher

The introduction of exotic species into new environments always poses the threat of unexpected economic costs and ecological imbalances. The recent introduction of the water hyacinth and walking catfish into Florida are dramatic examples of the types of problems which may occur. The primary goals of this research on the recently introduced Japanese alga, *Sargassum muticum*, have been 1) to document the possible negative effects of this alga, and 2) to find methods to alleviate any problems which may occur.

Sargassum muticum, a large kelp-like form, was first noted by the marina operators in Mission Bay, San Diego. By 1972, *Sargassum* had established a large population in the bay, where it grows in a dense band bordering the riprap embankments. There was concern the alga might spread further out into the bay interfering with boat traffic, water skiing, and swimming. In addition, dense growths of seaweed in the marinas blocked moorages, snarled propellers, and clogged water intakes of boat engines.

Other problems were experienced at Sea World, where the alga grows abundantly in two artificial lagoons holding porpoises used in Sea World's shows. The porpoises are fond of playing with the seaweed and it was feared that problems could arise if they ingested too much of this material. There were also complaints about the unsightly masses of floating seaweed, especially in the spring when the annual fronds are shed.

California survey

The first statewide survey of *Sargassum* was conducted in 1972, at which time populations were noted in San Diego, Avalon and Twin Harbors on Catalina Island, Oceanside, Dana Point, Newport, and Crescent City in northern California. It was completely absent from the central California coast. Since that time populations have appeared at San Onofre, Marina del Rey, Santa Barbara, and San Francisco Bay. The heaviest concentrations of *Sargassum* still occur at Mission Bay and Oceanside harbor. At the latter locality a great deal of effort is expended manually removing the seaweed. Populations in Marina del Rey, Santa Barbara, and San Francisco Bay are still small and it will be interesting to see if and how quickly they increase. The Berkeley marina, for example, has a population of approximately 15 plants which has remained constant for the past two years. This is very different from Mission Bay, where the alga quickly occupies any new substratum.

The situation in the harbors and marinas of southern California is unique since the man-made structures constructed in the estuaries provide a totally new habitat in this region. Prior to their development, the estuaries contained very little of the solid substratum required by most algal species for settlement and subsequent development. The construction of marinas, however, introduced an abundance of substratum which did not have an algal flora adapted to utilize it prior to the introduction of *Sargassum muticum;* the latter now provides structure to this new community. Diving surveys in Mission Bay have shown adult and juvenile fishes utilizing the *Sargassum* beds for food and shelter. Birds, such as plovers, grebes, and coots, use the beds as feeding grounds. The introduction of this alga, therefore, appears to increase local habitat structure.

There is no danger of the population expanding into the open areas of bays where the silt and sand bottoms prevent the settlement of *Sargassum* embryos. The local nuisance problems to boaters and swimmers can be solved simply by manually harvesting the seaweed and hauling it away. The plant has a tendency to regenerate from any portion left attached to the rock, thereby making the optimal time for harvesting February through March when the plant is just beginning to reproduce and the probability of regeneration is reduced.

Biological control of the Japanese alga

The use of sea urchins, *Strongylocentrotus purpuratus*, as a biological control mechanism appears feasible. A large settlement of urchins on the riprap embankments near the Islandia Hotel in Mission Bay totally cleared these rocks of a dense stand of *Sargassum* in six months. This population of urchins appears stable with no noticeable mortalities over the period of a year during which the temperature ranged from 48° to 75°F. The situation is more complex at Sea World,

where the use of urchins has been ruled out owing to health and safety problems with the porpoises. Here another biological control has been suggested. At Bird Rock, near La Jolla, dense turfs of the coralline alga, *Lithothrix aspergillum,* have been shown to prevent the attachment of *Sargassum* embryos. If a turf of *Lithothrix* could be established on the rocks in the Sea World lagoons, the density of *Sargassum* would be significantly reduced. The trial plots of *Lithothrix* being established this past summer were killed inadvertently, however, when the pumps maintaining water flow to the lagoons failed, dropping the seawater level below the *Lithothrix*. Hopefully, another trial will be established this fall.

The appearance of *Sargassum muticum* at outer coast localities such as Bird Rock and the Ecological Preserve in La Jolla has caused some concern, since a well-developed, natural assemblage of plants exists in these areas. A similar introduction of *Sargassum* into England spurred a large eradication program based on fears that this species would replace native species resulting in unknown consequences. The major fear in southern California was the possible competition with the surfgrass, *Phyllospadix*, which serves as the primary settlement substratum for the larvae of the spiny lobster, *Panulirus interruptus*. Experiments at Bird Rock have shown *Phyllospadix* to be a superior competitor for substratum, and there appears to be little threat to *Phyllospadix* populations from *Sargassum*.

During the summer of 1974, an extensive survey was conducted in British Columbia and Washington to assess the effects of *Sargassum* on the oyster fishery in these areas. This was undertaken since it can be assumed that *Sargassum* will eventually reach the oyster growing regions of northern and central California. There were, however, no complaints from oyster fishermen concerning this species. Some concern had been expressed in the early 1950's when the alga was first noticed, but no problems materialized.

In summary, the recent introduction of *Sargassum muticum* into southern California appears to be without significant negative consequences to the native marine community. The few instances of conflict with the recreational use of bays and marinas are localized and capable of being solved. The present course of action should consist in carefully monitored sea urchin additions to those areas where problems occur.

Publications

Deysher, L.E., Jr., The ecology of a colonizing species, *Sargassum muticum*. Paper presented at the Western Society of Naturalists Annual Meeting, Vancouver, British Columbia, Canada, 1974.

Cooperating Organizations

Sea World, San Diego California

Transportation Analysis in the Coastal Zone: Subregional Considerations for Local Coastal Plans

Thomas Dickert

One of California's more acute coastal zone management problems is transportational access to the coastal recreation areas. Levels of congestion on coastal highways and parking areas during summer holiday and weekend periods are increasing each year. Congestion is particularly acute in beach communities on the outskirts of metropolitan areas and rural, two-land sections of the Pacific Coast Highway. In most cases, the transportational access problem boils down to a traffic congestion conflict between visitors seeking coastal recreation attractions and residents of coastal communities. The recently enacted Coastal Act of 1976, recognizing this conflict lays out several policies to prevent coastal residential development from impeding transportational access by recreational visitors. In response to a request by the California Coastal Zone Conservation Commission for a study on the feasibility of applying transportational access policies, a four-month Rapid Response project was initiated.

Our research has focused on the effect of increased transportation, recreation, and private development on public access to—and within—the California coastal zone. The analysis was designed to portray competition for subregion highway capacity between residents and visitors during peak recreation periods. Two dissimilar areas were selected for developing and testing the analytic procedure: the Big Sur subregion of Monterey and San Luis Obispo Counties and the southern Orange County coast subregion (Fig. 1 and 2).

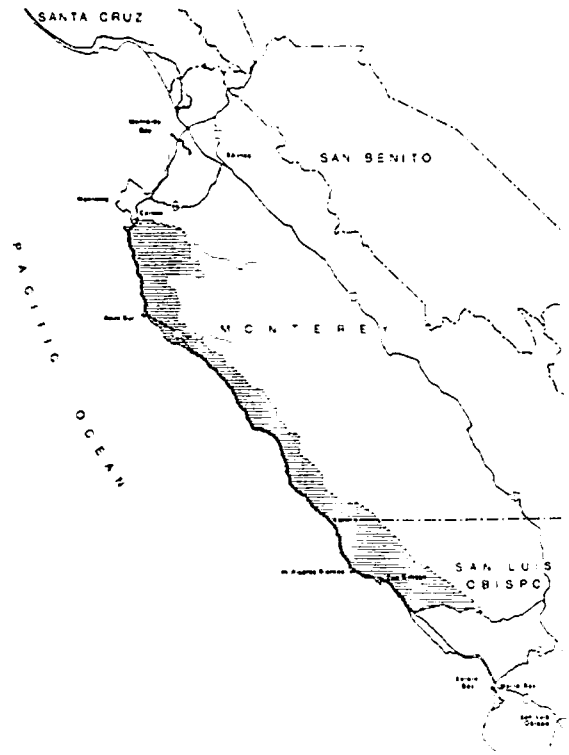


Fig. 1. Big Sur coast study area

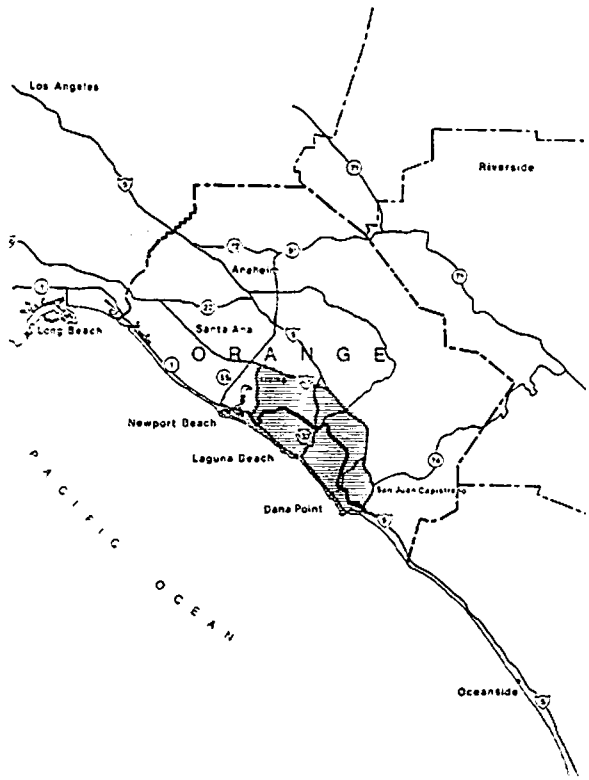


Fig. 2. Orange County study area

The Big Sur subregion is characterized by a simple circulation network and low intensity development in both the present situation and what is planned for the future. The entire subregion lies within the "coastal zone", and all development in it will require the approval of the California Coastal Commission. In contrast to Big Sur's remote location, six million people live within an hour's drive of the southern Orange County coast. The traffic network is also far more

complex than that of Big Sur. Analysis in Orange County was further complicated by the division of the study area into coastal zone and non-coastal zone sections.

Although the data catagories in Big Sur and Orange County analysis were similar, the analytic approach used in each area was significantly different. The two approaches reflect the differences in the subregions. A manual technique has been developed for the Big Sur subregion which points out the effect of increased local development under various assumptions of trip-making characteristics and future recreation levels (Fig. 3). In the Orange County subregion the analysis dealt with a problem that was larger by several orders of magnitude. The result was a computerized approach that simulates present and future traffic patterns over a peak recreation day (Fig. 4).

A report describing these techniques has been prepared for the Coastal Commission and general distribution. The report contains a review of related transportation and recreation methods, a presentation of existing data for each subregion, and a description of the application of the approach in context with the California Coastal Act of 1976. Finally, the application of the two analytic approaches in other transportational subregions, including those in other states, is discussed.

