University of California
IMR Reference Number 79-101
Sea Grant Publication Number 67

September 1, 1977 to September 30, 1978

sea GRANT
U-CALIFORNIA

CALIFORNIA SEA GRANT COLLEGE PROGRAM

ANNUAL REPORT 1977-1978

Table of Contents

Appendix

Introduction

The Sea Grant Program was created in 1966 by Public Law 89-688, the National Sea Grant College and Program Act. The purpose of the program is "to increase the understanding, assessment, development, utilization and conservation of the Nation's ocean and coastal resources by providing assistance to promote a strong educational base, responsive research and training activities, and broad and prompt dissemination of knowledge and techniques."

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.

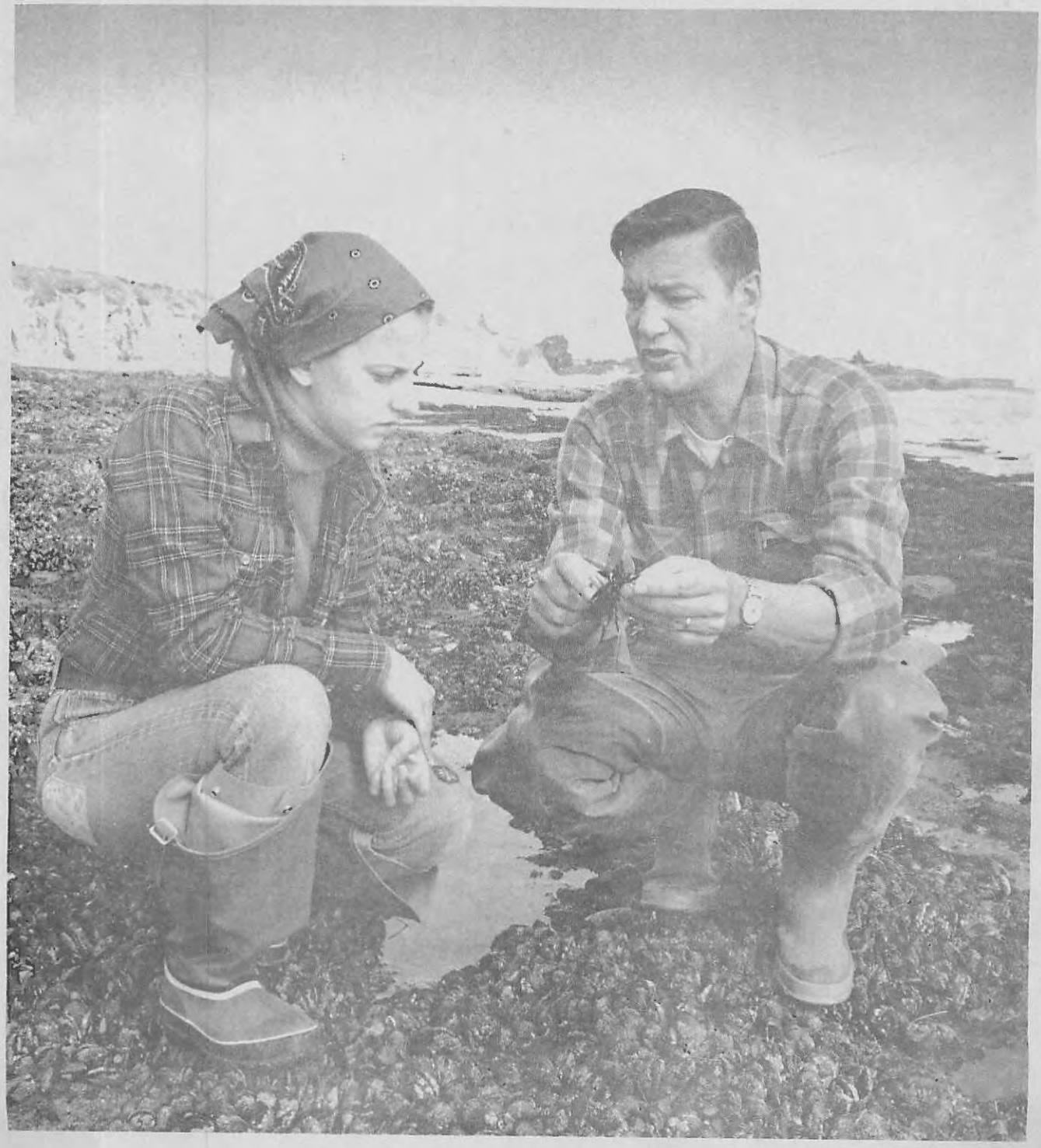
The policy of the California Sea Grant College Program is to seek out the most qualified research talent and the best applied research projects wherever they may exist within the state's institutions of higher education. This year there were Sea Grant projects at six University of California campuses, two State Universities, three State University laboratories, and at two private universities.

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 College and University 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; marine aquaculture; fisheries development, enhancement, and management; energy; and the development of new products from marine sources. Other education efforts and teacher training programs are conducted primarily through the Scripps Aquarium-Museum. Over 50,000 children tour the aquarium in organized groups each year. This program in turn serves as the statewide resource base for similar activities conducted on several campuses throughout the state.

In practice, then, Sea Grant is people working together to put good ideas into effect. On the surface this is a deceptively simple statement, one that belies the complexities of people working together, the development and refinement of good ideas, and the change inherent in putting something new into practice.

James J. Sullivan
Manager
California Sea Grant College Program

EDUCATION



UC Santa Cruz

Sea Grant Trainees

James J. Sullivan, *University of California, San Diego*

Graduate students are an integral part of most Sea Grant projects and a vital part of the UC Sea Grant College Program. 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 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.

In 1977-1978 there were 72 Sea Grant Trainees assigned to 47 projects on five UC, one State University campus, and at one Private School funded by the UC program. They functioned in virtually all areas of marine related research funded by UC Sea Grant.

Accounts of independent research accomplished by these students during the 1977-78 grant year are reported under the titles of the research projects with which they were associated. Meaningful completion of the projects with which they are associated can be used in partial satisfaction of their degree requirements. Their complete reports are available from the Sea Grant Publications office.

The primary functions of the University of California are education and research. Public service is considered to be an extremely important auxillary 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 responsibilites 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.

Marine Undergraduate Education at Santa Cruz

William Doyle, *University of California, Santa Cruz*

California is a maritime state with over 1,000 miles of coastline. The coastal lands and waters have become increasingly important to the state's citizens for fisheries, energy, wildllife and recreation. The coastal waters are readily accessible; more than 85% of the state's population lives within an hour's driving time of the coast. Future demands on coastal resources will not always be complementary; more often than not, they will conflict with each other. Moreover, extended jurisdiction over coastal resources raises new problems.

The primary role of the university in this context is to raise and sharpen questions, to develop new methodologies, and to educate and train students for future roles in the public and private arena. Because of its organizational structure and academic flexibility, the Santa Cruz campus of the University of California has the potential to provide undergraduate students having a solid disciplinary science background the opportunity to become involved in research (as undergraduates) on important marine policy, planning and legal issues. Because the graduate programs at UCSC are relatively modest, the faculty have sufficient time available to work closely with these students.

Coastal marine studies (coastal land, continental shelf and neritic zone) is an area of special concern at Santa Cruz, and relevant courses appear in many aspects of the undergraduate curriculum. Until recently, however, there has been no attempt to develop a coherent program of study directed toward marine issues. The interdisciplinary Environmental Studies program has taken the lead in this development and is now reorganizing its entire undergraduate curriculum and is establishing a marine studies pathway (focusing on marine policy, planning, legal and resource issues) through the major. All undergraduate majors in Environmental Studies must undertake an internship and do research on a relevant topic. Thus, the structure exists at Santa Cruz for undergraduate students to become involved in marine research of concern to Sea Grant.

Moreover, all students who are Environmental Studies majors must complete a double or joint major with an established discipline such as biology, chemisty, etc. This requirement provides a disciplinary base for all of these majors; the Environmental Studies program provides cross-disciplinary perspectives and methodologies. This perspective is extremely important for an understanding of involvement in the complex social and natural systems of the coastal zone. All of the Environmental Studies faculty interested in marine resource issues are members of the coastal marine studies committee; this interaction is enhanced by the membership of most of the marine and environmental studies faculty in College 8 of the campus. Thus, communication and interaction concerning marine affairs are fostered by the collegiate structure of the campus.

The overall project objective is to provide qualified undergraduate students (selected from those in the marine studies pathway of the Environmental Studies major, who have solid training in a standard discipline such as biology) with the opportunity to carry out a research project directed toward understanding a coastal marine research issue pertinent to the UC Sea Grant program. With appropriate course background and faculty guidance, many such problems are accessible to undergraduate students. Such participation will provide students the opportunity to become involved in issues of contemporary societal concern and should aid these students in choosing career pathways. The specific aim is to increase the pool of people trained to deal with both the scientific and the social issues involved in marine resource problems, and with the methodologies needed in both areas.

Students selected are normally in their junior year. Two types of opportunities are available -- off-campus internships and on-

campus research participation. Off-campus work will require specific preparations and additional work upon return to campus. Depending upon the nature of the project, student involvement (background preparation, work-plan development, research involvement, and report preparation) is expected to be for about one year and lead to a senior research thesis.

Eligible students will have a double major in a requisite science discipline and ordinarily in the Marine Studies pathway of the Environmental Studies major. An exception might be an occasional student who follows the policy and planning pathway, having obtained a marine perspective through selection of appropriate courses as electives. In all cases, a general course in oceanography will be required. We expect that all students selected will take 1) a lower division course focusing on major environmental (including marine) issues that require cross-disciplinary perspective for understanding, and 2) upper division courses in areas such as coastal zone planning and management, land and resources law, marine mariculture law, and problems in marine planning.

Students are selected by a committee of pertinent Environmental Studies and Coastal Marine Studies faculty and staff. These students work closely with the faculty sponsors during all phases of project planning, research development and report preparation.

At least once an academic year, a seminar series will be developed for interaction of the participants with each other and to establish interaction between these students and potential future participants. These special seminars will be an effective way to acquaint undergraduate students with the many opportunities in marine affairs available to students who wish to develop a cross-disciplinary perspective on marine issues.

There is a societal need in both the public and private sectors for people who have a cross-disciplinary perspective on marine issues, who understand the issues and terminology involved, and who have been trained in the methodologies needed to approach and understand these complex issues. Participation in pertinent research as undergraduates comes at a good time for students involved in making career choices and plans. In fact, it is essential in order to increase the manpower pool of qualified workers in this area that opportunities in the marine resource area be made known to students early. This project will aid UC Santa Cruz to provide a better focus and structure for our efforts in this area.

Sea Grant Program Management at San Diego State University

Richard F. Ford, *San Diego State University*

The Center for Marine Studies at San Diego State University is a special unit of the College of Sciences, serving more than 75 faculty and staff members. Its primary functions are to coordinate instructional, research and community service aspects of the multidisciplinary marine studies program on the campus and to provide supporting services to the faculty, staff and students involved. As part of these functions, the Center for Marine Studies continued to serve as the administrative office for Sea Grant projects at SDSU during 1977-78, representing one of several offices for campus coordination of the University of California's Sea Grant College Program. Sea Grant support represented approximately 20 percent of the total grant support for marine research at the University during the period September 1977-August 1978.

Richard F. Ford, director of the Center for Marine Studies, served as campus coordinator for the Sea Grant Program at SDSU and as a member of the University of California IMR Executive Subcommittee for Sea Grant. He was assisted by associate directors E. A. Keen and Richard W. Berry. With the help of the staff of the Center for Marine Studies they coordinated and aided in developing SDSU projects sponsored by Sea Grant and providing supporting services to the Project Leaders.

The Center provided liaison with the IMR Sea Grant Program Manager and his staff. Similarly, the Center provided coordination with the SDSU Foundation on budgetary matters and with local agencies and industries, such as the California Department of Fish and Game, the San Diego Unified Port District, the San Diego Gas & Electric Company and the Southern California Edison Company.

Clerical services were provided to assist Sea Grant Project Leaders in the preparation of large numbers of reports and manuscripts for publication. Marie Kolb was employed as the Sea Grant Clerical Assistant. A faculty research committee reviewed this material prior to submission in order to provide assistance to the SDSU investigators and help to assure high quality. A contribution series was coordinated by the Center for Marine Studies, which included this year nine papers resulting from Sea Grant research. Other technical reports concerning Sea Grant were produced. Boat operations, the SDSU marine laboratories, the SDSU diving program and other major services also were coordinated through the Center for Marine Studies in support of Sea Grant projects.

ADVISORY

Gary Beall

Marine Advisory Programs

Maynard W. Cummings, *University of California, Davis*

University of California Marine Advisory Services comprises a special program in the University's Cooperative Extension system which has statewide staffing in every county and campus-based, subject-matter specialists affiliated with teaching and research departments. Likewise, Marine Advisors are county extension staff members, most with a multiple-county responsibility for Sea Grant educational activities emphasizing local ocean and coastal resource interests and problem solving. They receive in-depth technical support and program assistance from Advisory Program subject-matter specialists with statewide assignments.

Staffing growth and coordination

In December, 1977, a Marine Advisor was placed in the last coastal area to receive such full-time local assignment, Los Angeles and Orange Counties. The University of Southern California Marine Advisory Program specialists had given local attention where possible to coastal zone and marine recreation planning in the Los Angeles harbor area but a full range of Sea Grant program activities is now being carried on.

The Los Angeles Marine Advisor, Barbara Katz, is particularly well qualified for this area assignment, having not only an advanced degree in marine resources management and experience as a marine science and recreation teacher and as a Marine Advisor in commercial fishing, but also very useful experience and management training in the marine transportation industry. This advisor is housed in the USC Advisory Program's waterfront office in the heart of the Los Angeles harbor area, along with a USC coastal planning specialist. Reductions in the USC staff have left only their coastal planning specialist but the inter-university office sharing is a harmonious and effective arrangement.

At the opposite pole of California's coastline, a new marine advisor has been placed at the Oregon border under a joint support agreement with Oregon State University's Marine Advisory Program. This position will function in the contiguous coastal counties, providing advisory services in California's most northern port, Crescent City, which has a sizeable seafood processing industry serving a commercial fishing fleet, and the Oregon port cities of Brookings and Gold Beach, which are too distant from OSU's marine agent at Coos Bay for effective regular service. The entire area has advisory needs in sport fishing, marine recreation, coastal planning and harbor development, and in commercial seafood production.

Better deployment of staff resources is expected by the establishment of the Crescent City position in place of two advisor positions in Eureka through Humboldt State University's Marine Advisory Program. Former HSU advisory program leader Stan Ludwig resigned in January, 1978, leaving one advisor, Fred Jurick, in Eureka to serve the Humboldt Bay area. With HSU Sea Grant in its second year as a contracting campus in the UC Sea Grant College, there is full program coordination statewide in advisory services.

Marine Advisory Program Review

The IMR Executive Subcommittee for Sea Grant requested an in-depth review of Advisory Services by a panel selected from outside UC and chaired by Subcommittee member Dr. Cadet Hand, director of the UC Bodega Bay Marine Laboratory. Panel members were Dr. Joe Busby, member of the Sea Grant National Advisory Council and director-emeritus of Florida Cooperative Extension, Dr. Wallace Klussman, Texas A&M Marine Advisory Program coordinator, Patricia Peyton, University of Washington Sea Grant Communications program leader, George Goodall, UC County Extension director in Santa Barbara County, Richard Teague and Ivan Thompson, assis-

tant directors, UC Cooperative Extension (available for one-half of the review period each).

The review provided UC Sea Grant management with a detailed analysis of the MAP organization and leadership, program priorities, operational methods, use of staff capabilities, audiences served in relation to total potential and needs, and clientele comments. This information will provide a basis for assessing program scope, direction and administration to date and for redirection of priorities and programs as indicated. An updated statewide plan for advisory services will be prepared. The review was highly beneficial.

Coastal resources planning

Several factors have combined to increase advisory activities in this subject area. The California Coastal Act mandates that local coastal planning be accomplished by each county in collaboration with state government and taking cognizance of all regulatory authorities. Local planning bodies and governments are hard pressed to obtain comprehensive and detailed information essential to preparation of their respective Local Coastal Plans (LCP) within the legal time frame. The Sea Grant College is the University's designated information source to government and the liaison to the California Coastal Commission. Carrying this information transfer to the local level, which has legal responsibility for LCP development, is the marine advisory staff. Their ability to provide planning assistance has been greatly strengthened by the presence of Marine Advisor Andy Manus, San Francisco, who also serves statewide as Coastal Resources Specialist in the UC advisory program and Jim Fawcett, USC advisory program Coastal Resources Planning Specialist. The specialist-advisor teamwork has produced significant accomplishments.

Manus has worked with the San Mateo County Planning Department on identifying recreational access sites and providing information on marinas and their support facilities. He also meets with the State Department of Parks and Recreation LCP group, State Department of Fish and Game biologist-planners, and with the Central Coastal Commission. He and Aquaculture Specialist Fred Conte developed an information package approach to assist county planning in considering future aquaculture industry needs in the coastal zone. This assistance is endorsed and appreciated by aqauculturists as well as planners.

The establishment of biological preserves in San Mateo County for protection of wild beach strawberries indigenous to Central Coast sand dunes was facilitated by Manus, county and state planners, and a UC researcher on strawberry culture. These are of great genetic importance to the State's 130 million dollar strawberry industry.

Los Angeles Marine Advisor Barbara Katz and University of Southern California Specialist Jim Fawcett prepared a flow chart and guide to the coastal permit process to meet the needs of local planners and coastal commission members.

Los Angeles and San Francisco Marine Advisors also aided in planning the second annual Boating Facilities National Conference, along with State Department of Boating and Waterways administrators and the director of National Boating Industry Associations. This conference will be jointly sponsored by the Association and UC Sea Grant Marine Advisory Programs in 1979.

Mr. Manus and Marine Resources Specialist Chris Dewees authored a coastal recreational brochure for the San Francisco Bay area. This publication is one in a national series underwritten by the Environmental Data Service (EDS) in conjunction with Marine Advisory Programs. Environmental information, climate and weather from EDS are blended with recreational facilities and resources information compiled by Marine Advisory Programs.

Seafood processing - seafood education

Seafood Technology Specialist Robert Price gives leadership to seafood education programs and works directly with the food processing industry toward problem solutions in sanitation, regulations, marketing and quality control, refrigeration, waste disposal, and processing methods. The Cooperative Extension County Home Advisors organized consumer education

workshops in which Specialists Price and Dewees explained seafood facts and demonstrated preparation. These meetings continue to be well attended and they serve a dual purpose in instruction of consumer science staff of the Cooperative Extension, as well as public education.

Cooperating with county marine advisors, Dr. Price conducted workshops in processing plant sanitation for industry personnel. Other county workshops were given in freezer sanitation and seafood refrigeration with cooperation of industry specialists. He also served with UCD Department of Food Science and Technology faculty in presenting several short courses on the Davis campus in squid processing, basic food microbiology, better process control, meat processing, advanced microbiology, and freezer sanitation which were well attended by industry.

The seafood industry was given assistance in the field on individual problems ranging from inferior quality "spotted clams" in Los Angeles to seafood waste and waste water disposal in plants on the North Coast with a variety of others in between.

Santa Barbara Marine Advisor John Richards and Seafood Technologist Price produced a second publication on shark meat preparation. This brochure on making smoked shark and shark jerky has been received with much interest. Mr. Richards and Santa Barbara fishermen demonstrated the product and distributed samples of the delicacy at the annual Santa Barbara Fishermen's Festival. Another popular Marine Brief published was "Seafood Myths and Misconceptions", by Dr. Price.

Aquaculture

Dr. Fred Conte, Aquaculture Specialist headquartered on the Davis campus, has statewide responsibilites in both salt and freshwater aquaculture and is equally supported by Sea Grant and Cooperative Extension. Although aquaculture has been practiced in California for a number of years, recent expansion of the salt water industry and accelerated interest in additional marine species as aquaculture candidates have increased the demand for educational and technical services through the Marine Advisory Program. Working closely with Area Marine Advisor, Dr. Conte has spent considerable time disseminating aquaculture information to the general public and responding to the needs of the industry. Information is provided on the current technology of commercial marine aquaculture and species undergoing research and development to interested individuals in the private sector and to corporations seeking possible capital investments. As secretary of an international organization, the World Mariculture Society, he has served as editor of the Society's newsletter which serves California's marine aquaculture interests both in the private industry and the public sector.

Of paramount concern to the development of marine aquaculture in California is its access to the coastal zone. The Marine Advisory Program was approached by both the coastal planners charged with developing Local Coastal Programs (LCP) affecting aquaculture siting within the coastal zone and representatives of the marine aquaculture industry interested in expressing their concerns into the LCP process. In response, the aquaculture specialist and Marine Advisors are conducting a continuing series of meetings between coastal planners and industrial representatives. The meetings are designed to formulate methods for aquaculture development within the framework of coastal planning.

In response to industry requests for increased university assistance in alleviating technical problems experienced by the aquaculture industry, Dr. Conte has aided the director of the UCD Aquaculture Research Program in reorganizing those programs with a greater emphasis on service to the industry. A major workshop was organized with commercial aquaculture companies and the aquaculture research staff of the University of California at Davis and the UCD-Bodega Aquaculture Laboratory. The workshop was conducted to increase communication, establish cooperative university-industry research and to stimulate university aquaculture research in areas applicable to the existing aquaculture industry. The meeting was attended by representatives of a majority of the commercial salt

and fresh water aquaculture companies in California and representatives of the seafood processing industry interested in aquaculture products.

The Aquaculture Specialist actively works with Dr. Robert Price, Extension Seafood Technology Specialist, to provide aquaculture information to the food processing industry. He has participated in briefing sessions for the Seafood Industry Committee and coordinated and chaired the aquaculture session for the meetings of the Northern California Institute of Food Technology. He has provided aquaculture information to individual seafood processors and established contacts between aquaculture firms and processors interested in aquaculture products.

Continuing aquaculture activities are the county-based salmon and steelhead trout rearing and enhancement programs in central and northern California. The programs by Area Marine Advisors address the goal of enhancing salmonid populations through fish culture and habitat improvement. All these activities represent the cooperative efforts of the Marine Advisory Program, marine specialists, industry, advisors from local organizations, county government, landowners, and California Department of Fish and Game.

Marine advisor area highlights
North coast:

Fred Jurick, Humboldt State University marine advisor in Eureka, planned and participated in a series of north coast workshops. One on marine safety involved Coast Guard demonstration of helicopter rescue tactics. In cooperation with Lazio Seafood Company, Mr. Jurick planned a Pacific Whiting Symposium which attracted over 100 industry attendees. The Lazio Company in Eureka has endeavored to initiate hake fishing and processing in California. Fishing drag gear and midwater trawl workshops were held in Fort Bragg, Eureka and Crescent City. An Australian fishing industry touring group was hosted in Eureka and Crescent City and shown the area's fishing resources. Much of Mr. Jurick's effort went into the satellite imagery program application to help fishermen in more efficient fish location. With marine advisors in Oregon and the cooperation of the National Environmental Satellite Service (NESS), National Weather Service (NWS), National Aeronautics and Space Administration (NASA), Pasadena Jet Propulsion Lab, and other government agencies, planning was done on a SEASAT fisheries experiment using weather information and oceanographic data derived from the special purpose satellite.

Before his resignation in January, 1978, Humboldt State University Marine Advisor Stan Ludwig devoted a great deal of effort to exploring the formation of an industry-run, non-profit fisheries development foundation similar to that in operation on the Atlantic and Gulf coasts. He was also instrumental in organizing inter-agency and university coordination for north coast fisheries exploration and enhancement to offset the adverse effects on the timber industry associated with expansion of the Redwood National Park.

Golden Gate - Fort Bragg

Area Marine Advisor Bruce Wyatt continued his salmon-rearing projects in numerous locations. In addition to pond and tank rearing activities, other salmon population enhancement is provided by spawning stream improvement projects carried on as county programs. From the first salmon-rearing projects designed by Mr. Wyatt and Specialist Chris Dewees, other counties have been inspired to similar programs and Mr. Wyatt has served as a resource person outside his 3-county area assignment. He also has actively engaged in midwater trawling gear improvement trials with commercial fishermen and in assisting fishermen seeking alternative fisheries to salmon, which has been declining economically. Mr. Wyatt has laboriously stayed with the satellite information program for fishermen, arranging for local instrumentation and posting the charts in spite of not having a reliable and regular transmission schedule from NESS. He also serves as technical fisheries advisor to County Fish and Game Advisory Committees in his area.

San Francisco Bay - San Mateo

Most of Area Marine Advisor Andrew Manus' activities are reported under Coastal Resources Planning, which with marine recreation, is his specialty. He was occupied with some other forms of assistance to commercial fishermen; two of these were facilitating understanding between fishermen's associations and agencies concerned with developments at Pillar Point Harbor, and smoothing regulatory obstacles faced by boatbuilders in getting their completed boats moved into launching positions. Mr. Manus also conducted Messrs. Elliott Macklow and Steve Taylor of NOAA motion picture productions, Washington, D. C., to the Bodega Bay Marine Lab and other Sea Grant projects in the San Francisco Bay area during their film planning trip to the area.

Monterey Bay

The Monterey Trout and Salmon Project described under Aquaculture is a large consumer of Area Marine Advisor James Waldvogel's time. Responsibilities in the project were thrust on him literally his first day on the job a year ago. He has given it technical direction and coordinated community support. He also has been the local contact with the marine aquaculture industry, most of which is in the Monterey area. Mr. Waldvogel arranged for two Monterey Bay fishermen's groups to meet with Oregon State University Marine Economist Fred Smith to work with in developing marine economic data sheets. He organized a Marine Advisory Program display at the annual "open house" held by the Moss Landing Marine Laboratories which was attended by over 6,000 people; other displays were presented at Santa Cruz and Monterey County Fairs. Mr. Waldvogel is advisor to a Sea Grant Trainee at UC Santa Cruz who is conducting an economic study of the rockfish sport fishery in Monterey Bay. The trainee is in the Sea Grant research project directed by Dr. Suzanne Holt, University of California, Santa Cruz.

San Luis Obispo - Santa Barbara - Ventura Area

Area Marine Advisor John Richards conducts a varied and vigorous advisory program in this 3-county area. Priority programs have included many forms of communication with and assistance to diverse commercial fishing interests. Mr. Richards provides market development assistance for underutilized species such as shark, squid and sable fish, as well as research and management cooperation with projects designed to protect and continue the use of fully exploited or scarce resources such as abalone, lobster, swordfish, halibut and white sea bass. He has worked with the U.S. Geological Survey and U.S. Bureau of Land Management as well as the State Lands Commission and oil companies in seeking to have removed and/or marked on navigational charts the location of exposed sea bottom structures such as wellheads and oil development debris which cost fishermen thousands of dollars annually in lost time and gear destruction; in doing this, he has successfully brought together the fishing industry leaders and industrial staff resulting in both charting and removal of such obstacles. It took a year's persistent follow-up to have removed one wellhead which at a 720 foot depth had claimed over $10,000 worth of gear from 4 different trawlers. Mr. Richards has held meetings to bring together abalone fishermen and university researchers, prepared special reports on the abalone resource, and serves as a member of the Sea Grant Abalone Research Advisory Committee. He has performed in similar fashion with the sea urchin research and industry interests. Mr. Richards has conducted varied education activities in 4-H youth marine science projects, consumer seafood education programs, Community College lecture series, and radio, TV, newspaper and newsletter programs. His displays, seafood preparation demonstrations and publications distributions at County Fairs and Fishermen's festivals have reached thousands of people annually.

Los Angeles- Orange Counties

Many of the activities of Area Marine Advisor Barbara Katz are previously reported. Much of her efforts have been with the marine transportation interests of Los Angeles harbor but there also has been much direct assistance to fishermen. Her timely and complete information releases on topics such as harbor facilities, gill net regulations, abalone research, financial management alternatives, have enabled fishermen to deal more effectively with these and other subjects. A new organization of commercial fishermen in her area looks to her for continuing information. Ms. Katz has furnished marine science leadership and subject matter information to Orange County 4-H youth programs. She maintains a very diverse program, with, for example, probably as much time spent with seafood processors and buyers as with fishermen.

San Diego County

Marine Advisor Art Flechsig has the only assignment limited to one county but San Diego contains an intensive concentration and wide array of marine activities. His waterfront office is literally next door to the tuna fleet anchorage. This is a tremendous fishery which accounts for a high percentage of California's landed seafood value. That industry is highly specialized, with problems and concerns often divergent from those of other fisheries in the state. Mr. Flechsig also works closely with the swordfish industry and, of course, with the seafood processors who utilize this and other valuable seafoods landed at San Diego. He arranged with NMFS for additional distribution of "Fishing Information Supplements" to be handled by him and other Marine Advisors. This will place valuable, timely information in the hands of more fishermen who want but do not receive it. Mr. Flechsig is a cooperator with San Diego State University researchers in a salmon aquaculture program for San Diego Bay. He has delivered aquaculture information in the area and gave an oceanography course at a community college; in addition, educational projects were conducted with county 4-H youth groups.

Publications and Public Advisory Services

Jeffery Frautschy

The oceans are a major factor in understanding man's role, position, and accomodation on this planet, and in comprehending the impact of his rapid emergence as a geochemical, geophysical and biological force. Thus, providing reliable information dealing with all aspects of ocean science is 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 1976-77 Annual Report, the 1977-78 and 1978-79 Program Directories, and the 1978-80 institutional proposal.

We gave editorial assistance in the preparation of a number of IMR/Sea Grant publications, issued several news releases, and participated in the UC dissemination of research results information program. A list of IMR/Sea Grant publications for the review year are appended at the back of the Annual Report.

Ocean Education for the Public

Donald W. Wilkie, David Coon and William T. Doyle
University of California, San Diego, Santa Barbara and Santa Cruz

U.C. San Diego Scripps Aquarium-Museum

The primary objective of the Aquarium-Museum is to increase public understanding of marine sciences through education programs and exhibits. The reputation and credibility of Scripps Institution of Oceanography render the public highly receptive to our educational efforts.

School group program

During the 1977-78 school year, 57,857 students took field trips to participate in the school group lecture and tour program at the Aquarium-Museum. This program is conducted by trained volunteer teachers (docents). Education materials are provided for each class. These include previsit & post-visit exercises, and answers for classroom use. A guidesheet with questions to be answered by students from their observation is provided for use at the Aquarium. This format, which was originated by the Aquarium-Museum 11 years ago, has proven so effective that it has been duplicated by a number of other museums, zoos, and aquariums.

Classroom outreach program

The lack of funds for bussing prevents many schools from participating in field trips. Outreach docents trained at the aquarium, travel to schools bringing with them marine specimens and presenting slide-illustrated lectures. In California, the combined effects of Proposition 13 and court-ordered desegregation have caused us to enlarge the Outreach Program.

Workshops for grade school students

Throughout the year classes in marine ecology were offered to first grade through high school students. These classes were self-supporting through fees charged to participants. The curricula were designed by aquarium staff members along with certified teachers who conducted the classes.

Mentally Gifted Minor Program (MGM) in marine sciences

Encouraging school districts to include more marine education in their curricula is a primary goal of the aquarium staff. We designed a week-long course which was offered in 15 schools under the Mentally Gifted Minor program at the 4th, 5th and 6th grade levels. San Diego City School District paid our docent teachers, provided classrooms, and utilized books from our library, slides, films and educational materials. We are pleased to state that the San Diego City Schools have asked us to design and conduct similar classes in the Mentally Gifted Minor Program at the junior high level during the 1978-79 school year.

Career experience program

High school students, who are considering a career in marine biology or aquariology are given an in-depth course, including laboratory and field work as well as classroom instruction. This program has been highly successful and students often return to the Aquarium through college and graduate school for further study.

Science writer internships & aquarium training program

Four Sea Grant science writer interns from UC Santa Cruz were tutored in practical science writing. In addition, college and high school students were trained in the practical aspects of aquarium management, such as water quality, feeding techniques, disease treatments, and collection of specimens.

Docent training

Each fall, interested community volunteers are intensively and rigorously trained in the field of marine biology through proficient lectures and fundamental lab work. This year laboratory sessions and compulsory examinations were added to upgrade their training. In addition, fees were charged to cover the cost of materials and to provide reference books. Docents both new and experienced were highly receptive to the more rigorous training.

Teacher education

The eighth annual symposium, Marine Birds, was presented as an in-service training for teachers with an attendance of 136. This symposium, which is self-supporting, provides current scientific marine information to teachers for their classroom use. Many teachers travel from all over California and Arizona to attend this popular function.

San Diego ecological reserve guide program

A group of individually trained docents acted as guides to promote conservation at the San Diego-La Jolla Underwater Park and the Ecological Reserve areas. During the daytime low tide series, these docents, wearing Scripps Aquarium jackets, patrolled the tidepool area to encourage conservation measures and answer questions.

Spanish language materials

Our education materials have been translated into Spanish, and Spanish-speaking docents are available to provide lectures and tours to school children from Spanish-speaking homes. These bilingual docents also act as guides and interpreters when the students and faculty of various Mexican colleges and high schools visit Scripps Institution and/or the Aquarium-Museum.

Junior oceanographers

The Junior Oceanographers Corps completed its 23rd year as a lecture and field trip club for young marine enthusiasts from the fourth grade through high school. Many J.O.C.'s enter the career experience and intern trainee program.

Advisory service

Numerous people consult Scripps for information on current scientific marine matters, and the aquarium staff responds to many of these inquiries. Teachers, schools, and school districts request education materials, books, slides, and films and assistance in designing courses. Other Sea Grant programs request assistance in setting up their marine education projects. We are cooperating with UC Davis in enlarging the 4H participation in marine areas, and with UC Santa Cruz in the science writer intern program. Other museums, zoos, and aquariums frequently request advice on both education programs and technical matters such as designing seawater systems, disease treatments, nutrition, and collecting techniques.

Santa Barbara

The Marine Science Institute, UCSB, provided an opportunity for school and community groups to examine and have a "hands on" experience with a large sample of marine plants and animals of the local area, and to learn about marine research activities at the University. UCSB students (11) provided diving skills to collect animals, created displays, and interacted with the tour groups (2,700 visitors). Community interest in ocean life and marine research at UCSB continues to advance at a rapid rate under this Sea Grant supported program.

COASTAL RESOURCES

Jens Sorensen

Coastal Wetlands Management Biological Criteria

R. W. Holmes, C. P. Onuf and C. H. Peterson
University of California, Santa Barbara

In the second of three years of our Sea Grant for coastal wetlands management we have completed the collecting and are well along in the analyses of samples for a general biological inventory of a lagoon and its surrounding salt marsh. In addition we have at least partially analyzed the results of manipulative experiments designed to work out some of the important competitive and predator-prey interactions of a coastal wetlands ecosystem. We are currently applying some of this basic background knowledge to the practical problems of the effects of siltation and of altering tidal exchange. Siltation probably now is the major threat to California's coastal wetlands, and increasing tidal flushing is probably the most commonly proposed corrective procedure.

Plant biomass and productivity.

We have measured salt marsh productivity by a tagging technique that includes measurements of mortality and growth on tagged plants. In addition we employed the more common procedure of harvesting at regular intervals and regarding the difference between maximum and minimum standing crops over a year as productivity. Two kinds of shortcomings in the application of the latter technique became evident in our analysis. First, the technique attributes differences between samples collected at different times exclusively to growth and ignores spatial heterogeneity. In our study, the differences in both total standing crop and total living plant material between samples collected at the same time were so large as to mask any systematic changes over the year, even where only a single species was present. The intuitively reasonable pattern of low winter biomass rising monotonically to a late summer maximum and falling back to the next winter's low only emerged when green growing tips were treated separately from the rest. Thus, where spatial heterogeneity is high, the reliability of the estimate will be low.

Unfortunately, having to base an estimate of productivity on changes in growing tips aggravates the second shortcoming. Clearly, part of primary productivity can be allocated to parts of plants besides growing tips, particularly supporting reproductive structures. Furthermore, some growing tips will die during the period of net increase. Net changes in growing tips alone will not account for these aspects of productivity, whereas changes in total standing crop would, under the idealized conditions of low errors of sampling, which arise from spatial heterogeneity and no loss of dead material during the period of net increase.

In our treatment the tagging technique accounts for reallocation and replacement of dead growing tips during the period of net increase, thus accounting for the 1.8 to 3.7 times higher estimates of primary productivity by the tagging than the harvest technique, depending on species and location within the marsh (Table 1). The disparity between the estimates calls into question the validity of many published estimates for other marshes, unless the marsh at Mugu Lagoon proves to be unusual in its degree of spatial heterogeneity or the growth characteristics of its plants.

Our analysis of the productivity of aquatic plants is incomplete. Hourly productivity at midday was determined on at least four days and for at least eighteen samples each month (68 days and 300 samples for the year). Based on some provisional factors, these measurements were converted to daily, monthly, and annual productivity. The contribution of the epibenthic microalgae of intertidal sand and mud flats and subtidal areas is by itself comparable to the productivity per unit area of the salt marsh: 436 g dry weight $m^{-2} \cdot yr^{-1}$ for epibenthic microalgae vs. 286 and 727 for low and middle marsh respectively. When we are able

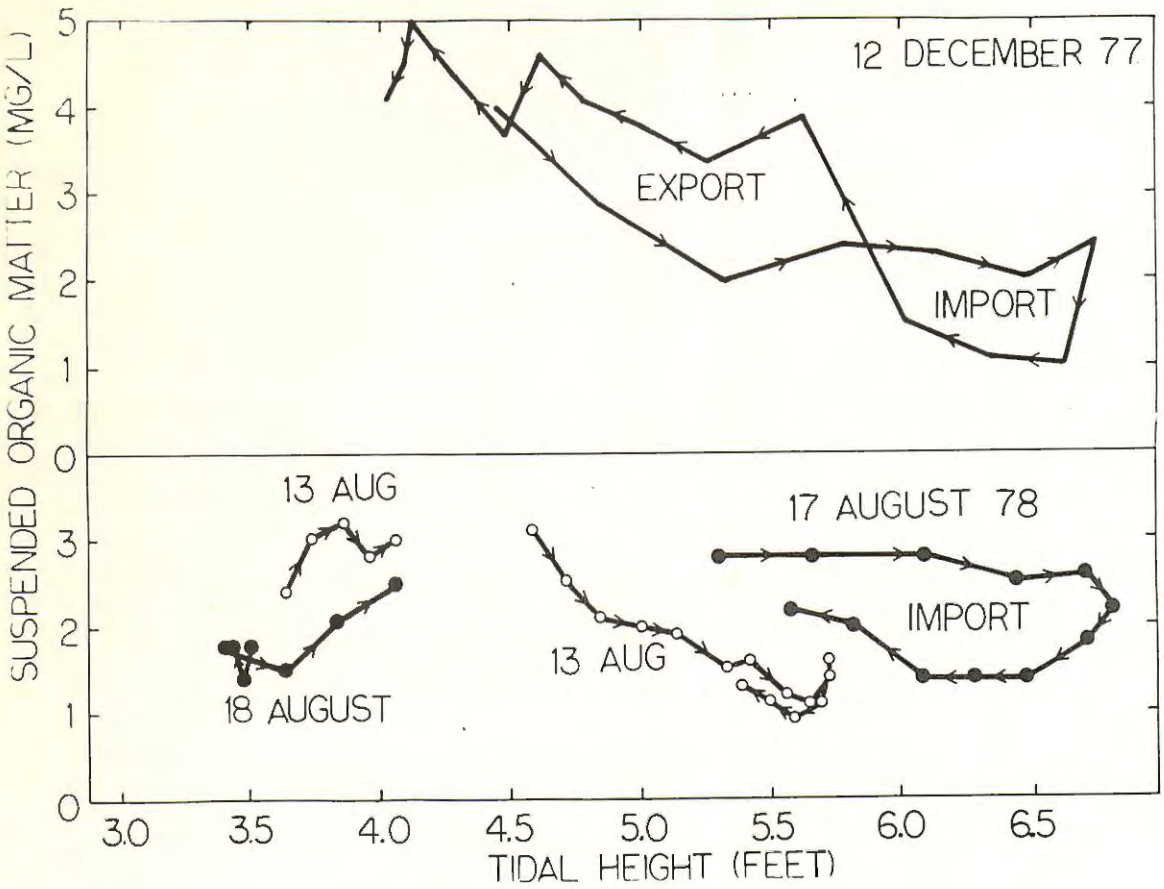

12 DECEMBER 77
EXPORT
IMPORT
13 AUG
18 AUGUST
17 AUGUST 78
IMPORT
13 AUG
SUSPENDED ORGANIC MATTER (MG/L)
TIDAL HEIGHT (FEET)
0
1
2
3
4
5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5

Figure 1.

to include the contributions of macrophytes, aquatic plants may well prove to be more productive than the vascular plants of the marsh in the total production of organic matter for the Mugu Lagoon coastal wetlands ecosystem.

Transport of organic matter

The quantity of suspended organic matter in the water of Mugu Lagoon has proven to be so variable and so complexly related to various features of the tidal cycle and other factors that we no longer entertain the hope of answering during the tenure of this grant even the basic question: is the coastal wetland ecosystem a net exporter of particulate organic matter to coastal waters or a net importer, either from coastal waters or terrigenous sources?

Some of the complexity is apparent in the relationship of suspended organic matter to tidal height (Fig. 1) on rising (arrows pointing to the right) vs. falling (arrows pointing to the left) portions of the same tidal cycle. The record for the 12 December tide shows an episode of importation close to the turning of the flood tide and apparently a more pronounced episode of export at intermediate stages of the tide. However, the difference is only apparent.

It is impossible to determine without more information whether the overall flux of organic matter is in or out on this tide, because the volume of water moving into and out of the lagoon is much greater around high tide than at other phases of the tide. (Especially for spring tides, when water spills out over the whole broad expanse of the marsh, the flooded area is huge compared to the area flooded at lower stages of the tide. Consequently, the amount of water required to produce a given change in deposition will be greatest near high tide, unless the lagoon and its surrounding marsh have vertical sides. This is seldom the case in natural lagoons.)

Good measurements of current velocities, channel cross-sections and area flooded at different heights of water will all be necessary to translate the record for 12 December into even a qualitative statement about net transport.

The August tracks show just how different the patterns can be four and five days apart: on the right, the high tide portions of one of the highest tides of the year compared to a moderate tide, and on the left the early period of rising water on two moderate tides. Obviously, a great deal more sampling is necessary before we can have any confidence in predicting what pattern will apply under a given set of conditions. Simple averages on an array of incoming and outgoing tides will not serve.

Meroplankton Studies (John W. Chapman)

Meroplankton, which occurs in the water column only at night, appears to be a major food resource of carnivorous fish. This is a summary of the meroplankton study in Mugu Lagoon with a discussion of problems encountered so far.

Hourly water samples of approximately 759 liters from each of two stations over the period of a night have been collected bimonthly since July, 1978. Collections have been made on various phases of the moon, tides and conditions of cloud cover. Five 93 cm^2 benthic samples have been collected on the same dates as water samples. Water samples and benthic samples are washed through a 0.5 mm mesh seive and the animals retained are preserved in formalin for later sorting, identification and counting. Fish collected in monthly seive hauls have been counted and measured with representative specimens saved for stomach analyses.

Data from July collections have been summarized in Figure 2 and Table 2. Only 5.6% of the benthic biomass is composed of meroplankton species, while 70.7% of the total biomass of identifiable species in fish stomachs are meroplanktonic (Fig. 2). The decline in abundance after moonrise and the slight increase at slack tide suggest negative responses to light and currents.

Fish are generally considered to be opportunistic visual predators, limited only by prey size (Blaber, 1977, and others). The greater percentage of meroplankton species in fish diets probably results from their greater availability. Blegvad (1922) speculated that the night time occurrence of

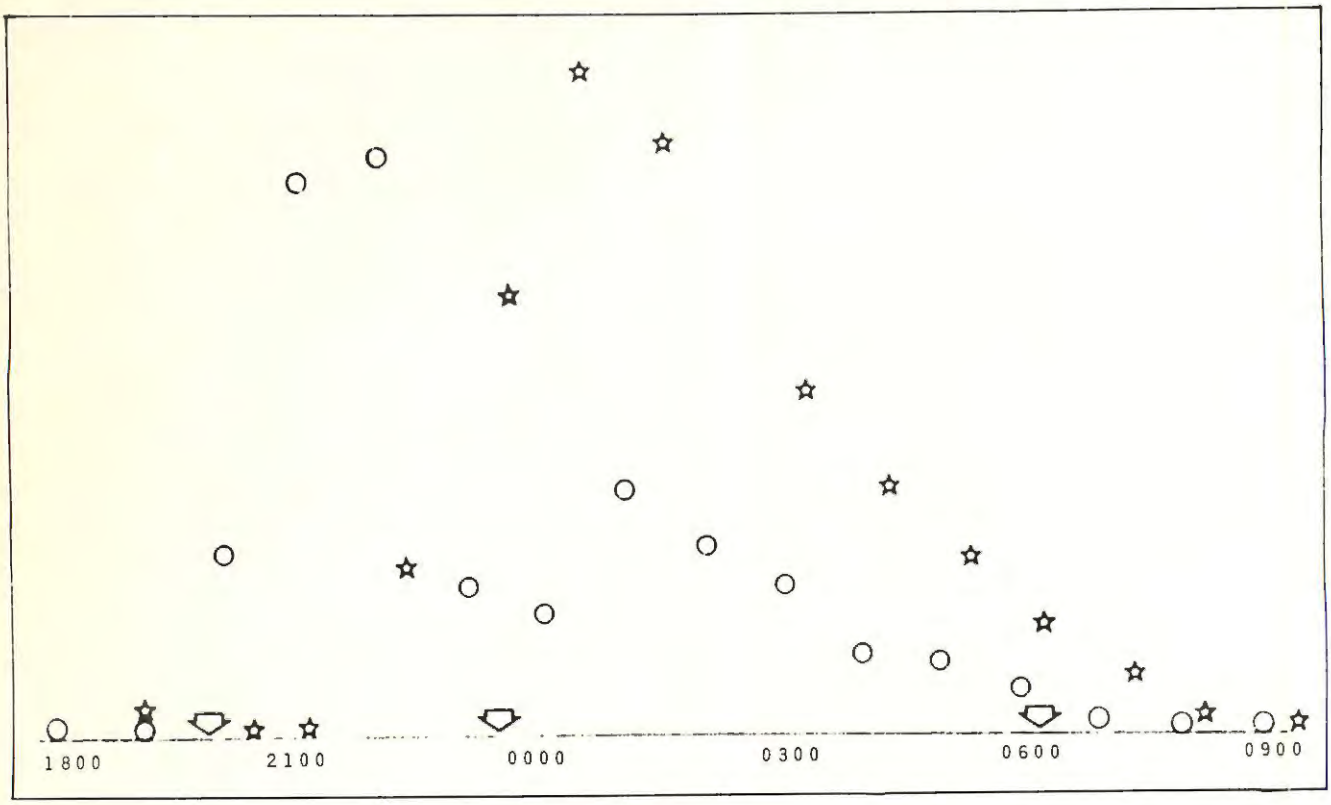


Figure 2

Corrected total concentration of *Corophium acherusicum, Mayerella acanthopoda, Oxyurostris pacifica,* and *Pontogeneia rostrata* (circles) collected from water samples, and tide height (stars) 22-23 July 1978. Arrows indicate sunset, moonrise (a full moon) and sunrise.

Table 2
Estimated non-mollusc invertebrate biomass in milligrams dry weight per m^2 and % biomass in the benthos, water and fish with a weighted fish total for July, 1978.

Sample type	Benthic	Water	Sculpin	Shiner	Pipefish	Total
Obligate benthic	7542.7/94.4	-	2.8/40.5	0/0	0/0	2.8/29.3
Planktonic	445.4/5.6	17.2/100	4.2/59.5	1.6/100	1.1/100	6.8/70.7
N=	2	31	47	111	25	183

meroplankton was in avoidance of fish predators. Alldredge and King (1977) experimentally demonstrated a photonegative response of meroplankton which further suggests avoidance of visual predators.

Meroplankton responds to other factors than light, however. Watkin (1939), Nagata (1966), and Williams and Bynum (1972) noted seasonal and lunar periodicity in abundances. They suggested that the lunar periodicity served to synchronize reproductive behavior. Unfortunately, the possible adaptive value of reproductive synchrony with phases of the moon was not discussed.

Hobson and Chess (1977) describe a negative response of meroplankton to currents. Tides and currents are, of course, also synchronized with phases of the moon. Juveniles as well as adults were found in plankton samples in this study and in those of Mills (1967) and Williams and Bynum (1972) which precludes entirely reproductive functions of vertical migration. William and Bynum (1972) noting the reoccurrence of many species in the water column in all seasons, speculated they may be feeding there. This is intriguing since many of their species and at least one of the Mugu Lagoon species are filter feeders.

The significance of all principle factors controlling meroplankton abundance must be determined before the significance of predation can be assessed. Current velocity and direction, light intensity, season and water quality are probably all important. The significance of these physical factors will be first assessed through analyses of field data. Conclusions generated from field data will be tested in laboratory conditions.

The intensity of fish predation on meroplankton will be determined indirectly. The adaptive value of restricted night-time activity in avoidance of fish predators will be tested under varied light conditions in the laboratory. The proportion of meroplankton productivity ingested by fish will be used as an indication of predation pressure. Monthly stomach analyses will be used to determine the average percent meroplankton in fish diets.

Growth increment per molt can be used to determine growth rates. Peracarida brood their young. Females can extrude only one batch of eggs per molt. Over 60% of the meroplankton biomass in collections so far is composed of Peracarida. Natality can, therefore, be determined from egg counts.

Ovigerous females placed in exclosures that have no other members of the same species will create known periods of recruitment. Growth rates of young can also be measured directly by this method.

The general information derived from this study will, hopefully, be useful for assessing the value of food resources of Mugu Lagoon to fish populations. More generally, the evolutionary significance of vertical migration will be investigated experimentally for the first time.

Invertebrates

The preliminary stages of analysis of our basic inventory of invertebrates and contents of fish guts are complete, but we have not made the appropriate compilations for reporting results. Our experimental analyses of the life histories of two species of clams that once were harvested in California bays and lagoons - common littleneck *(Protothaca staminea)* and wavy chione *(Chione undatella)* - yield opposite conclusions about their suitability for exploitation, even though the two cockle-like bivalves are morphologically, taxomically, and ecologically similar and often occur at similar densities.

At Mugu Lagoon *Chione* is characterized by low rates of mortality and recruitment. Furthermore, it appears to show no compensatory response in its reproductive success either among local plots of varying density or among years when adult clam density over the whole lagoon differs. As a result, *Chione* has little value as a sustained yield resource when compared to *Protothaca* which (1) recruits predictably and heavily each year, and (2) shows some adverse density dependence in both survivorship of adults and recruitment of juveniles. Such life history characteristics are extremely important determinants of the value of any natural biological resource.

Fish

We now have nineteen months of beach-seining data at four stations each month. Comparing collections between years for the seven months of overlap only (March to October), we can make some inferences about the effects of the second wettest winter in the 111 years for which rainfall records are available (Table 2).

The decline in total catch from 6,866 in 1977 to 5,335 in 1978, or 22%, is small enough to raise doubt as to whether it reflects a response to the large, though short term, reductions in salinity and the longer lasting effects of the heavy siltation, or whether it merely reflects normal year-to-year fluctuation. On the other hand, the great preponderance of species that showed declines as compared to those that increased between years (29 vs. 4, including 18 that were absent in 1978, against no new species added) suggests that the difference between years is quite general in its manifestation.

Three of the exceptions (staghorn sculpin, California killifish, and longjaw mudsucker) are the hardiest fish that we handled, judging from their survival in buckets during the sometimes prolonged process of measuring the catches. Presumably it is this hardiness, an indication of their closer adaptation to the lagoonal environment, that accounts for their relative success compared to other species in coping with the changes brought about by the rains.

In contrast, shiner surfperch, the most commonly caught fish in the lagoon both years, probably fared worse than their modest (7%) decrease in number between years would indicate. In 1977, we caught 1,231 shiners in June (almost entirely females and their newborn young), followed by catches of 521, 740, 57 and 71 in the next four months. In 1978, we caught almost twice as many in June (2,454), but very few thereafter (50, 31, 17 and 45 in the next four months). We infer that the lagoon in 1978 was less suitable for shiners, probably because of heavy deposition of silts and muds (as much as 15 cm in some areas), and that consequently either the survival of young was drastically reduced, or the young emigrated from the lagoon sooner.

Birds

Last year we reported our first year of censuses of water-related birds for the eastern arm of Mugu Lagoon and pointed out an apparent seasonal switch between sandy and muddy ends of the lagoon in the habitat utilized by shorebirds. The switch was repeated in the second year, more strongly for the top-feeders (sandpipers, dowitchers, dunlin, avocets) and less strongly for the probers (godwits, willets, curlews). We suspect that seasonal differences in the relative areas of sandy and muddy intertidal zone above water during daylight hours may account for the changes in the relative numbers of shorebirds in the two areas by altering the availability of suitable foraging habitat. This hypothesis remains to be tested.

We added the western arm of the lagoon to our census program in anticipation of the opening up of the western arm to greatly increased tidal flushing. The alteration is being undertaken as a mitigation for the loss of five acres of mudflat to a military construction project. Large numbers of shorebirds had previously used the area. We now have a full year of censuses prior to the impending alteration of the tidal regime by replacing the presently restrictive culvert system. Consequently, we should have a useful criterion for evaluating the effectiveness of the measure as a mitigation, at least as it applies to birds. Not only will we have a before and after comparison for the affected area, but also a simultaneous control (the eastern arm) for which we have an additional year of census data.

References

Alldredge, A. L. and J. M. King. 1977. Distribution, abundance, and substrate preferences of demersal reef zooplankton at Lizard Island Lagoon, Great Barrier Reef. *Mar. Biol.* 41: 317-333.

Blaber, S. J. M. 1977. The feeding ecology and relative abundance of mullet (Mugilidae) in Natal and Pondland estuaries. *Biol. J. Linnean Soc. London* 9: 259-275.

Blegvad, H. 1922. On the biology of some Danish gammarids amd mysids. *Rept. Danish Biol. Sta.*, No. 28: 1-103.

Hobson, E. S. and J. R. Chess. 1977. Trophic relationships among fishes and plankton in the Lagoon at Enewetak Atoll, Marshall Islands. *Fish. Bull.* 76: 133-153.

Mills, E. L. 1967. The biology of an ampeliscid amphipod crustacean sibling species pair. *J. Fish Res. Bd. Canada* 24: 305-355.

Nagata, K. 1966. Studies on marine gammaridean Amphipoda of the Seto Island Sea, IV. *Publ. Seto Mar. Biol. Lab.* 13: 327-348.

Watkin, E. E. 1939. The pelagic phase in the life history of the amphipod genus Bathyporeia. *J. Mar. Biol. Assoc. U.K.* 23: 46-481.

Williams, A. B. and K. H. Bynum. 1972. A ten year study of meroplankton in North Carolina estuaries: amphipods. *Chesapeake Sci.* 13: 175-192.

Publications

Holmes, R. W. 1978. Primary productivity and food-chain relationships in a southern California estuary - preliminary results. Paper presented at the National Symposium on Wetlands, American Water Resources Association, Lake Buena Vista, Florida, 7-10 November 1978.

Onuf, C. P. 1978. An analysis of ecosystem function in a southern California coastal wetland. Paper presented at the Organizational Meeting, Pacific Estuarine Research Society, 11-13 May 1978, Astoria, Oregon.

Onuf, C. P., M. L. Quammen, G. P. Shaffer, C. H. Peterson, J. W. Chapman, J. Cermak and R. W. Holmes. *In press.* An analysis of the values of central and southern California coastal wetlands. *Proceedings of the National Symposium on Wetlands,* American Water Resources Association.

Onuf, C. P. Tagging plants to measure salt marsh productivity. MS submitted to *Science.*

Peterson, C. H. *In press.* Predation, competitive exclusion and diversity in the soft-sediment benthic communities of estuaries and lagoons. *In* R. L. Livingston, ed., title of volume unknown.

Peterson, C. H. and S. V. Andre. An experimental analysis of interspecific competition among marine filter feeders in a soft sediment environment. MS submitted to *Ecology.*

Cooperating Organizations

U.S. Navy, Naval Air Station, Point Mugu, California

Audubon Society, El Dorado Chapter, Long Beach, California

U.S. Fish and Wildlife Service, Laguna Niguel, California

Coastal Wetlands Management: Biological Criteria
The Role of Algal Wrack in Sand Beach Community Dynamics

John S. Yaninek, student trainee and primary researcher
Frank A. Pitelka, faculty sponsor and collaborator
Bodega Marine Laboratory, University of California, Berkeley

This field research was conducted on algal wrack and associated invertebrates on Salmon Creek and Doran beaches, at the north end of Bodega Bay, in the period October 1977 - September 1978. Our report is divided into two parts, the first on algal wrack, the second and shorter part on associated invertebrates.

The variety and distribution of invertebrates on a high beach depend to a significant degree on the algae torn by wave action from their inshore attachments below low tide line and thrown up on the beach. It is well known that beach invertebrates vary in abundance through space and time (that is, they are strongly "patchy") because of physical changes in their habitat and because of seasonal features of their biology; but little attention has been given to the role of algal wrack in this pattern of patchiness. Therefore, the first objective of this study is to document the amount and timing of wrack deposition and persistence on beaches near the Bodega Marine Laboratory. The second objective is to identify invertebrates directly or indirectly influenced by the presence of wrack and to measure their abundance in relation to size and distribution of wrack islands.

This study coordinates with a larger research program sponsored by the National Science Foundation on "Factors of Nonbreeding Habitat in Shorebird Social Systems". The motivation was to understand the significance of time-space discontinuities, or "patchiness", of invertebrates on a soft-substrate intertidal habitat in the behavior of an important group of predators, shorebirds. They must cope with the patchiness of their invertebrate prey, induced partly by the come and go of wrack, hence this special study. More generally, the understanding of production dynamics on a sand beach depends on empirical knowledge of wrack biology, which, surprisingly, has been ignored heretofore in California as well as elsewhere.

Part I: Preliminary Analysis of the Distribution and Composition of Algal Wrack

Natural History of Wrack-producing Macrophytes

The marine macrophytes which produce the bulk of local beach wrack are represented by five genera of brown algae (Phaeophyta) and two seagrass genera (Spermatophyta: Zosteraceae). A brief description of the natural history of each species follows, taken from Abbott and Hollenberg (1976), Dawson (1966), and Johansen (1966).

Phaeophyta:

Cystoseira osmundacea. A perennial which is found from the upper sublittoral to about 10 m, attached to rocky surfaces; from 1 to 7 m long.

Egregia menziesii. A perennial, observed on Bodega Head during March-December and reproductively active between April and November. Found in the low intertidal to 7 m on rocky surfaces; up to 8 m long, floating. May be effectively annual in the intertidal.

Macrocystis integrifolia. A perennial found from intertidal to shallow subtidal (< 10 m), attached to rocky substrate; grows to the surface forming a canopy.

Nereocystis luetkeana. An annual which can persist up to

16 months, found on rocky substrates from intertidal to 17 m depth; grows to the surface forming a canopy. There are questions regarding timing in annual turnover -- disappearance of adults as well as appearance of juveniles.

Postelsia palmaeformis. An annual which fruits in late spring or summer after which its blades senesce; found in mid to low rocky intertidal areas only in very exposed sites.

Zosteraceae:

Phyllospadix spp. A perennial found from the low intertidal to a depth < 5 m attached to rocky substrates on surf-bound shores; grows up to a meter long.

Zostera marina. A perennial found on sandy substrates from low intertidal to a depth of 7m in sheltered bays; grows up to 1 m long.

The marine flora of the Pacific Coast undergoes a seasonal fluctuation in reproduction and growth, culminating in a peak biomass by late summer and early fall (McLean, 1962 and Neushul, 1967). The reduction in storm activity in late winter/early spring coupled with nutrient enrichment during the upwelling period may result in a spring phase of rapid growth followed by a slower summer growth. By the end of summer most annuals have reached maturity, and many perennials have regrown to peak annual densities and biomass.

The vertical distribution (both in the water column and in the sublittoral zone) and the morphology of a plant are perhaps the most important factors that determine its presence in wrack. Data on vertical zonation of the major wrack producers is provided by MacLean (1962). Locally, most species comprising wrack are found near the water's surface or reach the surface by the end of the growing season. Also, all of the major species, including the seagrasses, are positively buoyant (ZoBell, 1971). The importance of these points will be considered in the last section of Part I.

Wrack Population Dynamics

Settlement. Censusing for wrack settlement began in October 1977 but methodologic problems were not resolved until November. Wrack deposition began strongly by the end of September and increased through November, the time at which largest amounts settled in the 1977-78 season (Fig. 1). Settlement of new wrack began to decline in November. Correlating wrack settlement with storms will be done once storm data are received from the National Climatic Center. This analysis should show that storms generate drift algae which later become wrack.

The effect of daily and monthly tidal cycles on wrack settlement are being investigated. At present, data are insufficient to test for either effect. But since production of wrack is influenced mainly by seasonal storms, one expects that tides are incidental to wrack generation, but significant for wrack settlement. Beach debris is almost always deposited during high or receding phases of the tide.

Distribution. Wrack is not deposited randomly. Peak settlement occurred strongly on several sectors of Salmon Creek Beach throughout the season. This phenomenon of differential settling is negatively correlated with beach slope. The physiography of Salmon Creek and Doran beaches is being examined to evaluate the impact of a beach's location and positioning on the wrack distribution observed.

Wrack is dispersed across the beach in a wide band by spring tides and in a narrow band by neap tides. On three 50 m study plots set out to gather data on dispersion, wrack was present in measurable quantity during November and December, decreasing in January; and from February through May, there were no measurable quantities.