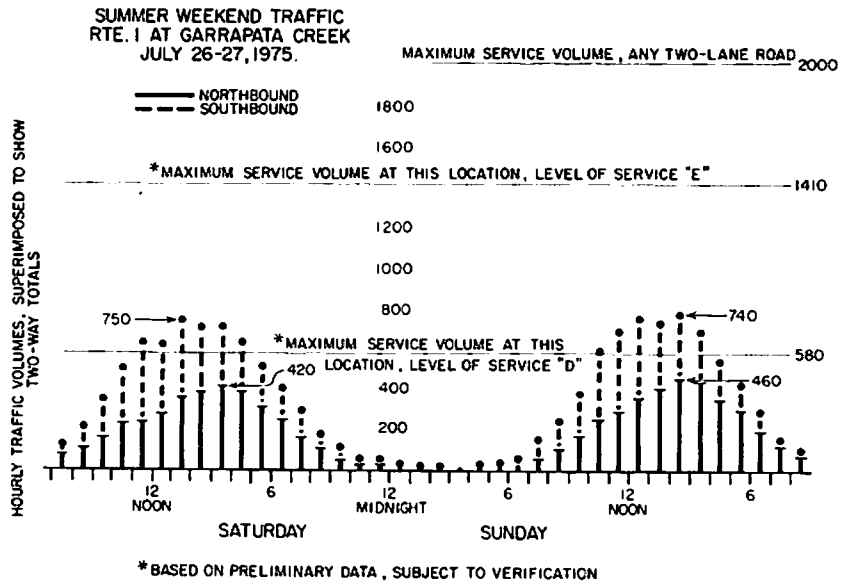


Fig. 3. Big Sur summer weekend traffic

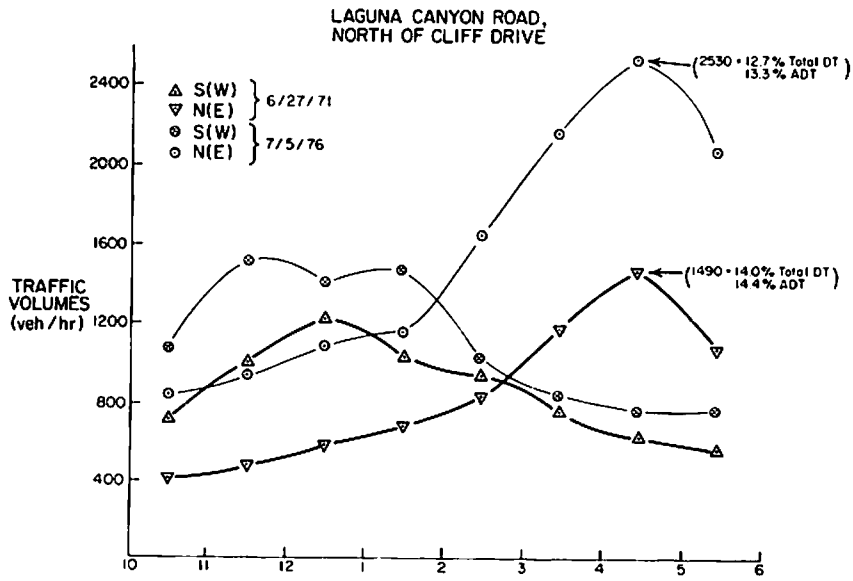


Fig. 4. Traffic volumes, southern Orange County coast

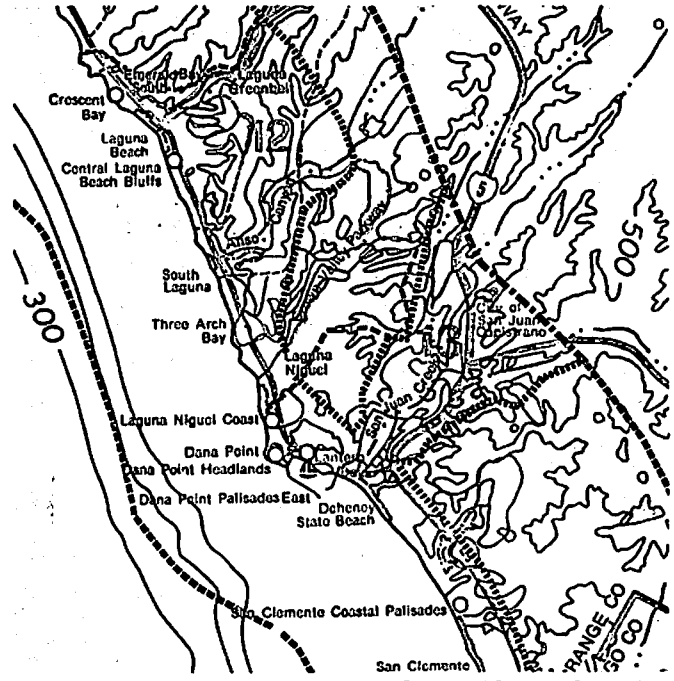
Fiscal Impact of Park Acquisition in Laguna Beach

Thomas Dickert

At this time, the Laguna Beach area is one of the California Coastal Zone Conservation Commission's pilot local coastal planning programs. Several acquisitions of open space land are being proposed within the city's jurisdiction. One of the major issues that has emerged is the potential fiscal impact of proposed park acquisitions. The Coastal Commission envisions that this issue will be a continuing source of debate in future local coastal planning efforts. In this project, a study was made of the cost/ revenue effects of such park acquisition in the city of Laguna Beach. The study entailed two phases. First, a site analysis was made. The relevant personnel in Laguna Beach, Orange County, state agencies, and the South Coast Commission were interviewed about the issues. The data available in Laguna Beach at the time needed to determine impacts were collected. The second phase of the work consisted in data analysis and report preparation.

The Laguna Beach study will be a chapter in the forthcoming report on the economic impacts of recreational acquisition and development.

This work supplements previous work done in Del Norte County which will also be a chapter in the report.



Courtesy of California Coastal Plan

Half Moon Bay Case Study

G. E. Goldman

This study estimates the private sector impacts of six hypothetical residential and commercial growth scenarios for a 58 square mile coastal watershed basin surrounding Half Moon Bay. The primary effects, as well as the San Mateo County secondary economic impacts, are estimated. Generally, our analysis indicates that more development leads to more private sector economic activity. Statewide effects of coastal legislation have also been analyzed.

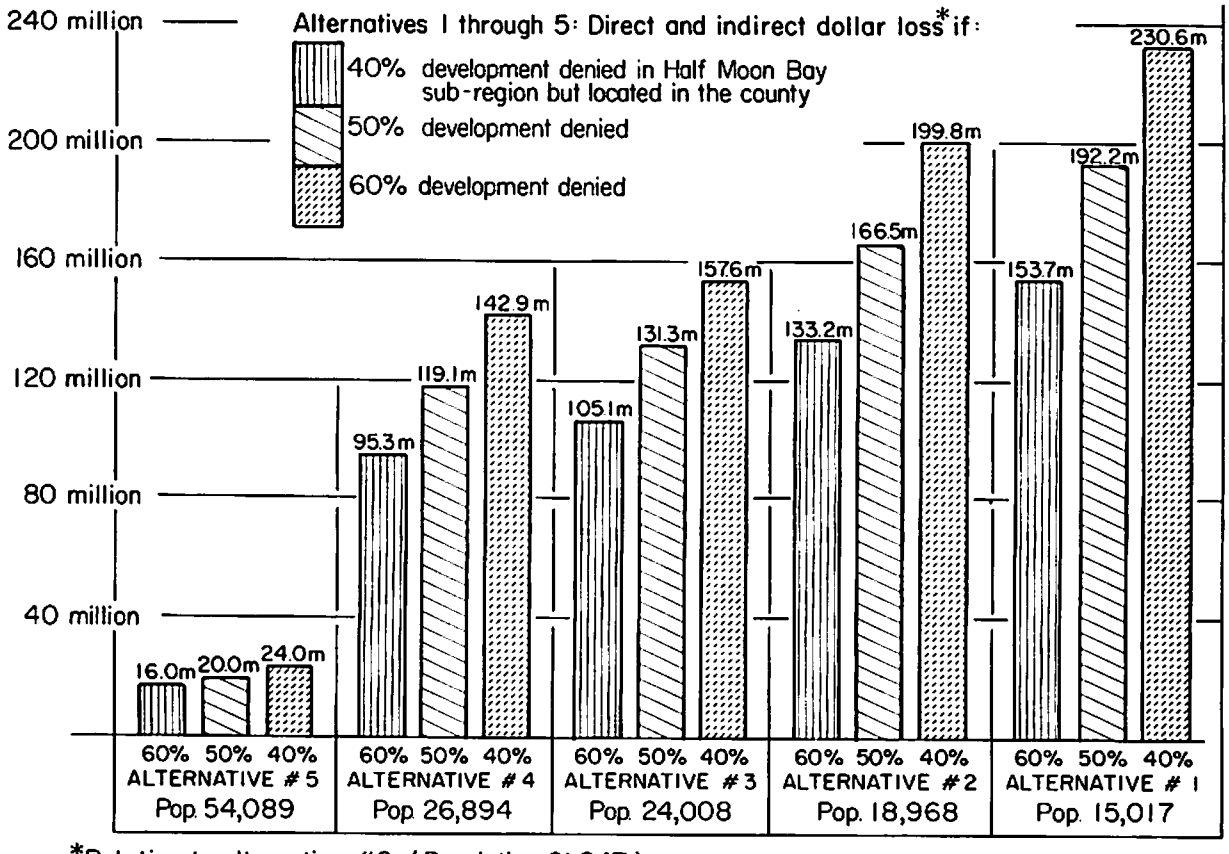
The six scenarios proposed in this study consist of four "lower growth" alternatives utilizing the Coastal Plan as a guideline, and two less restrictive growth alternatives representing the general plans of San Mateo County and the City of Half Moon Bay. These same growth scenarios were analyzed last year in a study relating to government costs and revenues. The complex process of analyzing both the Coastal Plans and the County and City General Plans were carried out by the University of California's Institute of Urban and Regional Development under the direction of Thomas Dickert and Jens Sorensen. The assessment of economic impact on the private sector was conducted by the University of California's Cooperative Extension Service.

Analysis

The analysis involved a four-step operation:

A. The assessment of physical impact for the six alternatives.
B. Converting the physical assessment into 1974 dollars for personal income, commercial sales and construction expenditures.

DOLLAR LOSS TO SAN MATEO COUNTY - 5 YEAR, 1975 THROUGH 1979
ECONOMIC EFFECTS OF RESTRICTIONS TO GROWTH: COUNTY WIDE



*Relative to alternative #6. (Population 61,247)

C. Estimating the loss of dollars spent using the most expansive alternative as a constant. In the study, Alternative 6 produced the greatest additional dollar sales in the area. Therefore, for simplicity in the figure, "Dollar Loss to San Mateo County," Alternatives 1-5 are the dollar losses compared to Alternative 6. In other words, the bar graphs represent the decreases in private sector sales compared to the base line of Alternative 6. The most expansive alternative (see Figure) could generate $200 million in the private sector in a five-year period, whereas Alternative 1's estimated impact is $12 million. The loss in that case would be $188 million. We assumed that 40 to 60 per cent of the lost revenues would leave the county's economy (and be spent elsewhere in the state).

D. An input-output model for San Mateo County was used to estimate the secondary effects of lost dollars.

Conclusion

Coastal legislation (Alternatives 1-4) could affect San Mateo County's private sector economy with a loss of between $95 million and $231 million in 1974 dollars. This would be for the first five years (1975-1980). The ever-widening gap is caused by the loss of personal income expenditures, commercial sales and construction expenditures. We found that the adoption of the Coastal Plan could cause geographical shifts of various kinds, but in all the economic health of the state would not be adversely affected.

Publications

Governmental costs and revenues associated with implementing coastal plan policies in the Half Moon Bay subregion, Cooperative Extension, University of California. In preparation.

Cooperating Organizations

San Mateo County Assessor, Finance Department, Redwood City, California

State of California agencies: Employment Development, Finance, Education, and Agriculture; Commissioner, Board of Equalization, Sacramento, California

U.S. Department of Commerce, Washington, D.C.

Neutron Capture Gamma Ray Spectrometry for Sulfur Analysis

Santa Barbara
R/R-8

A. E. Profio

This research project had as its objective the development of nuclear techniques for measurement of trace elements, especially sulfur, in petroleum as an aid to the identification of the origin of marine oil spills.

Neutron capture gamma ray spectrometry has been developed for analysis of sulfur in fuel oil and crude petroleum. Various Californium-252 neutron sources up to 0.2 μg maximum were used. A 7.6 cm diameter by 7.6 cm thick NaI(Tl) scintillation counter was used as the 5.42 MeV sulfur capture gamma ray detector. Optimum source-detector spacing in oil corresponding to maximum signal-to-background ratio was 18 cm.

Sulfur concentration in fuel oil was measured to within $\pm$ 0.25 per cent accuracy for a 5 liter sample, with 4.0 per cent sulfur, counted for 2000 seconds. Minimum concentration detectable is 0.27 per cent at 68.3 per cent confidence level.

A first order approximation on attenuation on background gamma rays due to density effects has been extended to crude petroleum. The effect of density was a decrease of 2.4 per cent counts for a 5.1 per cent increase in density.

An anticoincidence time gating method was applied to reduce the prompt fission gamma ray background. Anticoincidence gating increased the signal-to-background ratio over a factor of 2, from 0.21 to 0.44.

Publications

Cheng, D.K., Neutron capture gamma ray spectrometry for sulfur analysis, Thesis for M.S., chemical engineering, UC-Santa Barbara, June, 1976.

Profio, A.E., and D.K. Cheng, Neutron capture gamma ray analysis for sulfur, presented at and to be included in the Proceedings of the International Conference on Utilization of Californium-252, 26-28 April 1976, Paris.

Surfperch Mariculture

Kenneth S. Norris

A small-scale mariculture system for the live-bearing striped surfperch, *Embiotoca lateralis*, is being maintained on the campus at UC-Santa Cruz. During the year, the principal concerns have been simply maintenance and "de-bugging" of the system.

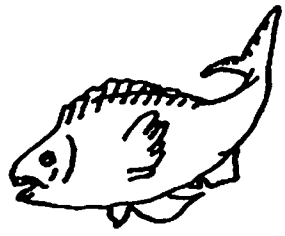
Controlled growth experiments are proceeding with the surfperch in a recycling artificial seawater system. The latter consists of two 500-gallon rectangular fiberglass tanks, complemented by filtering and cooling components. The original refrigeration system was found to be unreliable; it was replaced by one equally simple but much more dependable. Also, the problem of pump and filter maintenance was solved by installing a series of valves, permitting the water from both tanks to be circulated by one pump through either one or both of the two sections of the sand-and-gravel filter.

Minimizing system costs

The major costs of the system have been determined to be electricity for cooling, salt for mixing artificial seawater, and fish food; ways of minimizing these costs are under investigation. Wastes from shrimp processors may be combined with commercial salmonid food to lessen the cost of food. Surfperches seem to grow best in water slightly warmer than their normal surroundings, so the use of natural seawater for this system could minimize the first two costs.

Attention has also been given to improving field and laboratory methods. Although involving some inconvenience, the capture of fish in the wild is best done with diver-tended fish traps, since it permits the selection of healthy fish of particular sizes and sex. In the laboratory, continued observation of animals has been highly instructive in identifying disease in its early stages, and in its proper treatment. In laboratory investigations of nutrition, an oxygen bomb calorimetry technique has been calibrated and tested. This has been found to serve as a valuable, accurate method for quantifying potential productivity of the mariculture system.

Cooperating Organizations
California Department of Fish and Game, Monterey, California



Aquaculture of the Purple-Hinge Rock Scallop

Charles F. Phleger and David L. Leighton

The purple-hinge rock scallop, *Hinnites multirugosus*, appears to be a prime candidate for marine aquaculture. Objectives of this study are to develop suitable techniques for induction of spawning, to determine physical and nutritional requirements of larvae and juveniles, to test suitability of different rearing habitats, and to compare growth in bay and ocean environments.

The rock scallop, *Hinnites multirugosus*, a species native to the Pacific Coast of North America, may offer marine aquaculture a combination of qualities unequalled by any other shellfish. A popular quarry of the sport diver, the rock scallop is well known for its excellence of flavor when eaten in either raw or cooked form. Unlike most scallops, it cements to firm natural (and artificial) substrates after passing through free-living larval and juvenile stages. Furthermore, since the rock scallop occurs naturally in the ocean and within and near entrances to bays (from low tide line to depths over 100 feet) between Alaska and central Baja California, its survival and growth under a wide range of environmental conditions would appear assured. A preliminary study of spawning, larval culture and growth in the field provides encouragement to prospects for aquaculture of this shellfish (Leighton and Phleger, 1976a).

We have embarked upon an intensive study of the biology and culture of *Hinnites*. The primary aim of the program is to develop a hatchery technology to allow production of spat at low cost. This new technology would also permit extensive rearing schemes utilizing bay and ocean environments, with minimal maintenance requirements and it would facilitate mechanized harvesting.

In addition to research space at the La Jolla Laboratory of the National Marine Fisheries Service and laboratories at San Diego State University, the program utilizes a 25 ft boat which serves as a floating seawater laboratory and platform for habitat and growth tests (the *HMS Hinnites*). The boat is in Quivira Basin, near the entrance to Mission Bay, in waters supporting natural populations of rock scallops (Fig. 1).

Biological studies include investigations of reproductive cycles in scallop populations in ocean and bay environments (F. Jacobsen, Master's research) and natural recruitment and growth in Mission Bay. Culture studies are examining techniques for inducing spawning, physical and nutritional requirements of larvae and juveniles, pen rearing of juveniles in the bay, suitability of various materials and designs for rearing habitats, methods to induce symmetrical shell growth, and comparative growth studies in bay and ocean. We are now using the NUC Oceanographic Platform off the San Diego coast for ocean observations. Food quality and marketing potential were assessed by flavor profiling (conducted by Foremost Foods, Inc.), and chemical analyses of adductor muscle.

Culture and early development

Spawnings, whether induced or spontaneous, have been fewer than expected this year to date. Major periods of reproductive activity in Mission Bay scallops were October (1975) and April (1976), while Point Loma animals spawned most productively in January (1976). Most attempts to induce spawnings at other times this year have been unsuccessful; this failure is considered to be due to a lack of maturity in scallops sampled. This outcome suggests the desirability of developing procedures for conditioning adults for off-season spawning.

Larvae obtained from an April spawning this year have been reared through metamorphosis and byssal thread forming juvenile stages and are now, at an age of six months, approaching the time of cementation (Fig. 2). A description of early development, thermal optima and limits, and the preliminary results of feeding experiments are provided in Leighton and Phleger (1976b). Feeding and growth observations on larvae and postlarvae suggest several algae now being evaluated are of limited value as food for *Hinnites*. Further work on the subject is planned to begin soon. *Monochrysis*, *Isochrysis* and *Nannochloris* have supported fair growth and survival. However, juveniles produced in the laboratory on cultured algae and subsequently transferred to special mesh-bottom rearing containers on the floating laboratory and provided with natural plankton via continuously flowing air-lift seawater delivery, have shown significantly improved growth and survival over sibling progeny retained on the original diet.

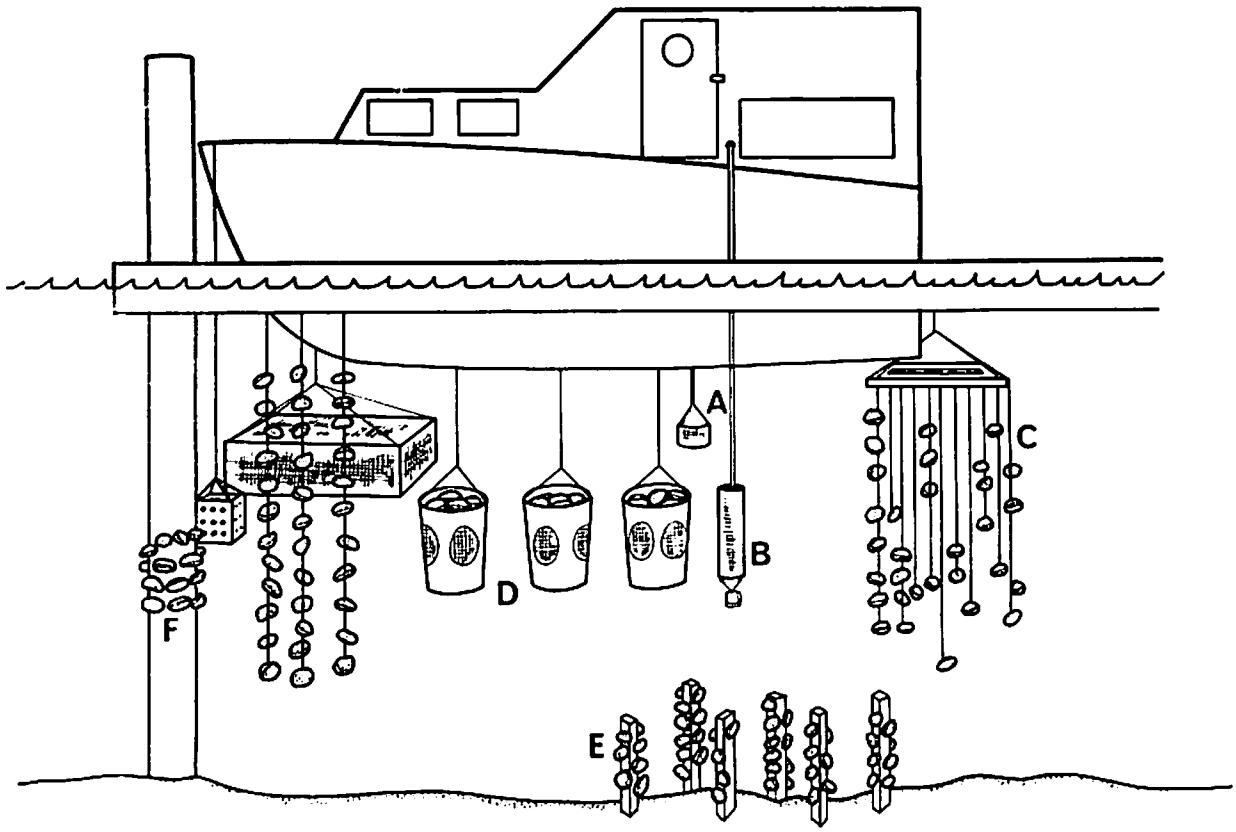


Fig. 1. Floating rock scallop culture laboratory

Recruitment and growth of scallops in Mission Bay

Free-living (byssal) juveniles were found beneath jetty rock and on concrete pilings from mid-May to fall (both 1975 and 1976). May samples have yielded tiny individuals only (2-7mm), while September collections ranged from 5 to 25 mm. Curiously, this year recruitment was relatively heavy on rock in the main channel in areas devoid of established adults. We are continuing our observations of these populations to see if possibly selective predation is the reason for eventual failure.

Caged juveniles and young adults were tagged and held beneath the floating laboratory. 1975 summer growth for juveniles averaged 7.9 mm/month. Thirty first-cementing individuals contained in stacked Nestier trays have been measured quarterly since October, 1975. Monthly rates of shell growth were 4.0, 5.1, and 3.0 mm for fall, winter and spring. Maturing scallops typically become more deep-shelled, and increments in diametric measure (height + width)/2 decrease with age. Young scallops 1.5-2.5 cm last fall reached 6.5-7.5 cm this September.