Persistence. The length of time stands of algae remain on the beach, correlated to time of year, was measured by tagging cohorts of recently settled wrack on six different dates and observing the rate of per-

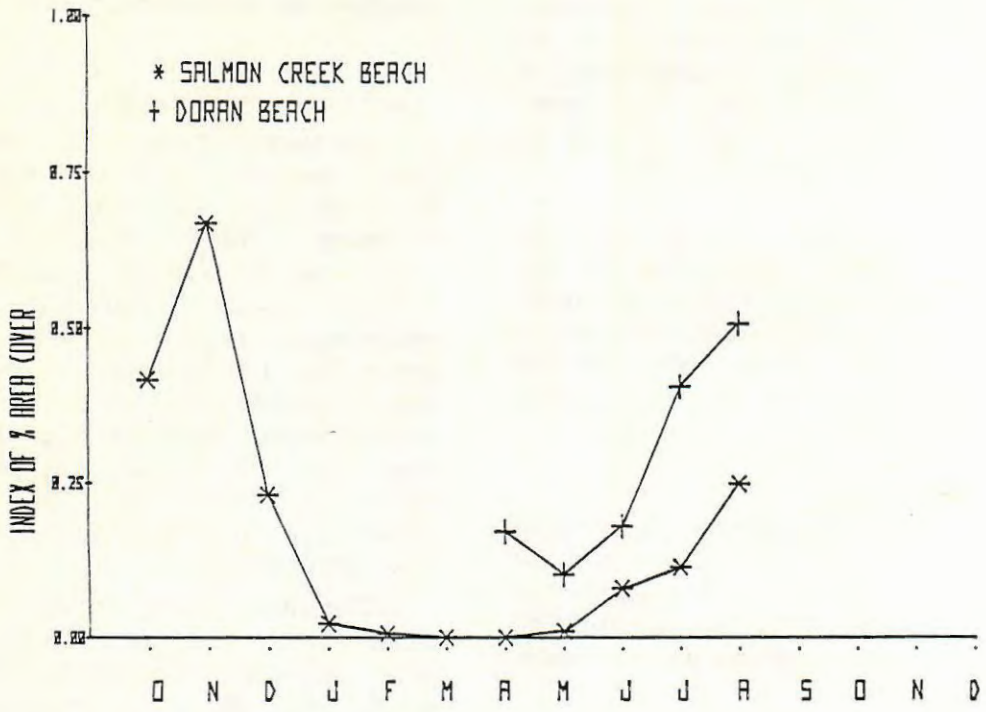


Figure 1. Seasonal abundance of wrack on Salmon Creek and Doran beaches in 1977-78 expressed as per cent cover on line transects between dunes and wash zone every 10 m for 1 km, and 1.5 km, respectively.

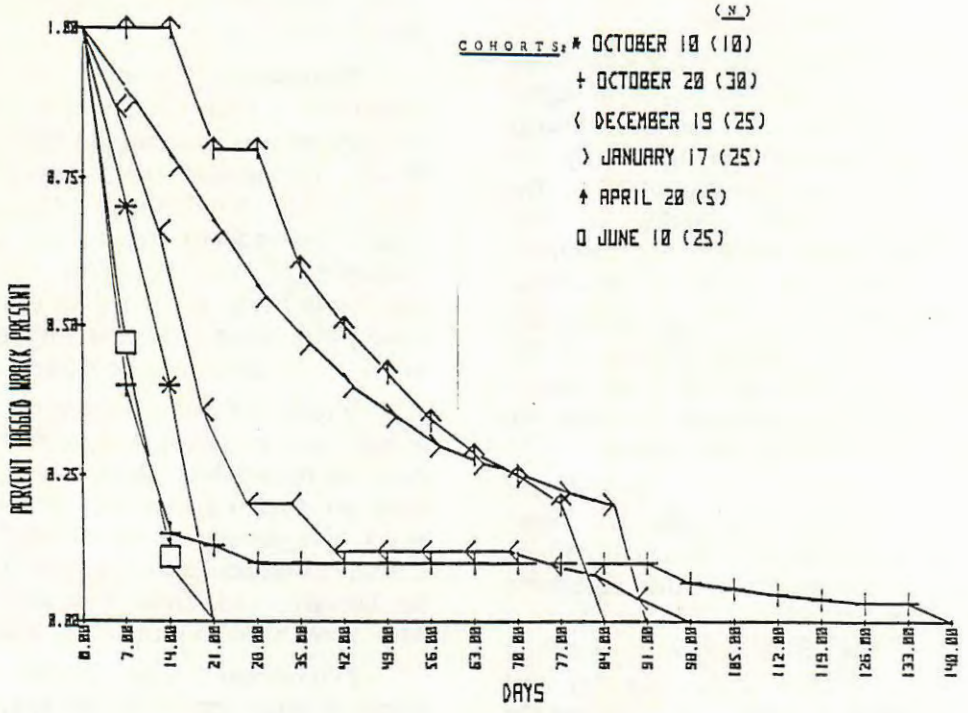


Figure 2. Survivorship curves for six cohorts of beached algae.

sistence (or "survivorship") as shown in Figure 2. The strongest point made in Figure 2 is that persistence is not strictly a function of the tidal cycle. If this were so, a regular biweekly component would be observable in wash-off, or loss. Parts of some tagged wrack clusters can persist for 140 days. Analysis of these data is continuing.

Decomposition. The structural integrity of wrack is continually changed by processes of physical and biochemical decay (Backlund, 1945). The rate of degradation depends on the species involved, time of year and length of time the wrack has been on the beach. Patterns of breakdown and their significance with relation to associated invertebrates are being followed.

Physical factors

Weather. The importance of seasonal storms in wrack phenology is well documented (Backlund, 1945; Gerard, 1976; Neushul, 1967; Neushul *et al.*, 1967; Rosenthal *et al.*, 1974; and ZoBell, 1971). Gerard (1976) found that the production of algal drift was a function of water movement intensity measured as the frequency of maximum wave heights generated by seasonal storms. The seasonal trend of these storms can be expressed by measurements of fluctuations in wave heights expressed as seas (locally generated wind waves) and swells (migrant wind waves). Figure 3 shows the monthly means. Seas develop rapidly during the fall with a peak in January. Springtime northwesterlies maintain seas in an elevated state, dropping off gradually through the summer to a low in September. Swells, on the other hand, are weak from May through October, followed by an increase in storm activity peaking in January. Swells are strong during February and March but begin to decline in April as the spring winds develop. The storm pattern for the 1977-78 season followed the general pattern. A more precise description of local storms and their relation to the pattern of wrack settling is being generated by recording sea state data twice each day.

Currents. Local nearshore surface currents are important in determining the dispersal of drift wrack. A knowledge of these local currents is essential in locating the potential wrack-delivering sectors of coast. One can expect seasonal variation in currents to influence differentially the movement of drift wrack. By establishing local seasonal patterns in surface currents, we may be able to define approximately the geographic limits of the coastal region producing local wrack. Data from drift bottles and oranges as current indicators will assist in this analysis.

Discussion -- The Wrack Story

This is a generalized account of the phenology of beach wrack near Bodega Bay as we perceive it now, incomplete though our data are. It will of course be refined by experience of the 1978-79 season.

Wrack deposition results from seasonal storms taking their toll of the luxuriant summer growth of benthic flora. What are the proximal causes responsible for wrack production? Kingsbury (1962) found that wave energy in the form of wave velocity (wave period) had a greater impact on attached marine algae than did wave pressure (wave height). This means that sea or locally generated wind waves are less influential in tearing attached algae than swell or migrant wind-generated waves.

Wave energy imparted to attached algae is greater on species with greater surface area (Neushul *et al.*, 1967). Although surface currents can depress canopies to a depth of 25 ft, wave surge (swell) has more energy, imparts higher velocity and is greater near the surface. Near-surface canopies thus receive more wave energy and transmit it through their stipes to the holdfast. That large-surfaced species are most likely candidates for wrack is supported by comparison of the algal community *in situ* with the fraction of it that becomes wrack.

All major wrack species in our system are found near the water's surface, either being attached near the water's edge or growing toward the surface with the aid of gas-filled bladders. *Postelsia* grows on the outer fringe of exposed rocky outcrops, surviving the brunt of intertidal wave energy. A strong correlation exists between the size

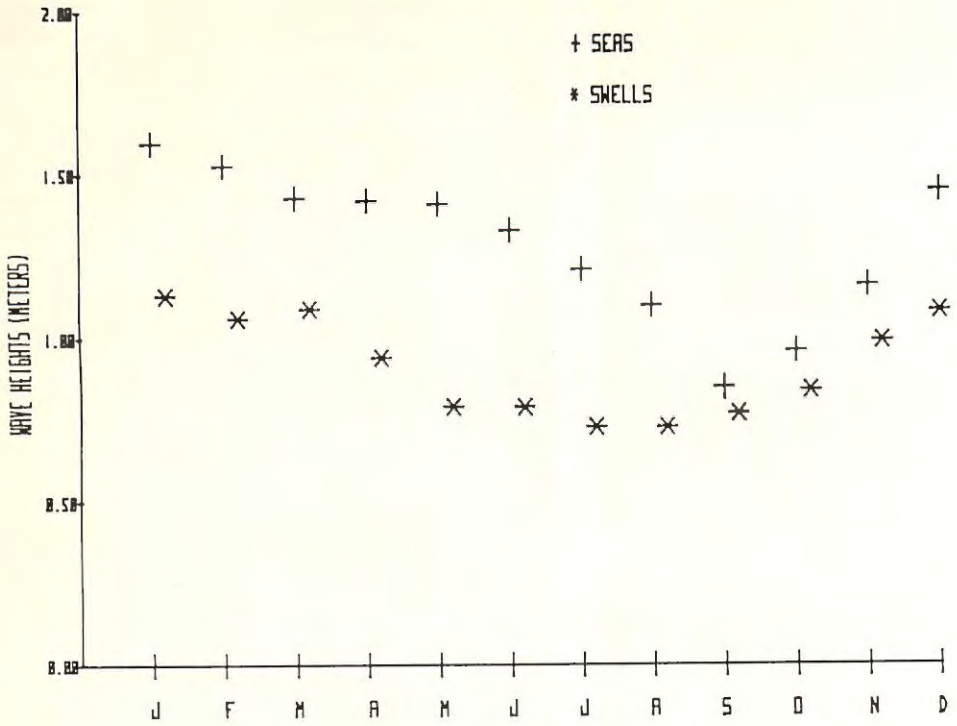


Figure 3. Seasonal trend of mean seas and swells as measured by wave heights for a position located approximately 60 miles off San Francisco.

Table 1

Ocurrence of Wrack-producing *Macrophytes* on beaches near Bodega Bay in the period October 1977-June 1978

Month	*Cystoseira*	*Egregia*	*Macrocystis*	*Nereocystis*	*Postelsia*	*Phyllospadix*	*Zostera*
October	+	+		+		+	+
November		+		+	+	+	+
December		+	+	+	+	+	+
January		+	+	+		+	+
February			+			+	
March							
April	+	+	+		+	+	+
May	+	+			+	+	
June	+	+	+	+	+		
July	+	+	+	+		+	+
August	+	+	+	+	+	+	+
September	+	+	+	+	+	+	+

of *Postelsia* plant (number of plants per clump) and the probability of that plant being removed at any one time (Stockton, pers. comm.).

Cystoseira, *Phyllospadix* and *Egregia* likewise are found near the lower low water mean. In the normal habitat of these species, the amount of wave energy is high, especially during storms. The floating canopy of *Nereocystis* and *Macrocystis* substantially increases the portion of the surface areas of these plants exposed to energy imparted by swells, transmitting it through their stipes to the holdfasts. Hence the strong representation of all these types in beach wrack.

Zostera probably comes from Bodega Lagoon, the only protected embayment in the vicinity of our study sites. The lagoon is protected from northwest winds. *Zostera* wrack is probably produced by southern storms which drive swells north along the coast.

Length of wrack season is partly a function of the amount of algae available for wrack production and partly -- also more importantly -- a function of the relative frequency and intensity of oceanic storms. During the past season, wrack production started in late summer, peaked in late October and early November, and fell to a low level in December. An examination of the monthly settlement of wrack on our study sites reveals that early storms yielded more newly deposited wrack than did later more violent winter storms, thus supporting the notion of a limited amount of potential wrack available each season.

Bodega Head appears largely responsible for most of the local wrack. This stretch of rocky coastline protrudes between beach-bordered Bodega Bay to the south and Salmon Creek Beach to the north. The finite area of potential wrack-producing substrate is thus relatively small.

Cohort persistence is influenced by the seasonality of storm activity. Wrack deposited early in the fall is subjected to more storms with increasing intensity through the winter and therefore has a low probability of persisting. Cohorts deposited in the fall are swept back to sea, covered by sand, or decomposed rapidly. Winter cohorts are quickly removed by storms if not thrown extremely high on the beach. Buried individuals are uncovered in the winter and contribute to an otherwise rapidly declining stand of surface wrack. The rate of decomposition is reduced by heavy rainfall, which interferes with biochemical decay (Backlund, 1945). In the spring, strong winds from the northwest quickly dessicate what little wrack is left. At this time, breakdown may be due chiefly to desiccation.

As the spring progresses, swell activity drops to a seasonal low coinciding with the "bloom" of algal annuals. This five-month period of reduced storm activity probably facilitates algal growth by the drop in seasonal wave energy, and also nutrient input from upwelling. As the summer ends, the cycle begins to repeat itself.

Although the basis of this discussion rests on much data, several speculations are laced into it. The coming season will be used to test the basic word model offered here.

Part II: Preliminary Results from the High Beach Faunal Study

The faunal study of the high beach community is providing a detailed account of constituent species. More than 65 are identified, and of these 55 are apparently limited to the beach environment. Thirty-six species are found regularly in wrack, 9 in open sand habitat, and 7 in both. Data on time-space aspects of habitat distribution are being gathered.

Thirty-eight of the 65 identified species are consistently important numerically. These include amphipods (beach-hoppers), dipterans (flies) and coleopterans (beetles). Amphipods follow the high water mark of the previous night's high tide and heavily utilize wrack when it occurs in the wave-wash area, as a refuge more than as a source of food. Two common species separate out habitat-wise, *Orchestoidea benedicti* in wrack and *O. columbiana* in open sand habitat.

The dipteran assemblage is dominated by three species from three families. Adults lay eggs in fresh wrack, larvae feed on or in the decomposing algal substrate for 2-6 weeks, then pupate, and hatch as adults 7 to

10 days later. Coleopterans, the most diverse taxon of high beach macroinvertebrates, include detritivores, saprovores, omnivores and predators. They include early wrack colonizers which are winged species seeking out newly stranded wrack islands.

Most invertebrates occurring on the high beach are found there associated with wrack. Therefore, it is not surprising that more species and greater abundances are found along sections of the beach covered by more wrack. In fact, a strong positive correlation even exists between amount of wrack and mean number of invertebrates found away from wrack in open beach. This reflects the influence of wrack in contributing organic matter to sections of beach otherwise described as "open sand" habitat.

Invertebrates found in core samples from beneath wrack islands are similar to those in wrack samples although densities are usually lower. Densities also fall off abruptly away from wrack islands. Most individuals in sand beneath wrack lie within a few centimeters of the algae. Depth distribution of a given species apparently is influenced by vertical position of the wrack island in the substrate, its mobility, and the form of settling contact, which influences the distribution of pupating insects.

A clear pattern of faunal succession is evident in decomposing wrack islands. Initial colonizers are winged, mostly beetles and flies. As the islands age (i.e., undergo physical degradation), number of species and their abundance also increase. The additional species include winged and wingless beetles, adult flies, and their larvae and pupae. Temporal patterns of succession vary spatially along an intertidal gradient. Islands located high intertidally are usually older and are less susceptible to tidal inundation, so last longer and have a more complex pattern of succession. Islands lower intertidally are younger, survive at lower rates, with associated fauna reflecting their age.

Tides and spring winds have a profound effect on composition of the wrack community. Tidal inundation generally decreases overall invertebrate densities, but *Orchestoidea* densities increase. The invertebrate assemblage of a given wrack island can recover from inundation and sometimes reach densities greater than previously present. Spring winds, on the other hand, impose a sustained depressing influence on wrack invertebrates; they quickly dry out wrack and apparently reduce the suitability of the resource. This is shown by a negative correlation between wind persistence and invertebrate densities.

Seasonal data on most beach species from the first year's work are too limited for comment now. But is has become clear that invertebrate densities rise as the amount of wrack increases, and so the seasonal component of variability is important. Invertebrate densities on open beach climbed from a low of 85 individuals per m^2 of wrack in July to 455 in October. Densities associated with seagrass and brown algae were 1-3 orders of magnitude higher in the course of the annual cycle, being highest in the period October-January.

The research on invertebrates to date is necessarily general because of the need to develop a base of qualitative data on the fauna itself, and it is necessarily limited by the basic information need, and scope of sampling program, for the wrack itself. However, the results being obtained should contribute to the NSF program on patchiness of beach invertebrates and its influence on predator (shorebird) behavior as well as to a more basic picture of dynamics in a community, the sand beach, wholly dependent on import of energy and nutrients, algal wrack probably being the chief component of that import.

Dawson, E. Y. 1966. Seashore plants of northern California. Univ. Calif. Press, Berkeley.

Egglishaw, H. 1960a. Studies of the family Coelopidae (Diptera). *Trans. Royal Entomol. Soc.* 112: 109-140.

Egglishaw, H. 1960b. The life history of *Fucellia maritima* (Haliday) (Diptera, Muscidae). *Entomologist* 93: 225-231.

Gerard, V. A. 1976. Some aspects of material dynamics and energy flow in a kelp forest in Monterey Bay, California. Ph.D. thesis, Univ. Calif. Santa Cruz.

Hamby, R. J. 1964. Drift bottle studies at Bodega Head, California. M.S. thesis, Univ. of the Pacific, Pacific Marine Station.

Harrison, P. G. and K. H. Mann. 1975. Detritus formation from eelgrass *(Zostera marina* L.): the relative effects of fragmentation, leaching and decay. *Limn. Oceanogr.* 20: 924-934.

Johansen, H. W. 1966. The benthic marine algae of Bodega Head region. *In* A marine ecological survey of the Bodega Head region. Submitted by Cadet Hand to the University of California, report UCB-34P-96-1: 35-112.

Kingsbury, J. M. 1962. The effect of waves on the composition of a population of attached marine algae. *Bull. Torrey Bot. Club* **89: 143-160.**

MacLean, J. H. 1962. Sublittoral ecology of kelp beds of the open coast near Carmel, California. *Biol. Bull.* 122: 95-114.

Neushul, M. 1967. Studies of subtidal marine vegetation in western Washington. *Ecol.* 48: 83-94.

Neushul, M., W. D. Clarke and D. W. Brown. 1967. Subtidal plant and animal communities of the southern California islands. *Proc. Symp. Biol. Calif. Is.:* 37-57.

Rosenthal, R. J., W. D. Clarke and P. K. Dayton. 1974. Ecology and natural history of a stand of giant kelp, *Macrocystis pyrifera,* off Del Mar, California. *Fish. Bull.* 72: 670-684.

Tenore, K. R. 1977. Utilization of aged detritus derived from different sources by the polychaete *Capitella capitata. Mar. Biol.* 44: 51-55.

ZoBell, C. E. 1971. Drift seaweeds on San Diego County beaches. *The Biology of Giant Kelp Beds (Macrocystis) in California.* W. J. North, ed. *Beihefte zur Nova Hedwegia* 32: 269-314.

Cooperating Organizations

National Science Foundation

University of California, Departments of Zoology, Entomology and Botany

University of California, Davis, Bodega Marine Laboratory and Department of Zoology

PG&E Department of Research and Development

National Climatic Center

University of California, Riverside, Department of Entomology

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

California Resource Agency, Department of Navigation and Ocean Development

References

Backlund, H. O. 1945. Wrack fauna of Sweden and Finland: ecology and chorology. *Opusc. Entomol. Supple.* 5: 1-238. Lund, Sweden.

Bolin, R. L. and D. P. Abbott. 1963. Studies on the marine climate and phytoplankton of the central coastal area of California, 1954-1960. *Calif. Coop. Oceanic Fish. Invest., Reports* 9: 23-45.

Coastal Wetlands Management
Effects of Disturbance on Estuarine Function

Joy B. Zedler and David A. Mauriello
San Diego State University

Research on the ecological functioning of the Tijuana Estuary was begun in 1976 and continued through the past 12 months. In addition, selected sampling was carried out in two disturbed wetlands, Los Penasquitos Lagoon and the San Diego River Flood Control Channel.

The Tijuana Estuary

With the availability of over a year's data we were able to describe in detail the following features of the Tijuana Estuary, a relatively natural southern California wetland.

Productivity. About 80 percent of the plant productivity occurs in the intertidal salt marsh, where both vascular plants and algal mats contribute to the estuarine food base. Vascular plant productivity occurs mostly between March and August, although biomass minima and maxima are somewhat different for individual species. Calculations of productivity that sum the species peaks give higher marsh productivity values than calculations which compare average biomass changes through time. The productivity of low, middle, and high marsh habitats for 1976 was 911, 728, and 595, and for 1977 was 832, 971, and 944 grams dry weight/m^2/yr (Table 1). Carbon content differs with marsh species; the grasses *Spartina foliosa* and *Monanthochloe littoralis* have the highest carbon percentage of dry weight (32 and 35%), while non-grasses average 25 percent. Weighting the species' dry weight productivities by the respective carbon contents results in the following carbon fixation values in 1977: low marsh 246, middle marsh 233, and high marsh 272 gC/m^2/yr. Algal mats are at least as productive as the vascular plants. Estimated net carbon fixation values are: 276 grams carbon/m^2/yr under low elevation *Spartina* canopy, an average of 264 under succulents which are characteristic of middle elevations, and 253 under *Monanthochloe,* which dominates the upper elevations. It is thus concluded that salt marsh algal mats and vascular plants are both important in providing organic matter to estuarine food chains. The significance of algal mats to food chains goes beyond their high productivity, since the algae photosynthesize year-round. Also, research elsewhere shows that algae are more easily digested than vascular species so that the food produced is immediately available to grazers, and the algal based grazer food chains can potentially support higher productivity of estuarine animals than vascular plant based detrital chains.

Algal mats respond to seasonal environmental factors of tidal inundation, light and temperature, with highest productivity in summer-fall, low productivity in winter, and declines in productivity whenever desiccation occurs. In 1977 there was a dip in algal productivity in April, when both tidal inundation and rains were infrequent. In June 1978 sand deposition in the main channel had reduced tidal flow, and desiccated algal mats were inactive. Algal mat productivity differs with overstory vegetation. Comparisons of mats in *Spartina foliosa* (tall, dense) and *Jaumea carnosa* (short, open) communities at the same intertidal elevation differed significantly in productivity, with the latter being 1.24 times as productive. Greater light penetration through *Jaumea* canopies no doubt causes the difference.

Algal films commonly cover the substrate of the shallow tidal channels within the estuary. Diatoms dominate the films, with bluegreens rarely developing mats. While their productivity can be as high as the marsh algal mat communities (up to 236 gC/m^2/yr), their limited habitat precludes a greater contribution to overall estuarine primary production. However, because of ready availability to a variety of grazer organisms, these algal films may play a disproportionately great role in supporting

Table 1

Ecological functioning of the intertidal salt marsh
Tijuana Estuary, California

Intertidal position	low	medium	high	
Vascular plants				
dominants	*Spartina foliosa*	succulents *Jaumea carnosa, Salicornia bigelovii, S. virginica, Batis maritima*	*Monanthochloe Salicornia subterminalis Suaeda californica*	
August 1977 above-ground standing crop (g/m^2, live only)	1099	1035	1268	
Annual above-ground NPP from harvest method, Smalley's calc. on species; summed ($g/m^2/y$)	832	971	944	
correcting for measured C contact by species ($g/m^2/yr$)	246	232	272	
Algal mats	under *S. foliosa*	under *J. carnosa*	under *B. maritima*	under *M. littoralis*
dominants	*Microcoleus lyngbyaceus* other fila. bluegreen	*M. lyngbyaceus* other fila. bluegreen	*fila. greens: Enteromorpha, Rhizocloniuum*	*M. lyngbyaceus Rhizoclonium* in "understory"
Average hourly GPP in 1977 (mg $02/m^2/hr$)	348	425	236	319
Estimated annual NPP assuming PQ-1.2; NPP-.85GPP ($gC/m^2/yr$)	276	341	188	252

the aquatic food web of the estuary.

Material exchange. Our understanding of the movements of nutrients and organic materials within Tijuana Estuary has increased significantly within the past 12 months. The studies have emphasized the quantification of material flows between the intertidal salt marsh and tidal creeks and between the main channels and the Pacific Ocean.

1. Marsh-tidal creek interactions. Ammonium was the dominant form of inorganic nitrogen exchanged between the intertidal salt marsh and the tidal channels. Except for March 1978, concentrations of ammonium were greater than nitrate or nitrite. The concentration of ammonium ranged from 0-16.8 μg-at N/1 with peak values occurring in winter and spring of 1978. Nitrate concentrations were generally lower than ammonium, ranging from 0.2-31.5 μg-at N/1, with the peak in March 1978, following a period of prolonged rainfall and flooding. Nitrite values were considerably lower, from 0.2 μg-at N/1. The intertidal salt marsh showed a net import of ammonium and a net export of nitrate during the sampling period. Overall, there was a net import of dissolved inorganic nitrogen from the tidal channels to the marsh.

Concentrations of dissolved organic carbon were considerably higher (1.3-10.7 mg C/1) than for particulate organic carbon (0.4-1.8 mg C/1) with maximum values reached during March 1978. Overall, organic carbon was exported from the salt marsh to the tidal channels, except for a short period during the spring of 1978. The majority of the carbon flux was accounted for by the dissolved form, while net movement of particulate organic carbon appeared to be negligible.

2. Channel-ocean interactions. Somewhat different trends were evident in the pattern of material exchange between the tidal channels and the Pacific Ocean. The primary components of dissolved inorganic nitrogen flux were ammonium and nitrate which exhibited seasonal fluctuations in concentrations near the mouth of the estuary. Concentrations were elevated during the spring runoff period and following occasional storms throughout the year (Fig. 1).

There was a net import of all forms of dissolved inorganic nitrogen into the estuary during the fall months following the peak growing season of the salt marsh vascular plant community. Throughout the remainder of the year, the dissolved forms of inorganic nitrogen were exported from the estuary. A similar pattern of exchange was observed for particulate organic nitrogen which was imported primarily during the months of September and October and for a brief period in June 1977. At other times, the flux was from the estuary to the ocean. The exchange pattern for particulate organic carbon closely parallels that for particulate organic nitrogen, with a net loss from the estuary except for a brief period in June and again in September and October, 1977. Dissolved organic carbon was also exported from Tijuana Estuary, except for September and October, 1977. Dissolved organic carbon was the primary component of the organic carbon flux in Tijuana Estuary, generally comprising over 70 percent of the organic carbon flux (Fig. 2). Overall, the results indicate that Tijuana Estuary is a net exporter of nutrients and organic matter to the Pacific Ocean. Only during the fall months, following the growing season, does there appear to be any appreciable import of materials into the estuary.

Disturbed Wetlands

We studied the ways in which estuarine functions have been altered by making comparable, but less extensive measurements in two disturbed wetlands. Los Penasquitos Lagoon (LPL) was chosen because its ocean connection is frequently blocked; hence the effects of less tidal activity can be suggested by comparing periods of open and closed conditions at LPL and by comparing LPL with the Tijuana Estuary (TJE). The San Diego River Flood Control Channel (FCC) was chosen for comparison because the vegetation had been altered both through dredging and flooding. The marsh still has tidal circulation, although sand deposition restricts tidal flow to the gaps between rocks in the Mission Bay jetty. In order of increasing distur-

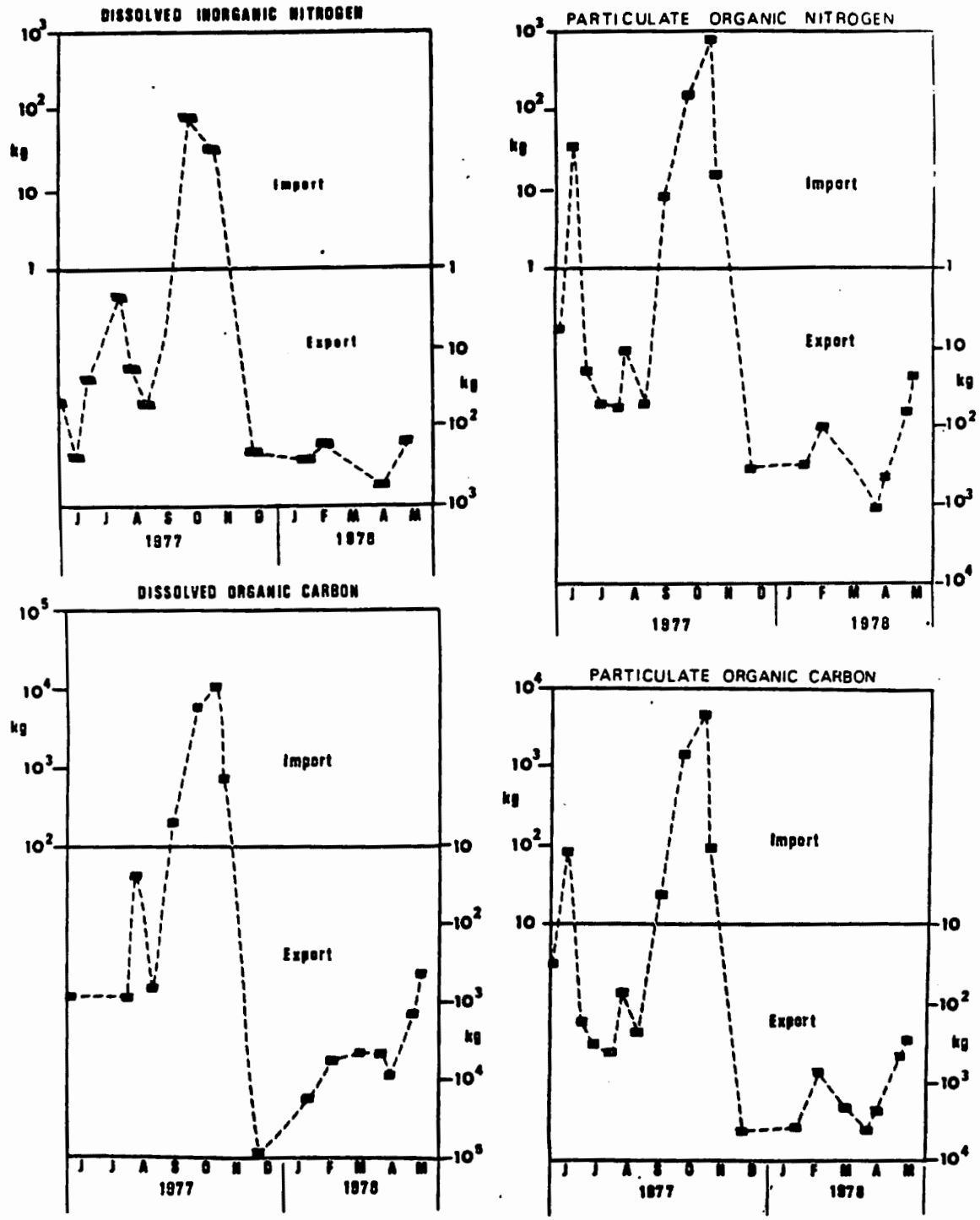


Figure 1. Amounts of dissolved and particulate nitrogen and carbon transported per day for several flood and ebb tide series.