Comparative studies of scallop growth are in progress. Test cages have been placed on supportive cross-members of the offshore platform at a depth of 10 meters. New installations will occupy 5 and 15 meter depths (J. Monical, Masters research) consisting of concrete-based quanset mesh cages. Similar structures are to be placed at additional stations on the Point Loma shelf, and in both Mission and San Diego Bays.

Tests of materials and concepts for rearing habitats

A number of artificial and natural materials are being employed in substrate suitability studies. Plastic mesh of a range of descriptions is used in cage construction and for experimental growing surfaces. Thinly cast concrete and asbestos board are finding wide application as surfaces acceptable to scallop cementation. Natural materials include shell of scallop, mussel and abalone. At the present time we are either securing juvenile scallops to concrete or asbestos boards with epoxy cement that sets underwater or introducing individuals to miniature plastic mesh cages distributed appropriately on substrates. The miniature cages are formed by heating polyethylene mesh which is glued or embedded in concrete or asbestos sheets. The "mini-cages" will be removed after scallops have

cemented firmly and gained the benefit of protection from predation during early vulnerable stages. This method is expected to lead to design and development of specially formed cages to be mass-produced in interconnected series for ready application to appropriate surfaces—a technique of obvious value to seed planting operations.

Encouraging results have been obtained in symmetrical shell growth of scallops enmeshed as juveniles in fine filament polypropylene mesh. Hinge-line ears are merely inserted into meshing; shell growth thereafter incorporates the mesh, allowing controlled distribution on growing surfaces, facilitating handling and subsequent har-

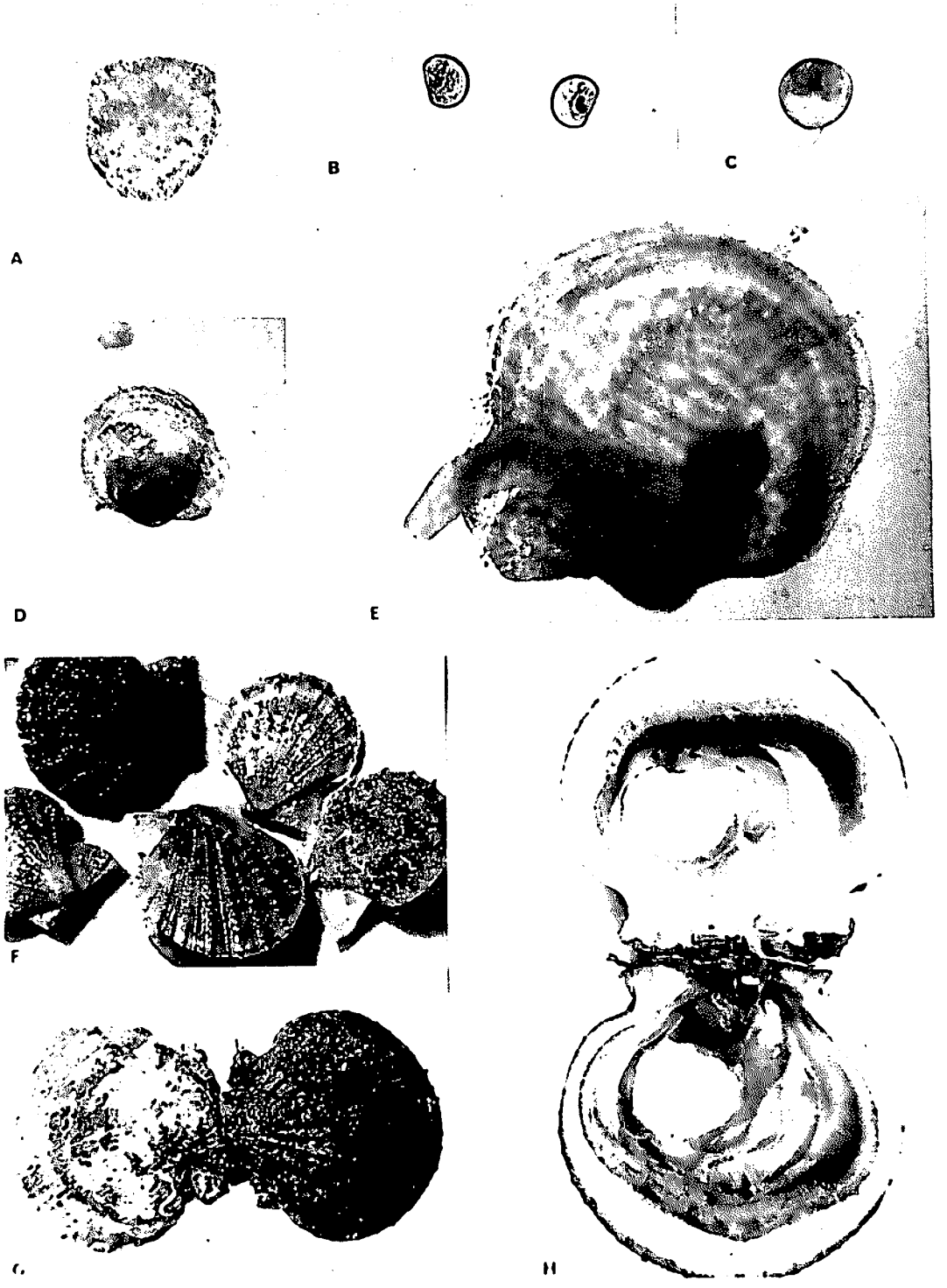


Fig. 2. Larval and juvenile stages of the purple-hinge rock scallop

DESCRIPTIVE FLAVOR ANALYSIS OF SCALLOPS BY FOREMOST FOODS RESEARCH AND DEVELOPMENT CENTER

AROMA						FLAVOR-BY-MOUTH					
Overall Impression	Nova Scotia H	Thailand MH	Atlantic Coast MH	Atlantic Coast MH	Rock Scallop H	Overall Impression	Nova Scotia MH	Thailand M	Atlantic Coast MH	Atlantic Coast MH	Rock Scallop MH
Sweet	X-1	X-1	X-1	X-1	X-1	Sweet	X-1	X-1	1	1	X-1
Buttery	X-1	X-1	X-1	X-1	1	Buttery	X-1	1	X-1	X-1	X-1
Milky	X-1	---	X-1	X	1	Scallop	1-2	1	1-2	1	1-2
Briny	X	X-1	X-1	X-1	X-1	Salty	X-1	X-1	X-1	X-1	X-1
Fried	1	1	X-1	1-2	X-1	Fishy	X	1-2	---	X-1	X-1
Scallop	1	X-1	1-2	1	1-2	Sour	X	X	X-1	X	X-1
Fishy	X	1-2	1	1	---	Earthy	X	X-1	X	X-1	X-1
Earthy	X-1	X	X-1	X-1	X-1	Milky	---	X-1	---	---	---
Oily	---	X-1	---	---	---	Oily	---	1	---	---	---
						Fried	1	1	X-1	1	X-1
FEELING FACTOR						AFTERTASTE					
Firm	+	+	-	+	-	Scallop	+	-	+	+	+
Chewy	+	+	-	-	+	Sweet	+	+	+	+	+
Sand grains	+	-	-	-	-	Sour	sl.	-	-	-	-
Tender	-	+	-	-	+	Buttery	+	+	+	+	+
Dry	-	+	-	-	-	Fried	-	+	-	+	-
Gritty	+	+	sl	-	-	Earthy	-	-	-	+	-
Fibrous	-	-	-	+	-						

SCALE: X = Threshold, 1 = Slight, 2 = Moderate, 3 = Strong, H = High, M = Medium, MH = Medium High, sl = slightly noticeable. Underlining indicates emphasis.

vesting. Preliminary results show good growth of mesh-held scallops at relatively high densities.

Methods of rearing scallops on structures which are to be positioned on the sand bottom not only permit exploitation of vastly greater farming areas offshore, but may also provide a growing environment with reduced predator incidence. Prototypes will soon be constructed and evaluated.

Flavor analyses and chemical studies

Foremost Foods Research Laboratory, Dublin, California, as referred to previously, has conducted a comprehensive series of flavor profile comparisons involving *Hinnites* and several brands of other scallop species. The rock scallop samples were rated very high on almost all desirable characteristics (see the Table). Qualities judged fell into four categories: taste, after-taste, aroma and texture.

Proximate analyses of adductor muscle were made on samples from Point Loma and Mission Bay. Dry matter consisted of 79 per cent protein, 2 per cent lipid, 13 per cent carbohydrate and 6 per cent ash. Gas chromatographic analyses of lipid and carbohydrate fractions are being made of these samples and of scallops deprived of food for several weeks. Preliminary results show strong contrasts in carbohydrate composition.

Dissemination of information

Aside from several planned publications in technical literature, a synopsis of findings will be compiled in form of a monograph, "Contributions to the aquaculture and biology of *Hinnites*". Chapters on reproduction, culture, rearing in the field, recruitment and growth in natural populations, physiology, marketing and component analysis will be authored by principal and student investigators.

Student research projects

Three graduates and one undergraduate student are currently associated with the program. Aspects of the reproductive biology of *Hinnites* are being examined by morphometric and histological comparison of two distinctly different populations of rock scallops (Mission Bay and Point Loma Shelf) by our Sea Grant Trainee, Mr. Fritz R. Jacobsen. Mr. Jim Monical is beginning an ambitious program to compare growth rates of juvenile scallops. These specimens are being collected in Mission Bay and introduced to cages at several stations in San Diego and Mission Bays, on pilings of the NUC platform and on the Point Loma shelf. Mr. Christopher Foe plans to study juvenile growth under controlled feeding at several temperatures. These three projects are Master's research programs. Undergraduate students receiving upper division credit are exploring less extensive, but nevertheless pertinent, problems.

Publications

Leighton, D.L., and C.F. Phleger, 1976a. Preliminary studies on the aquaculture potential of the Pacific Coast purple-hinged rock scallop, Proceedings of the World Mariculture Society.

Idem, 1976b. The purple-hinge rock scallop, a new candidate for aquaculture. Manuscript in preparation.

Cooperating Organizations

Foremost Foods Research Laboratory, Dublin, California

U.S. Navy

Biochemical and Genetic Control Applied to the Critical Stages in Culturing Abalone

Daniel E. Morse

A method of chemical control of reproduction in the abalone and other molluscs has been developed. It is based on our finding that hydrogen peroxide induces spawning by stimulating the enzymatic synthesis of prostaglandin endoperoxide.

Although the marine invertebrate animals constitute a vast and protein-rich food resource, lack of control of their reproduction and early development remains one of the principal barriers to the economical cultivation of these animals for human consumption.

In research supported by seed-money from the NOAA Sea Grant Program and the Marine Science Institute of the University of California at Santa Barbara, we have recently developed a chemical method for reproducibly and synchronously inducing spawning and reproduction in abalones, mussels, and oysters. We have characterized the biochemical and enzymatic mechanism of this effect, and have studied its applications to making shellfish production more economically efficient.

The addition of low concentrations of hydrogen peroxide to seawater was found to reproducibly cause synchronous spawning of gravid male and female abalones, mussels, and mangrove oysters. (The latter species is of commercial importance in areas of the Caribbean and Southeast Asia). Our biochemical analysis indicates that this effect may result from a direct activation of the enzyme-catalyzed synthesis of a hormone-like molecule (prostaglandin-endoperoxide) known to control reproduction in many species of higher animals.

This inexpensive and easily controlled chemical method may offer unique advantages for the control and synchronous induction of spawning in large numbers of animals, in both artificial and natural ponds and mariculture lagoons. Wide applicability is suggested to other molluscan species that are locally important as protein-rich food resources, and currently under investigation.

The chemicals involved are non-persistent, and pose no hazard to either food or water supplies. We have defined conditions under which the eggs and sperm shed in response to hydrogen peroxide treatment can be kept competent, and subsequently used to obtain very high yields of fertilization, hatching, and normal embryonic and larval development. This method is thus directly applicable to both mariculture-production, and the genetic management and improvement-breeding, of the protein-rich and highly palatable shellfish food resources.

Through the further use of these methods (which we find more reliable than the earlier "UV-method" developed by Kikuchi and Uki), we are now routinely inducing spawning, fertilization, and larval development of abalones on a daily "on-line" basis. We are thus in a unique position to attack an important obstacle to the economical development of the abalone mariculture industry in both the U.S. and Japan. This is the lack of knowledge in the identification and cultivation of food-organisms (diatoms and other algae) needed to ensure high survival rates in the very young post-larval abalones. We are currently using this system for the experimental analysis of species and cultivation techniques to provide the food required by the larval abalone as they settle out of the plankton, undergoing metamorphosis to become bottom-dwelling juveniles.

Our findings have been reported to the international mariculture and oceanographic communities at a U.N.-sponsored symposium in Caracas, Venezuela (July, 1976), and are described in two articles currently in press in the scientific literature.

Publications

Morse, D.E., H. Duncan, N. Hooker, and A.N.C. Morse, Hydrogen peroxide induces spawning in molluscs, with activation of prostaglandin endoperoxide synthetase, *Science*, in press.

Idem, An inexpensive chemical method for the control and synchronous induction of spawning and reproduction in molluscan species important as protein-rich food resources. Paper presented at the U.N. Symposium, Prog. Carib. Marine Research (CICAR-II), Caracas, July 1976; also in press, in Proceedings of the Symposium.

Cooperating Organizations

California Department of Fish and Game, Operations Research Laboratory, Monterey, California
Marine Science Institute, UC-Santa Barbara, California
Santa Barbara Mariculture Foundation, Santa Barbara, California

Optimization of an Artificial Diet for Lobster Culture

R. Barry Holtz

In this project, which aimed at the formulation of artificial dietary rations for lobster feeding, an experimental plan was used based on Response Surface Methodology (RSM). An initial 120-day feeding study was initiated to establish the importance of five dietary variables at five levels, requiring the formulation of 32 dietary tests and five determinations of chemical composition of each formulation.

The project comprised a five-variable, five-level (5 x 5) experiment designed with the assistance of Dr. Douglas Conklin, of the Bodega Marine Laboratory. This experiment required the formulation of 32 dietary plans. The RSM program allows the investigator to determine the complex interaction of up to five variables at five levels with a greatly reduced number of experiments. The experimental design satisfies the important elements of the Taylor Expansion Equation and, with the aid of the computer, permits the investigator to quickly identify optimum interaction of variables through graphic outputs such as contour maps. An amount of approximately 18 kg of each formulation was formulated and blended in the Foremost Research Center pilot plant, and approximately 2 kg of each dietary formula was extruded at the Bodega Marine Laboratory. Samples of the base blend before extrusion were subjected to the following analytical evaluation: Total protein, total fat, fiber, ash, carbohydrate (by difference), fatty acid composition, Vitamin A, Vitamin D, moisture (%), Mg, Ca, and PO_4. Samples of the extruded product were also monitored for those nutritional products that are most readily oxidized or heat-labile, e.g., fatty acids Vitamin A and Vitamin D.

To date, over 450 separate analyses have been performed on the artificial diets to monitor their base-line composition and stability during storage. In this way, changes in responses could be observed in line with the true value of the variables.

RSM input values determination

The values determined by chemical analyses, along with those calculated by formulary values, are and will be used to establish the variable and response values for RSM input. This will obviate the problem of those nutritional experiments that base interpretation on calculated values rather than those calculated from predetermined formula components.

Dietary variables were selected as follows for the 5 x 5 experiment:

Variable	*Range*
% Protein	0-40
Casein / ovoalbumin	100% Casein - 100% albumin
% Lipid	0-12
% Yeast	0-20
Canthaxanthin	0-500 mg

A typical mid-point dietary formulation was formulated as follows from the highest purity raw materials commercially available.

Material	%
Starch	10
Wheat gluten (binder)	15
Lipid	7
Vitamin mix	2
Casein / albumin	20
Mineral mix	3
Cellulose	28
Dried yeast	15
	100

The initial feeding trial at Bodega Marine Laboratory used a total of 576 animals. This number is higher than is anticipated in future RSM experiments. However, on the initial feeding trial, the statistical variance as calculated using the RSM approach will be compared directly to traditional statistical measures of variance. This will aid to demonstrate the efficiency of using smaller numbers of animals in future experiments.

The San Diego State University Aquaculture project has prepared space and equipment to accommodate a long-term feeding study scheduled to begin in January 1977.

Cooperating Organizations
Bodega Marine Laboratory, Bodega Bay, California
Foremost Foods Company, Dublin, California
San Diego State University, San Diego, California

Astaxanthin from Yeast

M. J. Lewis

The bright, orange-red carotenoid pigment astaxanthin is a necessary component in diets of various marine animals if natural color is to be maintained, yet sources are limited. It has been shown that the astaxanthin-containing yeast, *Phaffia rhodozyma*, is more than a laboratory curiosity and can grow and produce high yields of astaxanthin under conditions similar to those prevailing commercially. Various leads have been developed which may increase growth rates and yields of astaxanthin, and some experience has been gained with feeding trials of salmon and lobster which may lead to the development of a satisfactory artificial diet that maintains color.

The marine red fish and crustaceans are not able to synthesize their natural pigments. In order for their flesh to be colored, the animals must ingest these pigments in the diet. Pen reared salmon, for example, are pale in color because their diet lacks the carotenoid pigment astaxanthin. This problem could be solved, for example, by incorporating into the diet the red yeast, *Phaffia rhodozyma*, because it contains astaxanthin.

The primary objectives of the project were to determine whether this red yeast could be produced under commercial fermentation conditions and to develop a rapid assay for the pigment in the yeast. We also studied the influence of culture conditions upon yeast growth and pigmentation.

Culture conditions

Our work has shown that astaxanthin biosynthesis is dependent upon culture conditions of the yeast. The amount of sugar available in the medium influences both the type and amount of carotenoid produced; about two per cent sugar is optimal. Vigorous aeration of the medium must be maintained at all times for high pigment yields, and pH 4.5 is optimal for yeast growth and pigment production. The carotenoid content of the yeast changes during the growth cycle of the yeast; it increases throughout the growth phase and is highest soon after depletion of sugar in the growth medium. At this stage also, the formation of astaxanthin is most efficient. Different strains of *Phaffia rhodozyma* vary in the amount of cells and pigment they produce; the strain that is typical of the genus produces most pigment per gram of cells, but a strain isolated in Russia grows faster and hence produces more carotenoid per hour and more per liter of medium. These yeasts also grow much faster and produce more astaxanthin on a complex growth medium such as malt wort than on the defined media that have been the mainstay of our project to date.

Phaffia rhodozyma has a high content of astaxanthin—500 to 700 μg/g of yeast—and is high in fat, 15 per cent w/w. The protein content (25 per cent w/w) is rather low. It is likely, therefore, that the yeast will have to be mixed with other materials to make an adequate diet for fish.

Feeding trials

Two feeding trials have been conducted to date. In the first trial, rainbow trout were maintained in two deep tanks at 55° F and were fed pelletized white yeast or red yeast (*Phaffia rhodozyma*). The fish grew well under these conditions, but the control fish died when aeration was interrupted temporarily. We intend to repeat this experiment using brook trout in the near future and salmon fingerlings in the spring. A lobster feeding experiment has recently been completed, in which lobsters raised on white yeast and red yeast were compared with lobsters raised on live brine shrimp. The brine shrimp control far outgrew the yeast test animals and had a normal color. The color of the animals fed yeast was extremely variable and did not match the color of the lobsters fed brine shrimp.

Publications

Johnson, E. A., The biosynthesis of the carotenoid pigment astaxanthin by an imperfect yeast *Phaffia rhodozyma*. Paper presented at the annual meeting of the Institute of Food Technologists, Anaheim, California, June 1976.

Cooperating Organizations

Bodega Bay Marine Laboratory, Bodega Bay, California
California Department of Fish and Game, Sacramento, California
National Canners League, Sacramento, California

The Effects of Man-Made Structures on the Soft-Bottom Community

Paul K. Dayton and Noel Davis

The effect of man-made structures on the surrounding soft bottom community was examined. It was found that artificial structures do affect the adjacent sand dwelling animals. Fishes attracted by artificial reefs annihilate sea pens over a considerable surrounding area. Structures also cause an organic build-up in the sediment which results in an increase in deposit feeding animals around the structure.

As part of his increasing need to exploit ocean resources, man has been placing more and more structures on the sand bottom sea floor. These man-made constructions include artificial reefs, oil platforms, and bridges. Such structures subject the sand community to several kinds of perturbations. They cause scour and change the sediment characteristics, and they also attract predators which forage on sand bottom animals. The purpose of this project was to examine the effect of these man-made structures on the natural sand bottom community. This work was done in conjunction with Glenn VanBlaricom, a Scripps graduate student who is studying the sand infauna for his Ph.D. dissertation.

Our primary study site was an artificial reef which was installed in 40 feet of water off Torrey Pines in April of 1975. Constructed of quarry rock, it extends about 150 feet parallel to shore, is 40 feet wide and eight feet high. This reef has been named Torreypine Reef by the local divers. We began censusing it two weeks after installation and have continued to monitor it on a regular basis. Data were also collected from Fish 'n' Game Reef, a 12 year old rock reef similar in size to Torreypine Reef and located in 80 feet of water off Torrey Pines. Other structures studied included Oil Platforms Hilda and Hazel off Santa Barbara and Oil Platform Eva off Huntington Beach, as well as the Ventura Bridge in Mission Bay. Finally, to better understand some of the effects we had noted at Torreypine Reef, we constructed a small reef out of tires and other junk and placed it in 50 feet of water off Scripps Pier in June of 1976.

Effects of Torreypine Reef

Sand grain size analysis, sand ripple pattern analysis and percentage organic determination indicated that Torreypine Reef has had almost no physical effects on the surrounding sand. Growth of the giant kelp, *Macrocystis pyrifera*, became extremely lush on Torreypine Reef around June of 1976, and it is expected that this thick kelp growth may eventually increase the organic content of the sand around the reef.

The sand infauna around Torreypine Reef showed an initial depletion of abundances of all species within approximately 10 meters of the reef and a reduction in species number near the reef. The infauna underwent a subsequent recovery within a few months such that no trends as a function of distance from the reef could be discerned as of winter, 1976.