Table 2
Summary of estuarine functioning in disturbed and natural estuaries

	Tijuana Estuary (TJE)	Flood Control Channel (FCC)	Los Penasquitos Lagoon (LPL)
Type of disturbance	Relatively little	Vegetation alteration during construction; tidal flow restricted to movement through riprap	Frequent closure of ocean connection
Dominant vascular plants at low elevations	*Spartina foliosa*	*Salicornia virginica*	*Salicornia virginica*
Vascular plant standing crop (August 1978) in comparable low elevation habitats	1,031 g/m^2	970 g/m^2	4,316 g/m^2
Litter in comparable elevation habitats (August 1978)	139 g/m^2	254 g/m^2	477 g/m^2
Annual productivity of comparable low elevation habitats (calculated as increase in live plus increase in standing dead plants)	836 g/m^2/yr in 1976 830 g/m^2/yr in 1977	544 in 1978	2,792 in 1978
Salt marsh algal mat	Abundant mats, highly productive	Similar to TJE	Undeveloped in salt marsh
Phytoplankton communities	unproductive		Can develop blooms with closed mouth
Macrophytes in tidal channel	Rare	Frequently develop in quieter waters; *Zostera* occurs in subtidal areas	Become dense after long periods of closure

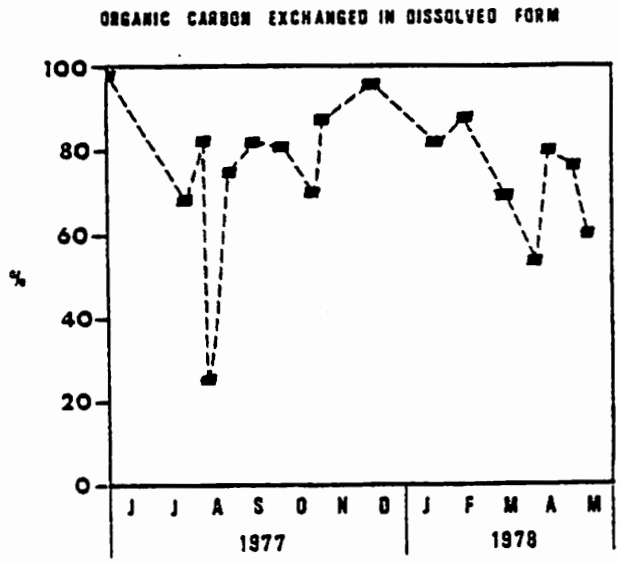


Figure 2. Proportion of organic carbon in the dissolved form exchanged by tidal water at the mouth of the Tijuana Estuary.

bance, we suggest that the ranking is TJE, FCC and LPL. Selected comparisons which have been completed in the last 12 months follow.

Salt marsh comparisons. Vascular plants are long-lived and can indicate the effects of long-term changes in estuaries. Thus we chose to measure standing crop and productivity in both FCC and LPL. The species composition of both disturbed salt marshes is much more homogeneous than at TJE. At FCC and LPL, pickleweed *(Salicornia virginica)* is the uniform dominant in the lower elevations of both disturbed marshes. Cordgrass is present only in small patches at FCC. Higher elevations of both disturbed marshes support *Frankenia* and *Distichlis.* It is likely that some of the reduction in diversity is due to past disturbance, since small-scale disturbances at TJE seem to produce the same effect.

Despite differences in species composition, standing crops of vascular plants in August 1977 and 1978 were similar ($\simeq$1000 g/m^2) for the FCC and TJE (Table 2). However, LPL supported 2-4 times that biomass. Examination of year-to-year differences in standing crop and in tidal flushing of LPL explains the results. The entrance of LPL was closed during March of 1977, a year of average rainfall. In 1978 the entrance closed in spring after an unusually wet season. Fresh water accumulated behind the sand plug and inundated the marsh for weeks during the early part of the growing season. This freshwater influence appears to be responsible for high standing crops, since research elsewhere has shown that facultative halophytes grow better in soils that are less saline than their usual habitat.

In the lower elevations, where fresh water stood the longest, the standing crop was 2.4 times as high as the upper elevations in August 1978, and 1.6 times higher than was the standing crop at the same elevation in 1977. In conclusion, higher biomass and taller stature of plants occur under freshwater conditions which are possible when tidal flushing is reduced or eliminated.

Patterns of litter, dead organic matter accumulation, also are explained by differences in tidal flushing. TJE, the most naturally flushed salt marsh, had accumulated only 139 grams/m^2 in the lower marsh. Comparable habitats at FCC had accumulated 254 g/m^2, and the poorly circulated lower marsh at LPL accumulated 477 g/m^2. We observe that litter accumulation increases with decreased tidal flushing. If this is a cause-effect relationship, we would predict even greater litter accumulation in upper elevations which are less frequently underwater. The higher marsh at LPL had extremely high litter accumulation at 2,635 g/m^2 in August 1978. Slight deviations from the pattern at TJE are explainable by differences in detritivore density, presence of *Spartina* stems which decompose slowly, and redeposition of litter at high elevation drift lines. The general pattern is one of increased litter accumulation with decreased flushing. The action of tides aids the decomposition process by providing moisture to the dead material and, as indicated at TJE, by leaching dissolved organic materials from the litter.

Vascular plant productivity, measured by assessing increases in live plus increases in standing dead plants, and separating out only the comparable low marsh habitats was 830-836 g/m^2/yr at TJE in 1976-77, 544 at FCC in 1978, and 2,792 at LPL in 1978. The lower productivities occur in the better circulated wetlands. It has been suggested elsewhere in the literature that productivity increases with tidal circulation. However, our data are better explained by examining soil salinities and species composition.

Both FCC and LPL are dominated by *Salicornia* spp. in the lower elevations. However, soil is less saline at LPL and the high plant productivity no doubt occurs in response to the influence of fresh water. Comparing July-August growth at LPL during 1978 (2,050 g/m^2/mo) growth in 1977 (850 g/m^2/mo) when rainfall was lower supports this hypothesis. Other factors no doubt contribute to differences in productivity, but the major difference between 1977 and 1978 was rainfall.

Low elevations at TJE have productivity which is somewhat greater than at FCC, and considerably less than at LPL. Since both FCC and TJE are tidally flushed and have relatively high soil salinities, one

might expect similar productivities, especially since August 1978 standing crops were so similar. However, species composition is different; *Spartina foliosa* dominates the low marsh at TJE, where it is the most productive of the 14 salt marsh vascular plants found there. Its lack of abundance at FCC may be the reason for lower productivity for a comparable habitat. It is replaced by *Salicornia virginica* which appears to have high productivities only under reduced salinities (as at LPL). The similar August standing crops in the presence of different productivities are explained by the growth habitats of the two species. *Spartina* dies to the ground after reaching maturity while *S. virginica* is a short-lived perennial which accumulates woody tissue. *Spartina* standing crops are lower at the beginning of the growth season, but equal to *S. virginica* in August; hence the productivity of *Spartina* is greater.

Salt marsh algal mat productivity was not monitored at FCC and LPL because of the time requirements for a thorough analysis of annual algal contributions. Visual observations and collections of algal mats for incubation under controlled conditions were used instead to compare their role in the three marshes. Algal mats are similarly abundant in TJE and FCC, where similar vascular plant biomass allows light penetration and where tidal flushing wets the soil. Mats collected in September 1978 from FCC and TJE had similar chlorophyll/m^2 and similar hourly productivity. In contrast, no mats were present at LPL where the soil surface was dry in the absence of tidal flushing. Soil samples bought back to the laboratory were wetted, but only bacterial films developed, suggesting little potential for algal development. Even with moisture in the field, the dense overstory and thick litter accumulation prevent penetration of light which is necessary for the development of algal mats.

These findings demonstrate significant differences in salt marsh structure and functioning for the natural TJE and disturbed FCC and LPL systems. Further differences exist in the aquatic (channel) portions of disturbed and undisturbed wetlands.

Channel comparisons. Several differences were found between channels of LPL and TJE (Table 2). The higher nutrient concentrations and development of algal blooms in LPL during the closed conditions are probably a direct response to closure of the ocean connection. Closure prevents the export of nutrients and prevents dilution of the phytoplankton. It also increases temperatures which would favor algal growth. That these differences are related to closure of the lagoon is supported by a natural experiment that occured in TJE during spring of 1978.

The flooding of the Tijuana River through the south arm of TJE severely restricted tidal flow in March 1978. Flood waters tended to move directly to the ocean and not into the upper part of the northern arm of the TJE channel where algal productivity was being monitored. The effect was to increase the residence time of water in the northern channel and allow the development of a plankton bloom during the flood conditions. The comparison of TJE with and without tidal circulation is similar to the comparison of LPL without tidal circulation and TJE during a normal year. Without tidal dilution, productivity increases significantly. If the period of closure is long enough, floating algal mats develop and dense stands of macrophytes develop on the channel edges. Because LPL has been closed to tidal flushing throughout much of the study period, there is little information concerning the pattern of material exchange within the lagoon. Following a brief period in January 1977, when the entrance to the lagoon was open, measurements of particulate organic nitrogen and carbon concentrations were taken. Concentrations increased from 45 μg-at N/1 of inorganic nitrogen and 300 μg-at C/1 of organic carbon (while open) to peaks of 200 μg-at N/1 and 1,100 μg-at C/1 for nitrogen and carbon, while closed. Following a second brief opening of the lagoon entrance in early spring 1978, measurements indicated a net export of nutrients and organic matter from the lagoon.

Publications

Mauriello, D. and T. P. Winfield. 1978. Nutrient exchange in the Tijuana Estuary. *Proc. Coastal Zone '78 Symposium on Technical, Environmental, Socioeconomic and Regulatory Aspects of Coastal Zone Planning and Management,* Vol. III: 2221-2228. Am. Soc. Civil Engr., New York.

Mauriello, D. and T. P. Winfield. 1978. The exchange of nutrients and organic matter in the Tijuana Estuary. *Bull. Ecol. Soc. Amer.* 59: 87 (abstract). Paper presented at the August 1978 meeting of the American Institute of Biological Sciences, Athens, Georgia.

Winfield, T. P. 1978. The exchange of nitrogen and organic carbon between a southern California salt marsh and its tidal creeks. *Bull. Ecol. Soc. Amer.* 59: 87 (abstract). Paper presented at the August 1978 meeting of the American Institute of Biological Sciences, Athens, Georgia.

Zedler, J. B., T. P. Winfield and D. A. Mauriello. 1978. Primary productivity in a southern California estuary. *Proc. Coastal Zone '78 Symposium on Technical, Environmental, Socioeconomic and Regulatory Aspects of Coastal Zone Planning Management,* Vol. II: 649-662. Am. Soc. Civil. Engr., New York.

Zedler, J. B. 1978. Salt marsh algal productivity in the Tijuana Estuary, California. *Bull. Ecol. Soc. Amer.* 59: 87 (abstract). Paper presented at the August 1978 meeting of the American Institute of Biological Sciences, Athens, Georgia.

Cooperating Organizations

California Department of Parks and Recreation

Dr. O. Holm-Hansen, Scripps Institution of Oceanography, University of California, San Diego

Hubbs-Sea World Research Institute, San Diego, California

Coastal Wetlands Management
Opening of Coastal Lagoons by Sand Fluidization

Douglas L. Inman and J. A. Bailard
Scripps Institution of Oceanography, University of California, San Diego

This review constitutes the final report on the Sand Fluidization portion of the UC Sea Grant Coastal Wetlands Management Project. Accordingly, it summarizes the activities of the project during the past two years.

Numerous lagoons occurring along the California coastline do not maintain open inlets to the sea at all times. The size of the channel is proportional to the tidal prism, defined as the volume of water that participates in each tidal excursion into or out of the lagoon. Decreases in tidal prisms result from sedimentation in the lagoons, a process that goes on naturally, but is markedly increased by man's intervention such as construction of housing developments and roads. Closure of the inlets of these marginally effective lagoons results when tidal-induced inlet currents are insufficient to keep the channel open in the presence of the longshore transport of sand across the entrance channel. Loss of exchange with the open ocean causes stagnation of lagoon waters and serious degradation of their quality. The principle objective of this project has been to apply the technique of duct-flow fluidization to the separate problems of opening and maintaining lagoon inlet channels.

Demonstration experiments were conducted at Penasquitos Lagoon and Agua Hedionda Lagoon, both located in San Diego County. These sites were chosen because they served to illustrate the basically different requirements for opening a closed inlet channel versus maintaining an existing open channel.

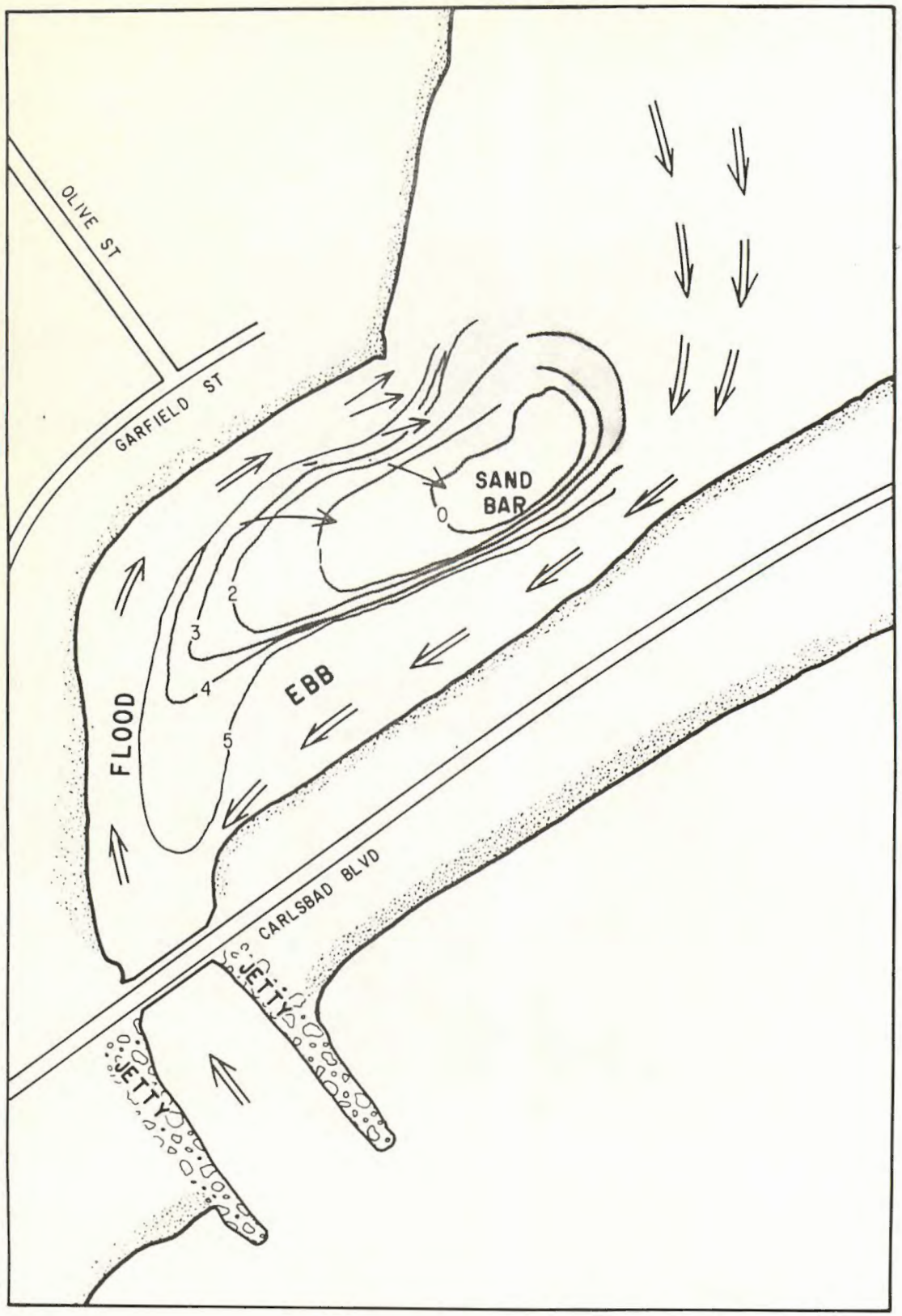
Penasquitos Lagoon

The principle efforts during the first year of the project were: 1) to study the dynamics of the Penasquitos Lagoon inlet, and 2) to develop and test a duct-flow fluidization system to open a recently closed inlet. The results of this phase of the project were presented in the 1976-1977 University of California Sea Grant Annual Report, and will only be summarized here.

The site monitoring program produced a better understanding of the dynamics of the channel morphology. Although the inlet channel was found to change position and cross-sectional area in response to changes in the wave climate and phases of the tidal cycle, the inlet channel was found to have a preferred or "equilibrium" geometry to which it would gradually return following a perturbation. This equilibrium channel position lay along the northern edge of the inlet, adjacent to the State Park parking lot. It should be noted, however, that the equilibrium channel position is the result of man-made control of the inlet, since old photographs show inlet channels on both the north and south sides of the lagoon. Changes in the wave climate were found to produce relatively abrupt changes in both the channel position and cross-sectional area. In fact, large waves, accompanied by high rates of longshore sediment transport were found to be the principle cause of closure for the inlet channel. On the other hand, biweekly changes in the phase of the tidal cycle (spring versus neap) were found to produce a gradual modulation of the cross-sectional area of the inlet channel. As expected, the cross-sectional area was largest during spring tides and smallest during neap tides.

The primary task of the first year's study was to design, construct and test a fluidizing pipe to open a closed inlet channel. This was accomplished by using a modified crater-sink sand fluidizing technique proposed by Inman and Harris (1970) and further developed by Harris *et al.* (1976). The fluidizing pipe was 49 m long, 10 cm diameter, with 0.145 cm diameter jets spaced 6.25 cm apart and angled at 45 degrees. The drive water flow rate was 33

Figure 1. Aerial photograph of the 210 meter long channel cut by the fluidizing system at Penasquitos Lagoon.



78.156-1

Figure 2. Inlet water current and sand deposition patterns at Agua Hedionda Lagoon.

liters/sec. A 210 m long channel was cut in five steps, removing approximately 600 m^3 of sand (Fig. 1). A major problem encountered during the channel cutting operations was the presence of extensive cobble deposits near the sand surface. The presence of the cobbles seriously reduced the rate at which sand could be removed from the channel, leading to the conclusion that a system of this size was unsuitable for this type of use in inlets with substantial cobble deposits. In lagoon inlets with few cobbles present, the results suggest that the system is well suited for re-opening a closed inlet channel.

Agua Hedionda Lagoon

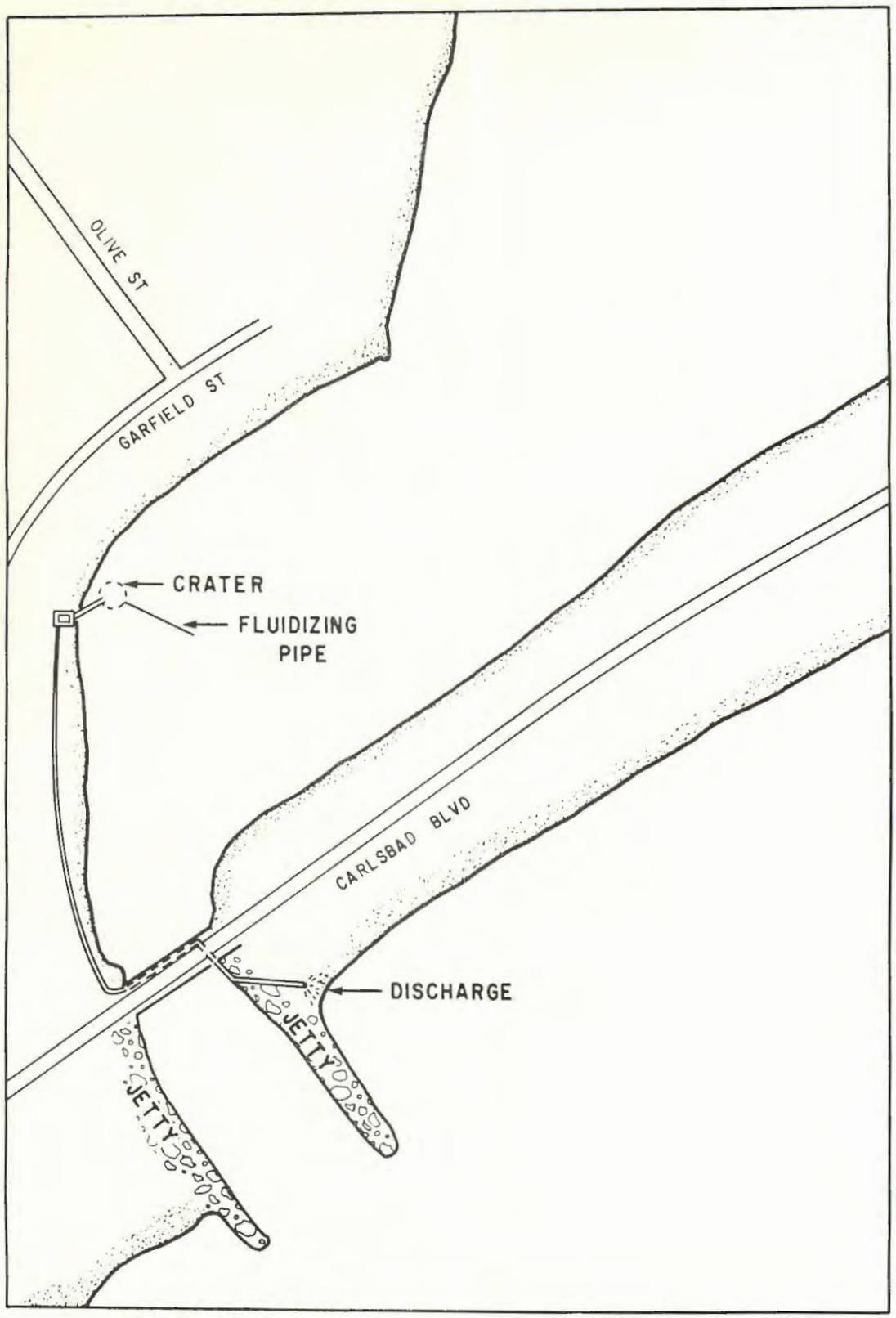
Having tested the feasibility of using fluidization to re-open a closed tidal inlet channel during the first year, the second year was devoted to evaluating the feasibility of using fluidization to maintain an open inlet channel. The study site chosen for this second phase of the project was Agua Hedionda Lagoon, located approximately 20 miles north of Los Penasquitos Lagoon. Agua Hedionda Lagoon was chosen primarily because it remains open year round, due to the periodic dredging of the sand accumulation within the inner reaches of the inlet channel. The principle tasks for the second year were the following: 1) to study the current and sedimentation patterns in the immediate region of the inlet channel, and 2) to develop and test a prototype sized crater-sink, duct-flow fluidization sand bypassing system. The purpose of the system was to intercept the influx of sand into the lagoon and return it to the down-drift beach face, thus preventing the usual buildup of sand just inside the lagoon.

Tidal Current and Sedimentation Patterns in Agua Hedionda Outer Lagoon

A knowledge of the tidal current (flood and ebb) and sedimentation patterns in the inlet region of Agua Hedionda Lagoon was necessary to insure the proper placement of the sand bypassing system. The following criteria were used in selecting a site for the system: 1) in order to assure proper placement of crater and fluidizer, the influx of sediment must occur over a known section of channel; 2) the depth of sand overburden must be at least a meter to provide sufficient "sink" to trap the sand; 3) most of the sediment should be transported as bed load to avoid being carried over the sediment sink; 4) for maximum efficiency the discharge line should be as short as possible; 5) a suitable site must exist for the pumps.

A survey to determine the location of a site satisfying these criteria was initiated in March, 1978. The survey included mapping of tidal current flow patterns and bottom bathymetry, and the measurement of the thickness of sand over-burden. The results of the survey are shown in Figure 2. The flow pattern of the tidal current showed that during flood, the inflowing water is channeled closely along the north and east sides of the lagoon. Upon passing the bend, the flow begins to move southward, while spreading out laterally and depositing its sediment load. A similar channeling effect is seen in the pattern of the ebb tidal flow but located on the west side of the lagoon. As the water passes into the outer lagoon, it is swept into a narrow channel along the west bank of the outer lagoon, finally exiting through the short inlet channel. The bottom bathymetry reflects this channeled flow pattern, with scoured channels along the north and west banks and a deposition bar in the central region of the outer lagoon. The slope of the bottom in the deposition area is very gradual on the north and east sides, but stands at the angle of repose on its west side.

The thickness of sand overburden reflected the combined effects of past dredging and subsequent sedimentation patterns. Generally speaking, the thickness of sand overburden varied from a minimum of zero near the inlet channel, to a maximum of 3 meters or more near the deposition area. Figure 3 shows the site chosen for placement of the bypass system. This site represents a compromise of all the placement criteria, but with the greatest emphasis on criterion 2, 4 and 5. The principle weakness of the site was that a non-negligible portion (approximately 50%) of the sand influx occurred as suspended load, due to the high water velocities at this point in the



78.155-2

Figure 3. Plan view of Agua Hedionda Lagoon inlet showing the placement of the crater-sink sand fluidization system.

inlet channel. Since the system only intercepts sand moving as bed load, it was only effective in catching half the sand entering the lagoon. A better site would have been approximately 50 meters further east, but this wasn't possible due to the limited amount (~200 m) of sand discharge line which was budgeted for this project.

System design and operation

Figure 4 shows the basic system consisting of a fluidizing pipe, a crater-sink, a discharge line and associated pumps. The design of the fluidizing pipe was based on a modified version of the analytic model presented by Bailard and Inman, 1975. Momentum principles were used to develop a set of different equations predicting pressures, velocities and jet discharges at all points along the pipe. These equations were solved numerically using the performance curves of the drive water pump as input conditions. An optimum configuration was selected using the following criteria: 1) the jet discharges along the entire pipe should be approximately equal; 2) the jet discharge rate should be a maximum for a given length of fluidizing pipe; 3) the pump operating conditions should be within normal range; 4) the sand transport capacity of the fluidizing pipe should approximately equal but not exceed the sand removal capacity of the crater-sink discharge pump.

The final system configuration chosen had the following characteristics. The spiral wound fiberglass fluidizing pipe was 25 m long, 10 cm (4 in) in diameter, and had 0.175 cm diameter jets angled at 45 degrees with a spacing of 6.25 cm. The fluidizing pipe was driven by a 4 inch diameter water pump powered by a gasoline engine. The discharge system consisted of approximately 185 m long, 15 cm (6 in) diameter pipe powered by a 6 inch, gasoline driven trash pump. Typical flow rates during the experiment were for the 4 inch pump, 15 liters/sec (240 gpm), and for the 6 inch pump, 49 liters/sec (784 gpm).

In order to test the ability of the system to intercept sand, a series of two experiments were performed on 17-18 May 1978. The experiments consisted of operating the system for periods of 90 minutes during flood tide and monitoring the amount of sand captured and bypassed by the system. This was done by measuring the flow rate and sand concentration in the discharge line every minute. The difference between the two experiments was in the depth of the fluidized trench, which was 60 cm on 17 May and 100 cm on 18 May. The results of the two tests are shown in Figures 5 and 6, which show the rate of sand capture as a function of time.

The average rate of sand captured for the 17 May and 18 May experiments were 2.75 and 3.1 liters/sec of sand respectively, measured in its "at rest" bulk condition. An interesting feature is seen in the 17 May experiment (Fig. 4), where after 55 minutes of operation, the rate of sand capture fell dramatically. This occurred when the increasing flood current began to round the edges of the trench, preventing flow separation, and allowing the flood current to sweep into the trench and carry away the sand (Fig. 7). This process which was termed "trench breakdown", was found to be less of a problem for the 18 May experiment. Apparently, the deeper trench retards the phenomena, although further investigation is needed. Additional study is also needed to develop a system to better control the suction line intake in the crater in order to prevent plugging of the intake line. Figure 6 shows where mid-way through the experiment on 18 May, the suction line intake from the crater became partially plugged, resulting in a decrease in the rate of sand bypassed.

The second part of the experiment was to release dyed sand several meters in front of the fluidizing trench and monitor the amount captured by the system. This procedure was to provide a measure of the capture "efficiency" of the system. Unfortunately, the dyed sand was significantly smaller in diameter than the *in situ* sand, and was thus buried by the processes of shear sorting (Inman *et al.*, 1966, p. 801). For this reason, very little of the dyed sand reached the trench, and only 3% of the dyed sand was caught by the system. However, two alternative methods are available from which an estimate of the capture efficiency of the system may be obtained. One method is to compare the rate of sand cap-

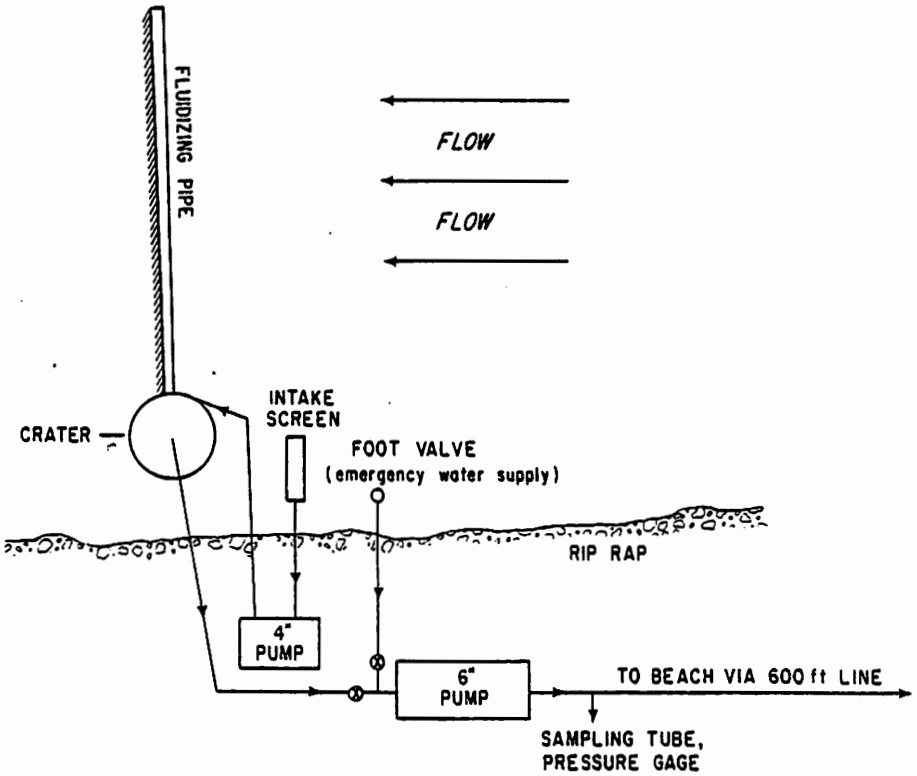


Figure 4. Schematic diagram of the crater-sink sand fluidization system used at Agua Hedionda Lagoon.