A striking reduction was recorded in the abundance of the sea pen, *Stylatula elongata*, the dominant epifaunal animal at 40 feet depth (density about 9 pens per square meter). Soon after installation of the reef, we noted that the tops of the sea pens close to the reef were bare of polyps. By June of 1975, a decrease in sea pen densities in the 30 meters closest to the reef was seen. By July of 1975, *Stylatula elongata* had completely disappeared in those 30 meters and reduced densities were recorded as far away as 80 meters from the reef. The area devoid of sea pens gradually moved farther and farther from the reef, so that by September of 1976 no sea pens were found within 120 meters of Torreypine Reef and densities were reduced at a distance of greater than 150 meters from the reef. Sea pens with bare tops were found in the area of reduced density. This dramatic disappearance of sea pens around the reef seems to be a result of predation from reef-associated fishes. Probably, the most important of these fish predators is the sand bass, *Paralabrax nebulifer*. A. O. Flechsig has observed sand bass feeding on sea pens (personal communication). We have also found pieces of the *Stylatula* pen in the stomachs of sand bass collected from Torreypine Reef. We are not sure, however, if the sand bass is the only fish responsible for the sea pen disappearance. It is likely that many of the fishes attracted to the reef forage on the sea pens to some extent.

To test the hypothesis that the sea pen disappearance was the result of predation and not some physical disturbance, we

constructed a small reef off Scripps Pier in June of 1976. At a distance of 5 meters from the reef we put a one meter diameter cage designed to exclude predators. A short distance from this predator-exclusion cage, we placed a control cage of the same size and supporting material but with no mesh so that predators had access to the interior. By August, reduced sea pen densities were recorded within 20 meters of the reef and the sea pens close to the reef and in the control cage had bare tops, while those in the exclusion cage were intact. By September, all but one of the six sea pens in the control cage were gone while the nine sea pens in the exclusion cage remained.

Effect of oil platforms

Besides artificial reefs, another kind of structure that man introduces to the sand bottom is oil platforms. Quantitative data were collected from Oil Platform Eva which lies in 60 feet of water off Huntington Beach. The grain size analysis showed a bimodal distribution out to about 20 meters from the platform. The coarse mode was probably due to drill cuttings, and the fine mode was the natural sand. The coarse mode was absent beyond 20 meters, and grain size analysis showed uniformly fine sand. The organic content of the sediment was extremely high within 30 to 40 meters of the platform. The infauna consisted of a background community of typical fine sand fauna for depths of 60 feet off semiexposed coast, but imposed on this were many additional deposit feeding species within 20 to 30 meters of the platform. There were many polychaetes and a great number of juvenile ophiuroids.

On the bottom directly underneath the platform were tremendous numbers of starfish feeding on mussels which fell from the structure. The dominant asteroids were *Pisaster brevispinous* and *Patiria miniata*. Total asteroid density underneath the platform was 29 starfish per square meter. The abundance of these starfish decreased dramatically a few meters away from the structure and by 20 meters, the epifauna consisted entirely of typical sand bottom animals. There was, however, a marked enhancement of the tube dwelling polychaete *Diopatra ornata* close to the platform. In the meter closest to the platform the density of these worms was 73, falling to 42 in the next meter and 33 in the third meter. From there the *Diopatra* densities averaged about 12 per square meter out to 60 meters away from the platform. Densities then fell to about three worm tubes per square meter out to 100 meters. A control transect done 300 meters from the platform showed a natural density of only about 0.5 worms per square meter. Since *Diopatra* is a deposit feeder, we believe this increase in density surrounding the oil platform is a result of the high organic content of the sediment.

Dives were also made underneath Oil Platforms Hilda and Hazel which lie in 100 feet of water off Santa Barbara. Although no quantitative data were taken, a similar build-up of *Diopatra ornata* was noted around these two towers. *Diopatra* densities are also enhanced around the base of Fish 'n' Game Reef and beneath Ventura Bridge. The average density of *Diopatra splendidissima* was 27 per square meter in the three meters closest to Ventura Bridge. The tube worms fell to an average of 10 per square meter for the next eight meters and 1.5 per square meter thereafter. The build-up in tube worms around these structures is thought to be associated with increase in organic content of the sediment as was the case under Oil Platform Eva. If the developing kelp bed on Torreypine Reef increases the organic matter in the sediment as expected, we anticipate an eventual increase in *Diopatra splendidissima* close to that reef.

Conclusion

In summary, we have found that man-made structures exert a considerable influence on the surrounding soft bottom community. This work is now being completed and the results will be prepared for publication within the next few months.

N. Davis is in process of completing her Ph.D. dissertation which examined the feeding behavior of the dominant sand bottom starfish, *Astropecten armatus* and *Astropecten californicus*. The diet of these sea stars was compared to the prey availability in different locations, and the importance of prey escape behavior and predator selectivity in the final make-up of the diet was assessed. This dissertation will be finished by the end of the year.

Cooperating Organizations

Southern California Coastal Water Research Project, El Segundo, California

International Biological Consultants, San Diego, California

Union Oil Company, Los Angeles, California

A Study of the Santa Barbara Party-Boat Fishery and Aspects of the Life History of the Olive Rockfish, *Sebastes serranoides*

Alfred W. Ebeling

There is increasing pressure by various interest groups on the marine resources of the Southern California Bight. In Santa Barbara, the sport and commercial fishing industry, oil companies, and numerous other business and recreational interests vie for both space and marine organisms.

It is the intent of this project to analyze the inshore sport fishing party boat industry. Emphasis will be placed on analyzing which fish are most important to the industry and which areas are fished most heavily. In addition, work will continue on the life history of the olive rockfish, *Sebastes serranoides*, an important sport fish.

Our work is divided into two parts: 1) studies of the Santa Barbara inshore party boat fishery, and 2) investigations of the life history of the olive rockfish (*Sebastes serranoides*). Sampling programs for both studies are well under way.

We feel that the following indicators are important in characterizing the party boat fishery.

a) Areas fished. There is increasing competition for the use of various habitats by various interest groups of people. For example, it is important to ascertain to what extent reefs, oil rigs, etc., are utilized by the sportfishing industry. Data are being collected in two ways. About once a week, we sample aboard the party boat and directly record the length of time fished in each area. We also interview the party-boat operator weekly or semiweekly. At that time he indicates the amount of time fished at each location during the preceding period. This method is quite accurate, as we have found close agreement between our direct measurements and the estimates of the operators. Thus far, Naples Reef and the oil rigs are the most heavily fished sites.

b) Length frequencies. About once a week we measure all fish brought aboard the vessel. It would appear from the data gathered that many of the fish taken, particularly the rockfish, are immature. This is particularly so of fish taken from the oil rigs, a very important fishing area. Therefore, we are collecting data on the size of maturity of the various local sport species, in an effort to determine to what extent the local fishery depends on juvenile fish.

c) Species composition and numbers of fish taken. We make direct counts on a weekly basis, interview the operators and utilize the records in their California Fish and Game log books. Various species of rockfish make up the bulk of the fish taken, with kelp bass being a distant second.

From our own data and from those supplied by the Fish and Game Department, it appears that the olive rockfish is a major constituent of both the party-boat and private-boat sportfishery in much of central and southern California. The following aspects are being investigated.

1) Age, growth and maturity—using otoliths to age fish. It appears that there are differences in growth rates between fish populations in different geographical locations. We are investigating the possibility that differences in ambient temperature may be a factor in the growth rates. We are examining gonads in both males and females to determine at what age and size the olive rockfish matures. Subsamples of ovaries of mature fish are being taken to estimate fecundity.

2) Movements—We have tagged over 1000 fish. Thus far, returns indicate that little movement occurs. It is possible that we may be able to use parasites as indicators of the relative amount of movement of individuals between adjacent groups of olive rockfish.

3) Parasites—We are making a survey of the parasite mix of the olive rockfish. Thus far, over 30 different species of parasites have been found. There are indications that some of the infections are seasonal or limited to certain geographical locations. As mentioned above, it may be possible to identify populations by noting differences in their respective parasite mix.

Cooperating Organizations

California Department of Fish and Game, Monterey, Long Beach, California

Environment Canada, Nanaimo, British Columbia, Canada

National Museum of Natural History, Smithsonian Institution, Washington, D.C.

Sea Landing Sportfishing, Santa Barbara, California

Causes of the Decline in Dungeness Crab in the San Francisco Bay Area

Berkeley
R/NP-1F

A. J. Horne

A dramatic decline in Dungeness crab landings has occurred since the early 1960's. Potential causes for the population failure suggested in the literature include physical factors such as temperature, salinity and currents; chemical factors such as heavy metals, petrochemicals, pesticides, polychlorinated biphenyls and chlorinated waste water effluents; and biological factors, such as disease, parasitism and competition for food. Durable halogenated organic compounds are formed in the disinfection of waste waters with chlorine. Preliminary data indicate toxicity to aquatic organisms at μg/l levels of these compounds. To establish the relationship between waste water chlorination activity and crab landings, a survey was conducted of municipal dischargers drained by the San Francisco Bay system. Significant increases in chlorine usage in municipal waste water treatment were found to occur immediately preceding the Dungeness crab population failure. Results of the survey have been published in a Report, authored by Peter P. Russell and Alexander J. Horne and issued by UC-Berkeley.

The project sponsored a meeting with the Department of Fish and Game and university research personnel to identify what research still needs to be done in this area.

Conference on the Standardization of Taxonomic Reporting of Marine Invertebrates

San Diego
R/NP-1K

Willard Bascom

Reports of environmental damage have been traced to misidentification of organisms. In November of last year, a number of taxonomic program managers met at a Sea Grant sponsored workshop to discuss and decide upon the best means of presenting taxonomic data and in making identification manuals. They also discussed various computer coding systems for invertebrate data.

It was agreed that in order to make more efficient use of the non-professional employed in taxonomic work, a series of illustrated taxonomic identification manuals would be published. These manuals should cover many organisms only in enough detail to give the non-expert taxonomists sufficient information to accurately and consistently identify their specimens. Strict guidelines were given for these manuals, so that their use will save many hours of technician time for government and private agencies involved in ecosystem analyses. In addition, a uniform data base would be built for the analyses and comparison of the data now being produced.

Another part of the conference was concerned with computer numbering systems for species name files. The primary purpose of such listing is to facilitate the analysis of biological data by providing the investigator with numbers that can be used in place of the genies-species identification. These numbers would also convey information on the taxonomic hierarchy of each species to others.

Three of the existing computer coding systems examined were capable of containing a national listing of species, complete with the companion appendices, without extensive modification. These are at least marginally large enough to contain more than a million species which may be encountered in North America and its adjacent marine waters. They are essentially non-overlapping in terms of the species contained in each coding system and have covered or will cover the majority of species throughout this country. The National Oceanographic Data Center has agreed to write translation programs for these three systems that will enable communication without the problem of different numbering systems.

It is intended to publish a brief summary of the results of this workshop in a variety of nationally known systematic publications, to advertise the fact that there are currently lists available to researchers that cover the nation which should be used rather than generating more new lists at great cost and duplication of effort.

Design and Development of a Squid Processing Machine

R. Paul Singh

Preliminary work was done on the feasibility of a fully automated squid processing machine, with a view to reducing appreciably the cost of cleaned squid fillet.

The objectives of this project were: to conduct a feasibility study of a horizontal conveying squid processing machine; to explore the possibility of increasing the processing efficiency with automatic feeding and handling of squid; and to compare the anticipated processing rates with other available squid processing machinery.

To meet these objectives, it was determined that several significant items would be studied:

A. The current cost and methods of cleaning California market squid (*Loligo opalescens*)
B. The physical properties of squid important to the cleaning process
C. Unit operations involved in the automatic cleaning of squid
D. Feasibility of a fully automated squid processing machine

A. Current costs and methods

The wholesale cost of California market squid in September, 1976, was $0.20/lb. Interviews with owners of fish companies in Monterey, California, revealed that very little of the annual catch (≈ 20,000 tons) was processed beyond whole canning or freezing due to the high cost of hand labor. Some restaurants which feature squid process them on site at a cost of $0.30-$0.50/lb of whole product. Considering that approximately one half of the animal's weight is discarded, the cost to produce one pound of cleaned squid fillet approaches $0.60-$1.00/lb. Since the current market in squid consists mainly of Mediterranean, Spanish, and Oriental groups who are used to purchasing whole squid at about $0.50/lb, it is evident why one processor's attempt to market hand-cleaned squid fillets at $1.80/lb failed.