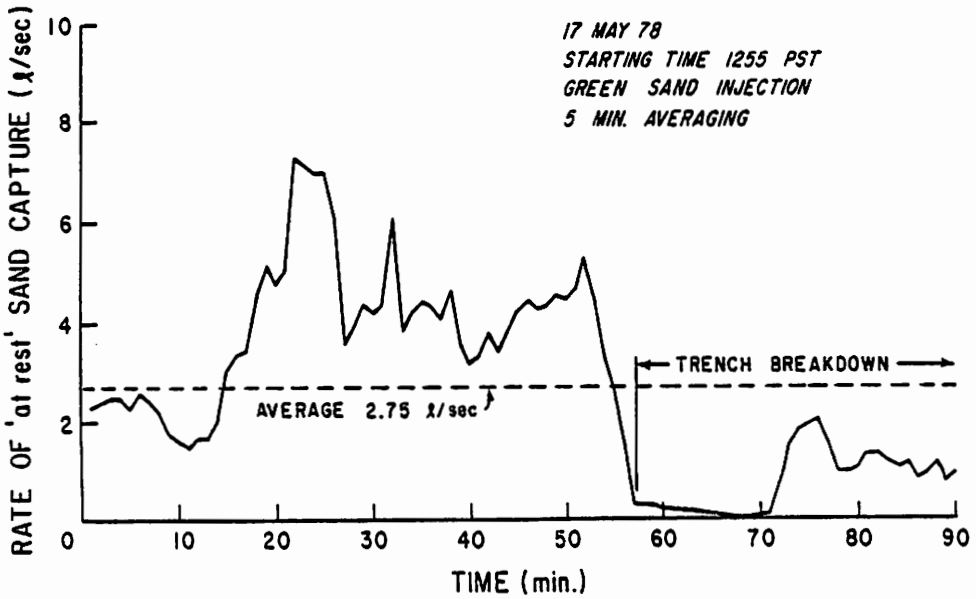


Figure 5. Rate of sand capture versus time for the crater-sink sand fluidization on 17 May 1978. The surface water velocity during the experiment was approximately a constant 1.3 m/sec.

ture with the average rate of sedimentation in the lagoon. If one assumes from the basis of the site survey that the lagoon acts as a perfect sediment trap (all sediment enters during flood tide and none leaves during ebb), and that the influx of sand is uniformly distributed across a width of 50 m, then the average rate during flood tides of sand passing by the 25 m long fluidizing trench is 3.6 liters/sec of "at rest" sand. Based on the figure, the capture efficiency of the system in terms of the percent of the average daily transport into the lagoon was 75% on 17 May and 86% on 18 May. It is doubtful, however, that these trapping efficiencies are realistic values, since the tidal range was larger than average during the two days of experiments.

Bagnold (1966) has shown that the sediment transport rate varies as the cube of the velocity. Since larger than average tidal variations induce larger than average water velocities in the channel, the sediment transport rate would also be larger than average. In fact, using the measured suface velocity of the water (130 cm/sec) in the Bagnold sediment transport model gives the sediment transport rate past the fluidizing pipe during both test periods as 6.2 liters/sec. Moreover, Bagnold's model predicts that approximately half of this would be bed load, and the rest suspended load. Therefore, the overall sand trapping efficiency of the system was probably about 50%, due to the high percentage of suspended sediment transport occurring at the test site. On the other hand, it appears that the system was approximately 100% efficient at trapping the sand being moved as bed load during the second day of tests when the trench hadn't "broken down." Presumably, had the system been situated further inside the lagoon where the flood current velocity is less and the relative fraction of bed load greater, then a larger portion of sand influx would have been intercepted.

In conclusion, the duct-flow fluidization process used in conjunction with the crater-sink concept has been found to be a potentially effective method for both re-opening closed lagoon inlets and for continuously maintaining open lagoon inlets. When used to re-open a closed lagoon inlet, the system is most effective when the sand through which the channel is cut is relatively free of cobbles. When the system is used to maintain an open lagoon inlet, it is most effective when used in relatively stable tidal lagoons which shoal gradually. Moreover, the system should be placed in a location where the sand influx is principally bed load, so as to maximize the sand trapping efficiency of the system. Further research is needed in a number of areas before a fluidizing technique can be routinely applied to coastal lagoon sedimentation problems. Areas for further research include: investigating the trench "breakdown" phenomena, quantifying the performance of an unburied fluidizing pipe at the base of an open trench, and developing a comprehensive site selection procedure.

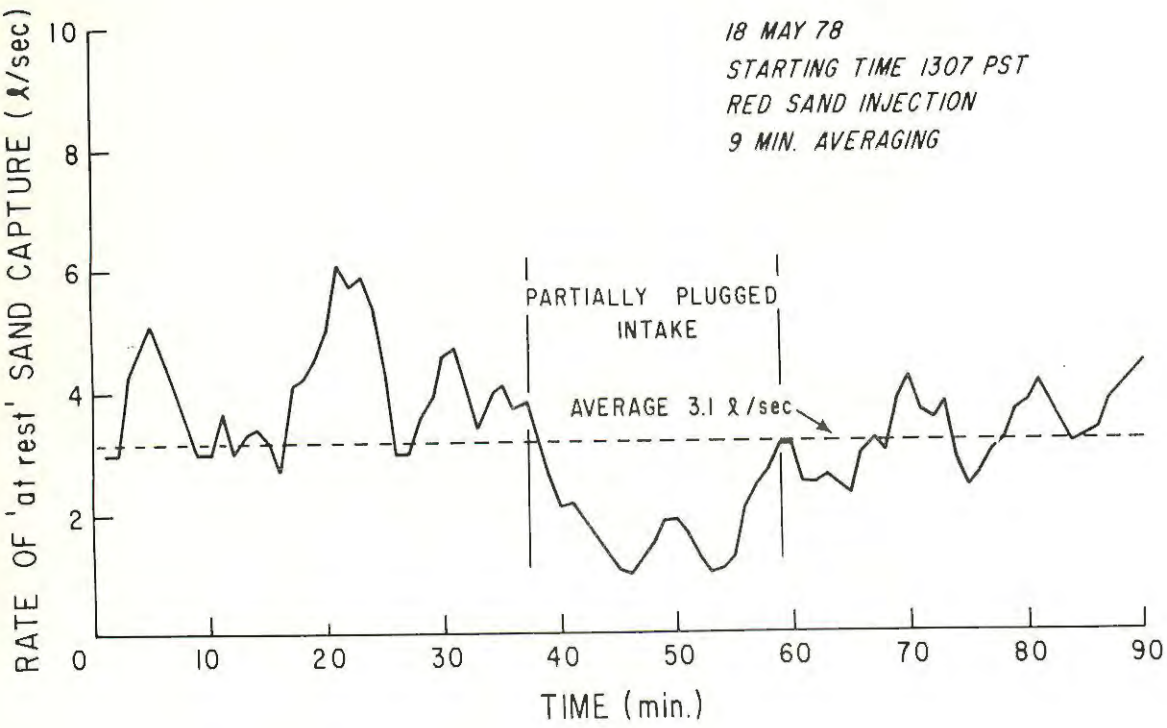


Figure 6. Rate of sand capture versus time for the crater-sink sand fluidization system on 18 May 1978. The surface water velocity during the experiment was approximately a constant 1.3 m/sec.

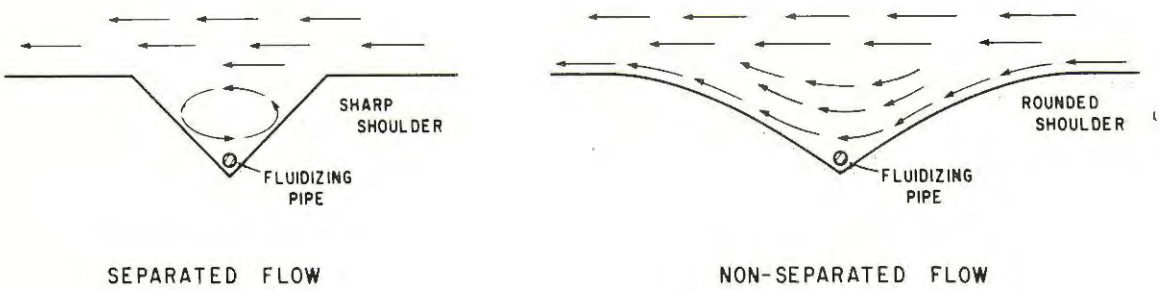


Figure 7. Schematic diagram showing cross-sectional view of the fluidizing trench. In normal operation, a sharp shoulder on the trench causes the flow to separate, resulting in a high efficiency of sand capture. If the water velocity becomes too great, the trench shoulder becomes rounded, allowing the flow to remain unseparated and resulting in a low efficiency of sand capture.

References

Bagnold, R. A. 1966. An approach to the sediment transport problem from general physics. *U. S. Geological Survey Professional Paper,* 422-J, 37 pp.

Bailard, J. A. and D. L. Inman. 1975. Analytic model of duct-flow fluidization. *Proc. Symp. on Modeling Techniques,* ASCE, San Francisco, California, September 3-5.

Harris, R. W., D. L. Inman, J. A. Bailard and R. L. Oda. 1976. Study and evaluation of remedial sand bypassing procedures. Contract Report H-76-1, U. S. Army Engineers Waterways Experiment Station, Corps of Engineers, Vicksburg, Miss.

Inman, D. L., G. C. Ewing and J. B. Corliss. 1966. Coastal sand dunes of Guerrero Negro, Baja California, Mexico. *Geol. Soc. Amer. Bull.* 77 (8): 787-802.

Inman, D. L. and R. W. Harris. 1970. Crater-sink sand transfer system. *Proc. 12th Coastal Engineering Conf.,* Amer. Soc. Civil Eng., New York, 2: 919-933.

Publications

Bailard, J. A. 1978. An experimental study of granular-fluid flow. Ph.D. thesis, University of California, San Diego.

Inman, D. L. and C. E. Nordstrom. 1977. Opening of coastal lagoons by sand fluidization. *University of California Sea Grant Annual Report, 1976-77:* 35-39.

Cooperating Organizations

San Diego Gas and Electric Company, Encina Power Plant

Development of Interpretive Methods and Materials for Marine Parks in Northern California

John D. DeMartini, *Humboldt State University*

In northern California, the California Department of Parks and Recreation has established two State Underwater Parks -- one at Salt Point near Ft. Ross, Sonoma County, and the other adjacent to the town of Mendocino, Mendocino County. The project leader, with the aid of Craig Seltenrich, a graduate student in the Department of Natural Resources Interpretation and Planning at Humboldt State University, is working with Dr. W. J. Barry, Mr. Burgess Heacox and Randolph Kelly of the California Department of Parks and Recreation to develop interpretive materials and resource management plans for the two parks.

Resource inventorying and description of intertidal and subtidal biotic assemblages

Extensive surveying of the biotas' intertidal and subtidal habitats was performed during the summer of 1977. Surveying of the intertidal and subtidal biotas was completed during the summer of 1978. Macrohabitats vary from sand to bedrock. Numerous microhabitats occur, especially in rocky areas, accomodating high species diversity. The biotic assemblages of the two parks are representative of the Sonoma and Mendocino County coasts. A description of both intertidal and subtidal habitats and their respective biotas is being prepared.

An access survey of the marine parks has been completed which defines major human impact areas for future development and control.

Development of interpretive materials

Themes of various aspects of the biotas of the two parks are in development and some have been produced (i.e., abalone biology, feeding strategies and intertidal organisms). Themes utilize 35mm transparencies produced during the summers of 1977 and 1978. The themes are constructed for interpreting an aspect of marine biology to all park visitors and are planned for 20-minute presentations.

Ranger-naturalist workshops

The second workshop was given during September at Asilomar State Park, Pacific Grove, and was attended by departmental ranger-naturalists and interpretive specialists, plus a ranger from Channel Islands National Monument. Workshop instructors included members of the Advisory Board on Underwater Parks and Reserves (Jill Fairchild, Robert Given, Daniel Gotshall, Wheeler North, James Stewart and Richard McKillop, Interpretive Specialist, California Department of Parks and Recreation). The workshop lasted four days and proved a success. It included diving, snorkeling, intertidal activities and presentations using the photographs taken during the summers of 1977 and 1978.

Geological and Historical Analysis of Coastal Zone Environmental Hazards

Francis P. Shepard and Gerald Kuhn
Scripps Institution of Oceanography, University of California, San Diego

The beaches, bluffs, and estuarine environments of California - and specifically San Diego County - are undergoing extreme developmental pressures. These areas are attractive from many points of view, but the basic background information available on which to make valid decisions pertaining to land use and resource management is very limited, particularly with regard to environmental hazards of a geological nature.

Progress to date

Overall project objective. We are demonstrating the methodology of collecting and preparing geological information essential to resource planning and management decisions. This involves compilation and use of many existing public records (plat maps, old land surveys, tax assessor records, aerial photographs, and Environmental Impact Statements and Reports for major projects). Our information has been augmented by interviews with long-term residents, information derived from newspaper files and collections of old photographs, together with data gathered from scientific literature. This base-line information will guide detailed field investigation and mapping.

Progress toward overall objective. During the first twelve months of this project, an information data base was acquired, researched, and organized on important meterological events (floods, storms and earthquakes) that may have had a marked influence on the coast in past years.

The coastal zone west of Highway 101 from south of Carlsbad to the southern boundary of Camp Pendelton (north of Oceanside) was mapped on photogrammetric maps of 1"=200' scale, and comprehensive geological data relevant to land use is being compiled. This involves several aspects which are listed below.

1. The adverse erosive effects of the storms of 1978 were documented, defined and mapped. This was a winter of exceptional storm activity with concomitant dramatic erosion effects.

2. Information on past meterological events (floods and storms) that have had a marked influence on the coast, have been sought, documented and organized.

3. Historical evidence (especially old land surveys and plat maps) showing the shoreline features and development has been collected. These have been compared with each other and with modern maps to document stability or change.

4. Tax assessment records of shoreline parcels are being researched for information as to diminished land area or elimination of parcels from the tax rolls as a result of inundation.

5. Newspaper files are being inspected for accounts of the effects of natural events such as storms at sea, heavy rains, and earthquakes.

6. Long-time residents of coastal areas are being interviewed to obtain observers' accounts of catastrophic changes.

7. Collections of historical photographs and memoirs are being searched for documentation of changes.

8. All faults, joints, fractures, and sea caves were mapped that are likely to aggravate sea-cliff erosion in the form of landslides, slumps, and sloughing of the bluff-forming sands.

Figure 1A

Figure 1B

Figure 1C

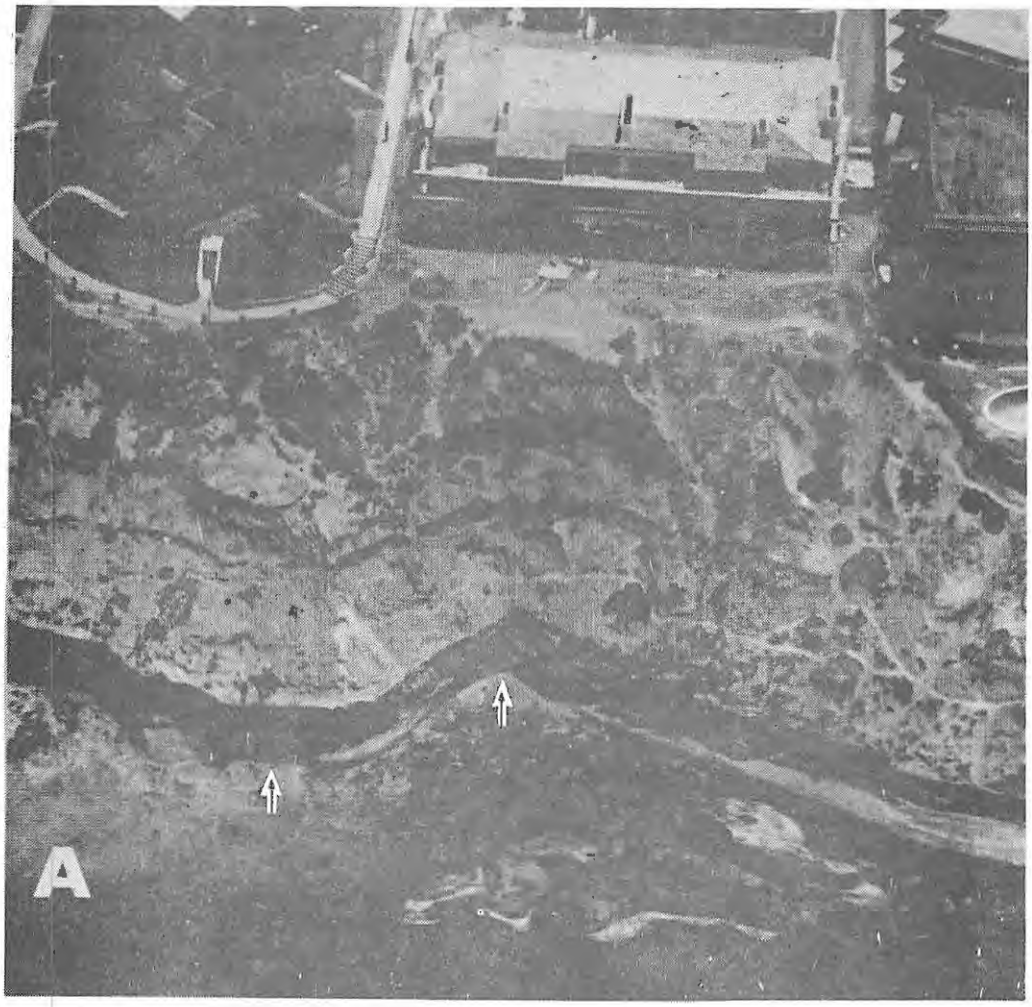


Figure 2A

Figure 1A. Erosion at a residence on the beach at Carlsbad, California. Note: Wave action and high tides have undercut the existing stair access and slope toe. *Photo: Sea Grant, January 21,1978.*

Figure 1B. The stair access, front porch and lawn were removed during the storms of January through March, 1978. Note: Excavation for a concrete seawall had begun at the time of this photo. *Photo: Sea Grant, April 4, 1978.*

Figure 1C. Erosion at this site has ceased temporarily due to the installation of a concrete seawall, the return of a protective summer beach berm and less active wave action. *Photo: Sea Grant, May 30,1978.*

Figure 2A. Recent development along the bluff top at Solana Beach, California. Note: Arrows indicate location of sea caves prior to sea cave roof collapse. *Photo: B and A Engineering, Del Mar, June 1974.*

Figure 2B. Sea cliff erosion at Solana Beach, California often occurs as the result of the collapse of a sea roof. Note: Following sea cave roof collapse, the overlying terrace sands fall to beach below. *Photo: G. Kuhn, November 5, 1976.*

Figure 2C. An adjacent sea cave roof collapsed in February 1977. Note: Wave action and high tides were removing beach sand and slope debris at the time this photo was taken. *Photo: Sea Grant, March 10, 1977.*

Figure 2D. The same sea caves at Solana Beach, California. These caves increased in size along zones of weakness in the sea cliff very rapidly during and following storms of February through April, 1978. *Photo: Sea Grant, July 10, 1978.*

Figure 2B

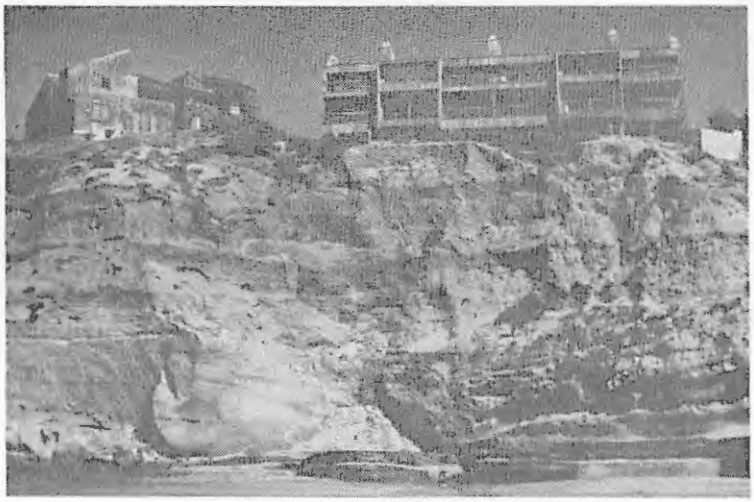


Figure 2C

Figure 2D

9. The performance of existing shore protection works is being evaluated.

10. The coastline is being mapped to the inland boundary set by the California Coastal Act of 1976 on 1:24,000 scale. This scale will show the regional geology including stratigraphy and structure and will supplement the 1:2,400 scale maps. All pertinent previous geological studies are being incorporated into this phase of study.

11. The general properties of the soils and rock units are being determined, particularly those types that are especially susceptible to erosion under natural, undisturbed conditions.

12. Photogeological examination and interpretation of aerial photography from earliest available photos to the present will be compared along with recently available Landsat, infrared and/or near-infrared photography. This will aid in defining regional topographic lineations and alignments related to faulting and folding.

13. We are attempting to identify areas subject to slope-stability problems. An example of the impact of recent urbanization upon coastal lagoons is given below.

Numerous coastal sites, which had reported virtually little or no erosion in recent years prior to the winter of 1978, experienced very rapid shoreline retreat during and following the storms of January through April, 1978. Other sites that have been actively retreating in past years also showed a rapid increase in erosion in this short period of time. Examples are given below.

Along the beach at Carlsbad, California, unprotected lots and buildings exist between protected structures. Figure 1A shows a site in January, 1978, where the slope under the beach stair access was being cut back. Following the storms in February, the stair access and lawn were destroyed and the porch collapsed (Fig. 1B). During the first week in April, 1978, excavation for a seawall foundation had begun (Fig. 1B). By July, the seawall had been constructed and the summer beach berm had returned (Fig. 1C).

Sea-cave development and collapse presents problems where buildings have been located too close to the bluff-top edge (Fig. 2A). Following the collapse of a sea-cave roof, the overlying sands will also fall to the beach below (Fig. 2B). During a period of rapid beach-sand removal in March, 1977, the base of this same cliff was actively eroded and another sea-cave collapsed (Fig. 2C). During the winter of 1978, the remnant sea-cave shear zone widened and a larger sea cave was the result (Fig. 2D).

Sea-cliff retreat often occurs as episodic, catastrophic, and site-specific events. An example of this last is a site that has had a history of land-sliding dating back to 1941. The Self-Realization Fellowship Temple, built in 1939 (Fig. 3A), collapsed following the storms, heavy rainfall, and runoff of 1941 (Fig. 3B). At this same location in 1978 (Fig. 4A) the cliff face collapsed 12 to 16 feet landward, 110 feet in length and 42 feet vertically (Fig. 4B).

Prior to development, siltation and sedimentation affected the lagoons, primarily during years of extremely heavy rainfall. Figure 5A shows a newly graded site where storm drains were being installed. By 1975 a recently incised channel and well-developed alluvial fan was clearly visible (Fig. 5B). A photo taken in April 1978 shows that this particular fan has moved farther downslope covering existing vegetation. Surface runoff, concentrated sheetflow and water exiting storm drains flows along inherent weaknesses such as trails, roads, or pipeline down through the canyons and slope face, cutting downward through slope wash and contributing to the siltation and sedimentation around San Diego County lagoons.

The results of this project as they develop are being made available to the city planners of Carlsbad and Oceanside, and to the San Diego County Integrated Planning Organization. Since September, 1977, the following corporations have acquired and utilized information gathered by this study:

Figure 3A. Looking Northwest at the Self Realization Temple in Encinitas, California. The Temple was one of four buildings along these cliffs in 1939, was 4 stories high, and appeared to have an adequate bluff-top setback at that time. *Photo: Self Realization Fellowship, Encinitas, 1939.*

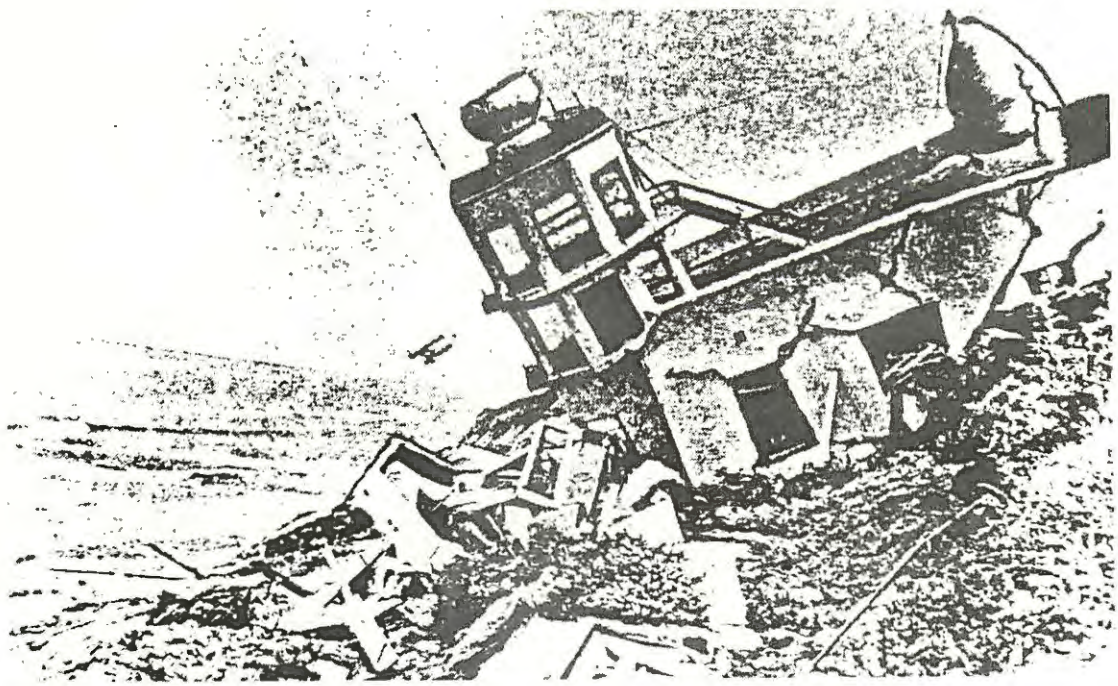


Figure 3B. The Self Realization Temple collapsed following the period of severe storms, large 30 foot swells, and heavy sediment saturation of 1940-41 period. *Photo: Self Realization Fellowship, Encinitas, 1941.*

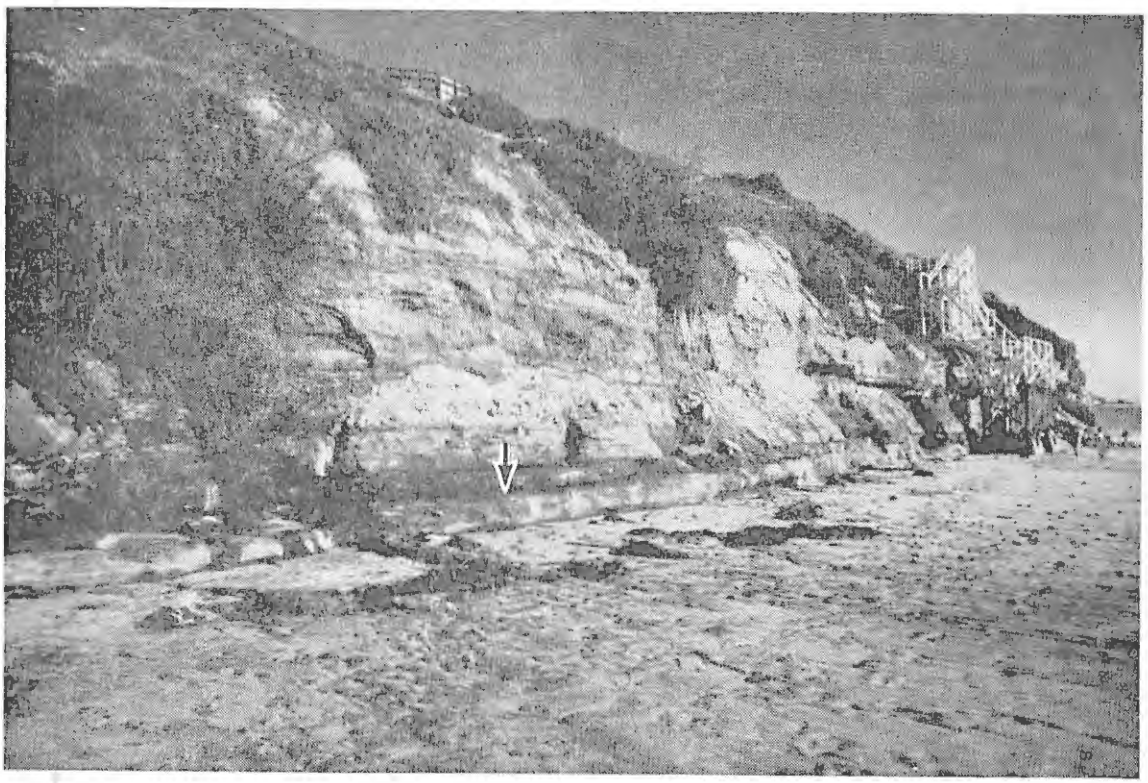


Figure 4A

Figure 4B

San Diego County Integrated Planning Organization, Sanitation and Flood Control, Tax Assessors Office, and Land-use and Environmental Regulations; the Atchison, Topeka, and Santa Fe Railroad; City of Del Mar; City of Carlsbad; City of Laguna Beach; State and Regional Coastal Commission; and the State Lands Division, and numerous leading institutions and engineering geology firms, including C. W. LaMonte, Leighton and Associates, Stickel and Associates, and Woodward-Clyde consultants. Also, local coastal programs are utilizing maps and information derived from this project.

Publications

Kuhn, Gerald G. 1977. Coastal zone ecology and related sea cliff erosion, San Dieguito River to San Elijo Lagoon, San Diego County, California. San Diego Integrated Planning Office Contract #11596-0800E.

Kuhn, Gerald G. and F. P. Shepard. 1979. Accelerated beach cliff erosion related to unusual storms in Southern California. *California Geology* 32(3): 58-59.

Cooperating Organizations

California Coastal Zone Commission, San Diego Region

County of San Diego

U.S. Navy, Naval Air Station, Photographic Reconnaissance Section, Miramar, California

California State Lands Commission

Figure 4A. THe sea cliff along the Self Realization Fellowship property, Encinitas, California. Note: Arrow points to area where excessive spring sapping of cliff face was seen to occur in February, 1978. *Photo: Sea Grant, February 3, 1978.*

Figure 4B. Looking from the same position along the sea cliff at the Self Realization Fellowship property following the cliff collapse of April 26, 1978. The cliff failure measured 110 feet in length along the beach, 12 to 16 feet landward and a maximum of 42 feet vertically. Following the storms of January through April 1978, the cliff face, already lubricated by year round ground water spring sapping, separated along parallel joint sets and fractures and collapsed. *Photo: Sea Grant, May 2, 1978.*

Figure 5A. Looking south along recently graded hilltop overlooking a coastal lagoon. *Photo: Sanitation and Flood Control, County of San Diego, 1972.*

Figure 5B. This is the same hilltop now occupied by a recently completed subdivision. Surface runoff concentrating on the upper slopes, was diverted into storm drains which move the water downslope. As the water moves down to the lagoon, large channels are cut through existing slope wash, depositing alluvial fan debris in the lagoon and tidal flats. *Photo: SIO-OLR, 1975.*

Figure 5C. This alluvial fan continued to grow during the wet winter of 1978. *Photo: SIO-OLR; April 1978.*

Figure 5A

Figure 5B

Figure 5C

Geological and Historical Analysis of Coastal Zone Environmental Hazards and Liability for Losses Caused by Them

Richard G. Hildreth, *University of San Diego, School of Law*

Concurrent work in two disciplinary areas, geology and law, identified coastal zone environmental hazards and the legal principles applicable to both losses caused by such hazards and governmental responses to the identified hazards. The project leader and Sea Grant trainee participated in field trips conducted by the geological researchers to coastal bluff problem areas in north San Diego County and consulted with attorneys, developers, and the planning staff of Oceanside, Carlsbad, San Diego County, the California Coastal Commission, and the Oregon Department of Land Conservation and Development.

A project report was completed dealing with:

1. private and public tort liability with respect to coastal natural hazards;
2. the role of insurance in coastal natural hazards management;
3. existing and proposed regulatory responses to coastal natural hazards;
4. the constitutionality of existing and proposed regulatory responses; and
5. legal issues surrounding the use of shoreline protective devices.

A portion of the project results have been published by the trainee (Somerville, 1978).

Some principle findings of the project are:

1 The doctrine of sovereign immunity can no longer be relied upon to immunize government from liability for the consequences of regulatory actions in coastal hazard areas.

2 The private liability rules and liability insurance coverages from development losses suffered in hazardous coastal areas contribute to mismanagement of coastal natural hazards.

3 The courts will support regulatory solutions to coastal natural hazard problems which are based on adequate (not necessarily exhaustive) scientific investigation.

With respect to finding (3), a major question is how the costs of scientific investigation of hazardous conditions should be allocated among private developers and public agencies. With respect to geologic hazards, one approach is to require applicants for development permits to provide a geologic report. To utilize this approach, regulatory agencies must attempt to assure report accuracy through criteria for adequate reports and independent report review.

The courts generally hold that landowners are not entitled to compensation for development prohibitions based on adequate scientific information. However, compensatory land use control techniques may be used to reduce the hardship to individual property owners.

Publications

Somerville, M. M. 1978. Government Tort Liability, *The Urban Lawyer* 10: 376-395.

Cooperating Organizations

California Coastal Commission

Oregon Department of Land Conservation and Development

Oregon Soil and Water Conservation Services

Cities of Carlsbad and Oceanside, San Diego County, California

Kelp Bed Mariculture and Resource Management

M. Neushul and David Coon
University of California, Santa Barbara

The objective of this project has been to learn how to cultivate and manage California marine plant resources, particularly the giant kelp, *Macrocystis*. We have been successful, during the final year of this project in developing new propagation techniques. In the laboratory, we have been able, for the first time, to repeatedly mass produce genetically uniform kelp, by inducing fertility in fragments of gametophytic plants grown from single spores. With this technique, we have also produced two crops of intergeneric hybrid kelp plants that have been outplanted in the sea. Kelp plants were also produced from wild spore populations (seven culture sets). Sporophyte plants were produced from gametophyte cultures held in storage for up to two years. The results of the work on hybrids have been published in a paper by Sanbonsuga and Neushul, 1978.

Kelp plants were cultured from the dish culture size to large size and ultimately to reproductive maturity in our seawater greenhouse, which has also enabled us to bring outplanted plants back from the sea for short periods for observation. Plants were grown in the sea within and adjacent to the large natural kelp bed just off the UCSB campus. A variety of substrate structures and materials was used in outplanting experiments, including cremona string (used extensively in Japanese *Porphyra* culture), plastic rope, plastic floats, plastic pipe, plastic mesh, thin plastic tape and monofilament line (shown in Fig. 1). The cremona string and monofilament lines were the most effective. Our efforts to utilize the natural substrates of *Diopatra* tubes (a common initial anchoring point for juvenile plants in beds of our region) were successful, but while we were able to induce the animals to incorporate juvenile *Macrocystis* into their tube structure, we were unable to prevent them from grazing on the plants.

Over 300 small *Macrocystis* plants have been grown in the field up to 15 cm in size in a single outplanting. More than 100 plants have been grown and followed in the field from the 10 cm size to 4 to 5 meters in length, including 20 hybrid plants.

Ecophysiological studies linked our laboratory and field work. One of the most useful comes from studies of the nutrient requirements of *Macrocystis* by Sea Grant trainee William Wheeler. A section of his thesis abstract is reproduced here.

The availability of macronutrient, and nitrogen in particular, influences the growth of *Macrocystis* plants. The uptake of nitrate, but not ammonium or phosphate is influenced by irradiance. *Macrocystis* appears to take up both nitrate and ammonium simultaneously, but does not take up nitrite. All three uptake processes are affected by water speed, in much the same way as is inorganic carbon. The uptake of nitrate and ammonium appears to be controlled by Michaelis-Menten like processes; Vm for nitrate being 75 while ammonium's is 275 nmoles per square centimeter per hour. Km's are 13 and 90 μM respectively.

The importance of nitrogen levels for the growth and development of young *Macrocystis* sporophytes is evident in Figure 2, which shows the striking results obtained when slow release fertilizer is applied to populations of very young sporophytes in the sea.

The growth and development of large kelp plants and of growth in whole kelp beds was also studied. We were fortunate to be able to use the commercial harvest data of Stauffer Chemical Co. which we were able to convert to a "catch per unit effort" value, expressed as tons harvested per hour of harvester operation. This figure (see Fig. 5) illustrates seasonal variations in the extent of the harvestable kelp canopy. We have combined this data with our measurements of light and nutrient (nitrogen) levels to give a picture of the relationships involved

Figure 1. *Macrocystis* sporophyte plants grown in the sea, obtained from controlled genetic crossing of gametophyte lab cultures.

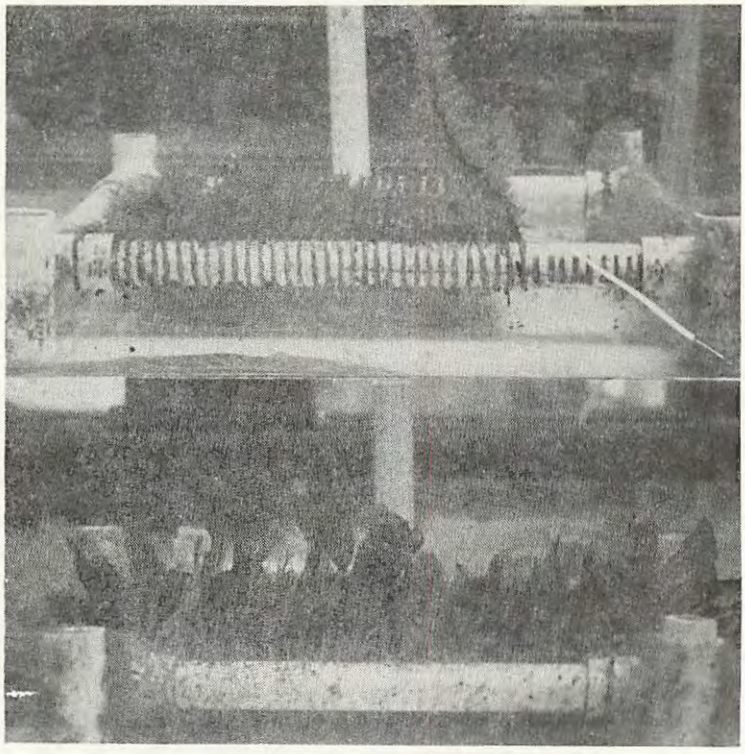


Figure 2. In-the-sea fertilization effects. Above, juvenile sporophytes without nutrient addition. Below, juvenile sporophytes with fertilization. Both groups started from the same culture at the same time.

(Figs 3, 4, 5).

Much useful data was developed in a thesis by Sea Grant trainee Bruce Harger which dealt in large part with the seasonal physical climate in a kelp forest and biological changes on hard substrate within it. In general, harvest yield correlates with solar irradiance levels during the year. However, we would predict from our laboratory work and simple preliminary field experiments that changes in nutrient levels may alter this pattern. When the typical spring "pulse" of surface nitrogen was low and dropped rapidly in 1976, harvest yields fell throughout the remainder of that season. Studies of the growth of entire plants in the fields have shown that the growth rate remains (for a total plant) relatively constant seasonally. However, the biomass in the plants changes, with spring fronds having more weight per unit length than late summer-early fall fronds.

Because of the importance of nutrients to kelp growth and yield, our measurements of local nutrient levels have been used by kelp harvesting companies in southern California. The seasonal change in kelp canopy has also been studied with aerial photographs of the bed adjacent to UCSB. In this bed we have just completed a long term study on harvesting effects. With the cooperation of Stauffer Chemical Co., a specific area was left unharvested for over four years. We maintained sampling transects in this area, and this year completed the final benthic sampling in the harvested and unharvested areas for analysis, and comparison with the aerial records and the seasonal yield data.

During this past year, our work on the biology of edible seaweed, *Porphyra,* was completed. Its feasibility as a marine crop plant was investigated by Sea Grant trainee James Woessner, who completed his M.A. thesis on this research. In other work on red algae of economic significance, we have investigated the propagation of the tropical plant *Eucheuma* as a source of carrageenan. After special permission was obtained, plants were collected in Mexican coastal waters and grown in the lab and the sea (with California Department of Fish and Game approval). Growth rates were recorded for various light, temperature, and nutrient conditions. These warm water plants (23-29° C) seem to do well in the colder temperatures of the Santa Barbara region (10-19° C), growing at temperatures in the 14-16° range. However, rates which were initially as high as 10% per day for the first several months after transplanting have now dropped in winter to 1-2% per day. As with our investigations of *Macrocystis,* we also examined nutrient relations in this plant and conditions controlling reproduction. We have been able to hold young gametophyte stocks of *Eucheuma* in the lab for over a year in our "seed stock" cultures. During a recent visit here, by a delegation from Ensenada, considerable interest was expressed in using our work on *Eucheuma* as a basis for farming this valuable plant in Mexico.

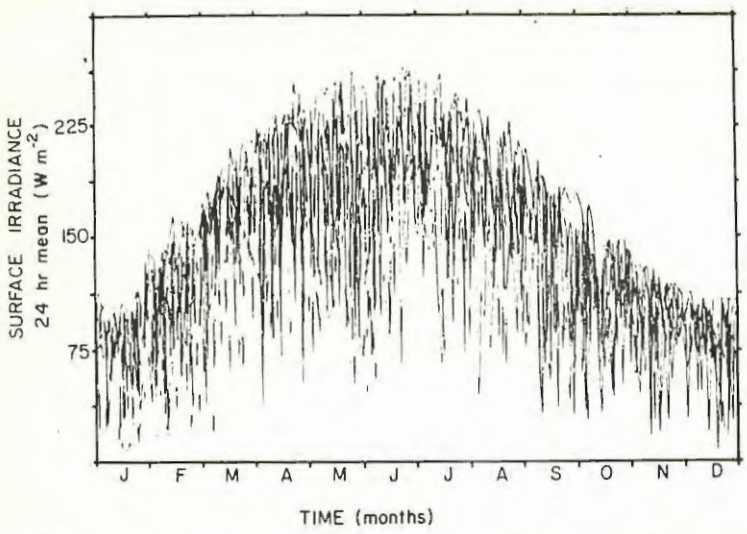


Figure 3. Surface irradiance measures at UCSB. A ten year cumulative pattern is shown.

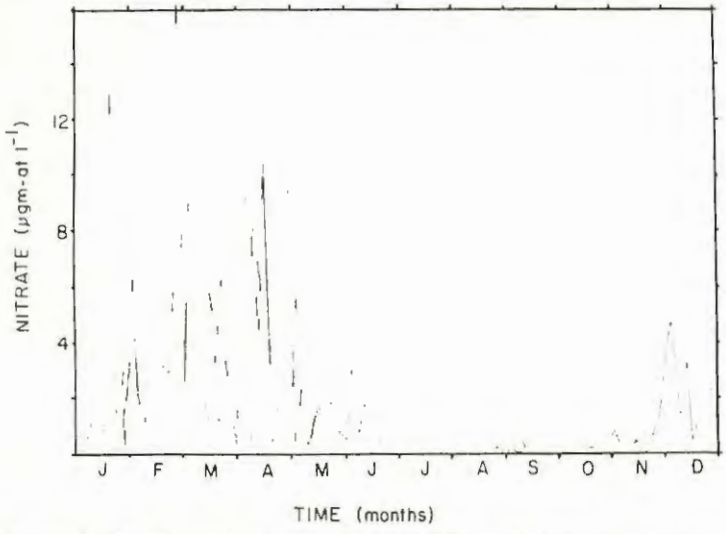


Figure 4. Surface nitrate levels off Goleta, California. A four year summary is shown.

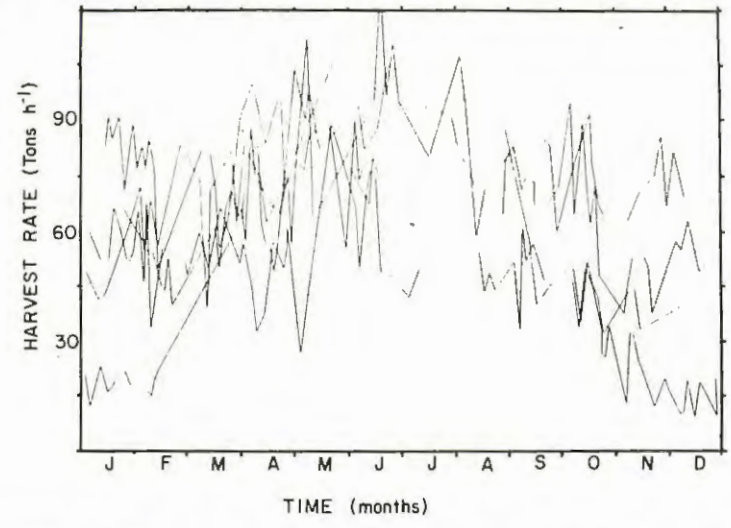


Figure 5. Harvest yield in wet tons of kelp per hour. Summary from four kelp beds from 1973-1977.

Publications

Charters, A. C. and M. Neushul. *In press.* A hydrodynamically defined culture system for benthic seaweeds. *Aquatic Botany.*

Neushul, M. *In press.* The propagation, cultivation, and harvest of the giant kelp, *Macrocystis. Proc. of the Seminar on Cultivation and Utilization of Economic Algae.*

Neushul, M. 1978. The domestication of giant kelp, *Macrocystis,* as a marine plant biomass producer. *In: The Marine Plant Biomass of the Pacific Northwest Coast,* R. Krauss, ed. p. 163-181. Corvallis: Oregon State University Press.

Okuda, T. and M. Neushul. Unpublished. Studies of red algae spores, with microvideo techniques. Submitted to *American Journal of Botany.*

Sanbonsuga, Y. and M. Neushul. *In press.* Hybridization and genetics of brown algae. *Handbook of Psychological Methods, Volume II,* Cambridge University Press.

Wheeler, W. N. Unpublished. Photosynthetic adaptations of the giant kelp, *Macrocystis.*

Wheeler, W. N. Unpublished. Nitrogen physiology and ecology of the giant kelp, *Macrocystis.*

Wheeler, W. N. Unpublished. Mass transport and carbon fixation in the giant kelp, *Macrocystis.*

Wheeler, W. N., M. Neushul and J. W. Woessner. *In press.* Marine agriculture -- progress and problems. *Proc. of Pathology of Marine Algae: Current Status and Future Prospects.*

Cooperating Organizations

Stauffer Chemical Company

Kelp Forest Ecology of the Central California Coast

John S. Pearse and Anson H. Hines
University of California, Santa Cruz

The kelp forest off the Hopkins Marine Life Refuge, Pacific Grove, California, was studied by measuring standing crops, population dynamics, and trophic interactions of major primary producers, herbivores and carnivores. Giant kelp plants are the major producers in the forest and form the main forest structure. Physical disturbance by storms is the main factor limiting kelp production. About 23 kg wet weight of kelp are produced in each square meter per year. Less than 5% of this production is consumed directly by grazers, but 20-30% is consumed by benthic herbivores feeding on unattached kelp litter. Undetermined additional amounts are consumed by suspension feeders, but most of the kelp production is exported out of the forest to other communities. Sea stars are conspicuous predators on turban and vermetid snails, but they have only a minor regulatory role on their prey. In contrast, sea otters exert a major regulatory impact on some of their prey items, particularly kelp crabs and abalones. The habitats, sizes, and densities of abalones are all limited by sea otter predation, and the abalone population probably turns over every two to three years, or less. These studies indicate that storms and a relatively few number of species regulate the major ecological interactions that maintain kelp forests as rich ecosystems.

In our overall goal of understanding "how a kelp forest works," we determined the principle pathways of energy and material flow in one central California kelp forest. The species that have dominant roles in the ecological interactions of the system were investigated by measuring seasonal and annual changes in their standing crops, population dynamics, and trophic interactions. These species included the major primary producers, herbivores, suspension feeders and carnivores in the kelp forest community. They could have primary roles in regulating the productivity and ecology of the kelp forest ecosystems.

Our study focused on a small kelp forest in 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 populations. During the third year of our three-year project we continued quantification of the seasonal and annual changes of the major primary producers and herbivores in the forest. In addition, rates of feeding, growth and reproduction were determined for the five species of grazing spider crabs in the forest. The major focus for the final year, however, was on certain predators (sea stars and sea otters) which might regulate herbivore populations, and on the major sessile animals (vermetid snails, corals) which dominate substrate space.

Production by the giant kelp plants *(Macrocystis pyrifera)* was estimated to be about 23 kg wet weight (2.2 kg dry weight) per square meter per year during an initial 18-month investigation by former trainee Val Gerard. During the past five years the giant kelp canopy surface area, plant density, and plant size fluctuated seasonally, increasing in the summer and decreasing in the fall and winter as storms thinned out the forest. Differences in storm frequencies and intensities resulted in different annual patterns of change in the forest. Storms tore out most of the plants in the forest in only one year (1974), and this event was followed by heavy juvenile recruitment the following spring. Effects of grazing appeared to be minor, although unusually high densities of turban snails may have been partly responsible for the failure of full canopy development in one year (1976). Overall, the population of giant kelp plants has remained remarkably stable, while the turnover of individual plants is probably quite high. The population of pea kelp plants *(Cystoseira osmundacea)*, the major understory plant, and of the ground cover foliose red algae also have remained very stable.

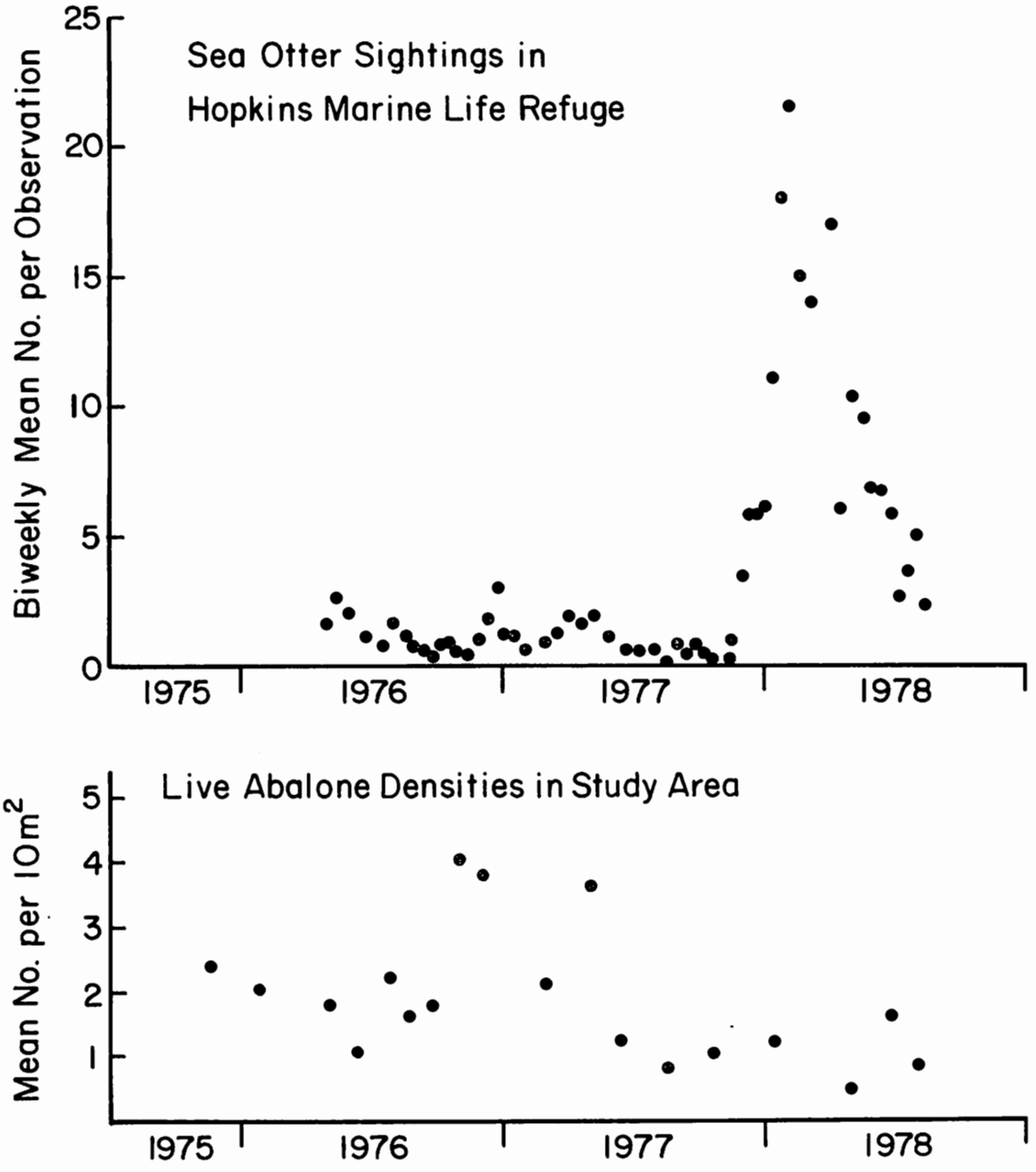


Figure 1. Densities of sea otters and abalones in the study area of the Hopkins Marine Life Refuge, Pacific Grove, California. The establishment of a female sea otter rafting area resulted in an increase in numbers of sea otters sighted in early 1978.

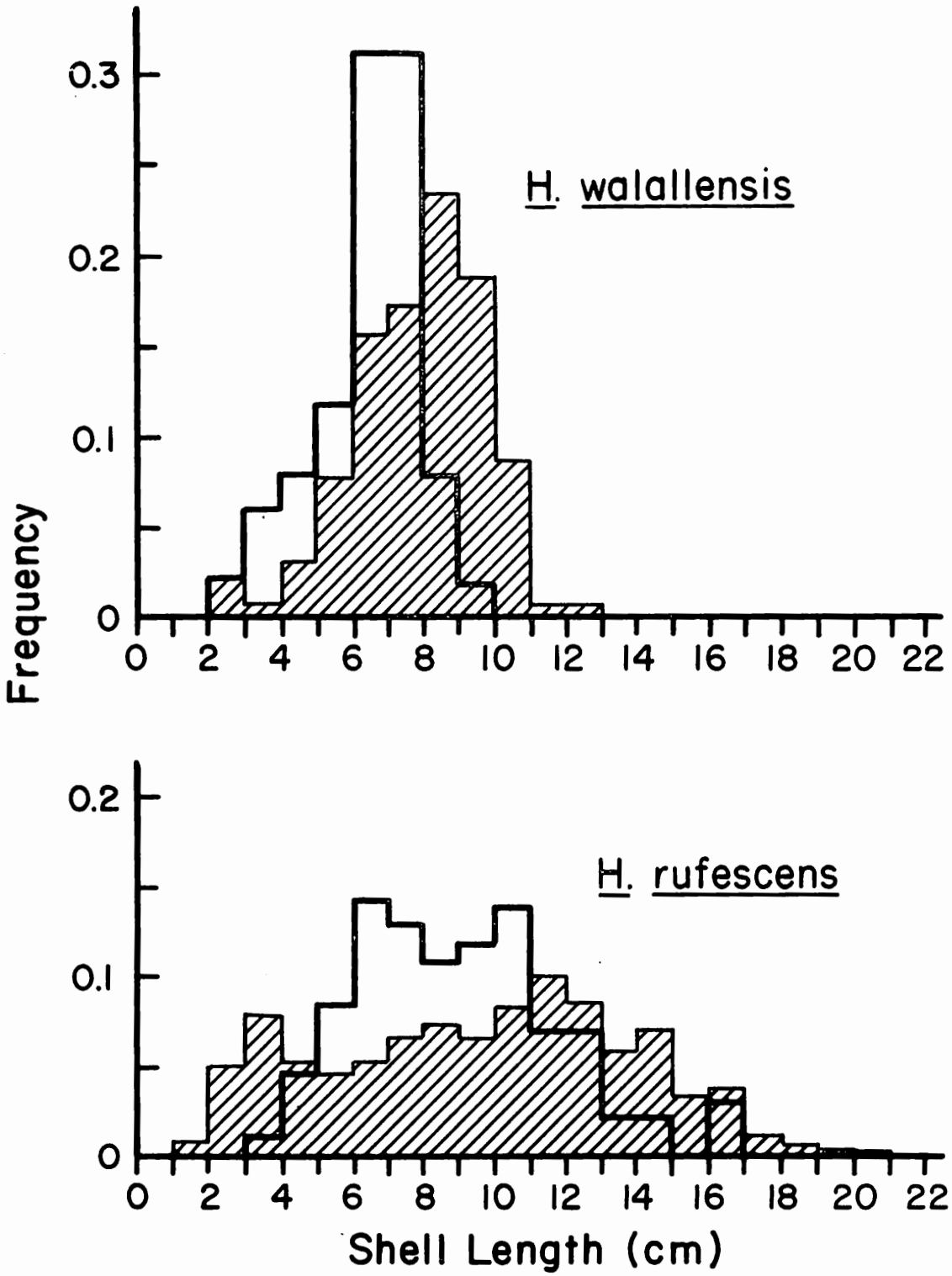


Figure 2. Size frequency distribution of live abalone (open) and fresh abalone shells (hatched) in the study area. Live abalone data collected in 1976 and taken from Cooper *et al.* (*Veliger* 20:163, 1977). Abalone shell data includes all fresh shells collected between November 1977 and July 1978 (see Fig. 3).

Populations of some of the major herbivores in the forest also remained very stable during this study, particularly those of batstars *(Patiria miniata)* and abalones *(Haliotis rufescens* and *H. walallensis).* Spider crab populations *(Pugettia producta, P. richii, Mimulus foliatus, Loxorhynchus crispatus* and *Scyra acutifrons)* all showed repeated seasonal oscillations, while those of turban snails *(Tegula pulligo, T. montereyi* and *T. brunnea),* and sea urchins *(Strongylocentrotus purpuratus)* were more variable. Unusually high recruitment of snails and sea urchins occurred in the fall of 1975, but the densities of these species dropped during the following year and then remained relatively constant.

One species of spider crab *(Pugettia producta)* and all three species of turban snails were major grazers on attached giant kelp plants, and they directly consumed up to about 4% of the kelp produced. Most of the kelp produced was lost as litter (drift) broken from the plants by water movement (a process probably enhanced by direct grazing). Herbivores on the forest floor (batstars, abalones, spider crabs, turban snails, sea urchins) fed on this litter and consumed 20-30% of the kelp produced, thereby maintaining some of this resource within the food web of the forest. Suspension feeders such as vermetid snails (mainly *Petaloconchus montereyensis),* which at mean densities of over 6000 individuals per square meter are major space occupants, also consumed an undetermined amount of the kelp produced, in the form of small particulate material. Most of the kelp produced, however, was carried out of the forest by water movement to provide a food base for surrounding communities.

Solitary corals *(Astrangia lajollaensis, Balanophyllia elegans* and *Paracyathus stearnsii)* and a corallimorph anemone *(Corynactis californica)* are conspicuous sessile predators which perhaps influence larger animals by occupying space and feeding on larvae. Ongoing studies by trainee Yusef Fadlallah show that these species have very different life-history strategies. *A. lajollaensis* and *C. californica* reproduce mainly by asexual fission, and colonies of these animals dominate large areas of rocky surfaces; the former species covers the bases of most vertical rock faces while the latter cloaks the tops of many rock outcrops. The other two species only reproduce sexually. *B. elegans* broods its embryos to relatively late stages, and individuals are found scattered nearly at random throughout the forest floor. *P. stearnsii* apparently spawns freely into the sea and its larvae are presumably dispersed widely. Individuals of this species are both the largest and least common corals in central California kelp forests.

Predatory sea stars, particularly *Pisaster giganteus,* also are conspicuous and would appear to have a major impact on their prey species. Because their major prey species are vermetid snails, the main space occupants, and turban snails, the most important grazers, sea stars might be expected to have a profound impact on the whole kelp forest ecosystem. Ongoing studies by trainee Christopher Harrold, however, indicate that predation by sea stars probably has only a minor impact on their prey populations. The sea star densities during the past four years have remained stable at about one per ten square meters. Over half the animals are inactive and remain cryptic within crevices at any one time, and long-period observations suggest that individuals remain inactive for several days at a time. Of those animals feeding, about one third are feeding on vermetid snails while another tenth are feeding on turban snails. Calculations indicate that only about 2% of the vermetid snail and perhaps 10% of the turban snail standing crops are consumed by sea stars each year. Physical disturbance, mainly during storms, probably is the major cause of mortality to these snails.