The hand cleaning operation, which takes about 30 seconds per animal, consists of the following steps:

1. Cutting off the tentacles (optional if the tentacles are saved).
2. Pulling the head and viscera from the mantle.
3. Pulling the skin off the mantle.
4. Slicing the mantle open and scraping off the remaining viscera, and the pen.
5. Finally washing the fillet.
6. Scoring the meat to prevent curling (optional) when cooked.

B. Physical properties

The physical properties of the squid should be determined to allow for development of methods of performing the unit operations involved in cleaning. The properties of interest include friction coefficients of the squid on machine materials, mass distribution, forces required to remove viscera and skin, attachment points, variability of properties with temperature, handling, storage, and size distributions.

Insufficient time precluded accurate determination of most of these properties. However, several preliminary conclusions could be drawn from qualitative measurements and comparisons. It was shown that squid will orient themselves mantle first when sliding down a metal chute. This is due to the fact that the mantle slides more easily than the arms and tentacles, thus accelerating faster and hence pulling the head end along. Further tests are required to determine the best slide angle and length for orientation.

Evisceration and skinning are readily accomplished by blasting with water, air, or both in combination. It was found that the skin of squid which had been chilled (or "bleached") first was more easily removed than that of fresh squid. Also, the skin is attached very firmly to the anterior end of the mantle. Cutting at that point facilitates skin removal. Further research into forces required to eviscerate and skin will lead to optimum water/air pressures, nozzle types, and cutting angles.

A 100 pound sample of squid caught on September 28, 1976, in Monterey Bay showed a mantle length distribution of 12 to 26 cm, of approximately linear distribution. Some method of accounting for size variation at the input to the processing is being developed.

C. Unit operations

The basic unit operations in automatic squid processing follow from the cleaning procedures:

1. Inputting the raw material into the process.
2. Beheading and cutting the anterior of the mantle to facilitate skin removal.
3. Slitting the mantle open to expose the viscera.
4. Evisceration
5. Skinning

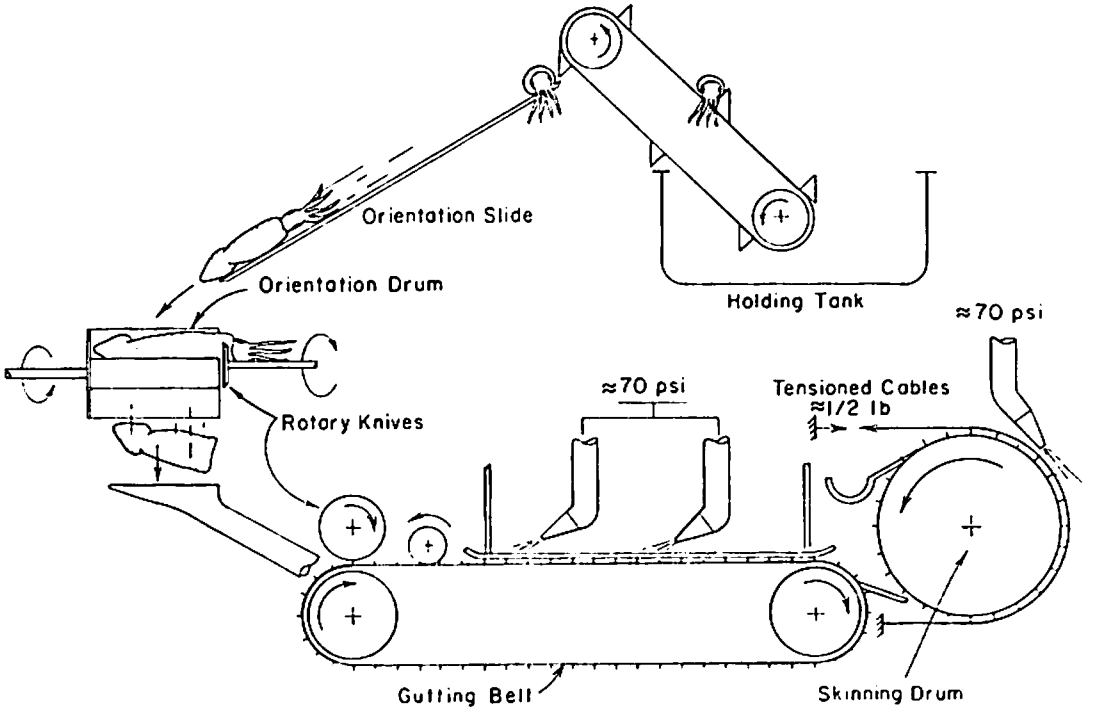
D. Feasibility of a fully automated squid processing machine

The unit operations listed above have been accomplished in the following ways, with the aid of a device constructed in the laboratory (see the Figure). This device proves the feasibility of fully automating the cleaning process, as those operations which had not been previously accomplished were, in fact, accomplished on the device. The diagram is a representation of a system incorporating these operations:

1. The squid are removed from a chilling tank or holding tank.
2. The conveyor drops the animals on to the orientation chute, where they align themselves tail first.
3. The orientation drum rotates and the squid foreparts are removed by cutting just posterior to the leading edge of the mantle.
4. The mantle is slit open and laid flat, and the soft parts are brushed off as the mantle is pressed onto a holding belt (spiked).
5. As the mantle passes under a set of nozzles, the remaining viscera and pen are blown away.
6. The mantle is transferred to a drum, where a roller presses it onto another spiked belt.
7. Tensioned rough cables begin to pull on the skin as the drum rotates underneath.
8. At the appropriate point, water/air removes the skin, and the process is complete.
9. The final product is scored by the spikes which will prevent curling.
10. The fillet is scraped off the skinning drum and is ready for further processing.

Processing rates cannot be determined at this stage; however, a rate of 30 squid per minute (or 150 lb/hr) per channel is a preliminary estimate. The cost of this processing is minimal, perhaps adding a cent per pound ($1.50/hr).

The next step in the development of an automatic machine is to construct a pilot model machine based on the physical properties which will quantitatively be determined. Accurate scale-up determinations, cost analyses, and product usage and development would follow.



SQUID PROCESSING MACHINE

Development of an Anticancer Substance from the Brown Seaweed, *Dictyota*

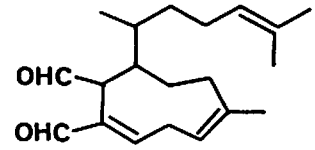
William H. Fenical

The chemical structure of a promising antileukemia compound has been unraveled. The compound has been extracted only from a common seaweed occurring in one particular location.

Early in 1974, a unique substance was isolated from the diethyl ether extracts of the brown seaweed *Dictyota flabellata* (Collins) Setchel et Gardner. While this species of seaweed is common along many coastlines, and has subsequently been collected and analyzed from numerous habitats, only *D. flabellata* from Sandy Beach, Puerto Penasco, Mexico, was found to contain this interesting substance. Chemically, the compound is composed of only C, H and O, with a molecular formula of $C_{20}H_{30}O_2$. The substance was recognized by instrumental analysis as a diterpenoid structure with two aldehyde functional groups. While this compound was structurally very exciting, it was not further investigated at that time due to limitations in sample size.

A collaborative investigation of this dialdehyde was initiated during 1976 between the Department of Chemistry and myself, and the School of Medicine of the University of Hawaii. This collaboration was based upon their discovery that the dialdehyde showed high levels of antileukemia activity in mice. A thorough investigation of both the chemical and medicinal properties of this structurally unknown substance was therefore clearly warranted.

As a result of "Rapid Response" funding in June of this year, we were able to finance a massive collection of *D. flabellata* and the subsequent isolation of this substance in small, but sufficient amounts. Resulting from more extensive chemical work, we can now report the structure of this compound as below:



In addition to the dialdehyde, there exist in *D. flabellata* and other *Dictyota* species a variety of interesting and potentially biomedically valuable compounds. Subsequent testing of a variety of crude extracts from various *Dictyota* species has shown that antileukemia activity is a characteristic of this plant. The dialdehyde is now being thoroughly tested and other substances are available for purification and bioassay.

Power from Salinity Gradients

John D. Isaacs, Gerald L. Wick and Kurt S. Spiegler

Membranes designed for use with highly saline solutions were tested for possible application to salinity gradient energy conversion devices.

Within the past few years there has been an upsurge of interest in renewable energy sources. One such a source has received little recognition and attention—salinity gradient power. This power is manifest at the interface of two solutions with different concentrations of dissolved salt, such as where rivers flow onto the ocean. The energy is represented by the osmotic pressure difference between the two solutions. In the case of fresh water and seawater the osmotic pressure difference is about 24 atmospheres. This pressure is equivalent to a head of water standing 240 meters—the height of a large dam. Various schemes have been discussed for retrieving this energy (Wick and Isaacs, 1976) and the most immediately promising ones utilize membranes.

In particular, we have been investigating the properties of permselective membranes that might be suitable in a salinity gradient energy conversion device known as reverse electrodialysis.* It is well known that upon shutting off a conventional electrodialysis unit, a counter-voltage is obtained. In other words, the unit acts as a battery. In normal operation, electrical current passes through the unit composed of hundreds of cells of saline water alternately separated by anion and cation selective membranes. The electrical current drives the dissolved salt from alternate cells, leaving fresh water behind and forming brine in the complementary alternate cells. It is seen that the passage of the electric current separates the salty water into fresh water and more concentrated brine.

Reverse electrodialysis takes brine and fresher water as sources, and extracts electricity from the transfer of salt from brine to fresh water. It appears that the most immediate scheme for exergy production will use concentrated solutions in half of the cells. For these higher concentrations, the osmotic pressure differences and the voltages will be much higher. For example, the osmotic pressure difference where fresh water flows into the Great Salt Lake is about 500 atmospheres. Thus one cubic foot of freshwater flow per second into the Lake represents about one megawatt of power!

Very little work has been done to understand the properties of membranes in highly saline water. The Japanese have developed such membranes in order to concentrate salt by electrodialysis, but the necessary data for salinity gradient power have not yet been generated.

During the six months that this rapid response project was funded, we initiated a program to measure the properties of these membranes from Japan. In particular we measured the electrical resistance of several membranes in equilibrium with solutions having a wide range of salt concentrations. Other properties need to be measured, such as the selectivity of these membranes for different ions, the water transport through the membranes and the salt diffusion. All of these properties need to be tested before the applicability of these membranes to reverse electrodialysis can be evaluated. However, the resistance data are consistent with the use of these membranes for reverse electrodialysis. These measurements serve as the departure point for future studies.

*In electrodialysis, the concentration and/or composition of electrolyte solutions is altered as a result of electromigration through membranes in contact with these solutions. Electrodialysis units are stacks of narrow compartments through which the feed solution is pumped. These compartments are separated by alternating cation-exchange and anion-exchange membranes which are selectively permeable to positive and negative ions, respectively. The terminal compartments are bounded by electrodes for passing direct current through the whole stack. (From Perry's Chemical Engineering Handbook, 5th Edition, McGraw-Hill, 1973.)

Publications

Wick, G.L., and J.D. Isaacs, 1976, Utilization of energy from salinity gradients, Institute of Marine Resources, University of California. IMR reference number 76-9.