Sea otters *(Enhydra lutris),* like sea stars, are conspicuous predators which feed on a wide variety of prey, including major kelp forest herbivores. Our studies indicate that sea otter predation has a major impact on the population of spider crabs, especially *Pugettia producta,* and abalones, despite the stable densities seen with these species. Abalone densities, for example, have not changed significantly for the past four years (and these densities are the same as those estimated in 1972), despite the continual presence of sea otters and even a marked increase in early 1978 (Fig. 1). Almost all abalones in the study are cryptic within crev-

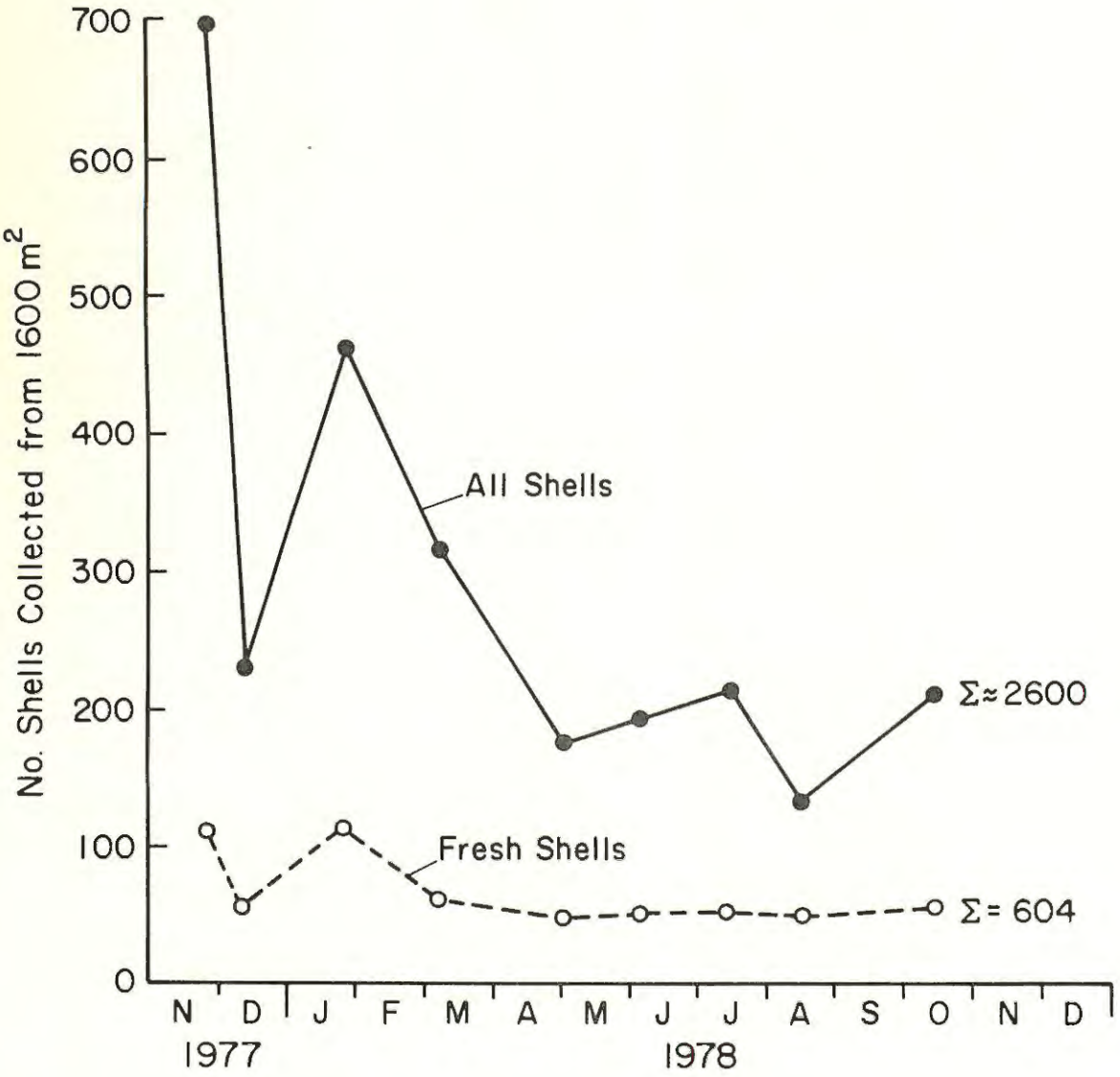


Figure 3. Number of abalone shells collected from study area. Old and deteriorated shells uncovered by shifting sands included in "all shells" category; most of the fresh shells bore characteristic breaks and chips indicative of sea otter predation.

ices, and the stable densities we estimated suggest that constant sea otter predation restricts the abalones to crevices. Comparison of the sizes of live abalones and fresh shells resulting mainly from sea otter predation shows that most of the shells are slightly larger than most of the live animals (Fig. 2). Moreover, collections during the past year of all the abalone shells within our study area (Fig. 3) yielded about 2600 shells, of which over 600 were freshly produced almost exclusively by sea otter predation (they bore characteristic chips). About 50 new shells were produced each month. However, the live abalone densities we estimated remained unchanged (Fig. 1) with about 350 animals in the area.

values indicate an annual turnover rate of abalones of nearly 200%, and it seems clear that we have under-estimated the population size of live abalones, perhaps by not finding many of the juveniles (e.g., Fig. 2). However, associated earlier studies by Dan Costa, using estimates of caloric requirements of sea otters and percentage feeding data from our area, indicated an annual turnover rate of the abalone population of over 30%. There can be little doubt that predation by sea otters has an enormous impact on all aspects of the population dynamics of abalones.

Publications

Pearse, J. S. and A. H. Hines. 1978. Expansion of a central California kelp forest following the mass mortality of sea urchins. *Marine Biology* 50, in press.

Hines, A. H. 1978. Paradoxical mortality rates of subtidal abalone in an area long-foraged by sea otters. Paper presented at 59th Annual Meeting of the Western Society of Naturalists, University of Puget Sound, Tacoma, Washington, December 27-30, 1978.

Cooperating Organizations

California Department of Fish and Game

Hopkins Marine Station, Stanford University

Thermal Variability in Coastal Waters in the Southern California Bight

Clinton D. Winant and Alan Bratkovich
Scripps Institution of Oceanography, University of California, San Diego

This project is a statistical study of the natural variability of the oceanic temperature field in the shallow coastal waters of the Southern California Bight. Specific objectives include: 1) the collection and preparation of data catalogs of sufficient length and spatial diversity to be useful in identifying temporal variability on a seasonal scale and on spatial scales comparable to the width of the continental shelf in this area, and 2) the identification of statistical quantities that would be useful in characterizing the behavior of the oceanic temperature field. This information can be utilized as input to large numerical modeling schemes for coastal environments and also as criteria for the evaluation of coastal sites for power plants or other large facilities that may impact coastal waters.

Project activities to date have focused upon the acquisition of over two hundred current and temperature records from our own instrument arrays on the continental shelf at the San Onofre Nuclear Generating Station (SONGS) and about 45 km south, adjacent to the city of Del Mar. These records have been supplemented by wind and atmospheric pressure data in addition to sea surface elevation data from tide stations located in the area. Selected portions of this data catalog have been prepared for further statistical analysis and to form the basis for more extensive investigation in the future.

Project efforts in the coming year will be oriented towards analysis and interpretation of the data sets with special emphasis placed upon the identification of statistical quantities that will be useful in coastal modeling and planning situations. Our final report will be user-oriented to provide coastal zone users with an understanding of the dominant natural processes that affect ocean thermal variability on the time and space scales relevant to their particular concerns.

Cooperating Organizations

California Coastal Zone Commission, Marine Review Committee

National Science Foundation

Internal Waves Over Shelf and Canyon

Charles S. Cox, *Scripps Institution of Oceanography, University of California, San Diego*

Work on this project primarily consisted of analysis of JOINT-I data set (near northwest Africa) in order to understand tidal motions and interactions over the sloping topography. The data consists of temperature, conductivity currents and pressures measured by sensors at evenly spaced intervals from surface to bottom on six moorings on the continental shelf off northwest Africa.

Decomposition of the data using empirical orthogonal eigenfunctions shows that in depths shallower than 800 m a significant part of the internal wave energy resides in first mode waves that propagate shoreward. Examination of the energy flux and energy density of these waves indicates that:

1. The origin of the internal wave energy appears to be the deep ocean.
2. The energy density of the internal waves increases shoreward in the deep coastal waters subject to a constant energy flux requirement.
3. The energy density in shallow coastal waters is nearly saturated, i.e. the maximum amplitudes are limited by a finite depth and thus the local energy levels are determined by the local Vaisala frequency and depth.
4. The energy flux is largely dissipated rather than reflected back out to the deep sea.

Publications

Gordon, R. Lee. 1978. Internal wave climate near the coast of northwest Africa during JOINT-I. *Deep-Sea Research* 25: 625-643.

Gordon, R. Lee. 1977. Internal wave climate near northwest Africa during JOINT-I. Paper presented at meeting of the American Geophysical Union, June 1977.

Gordon, R. Lee. 1976. Internal waves within submarine canyons. Paper presented at meeting of the American Geophysical Union, December 1976.

Coastal Governance 1977-78: First Steps in Implementing California's 1976 Legislation

Stanley Scott, *University of California, Berkeley*

The 1977-78 work was quite varied, comprising publication of two articles on California's coastal planning in the *Public Affairs Report* of the Institute of Government Studies, University of California, Berkeley; collaboration on a coastal workshop report (sponsored by Sea Grant) distributed by the Institute; preparation of two essay-book reviews and their acceptance for further publication in the *Coastal Zone Management Journal;* preparation of two draft manuscripts and their distribution to a limited readership for review and comment; preparation of a third manuscript for in-house editing and revision; conduct of a large number of interviews; analysis of interview transcripts and legislative files from 1976-77; and provision of advice and consultation to a substantial number of faculty members, researchers, students, policymakers and interested citizens, as well as official coastal monitors representing the State Department of Finance and the U.S. Office of Coastal Zone Management.

In the February, 1978 *Public Affairs Report,* Lenard Grote, a Pleasant Hill city councilman, former President of the Association of Bay Area Governments, and a member of a regional coastal commission, outlined his understanding of the way the California coastal planning experiment is working, and focused attention on some state-local conflicts that he sees as crucial. Basically Grote urges vigilance on the part of environmental groups for fear that development-oriented interests may get the upper hand when the local coastal programs (LCPs) are certified and the coast reverts largely to local control. Grote also urges that the state take a stronger role in funding the activities and programs required to implement certified LCPs and achieve the state's coastal goals. The report went to a regular readership of approximately 3,300 plus special mailings to local officials and coastal commission members. It received good attention in the press.

The June-August 1978 double issue of the *Public Affairs Report* featured a special progress report on coastal planning in California prepared by Stanley Scott. The report was written in a style aimed at reaching a large audience of interested readers not having expertise in coastal matters, while also presenting the basic research findings in sufficient substance to interested students of coastal governance. In addition to the general readership of about 3,300, special mailings totaling approximately 600 copies were sent to specially targeted recipients such as the city and county managers and planning directors of local governments on the coast, members of the state coastal commission and the six regional commissions, members of key California Senate and Assembly standing committees, California members of key Congressional standing committees, and a number of departments and agencies of the State of California. In addition, the statewide Sea Grant Administration obtained 150 copies for distribution.

A Sea Grant Coastal Workshop held in Los Angeles, April 24-25, 1978, formed the basis for a 17-page consensus report, of which Stanley Scott was principal author, assisted by Jens Sorensen and other participants. This document presented a consensus reached by local planning staff from 14 representative local governments engaged in coastal planning. The consensus report, expressing concern that the California Coastal Commission was not giving adequate attention to the needs of local governments or to the variety of planning situations confronted, was widely distributed among local officials of coastal cities, as well as to state and regional coastal commission members, and interested citizens and coast-watchers.

Two essay-book reviews prepared by Stanley Scott were accepted for publication in the *Coastal Zone Management Journal:* (1) "Book Review": *Coastal Resources Management: Institutions and Programs,* by Joseph M. Heikoff (published in CZMJ, vol 4, no.

3, 1978); and (2) "Notes on California's Coastal Governance: A Reply to Peter Douglas," (published in CZMJ, vol 4, no. 4, 1978).

In April and May, 1978, Joseph Bodovitz and Stanley Scott sat together for eight one-and-one-half hour tape-recorded interviews. This was shortly after Bodovitz had resigned as Executive Director of the California Coastal Commission, and while he was teaching in the Department of City and Regional Planning, UC Berkeley. The interviews were structured with a pre-arranged set of theme questions intended to explore Bodovitz's recollections and perceptions of the working of California's coastal planning experiment during his term of service. A manuscript of approximately 270 pages resulted and is now being read by selected coastal commissioners and staff, other observers of coastal planning, faculty members, and coastal researchers. Further interviews with Bodovitz and perhaps other current or recently resigned coastal staff members are contemplated. The goal is a series of essay-like papers presenting "insider's views" of coastal planning processes, along with critiques and commentary provided by Scott and other observers.

Sea Grant trainee Peverill Squire analyzed legislative interviews and files in preparing a 112-page manuscript on the history of California's 1976 coastal statutes. The first revision of this manuscript has been read by approximately 40 readers who are particularly knowledgeable about the legislative process. The manuscript is now being revised, on the basis of readers' comments plus a few follow-up interviews, for projected publication in 1979.

Sea Grant trainee Roger Herrera conducted 32 interviews in coastal communities from San Diego to Eureka, focusing primarily on the city and county personnel responsible for local recreation and park programs and facilities along the coast. They were asked to evaluate local recreational problems and issues on the coast, especially as these may relate to coastal planning in the future. A rough draft of approximately 300 pages was prepared, organizing a "first-cut" of the interview material. That draft has been reworked and pared down by 1978-79 trainee Michael Heiman to a reading draft of about 100 pages for circulation to selected readers for review and comment, editing and issuance as a working paper. .

In addition to the special series of interviews with Joseph Bodovitz, mentioned earlier, 106 interviews and 50 updating re-interviews were conducted with a wide range of coastal participant observers. The results of these interviews were used to assist in preparing the manuscripts and publications already noted, and also will be analyzed and the findings reported in 1978-79 and in later coastal writing efforts stimulated and made possible by this project.

Finally, Institute of Governmental Studies staff provided advice and consultation to many faculty members, researchers, students, policymakers and others. Two good examples were sessions with representatives of the U.S. Office of Coastal Zone Management assigned to review and evaluate California's coastal planning effort, and with representatives of the California State Department of Finance on a similar mission.

Publications

Bodovitz, Joseph E. and Stanley Scott. 1978. Eight coastal interviews. Institute of Governmental Studies, University of California, Berkeley.

Grote, Lenard. 1978. Coastal conservation and development: balancing local and statewide interests. *Public Affairs Report* 19(1). Institute of Governmental Studies, University of California, Berkeley.

Scott, Stanley. 1978. Coastal planning in California: a progress report. *Public Affairs Report* 19(3-4). Institute of Governmental Studies, University of California, Berkeley.

Scott, Stanley. 1978. Book Review: *Coastal Resources Management: Institutions and Programs*, by Joseph M. Heikoff. *Coastal Zone Management Journal* 4(3): 337-354.

Scott, Stanley. 1978. Notes on California's coastal governance: a reply to Peter Douglas. *Coastal Zone Management Journal* 4(4): 475-486.

Scott, Stanley, ed. 1978. Coastal planning issues: a consensus report. Institute of Governmental Studies, University of California, Berkeley.

Squire, Peverill. Legislative history of the 1976 California Coastal Act. Institute of Governmental Studies, University of California, Berkeley. (manuscript in progress 1978).

Cooperating Organizations

California Coastal Commission, regional planning staff

Coastal Zone Management: Methods for Plan Development, Evaluation, and Monitoring of Local Programs

Thomas Dickert, *University of California, Berkeley*

During 1977-78, the California coastal zone management program embarked on the implementation phases of its work. About half of the California local governments began preparation of their local programs to bring their land use into conformance with the policies of the Coastal Act. Our research was intended to develop methods which would assist in the preparation, review, and monitoring of these programs. The research has been focused in two major areas: 1) determining the feasibility of a parcel-based information system to assist in cumulative impact assessment, and 2) the development of methods for relating the intensity of land use on an estuarine watershed to impacts within the estuarine regime.

One of the most difficult problems facing local governments in the preparation of local coastal programs is determining assessment and management methods for cumulative impacts of development within their jurisdiction. Cumulative impacts, as used here, refers to the environmental, social, and economic effects of all land uses permitted by the land use plan and implementing ordinances. Policies of the California Coastal Act require that local governments consider the cumulative impacts of development (§30250(a)) in preparation of their local coastal programs. Cumulative impact assessment is a most difficult problem, because most local governments do not have environmental and land-use data in a form that can be easily manipulated to provide quantitative impact estimates.

One method we have developed to provide quantitative impact estimates is a parcel-based information system. The system differs from earlier work on automated geographic information systems in using the land parcel as the geographic unit to reference environmental and other land-use data. Thus, the system couples records from the County Assessor's files (e.g., land use, zoning) with geographically specific environmental data (e.g., soils, geology). Because the system builds upon an existing data base, it is extremely cost-effective.

A feasibility study to illustrate the application of the parcel-based concept was undertaken in a case study of the Montara-El Granada portion of San Mateo County. This portion of the Half Moon Bay subregion was selected because of our earlier work in the area. County records were acquired and about twenty variables placed on computer tape. An additional fifteen environmental and land-use variables were encoded from mapped data, including, for example, flood-prone areas, landslide susceptibility, liquefaction potential, slope, soil and agricultural capability, tsunami run-up, and vegetation type.

Demonstration uses of the system have included:

1. Cross-tabulation of parcel characteristics: listing all parcels within a specified size-class with similar resource characteristics.

2. Estimating the degree of conflict between California Coastal Act policies and existing zoning: listing all parcels (by size-class) which are over-zoned for urban use and also possess resource characteristics specified in the Coastal Act (e.g., geologically hazardous areas, prime agricultural lands, etc.).

3. Estimating the degree of conflict between the existing county zoning and service system capacities: using the number of parcels in a specified zoning class, coupled with unit consumption factors (i.e., trips/amount/day, etc.) to estimate the highway, wastewater, and water-supply requirements for the level of development expressed in the existing county zoning.

4. Estimating the number of similarly situated landowners: listing all parcels with a similar set of resource characteristics which would be affected by a particular planning policy. The number of similarly situated landowners has also been estimated for specific project review examples, for use by the Coastal Commission. In the project review context, the quantitative estimates proved particularly convincing in illustrating the community-wide implications of a single project decision.

As background to the development of the parcel-based system, two important studies were conducted: a review of nine existing information systems from other coastal states, and a survey of assessors' offices in California coastal counties. The review of information systems points out the pitfalls to be avoided in developing such systems, and provides detailed analyses on the purposes of each system, the types of data used, analyses performed, and the planning products produced. The assessors' survey documents the current scope and availability of automated files within California. A principle finding is that most California offices have their files in automated form, thus insuring the transferability of the parcel-based concept developed in this research.

Research was initiated in the Elkhorn Slough estuary to relate the intensity and type of land use on an estuarine watershed to impacts within the estuarine regime. The Elkhorn Slough estuary in Monterey County was selected as a case study site because it is typical of the rapid urban and agricultural development within many California estuarine watersheds. Field work conducted during the year has included: 1) definition of the watershed boundary, particularly the extent to which inter-basin transfers occur as a result of urban and agricultural diversions; 2) mapping and documenting the extent to which erosion and sedimentation are occurring as a result of urban and agricultural uses on the watershed; and 3) measurement of runoff and sedimentation rates at selected locations within the watershed.

The effect of land-use changes on the estuarine environment is being established through analysis of historical documents over the past 130-year period. Collection of historical maps, aerial photographs, and other survey data from the files of U.S.G.S., Army Corps of Engineers, State Lands Commission, and other libraries is in progress. The initial collection indicates that documentation is available at approximately a one-decade frequency over the 130-year time period.

A review of the literature on Elkhorn Slough has resulted in a bibliography of about four hundred fifty citations, including both planning and scientific documents. In addition, the estuarine management literature from other coastal areas was reviewed, focusing on quantitative methodology to link upstream land uses and estuarine processes.

Preliminary research findings have been presented to the Central Regional Coastal Commission, the Monterey County Planning Commission, and several citizen groups. The watershed boundary established in the research is being used by the Coastal Commission in developing its recommendations for legislative boundary changes.

Publications

Bandarin, Francisco, Scott McCreary and Thomas Dickert. 1978. Elkhorn Slough case study: bibliography (Background Paper No. 1). Institute of Urban and Regional Development, University of California, Berkeley.

Dickert, Thomas and Jens Sorensen. 1978. *Collaborative Planning for the Coastal Zone: A Process for Local Program Development, Volume I.* Institute of Marine Resources, La Jolla, IMR No. 76-14, Sea Grant Publication No. 52.

Dickert, Thomas, Scott McCreary and Eric Metz. 1978. *A parcel-based information system for cumulative impact assessment* (working draft). Institute of Urban and Regional Development, University of California, Berkeley.

Idem, 1978. Cumulative impact assessment for coastal zone planning. Paper presented at Coastal Zone 1978, ASCE, March 11-14, 1978, San Francisco.

Dickert, Thomas, Andrea Tuttle and Sun Yuan. 1978. Hydrology and land use planning for the coastal zone: Elkhorn Slough case study (Background Paper No. 2). Institute of Urban and Regional Development, University of California, Berkeley.

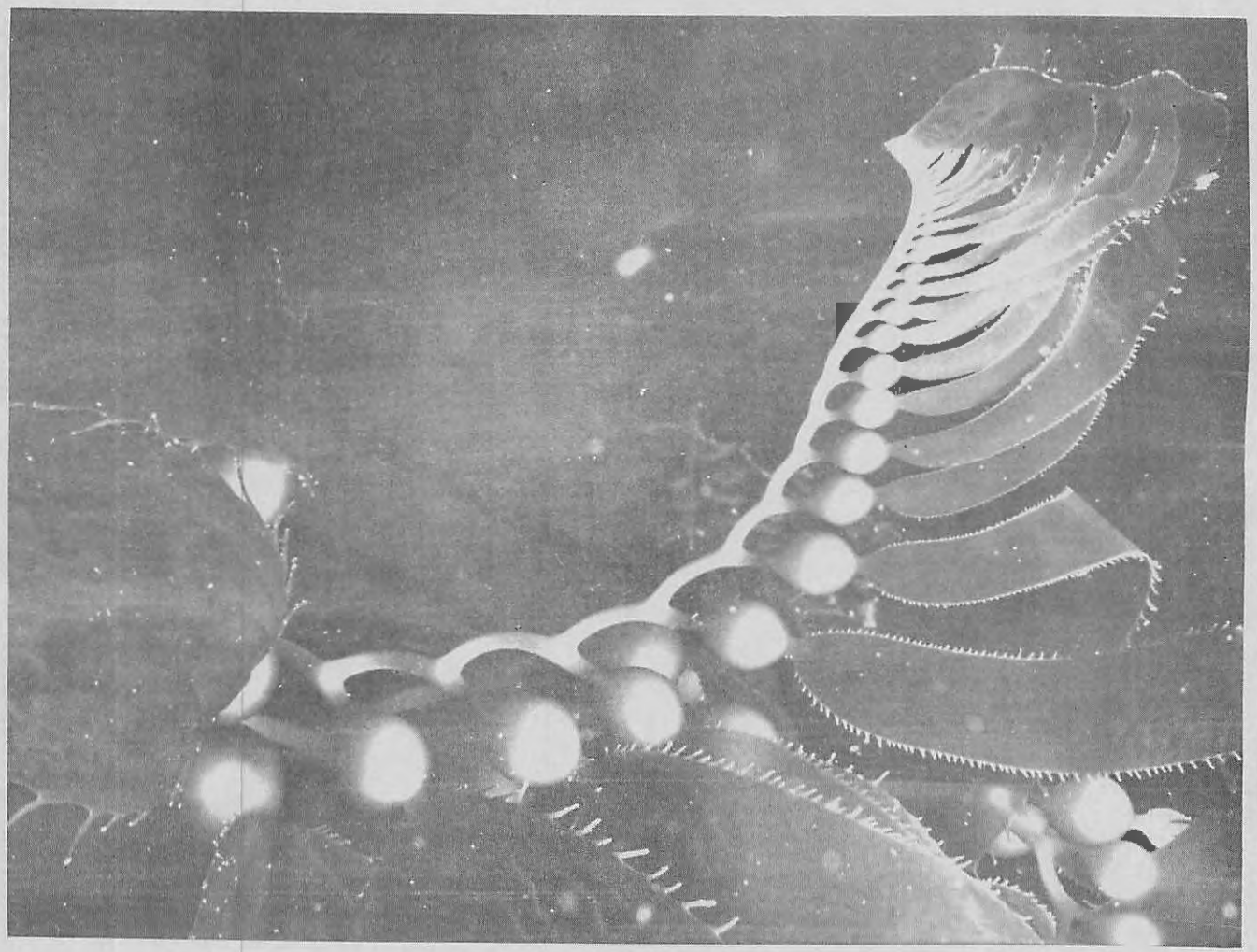
Cooperating Organizations

San Mateo County, Assessor's Office and County Planning Department

Monterey County, Planning Department

California Coastal Commission, San Francisco and Santa Cruz regions

AQUACULTURE



Karen Straus

The Development of the Science and Technology of Aquaculture

Cadet Hand, with the assistance of Louis Botsford, Douglas Conklin, William Fisher, Michael Hartman, Dennis Hedgecock and Edgar Nilson
Bodega Marine Laboratory, University of California, Berkeley

This annual report is the second for a two-year project initiated in September of 1976. As this report will be the final one for the project entitled "The Development of the Science and Technology of Aquaculture," we have attempted to integrate and summarize progress made during the entire period in order to provide a comprehensive overview.

Broodstock development

Lack of control over reproduction impedes the commercial development of crustacean aquaculture. Dependence on wild larvae or juveniles precludes genetic improvement for behavior and quality (domestication), and ties the culture to availability of wild stock. *Homarus* two obstacles in particular have prevented a steady supply of larvae and interfered with selective breeding: (1) low percentages of proper ovarian development and oviposition among adult females maintained in the laboratory, and (2) a two-year cycle in the female's egg clutch production. To investigate the role of certain environmental cues -- temperature changes and photoperiod cycles -- we conducted two major experiments, one in each of the preceding Sea Grant years. In each, seventy-two adult lobsters were held in large tanks and fed either fresh or frozen seafood or frozen agar-gelatin cakes compounded from various autoclaved seafoods. Full details of our experimental systems and protocols may be found in Hand *et al.* (1977) and in Hedgecock *et al.* (1978). The most recent experiment (1978) was described at the 1979 World Mariculture Society meeting, in Honolulu, January 22-26. The results of these past two years' experiments have brought us significantly closer to achieving full husbandry of the lobster.

In the first year (1976-1977) our experimental temperature treatments were three: low (10-15° C), medium (14-18° C), and high (18-22° C), and in each of these experiments, long day (16:8h) was contrasted with short day (8:16h) light-dark cycles. Molting and mortality were higher at mid- and high temperatures; conversely, extrusion was higher in the low temperature condition. Photoperiod effects were seen only in the low temperature treatment where long days accelerated molting. These results matched well with those of Dr. David Aiken of Canada. Under the best conditions of this experiment, however, the rate of extrusion was only 22%.

In the next experiment we decided to test both the effects of cold period (7° C) and long day photoperiod onset. Again, we found no requirement for, nor disadvantage of, a cold winter period during ovarian maturation. This means that ambient seawater temperatures like those at Bodega Bay, California, are ideal for holding lobster broodstock. More interestingly, a dramatic stimulation of extrusion was evident in all conditions in which photoperiod increased from short days to long days.

Note that the rate of extrusion under the best conditions of this second experiment was 56% (an average of 44.4% over five such treatments vs. 18.5% extrusion in three short day or dark treatments). These results, together with data on other laboratory held individuals, suggest that manipulation of photoperiod may be a key to controlling the delicate interplay of molt and reproductive cycles in lobsters. It apparently allows an inexpensive means of timing egg extrusions for year-round availability of seed. We are testing and refining our hypotheses in a current, third experiment in this series.

A final lesson from the past two years research is that the increasing availability and use of adult broodstock that have been held at the Bodega Marine Laboratory for several years allows more information to be obtained from each succeeding experiment.

It becomes possible to analyze data on the intervals between molts and between extrusions and the relationship of these cycles. Our present colony comprises 111 American and 14 European lobster females. Molt and reproductive histories on each individual are completely computerized. The vision of a sizable lobster broodstock colony selectively bred for improved production seems much closer than it did two years ago.

Larval biology

Efforts of the Larval Biology group have concentrated on problems involved in the development of a hatchery technology for the Dungeness crab, *Cancer magister.* These problems include the design of a system to mass rear larvae to first instar, to develop a suitable dietary regime for the larvae and to help develop treatments for whatever diseases may be identified.

A mass rearing system was developed and tested (Hartman, 1977). It uses an outside airlift to move oxygenated water slowly upward through a cylindrical rearing chamber. Larvae are confined to the chamber by screens at each end. The relatively simple design and flow characteristics of this system should allow it to be scaled up for hatchery level production if desired.

Several varieties of unicellular algae have been evaluated as dietary components for use either alone, in combination (Hartman and Letterman, 1978, in press; Hartman, submitted for publication), or for use with other diet components such as *Artemia salina* nauplii. The latter study by Hartman examines 15 single algal species as food for Dungeness crab larvae. Of the algal species examined, the four providing the best survival were then used in combination. These four species were *Thalassiosira pseudonana, Skeletonema costatum, Tetraselmis suecica* and *Phaeodactylum tricornutum.* The diets composed of combinations generally did better than individual species. The diet of the diatoms *Thalassiosira* sp. and *Skeletonema* sp. and the chlorophyte, *Tetraselmis* sp. provided the best survival, especially through later molts.

Several parameters which may effect the viability of each of the algal species for larval rearing were noted: the behavior of each alga in the culture environment with respect to its availability to the crab larvae, the influence of a static culture vessel and its size upon the behavior of both algae and larvae, and finally, the ability of the larvae to capture algae of the size being fed.

Experiments subsequent to the above attempted to evaluate *Artemia salina* nauplii in combinations with *Skeletonema* sp. and *Tetraselmis* sp. and antibiotics (chloramphenicol and penicillin with streptomycin) in static culture and the mass rearing system mentioned earlier. They were plagued by diseases and epibiotic fouling by a variety of organisms, causing extreme disparities in larval survival between replicates within control groups and test diets. Disease organisms we identified with the help of the Pathology/Water Quality group were *Lagenidium* and *Vibrio.* Bacteria and filamentous algae and fungi were responsible for the fouling. After this experience a series of experiments were conducted to test various treatments. In brief, treatments tested included malachite green dip (10 ppm for 10 min) of *Artemia* nauplii before feeding, malachite green dip (10 ppm for 5 min) of larvae once between each molt, and the antibiotic chloramphenicol (at 1 ppm) in *Artemia* hatch water and/or in the larval culture water. Decapsulation of *Artemia* cysts used as food was also tried in combinations with the above in an effort to keep the cultures clean and healthy. Results from the foregoing were either negative or inconclusive.

Throughout our efforts with the treatments mentioned above, it was noticed that the larvae from some individual females were far less vigorous than larvae from others and that starvation controls from these groups showed a mean time to death which could vary from 2 to 7 days. This led us to start sampling eggs from extrusion to hatch, to test them for total lipid, energy phospholipid, and triglyceride as a possible index of energy available to hatching larvae, and to relate this to culture success.

Nutrition

The need to understand the nutritional requirements has often been cited as a

prerequisite to intensive culture of crustaceans. However, before nutritional requirements can be delineated, it is necessary first to develop an acceptable and readily modifiable artificial diet. This has, unfortunately, not been achieved for the lobster nor for crustaceans in general in spite of intensive research efforts. Compared to a diet of live or fresh food items, artificial diets in which nutrient content can be manipulated produced only marginal growth and survival. Quite often an improvement in one parameter, either growth or survival, is to the detriment of the other. An additional problem is the difficulty of readily monitoring food intake. As the actual amount assimilated is open to question, a positive growth response may be due to increased consumption and not to an improved nutrient combination. The unpredictable combination of these factors has hampered the rational development of an artificial diet and effectively stymied the commercialization of intensive crustacean aquaculture.

Research over the past two years has been aimed at identifying those elements of fresh food diets which make them superior to artificial diets. As the general outline of nutrient requirements for arthropods is thought to be understood, based on the work with insects, a possibility existed that a slightly different but critical ratio of nutrients was required. A large experiment in cooperation with Foremost Foods and San Diego State University examined this possibility. A multivariant approach, response surface methodology (RSM), was used to examine the interaction among major nutrient classes. The results were disappointingly negative, indicating that although some interaction was present, the critical factor still had not been pinpointed.

Another possibility was that in an attempt to assure that all possible requirements had been met, diets were too high in some ingredients, leading to actual toxicity. In order to examine this possibility, the artificial diets were fed in combination with live brine shrimp, *Artemia salina*, which was known to be an excellent diet for juvenile lobsters. The results were strikingly clear. Even a slight supplementation (every fourth day) of the artificial diet with the live food produced growth rates and survival comparable to a complete live food diet. This and other supplementation experiments using a variety of non-living food such as beef heart, beef liver, and garden vegetables indicated the artificial diets were not toxic but deficient in one or more essential nutrients.

We were then able to use the artificial diets with a supplement of beef liver to examine the role of pigmentation. In a series of experiments carried out in cooperation with Eric Johnson and Dr. Michael Lewis, UC Davis, we determined that pigmentation was controlled by diet. Normally, pigmented lobsters could be produced using a variety of carotinoid-containing foodstuffs added to the artificial diet. One of the most effective was paprika extract. More importantly, pigmentation did not have an effect on growth and survival of the animal in the laboratory.