PROGRAM SUMMARY

PROGRAM DEVELOPMENT	FY72	FY73	FY74	FY75	FY76
PROGRAM MANAGEMENT					
Management and Program Development (Frautschy)	O	O	O	O	O
New Projects (Frautschy)	N	O	O	O	O
EDUCATION/TRAINING					
Graduate Education in Applied Ocean Science (Anderson)	O	C	-	-	-
Sea Grant Trainees (Frautschy)		O	O	O	O
Scientific Diving Supervisor Training (Stewart)	C	-	-	-	-
Undergraduate Training in Marine Technology (Flittner)	O	O	R	C	-
Sea Grant Educational Services (Hurley)	-	-	N/C	-	-
ADVISORY					
Ocean Education for the Public (Wilkie)	O	O	O	O	O
Marine Advisory Services (Cummings)	N	O	O	O	O
Publications and Public Advisory Services (Sullivan)	-	N	O	O	O
Ocean Engineering Data Center (Johnson)	-	N	C	-	-
Geophysical and Geological Data Center for Information on Petroleum Resources (Chase)	C	-	-	-	-
Improvement of Methods of Predicting Sea-Surface Temperatures (Gibson)	C	-	-	-	-
Marine Advisory Services Expansion (Flittner)	C	-	-	-	-
San Diego Law Review (Bratton)	-	-	N/C	-	-
COASTAL ZONE STUDIES					
Predictive Methods and Information Systems in Coastal Zone Management (Twiss)	N	O	R	C	-
Physical Criteria for Coastal Planning (Inman)	O	O	O	O	C
Biological and Ecological Studies of Normal Populations (Newman)	C	-	-	-	-
Ecological Studies of the Nearshore Zone (Dayton)	O	O	O	C	-
Ecology of Santa Cruz and San Mateo County Coasts (Doyle)	N	O	C	-	-
Natural Seepage in the Santa Barbara Channel: Physiochemical Aspects (Mikolai)	N	C	-	-	-
Seismicity and Earthquake Hazards of the Santa Barbara Channel Area (Sylvester)	N	C	-	-	-
Sea Coast Planning Project (Hetrick, *et al.*)	N	C	-	-	-
Monitoring of Pollution Parameters in San Francisco Bay (Wildo)	-	N	C	-	-
Recreation Resources of Los Angeles County Coast (Egstrom)	-	N	C	-	-
Trace Metal Analysis of Oily Beach Pollutants in the Santa Barbara Channel (Mikolai)	N	C	-	-	-
Organizational Arrangements for Coastal Management (Lee, Scott)	-	-	N/C	-	-
Development and Assessment of Legally Permissible Methods for Coastal Management (Heyman)	-	-	N	T*	-
Experimental Study of the Tomales Bay "Sneaker Wave" (Fischer)	-	-	N/C	-	-
Legal Techniques for Marine Resources Management (Bowden)	-	-	N/C	-	-
Design of a Computer-Automated Map (Pepper)	-	-	N/C	-	-
Determination of Physical Changes of Southern California Coastal Lagoons (Phillips)	-	-	-	N/C	-
Oceanographic Inventory of the Southern California Shelf (Fischer, Berry)	-	-	-	N	C
Subtidal Ecology of Carmel Bay (Thompson)	-	-	-	N/C	-
Management of Beach and Dune Vegetation (Barbour)	-	-	-	N	O
Diving Safety Research Project (Egstrom)	-	-	-	N	O
Management of Cumulative Impacts of Coastal Development (Dickert)	-	-	-	-	N
Issues of Coastal Governance (Lee, Scott)	-	-	-	-	N/C
San Francisco Bay Project: Reference Collection, Bibliography, Identification Keys and Specimen Depository (Lee)	-	-	-	-	N
FISHERIES/AQUACULTURE					
Uses of Waste in Aquaculture (Cooper, Holmes)	-	N	C	-	-
Rearing of Larval Fishes (Laskor)	O	C	-	-	-
Economics of Aquaculture (Johnston)	-	N	O	O	C
Development of Aquaculture Systems (Shlesor)	N	O	O	O	C
Studies of Vertical Migration of Zooplankton Enright, Isaacs)	C	-	-	-	-
Use of Thermal Effluent in Aquaculture (Ford, Van Olst)	O	C	R	O	C
California Spiny Lobster Growth (Dexter)	O	T*	-	-	-
Pesticides in the Plankton and Fish of the California Current (Longhurst, Lasker)	C	-	-	-	-
Protective Measures for Lobster Aquaculture (Schapiro, Steenbergen)	O	R	O	C	-
California Spiny Lobster Fishery and Related Population Characteristics During Period of Reduced Fishing Effort (Farris)	C	-	-	-	-
Abalone Culture (Leighton, Wilson)	N	C	-	-	-

PROGRAM DEVELOPMENT	FY72	FY73	FY74	FY75	FY76
FISHERIES/AQUACULTURE (cont'd)					
Seaweed Resource Management (Neushul, Coon)	N	O	O	C	-
Gelidium Resource Management (Barilotti)	-	N	C	-	-
Salt-Tolerant Plants (Epstein)	-	N	O	O	C
Fishes of the Santa Barbara Kelp Forest (Ebeling)	O	C	-	-	-
The Juvenilizing Factor in Crustacean Eyestalks (Faulkner, O'Connor)	C	-	-	-	-
Ecology of Benthic Herbivores in the Sea (Connell, Murdoch)	C	-	-	-	-
Ecosystem Studies and Mariculture Potential of a Coastal Lagoon (Holmes)	C	-	-	-	-
Toxins from Marine Dinoflagellates (Rapoport)	-	-	N	C*	-
Mass Culture of Toxic Dinoflagellates (Haxo)	-	-	N	C	-
Economics of Marine Resources Decision Modeling (Sullivan)	N	O	R	C	-
Feasibility of a Black Cod Trap Fishery in Monterey Bay (Cailliet)	-	-	N/C	-	-
Development of a Commercial Aquaculture System for the Crab *Scylla Serrata* (Harrison)	-	-	-	N	C
Marine Ecology of the Central California Coast (Doyle)	-	-	N	C	-
Kelp Forest Ecology of the Central California Coast (Pearse)	-	-	N	C	-
The California Market Squid Fishery (Thompson, Frey)	-	-	-	N	O
Optimal Management of Sea Urchin Fisheries (Dayton)	-	-	-	N	O
Effect of Fishing Sea Urchins on the Marine Ecosystem (Connell)	-	-	-	N	O
Determination of Appropriate Levels of Fees for Vessels Fishing for Yellowfin Tuna in the Eastern Tropical Pacific (Flagg)	-	-	-	N/C	-
Protective Measures for Shellfish Aquaculture (Schapiro, Steenbergen)	-	-	-	-	N
Kelp Bed Mariculture Resource Management (Neushul, *et al.*)	-	-	-	-	N
A Genetic Program for Improvement of Carrageenan in Red Algae *Gigartina* (West)	-	-	-	-	N
Effects of Public Regulations on the California Aquaculture Industry (Bowden)	-	-	-	-	N
MARINE PRODUCTS					
New Antioxidants for Marine Lipids (Olcott)	N	O	R	O	-
Studies of Fish Muscle Proteins (Brown)	N	O	O	O	O
Natural Fermentation of Marine Products (Crisan, Miller)	N	O	O	C	-
Histamine Toxicity from Fish Products (Olcott, Bjeldanes)	-	-	-	-	N
Methods for Quality Assessment in Fishery Products (Chang)	-	-	-	-	N
Limited Entry Assessment of California Fisheries (Wyner, Harding)	-	-	-	-	N/C
Pharmaceuticals from Marine Organisms (Faulkner)	O	O	R	C	-
Natural Compounds from Marine Organisms (Sims)	N	O	C	-	-
Seaweed Products: Application in Algae Control, Mariculture and Agriculture (Fenical)	-	-	-	N	O
Naturally Occurring Halogenated Compounds: Their Interference in Pesticide Pollution Analysis (Fenical)	-	-	-	N/C	-
Antiviral Compounds from Algae as a Potential Marine Resource (Vedros)	-	-	-	-	N
Marine Natural Products Chemistry of Fouling Organisms (Faulkner)	-	-	-	-	N
OCEAN ENGINEERING					
Enhancement of Natural Marine Productivity by Artificial Upwelling (Isaacs, Schmitt)	C	-	-	-	-
Wave Climate Modification in Harbors by Dynamic Breakwater (Isaacs)	-	N	O	R	C
Unmanned Sea Floor Work Systems (Anderson)	O	C	-	-	-
Engineering Properties of Sea Floor Sediments (Noorany)	N	O	C	-	-
Synthesis of Forces on Marine Structures (Pauling)	N/C	-	-	-	-
Underwater Cable Dynamics (Webster)	N	C	-	-	-
New Applied Developments (Isaacs)	O	O	O	C	-
Acoustic Holographic System for Underwater Search (Wade)	N/C	-	-	-	-
Composite Materials for Ocean Construction (Tetelman)	N	C	-	-	-
Biological Effects of Waste Heat Effluents of Coastal Power Plants (Smith, Hand)	-	-	-	N	C
Stress-Induced Fish Parasitism: Effects of Waste Heat Effluent (Noble)	-	-	-	-	N
Stray Electrical Current Hazards to Prestressed Concrete Construction in Seawater (Cornet)	-	-	-	-	N

N = New Project
O = Ongoing Project
R = Restructured Project
C = Completed Project
T = Terminated Project
*No Final Report

ACTIVITY BUDGET SHEET
1975-76

	NOAA Grant Funds	Matching* Funds
MARINE RESOURCES DEVELOPMENT		
Aquaculture	338,532	385,964
Living Resources	104,518	120,403
Mineral Resources	27,440	57,774
Marine Biomedicinals & Extracts	50,002	37,212
SOCIO-ECONOMIC & LEGAL STUDIES		
Marine Economics	10,849	9,101
Ocean Law	8,196	12,096
Socio-Political Studies	34,687	14,197
MARINE TECHNOLOGY RESEARCH & DEVELOPMENT		
Ocean Engineering	81,836	90,443
Resources Recovery & Utilization	96,099	114,957
MARINE ENVIRONMENTAL RESEARCH		
Research & Studies in Direct Support of Coastal Management Decisions	36,364	35,472
Ecosystems Research	54,620	38,621
Pollution Studies	34,480	11,840
Applied Oceanography	88,814	56,884
MARINE EDUCATION & TRAINING		
Other Education (Sea Grant Trainees)	276,210	30,690
ADVISORY SERVICES		
Extension Programs	250,255	164,941
Other Advisory	71,430	63,446
PROGRAM MANAGEMENT & DEVELOPMENT		
Program Administration	210,668	180,765
Program Development	75,000	17,124
TOTAL	$1,850,000	$1,441,930

* Includes $356,035 of state funds which were authorized in 1973 under Senate Bill 755 authored by Sen. John Stull, and recommended for matching funds by the Resources Agency Sea Grant Advisory Panel.

MATCHING FUNDS SOURCE
1975-76

AGA Corporation, Divator Division
AMF Voit, Inc.
Aquarium-Museum Docents
California Academy of Science
California Cooperative Oceanic Fisheries Investigation
California State University, Northridge
Counties of Marin, Mendocino and Sonoma
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Sportsways
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- Department of Fish and Game
- Department of Navigation and Ocean Development
- Division of Gas and Oil
- Legislature Appropriation
- Resources Agency

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La Jolla, California 92093

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* Includes members of the IMR Executive Subcommittee for Sea Grant.

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