Specific identification, however, of those nutrients contained in the supplements which were critical for survival and growth proved to be perplexingly difficult. Surprisingly, grinding and the subsequent incorporation of these supplements for various extracts in the pelletized artificial diet was completely ineffective. It is believed, however, that this can be explained based on the results of some concurrent experiments which were carried out on the artificial diets and on the lobsters' feeding behavior. In studying consumption patterns, it was noted that lobsters do not feed rapidly. These experiments indicated that lobsters under our experimental conditions fed continuously throughout a 24-hour period. Other experiments carried out in cooperation with Mike Goldblatt and Dr. Duane Brown, UC Davis, indicate that the majority of water soluble vitamins have leached from the pellet after only two hours immersion in seawater. This leaching is not correlated with the particulate loss, the traditional measurement of aquatic diet stability.

Based on our past two years' research, we hypothesized that the ineffectiveness of artificial diets for lobsters is due to water-soluble vitamin deficiencies resulting from the combination of the rapid leaching and the extended feeding period of the animal. Preliminary experiments with stabilized vitamin sources, both natural and artificially microencapsulated, have tended to support

this hypothesis. Definitive proof is yet to be produced. Appropriate microencapsulation techniques which will retain water-soluble nutrients and are compatible with the animal's digestive physiology are still in the developmental stage. It is felt, however, that we are close to overcoming the problems which have been associated with artificial diets, a vital step in the eventual commercialization of lobster aquaculture.

Pathology/Water quality

The Pathology/Water Quality group of the Aquaculture Program at the Bodega Marine Laboratory has studied diseases and disease-related problems of marine crustaceans of interest in aquaculture. Studies carried out have dealt primarily with diseases of the American lobster *Homarus americanus* and the Dungeness crab *Cancer magister.* The project has provided supportive services to other projects within the Aquaculture Program. Chemical and microbiological water quality parameters are monitored and experimental animal mortalities are investigated.

Epibiotic fouling of the eggs of the Dungeness crab was studied in the field and in the laboratory. Field studies suggested that a relationship existed between the nutrient level in the water and the degree of epibiotic fouling and that the degree of fouling is related to egg mortality. A laboratory study investigated the relationship between epibiotic fouling and mortality. The number of measurable filaments of epibiotic fouling and the number of egg mortalities increased when eggs were held in nutrient enriched seawater. When the eggs were treated with antibiotics, the number of egg mortalities decreased, but the number of filaments continued to increase. This suggested that mortalities may be due to non-filamentous, antibiotic-sensitive organisms. Darkness and ultraviolet irradiation had no effect on filaments or egg mortalities. The degree of epibiotic fouling and number of egg mortalities were found to decrease with increasing depth into the egg mass. A new field study was conducted in which epibiotic fouling and egg mortality data were collected for a standardized location on the egg mass. The study again showed a correlation between the nutrient level of the water, epibiotic fouling and egg mortality.

Chemotherapeutic treatments for epibiotic fouling of Dungeness crab larvae were evaluated. The results showed that the addition of antibiotics to sea water increased the survival of larvae in the laboratory. Malachite green treatments were unsatisfactory due to the toxicity of malachite green to the sensitive larval stages.

The susceptibility of juvenile American lobsters to chitinolytic bacteria was investigated. The greatest susceptibility was found on animals fed a long-term synthetic diet and on animals that were treated with malachite green and fed on a short-term synthetic diet. Mechanical injury and heavy innoculation of bacteria did not increase susceptibility. Long term synthetic diet and malachite green treatment were implicated in the weakening of the non-chitinous epicuticle, allowing chitinolytic bacteria to gain a portal of entry for attack of the cuticle.

The toxicity of malachite green to American lobster larvae was determined. Larvae were subjected to a 16 minute treatment of malachite green at varying concentrations in one study and were treated at 20 ppm for varying exposure periods in a second study. Treatment of larvae with concentrations greater than 8 ppm for 16 minutes or for longer than 8 minutes at 20 ppm decreased survival. Increased exposure period also produced a prolonging of the time to reach the fourth larval stage.

Buildup of bacteria in the aquaculture system was found to be a problem. Antibiotic treatments of the water were developed and evaluated to alleviate this condition. *Artemia salina* used as a food in larval rearing systems were found to be a source of contamination of the system with pathogenic *Vibrio* sp. Rinsing *Artemia* with a malachite green solution eliminated the contamination.

Scanning electron microscopy techniques were used to study two disease syndromes of the exoskeleton of the American lobster. One disease begins with a degradation of the epicuticle while the second type apparently begins on the inside surface of the exoskeleton.

A disease diagnostic laboratory was established. This laboratory is capable of

diagnosing most microbial disease problems found in marine aquaculture. The laboratory has the capacity to perform histological examinations of tissues from diseased animals. Diagnostic services were provided in support of other projects at the Bodega Marine Laboratory and to other individuals requesting the service.

Systems analysis and economics

Since the major, long-term objective of our research in aquaculture is the development of economically feasible lobster culture, a means of evaluating results and directing research is needed that "translates" our experimental results into economic terms. The tools used to accomplish this task must integrate both physical systems and biological results into a form that reflects the status of research as a whole. We have used techniques of mathematical modeling, optimization theory and simulation to fulfill these requirements.

We have developed a mathematical model of the biological, physical, and economic aspects of culture and used this model to determine optimal culture methods, project culture costs, and to direct research. An initial model was constructed based on available data and assumptions and was used to determine the sensitivity of the output (cost) to poorly known or assumed parameter values. Experimental effort was concentrated towards improving the values of these parameters. As research has progressed, the model has become increasingly realistic. In addition to directing research towards improvement of our quantitative knowledge of lobster culture, we also use sensitivity analysis to determine the best way (least research cost) of reducing culture costs. This is done by comparing the reduction in culture cost due to a proposed research advance and the cost of research for each of the proposed research projects. We use optimal control theory to determine optimal temperature, container sizes, and flow rates in lobster culture. Computer simulation is used to project culture costs under different assumed conditions.

In the past year we have concentrated our efforts toward examining the effect of growth and metabolic rates on culture costs. The results obtained, the relative economic importance of growth and metabolic rate (or conversion ratio), provide guidelines for research and development in new artificial feeds, genetic selection, and optimal feeding levels. In addition to work on lobster aquaculture, we began analysis of the northern California Dungeness crab fishery. This work is related to the causes and economic implications of abundance cycles.

Publications

Armstrong, D. A. and W. S. Fisher. 1977. Fungal disease of Dungeness crabs. *In* Sinderman (ed.), *Disease Diagnosis and Control in North American Marine Aquaculture. Developments in Aquaculture and Fisheries Science* 6: 137-141. Elsevier Publishing Co., Amsterdam.

Botsford, Louis W. 1977. Current economic status of lobster culture research. *Proc. 8th Annual World Mariculture Soc. Mtg.* 8: 723-739.

Botsford, L. W., J. C. Van Olst, J. M. Carlberg and T. W. Gossard. 1977. The use of mathematical modeling and simulation to evaluate aquaculture as a beneficial use of thermal effluent. *Proceedings of the 1977 Summer Computer Simulation Conference:* 405-410. Chicago, Illinois.

Botsford, L. W. and D. E. Wickham. 1978. Behavior of age-specific, density-dependent models and the northern California Dungeness crab *(Cancer magister)* Fishery. *J. Fish. Res. Bd. Canada* 35: 833-843.

Conklin, Douglas E., Kathryn Devers and Clark Bordner. 1977. Development of artificial diets for the lobster, *Homarus americanus. Proc. 8th Annual World Mariculture Soc. Mtg.* 8: 841-852.

Fisher, William S. 1976. Relationships of epibiotic fouling and mortalities of eggs of the Dungeness crab *(Cancer magister). J. Fish. Res. Bd. Canada* 33(12): 2849-2853.

Fisher, W. S. 1977. Dungeness crab diseases. *In* Sinderman (ed.), *Disease Diagnosis and Control in North American Marine Aquaculture. Developments in Aquaculture and Fisheries Science* 6: 135-136. Elsevier Publishing Co., Amsterdam.

Fisher, W. S. 1977. Microbial epibionts of Dungeness crabs. *Ibid:* 142-146.

Fisher, W. S. 1977. Shell disease of lobsters. *Ibid:* 158-162.

Fisher, W. S. 1977. Microbial epibionts of lobsters. *Ibid:* 163-167.

Fisher, W. S. 1977. Epibiotic microbial infestations of cultured crustaceans. *Proc. 8th Annual World Mariculture Soc. Mtg.* 8: 673-684.

Fisher, W. S. and Richard T. Nelson. 1977. Therapeutic treatment for epibiotic fouling on Dungeness crab *(Cancer magister)* larvae reared in the laboratory. *J. Fish. Res. Bd. Canada* 34(3): 432-436.

Fisher, W. S. and R. T. Nelson. 1978. Application of antibiotics in the cultivation of Dungeness crab, *Cancer magister. J. Fish. Res. Bd. Canada* 35: 1343-1349.

Fisher, W. S. and E. H. Nilson. 1977. *Haliphthoros* disease of lobsters. *In* Sinderman (ed.), *Disease Diagnosis and Control in North American Marine Aquaculture. Developments in Aquaculture and Fisheries Science* 6: 173-177. Elsevier Publishing Co., Amsterdam.

Fisher, W. S., E. H. Nilson, J. F. Steenbergen and D. V. Lightner. 1978. Microbial diseases of cultured lobsters: a review. *Aquaculture* 14: 115-140.

Fisher, W. S. and D. E. Wickham. 1977. Egg mortalities in wild populations of the Dungeness crab in Central and Northern California. *Fish. Bull.* 75: 235-237.

Gallagher, M. L., W. D. Brown, D. E. Conklin and M. Sifri. 1978. Effects of varying calcium/phosphorus ratios in diets fed to juvenile lobsters *(Homarus americanus). Comp. Biochem. Physiol.* 60A: 467-471.

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. *Proc. 7th Annual World Mariculture Soc. Mtg.* 7: 363-378.

Hand, D., T Albany, L. Botsford, D. Conklin, R. Daggett, B. Fisher, M. Hartman, D. Hedgecock, K. Nelson and E. Nilson. 1977. Development of aquaculture systems. University of California Sea Grant Publication #58, Institute of Marine Resources (IMR 77-105): 97 pp.

Hartman, Michael C. 1977. A mass rearing system for the culture of Brachyuran crab larvae. *Proc. 8th Annual World Mariculture Soc. Mtg.* 8: 147-155.

Hedgecock, Dennis. 1977. Biochemical genetic markers for broodstock identification in aquaculture. *Proc. 8th Annual World Mariculture Soc. Mtg.* 8: 523-531.

Hedgecock, D., K. Nelson, J. Simons and R.A. Shlesher. 1977. Genic similarity of American and European species of the lobster *Homarus. Biol. Bull.* 152: 41-50.

Johnson, E. A., D. E. Conklin and M. J. Lewis. 1977. The yeast *Phaffia rhodozyma* as a dietary pigment source for salmonids and crustaceans. *J. Fish. Res. Bd. Canada* 34: 2417-2421.

Nelson, Keith. 1977. Genetic considerations in selective crustaceans species. *Proc. 8th Annual World Mariculture Soc. Mtg.* 8: 543-555.

Nelson, K. and D. Hedgecock. 1977. Electrophoretic evidence of multiple paternity in the lobster, *Homarus americanus* (Milne-Edwards). *American Naturalist* 3: 361-365.

Nilson, E. H. and W. S. Fisher. 1977. *Lagenidium* diseases of lobsters. *In* Sinderman (ed.), *Disease Diagnosis and Control in North American Marine Aquaculture. Developments in Aquaculture and Fisheries Science* 6: 168-172. Elsevier Publishing Co., Amsterdam.

Wickham, D. E. 1978. A new species of carcinonemertes (Nemertea: Carcinonemertidae) with notes on the genus from the Pacific Coast. *Proc. Biol. Soc. Wash.* 91(1): 197-202.

Wickham, D.E. and W. S. Fisher. 1977. Worm predation of Dungeness crab eggs. *In* Sinderman (ed.), *Disease Diagnosis and Control in North American Marine*

Aquaculture. Developments in Aquaculture and Fisheries Science 6: 147-150. Elsevier Publishing Co., Amsterdam.

Cooperating Organizations

Bodega Bay Fishermen's Marketing Association, Bodega Bay, California

Brigham Young University, Department of Biology, Provo, Utah

California Department of Fish and Game, Granite Canyon Laboratory, Humboldt, Menlo Park and Sacramento offices

California Water Quality Control Board, Sacramento, California

East Carolina University, Department of Biology, Greenville, North Carolina

Foremost Foods, Research and Development, Dublin, California

H & M Wholesale Lobster Company, Petaluma, California

LFE Environmental Analysis Laboratories, Richmond, California

Massachusetts State Lobster Hatchery, Martha's Vineyard, Massachusetts

National Marine Fisheries Laboratory, Auke Bay Fisheries Laboratory, Auke Bay, Alaska

San Diego State University, Departments of Biology and Microbiology

San Francisco Bay Brand, San Francisco

University of California, Davis, Departments of Food Science and Agricultural Engineering

Washington Department of Fisheries, Whitney Point Shellfish Laboratory, Quilcene, Washington

Use of Thermal Effluent in the Culture of Crustacea and Fishes

Jon C. Van Olst, Richard F. Ford, and James M. Carlberg
San Diego State University

Waste heat from fossil-fueled power plants represents a large and unutilized energy source. Approximately 40-50% of the heat generated in burning oil and natural gas cannot be used to produce electricity and is lost to the environment in the plant cooling water. Aquaculture is a beneficial use of power plant thermal effluent which shows outstanding potential. Our previous work has shown that no serious pollutant problems appear to be associated with the effluent from fossil fuel plants, and that growth of American lobsters and other species is greatly accelerated at the elevated temperatures available. Increased growth rates often result in decreased labor, energy and production costs in commercial aquaculture, which can make the proposed venture economically viable.

The objectives of this program are to assess the benefits and problems involved in using thermal effluent as an economical source of heat in the culture of several marine animals of commercial importance and to develop the biological and technical information necessary for their successful culture. The research is being conducted at two aquaculture laboratories operated by San Diego State University (SDSU) at the Scripps Institution of Oceanography and the Encina Power Plant of San Diego Gas & Electric Company. In addition, several aspects of the work are being conducted at the Ormond Beach Generating Station of the Southern California Edison Company (Fig. 1), which has funded a substantial part of our lobster culture research since 1973.

Our research is demonstrating that thermal effluent is a low-cost and essentially pollution-free water resource that can be employed safely in the culture of the American lobster, *Homarus americanus*. Since 1970 Sea Grant has supported related research to develop the techniques and systems necessary for an economically viable lobster farming industry. Close cooperation has been maintained between the two major research groups involved on the West Coast, at SDSU and UC Davis (UCD). A very large amount of relevant information is now available. Major accomplishments include: 1) the development of satisfactory systems for larval culture; 2) the development of automatic feeding systems for larvae; 3) information on feeding requirements, activity patterns, and social behavior of the American lobster and the potential ecological dangers involved in introducing it in the wild as an exotic species to Pacific coastal waters; 4) the development of techniques for mass rearing of juveniles; 5) information on optimal feeding rates for larvae and early juveniles; 6) information on optimal temperatures for lobster culture; 7) detailed evaluations concerning the use of thermal effluent in lobster culture; 8) information on the diagnosis, treatment, and prevention of diseases; 9) the development of methods for analysis of cost-effectiveness; 10) the development of several promising artificial diets; and 11) the development of new rearing systems for use in commercial culture of juvenile lobsters to a marketable size.

The consensus of the scientists involved is that most of the essential information necessary to test the commercial feasibility of lobster aquaculture has been developed during the course of these studies. The next logical step is to develop a pilot-scale or demonstration-scale production system to test the results of this research and evaluate the most promising culture techniques and systems we have developed. A pilot operation will serve as the central focus for a National Lobster Culture Research Project, for which plans are now being developed. This program and its centralized pilot-scale production system will provide a mechanism for those actively engaged in lobster research to test and modify present technology in a prototype production facility. To facilitate this goal, during the past year several experiments

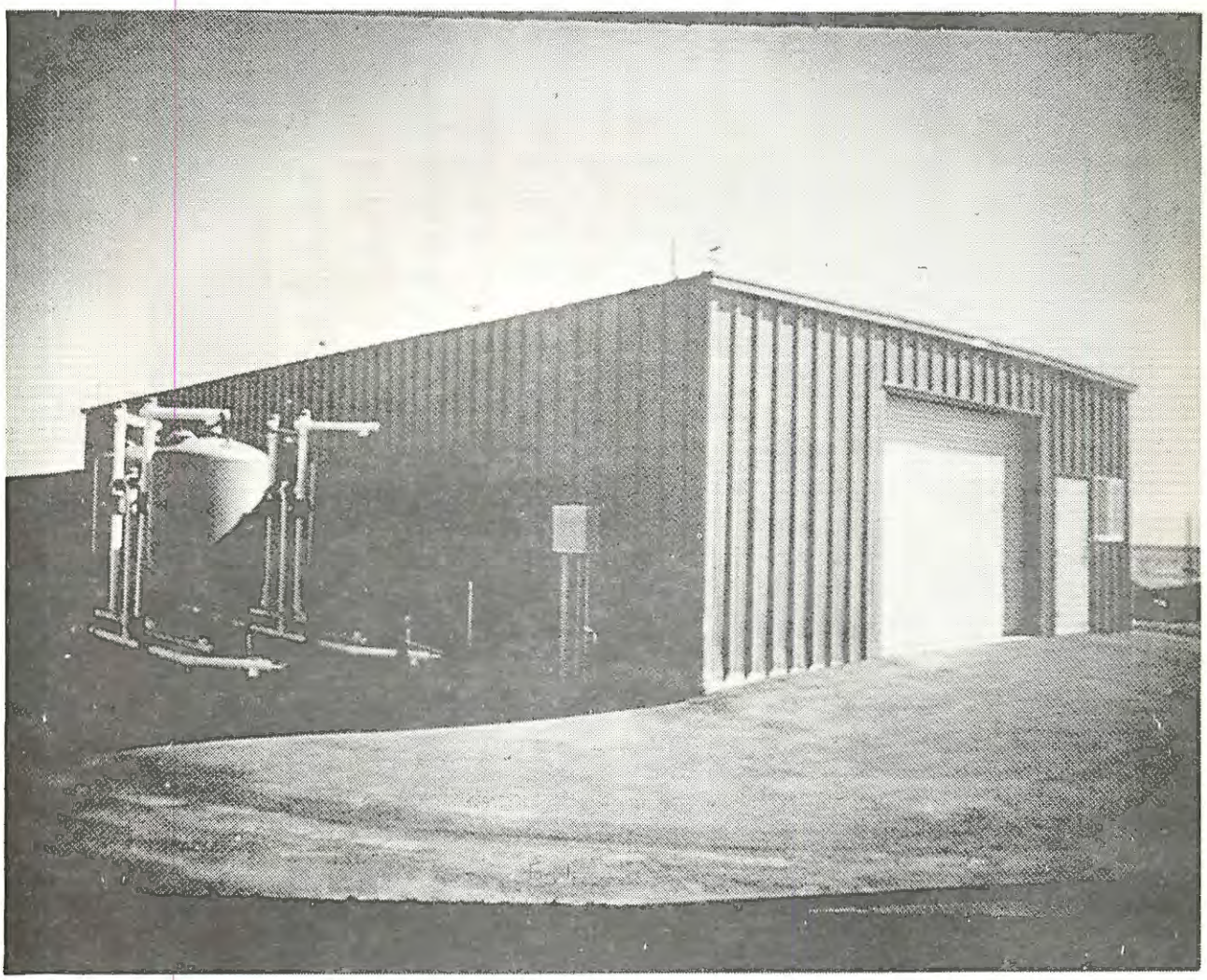


Figure 1. The Ormond Beach Aquaculture Laboratory was constructed recently at the Southern California Edison Company's generating station near Oxnard, California. This site is ideally suited for future pilot-scale lobster culture research planned by SDSU and the Bodega Marine Laboratory.

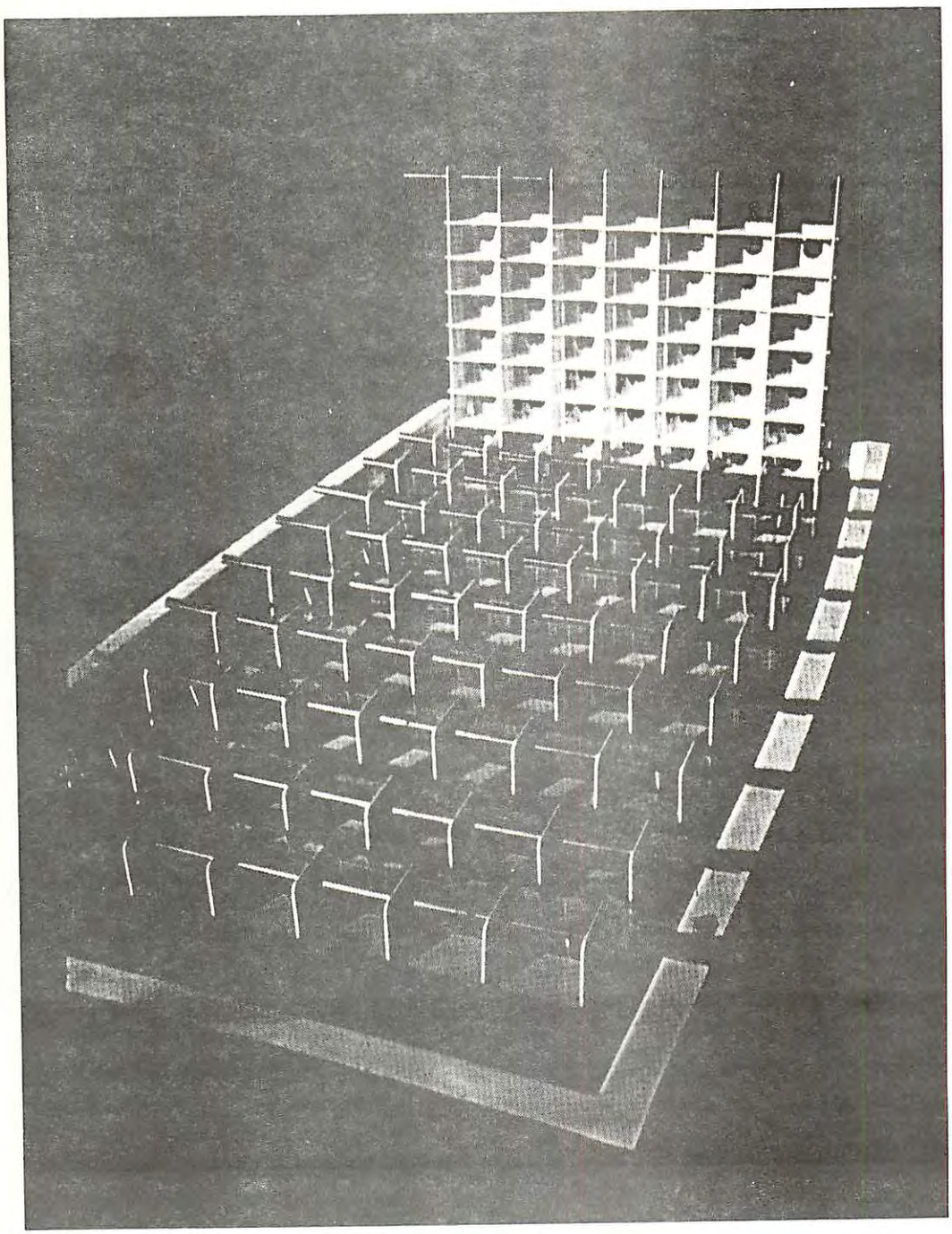


Figure 2. In this prototype culture system lobsters are held in individual containers which are suspended vertically in deep tanks or raceways. The containers are lifted vertically to provide for feeding, harvesting, and maintenance operations.

were conducted which relate specifically to the development of the pilot-scale program.

Culture system design

Two major types of production systems for individual rearing of lobsters are being evaluated for use in the pilot-scale study. These are a flushing tray system and a deep tank system. The flushing tray system, developed cooperatively by our group and David Aiken of the Canadian Fisheries and Marine Service, consists of cantilevered racks of partitioned trays which are flushed periodically to remove accumulated wastes. The deep tank system, developed at San Diego State University, consists of three-dimensional arrays of perforated holding cages suspended in one deep tank or raceway (Fig. 2). Prototypes of both systems have been developed and perform satisfactorily. From the standpoint of production costs, the deep tank systems may prove to be less expensive than the flush tray system, because it is not necessary to provide a separate container for the seawater at each vertical level in the array and better use is made of available space. However, access to the cultured animals is more convenient in a tray system because each rearing compartment is open to the water surface. In order to select the most promising system for commercial application, production cost estimates are being developed, including costs of feeding, harvesting, transferring, monitoring and waste treatment. The scale of the pilot test will be established at the smallest level of operation that will permit accurate extrapolation of the results to commercial scale (Fig. 3).

Effects of temperature

The American lobster exhibits a maximal rate of growth at a
constant temperature of 20-22° C. However, constant temperatures are rarely encountered in nature or in the aquaculture environment. Also, due to variations in electric power demands, the effluent temperature of most generating stations varies considerably, with daily cycles of 6-9° C. Periodic shut-downs for maintenance, inspection and repairs and standard operating practices for heat treatment of the cooling system cause additional fluctuations. Because of this, knowledge of the effects of sudden temperature changes on subsequent growth and survival is essential in culturing lobsters in thermal effluent.

A series of experiments were conducted to determine the effects of temperature change on growth of juvenile lobsters. Lobsters acclimated to the optimal culture temperature of 22° C were subjected to thermal shocks within the range of temperatures from 0.5-32° C. All groups survived exposure to the lower limit of 0.5° C. Larger juveniles suffered significant mortality at 31° C and sudden exposure to 32° C proved to be lethal for juveniles of all sizes (Fig. 4). When a more gradual rate of temperature change (one degree per day) was provided, survival at higher temperatures increased significantly.

Some fish and invertebrates cultured under conditions of fluctuating temperature exhibit higher survival and grow faster than when cultured at constant temperatures. A second experiment was designed to assess the detrimental or potentially beneficial effects of fluctuating temperature on lobster growth and survival. In this study lobsters were subjected to a temperature regime that fluctuated between 22 and 15° C over a 24-hour cycle. After four months of culture, groups exposed to fluctuating temperature showed significantly lower rates of growth and survival when compared to groups maintained at a constant 22° C. This result may be due in part to the lower value of degree-days for the fluctuating temperature groups. However, a subsequent high-temperature stress test indicated that lobsters cultured for four months in fluctuating temperatures were less tolerant of sudden exposures to 31° C than were controls held at constant temperatures. Therefore, it appears that a considerable degree of temperature control will need to be employed in commercial lobster production at generating stations, in order to avoid problems of reduced growth and sensitivity to sudden temperature changes.

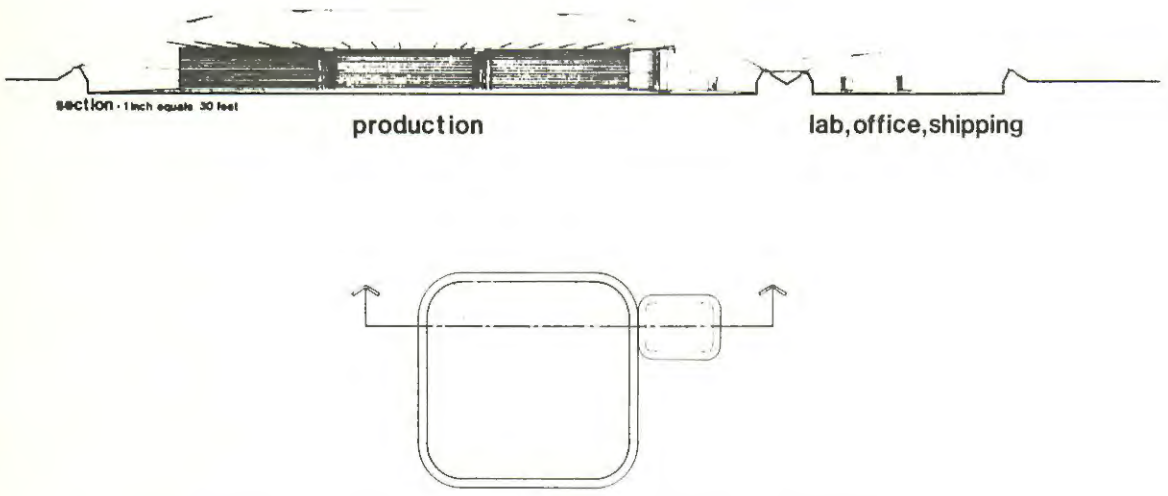


Figure 3. Artist's conception of commercial lobster production facility in which the flushing tray culture system is employed. An inflatable greenhouse dome covers the structure.

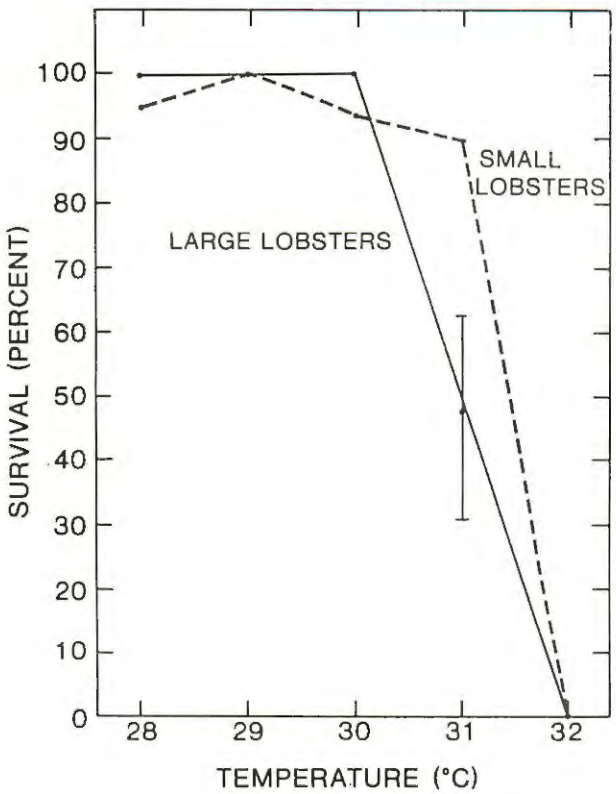


Figure 4. Survival of small (3.5 - 7.5 mm carapace length) and large (9.0 - 21.5 mm carapace length) *Homarus americanus* following transfer from 22° C acclimation temperature to several higher test temperatures.

Broodstock management

The institutional market for lobsters in the United States demands a steady supply of live or fresh-frozen one-pound adults. To meet this requirement and to ensure economical operation and utilization of the culture facility, a broodstock program to provide berried females on a year-round basis is necessary. We have demonstrated that continuous production of larvae is possible when females are held at various temperatures to accelerate or retard egg development prior to hatching. However, it will be more difficult to provide a dependable source of berried females. Three potential sources are: females captures from the wild that are carrying eggs, females that have previously mated and will extrude eggs, and females produced by a controlled broodstock program. Lobsters have been mated successfully in the laboratory for many years. However, successful egg extrusion and pursuant hatching have been accomplished only infrequently. Our recent efforts to hybridize the American lobster, *H. americanus,* and the European lobster, *H. gammarus,* have resulted in increased numbers of mating leading to successful hatching. The progeny from several hybrid crosses (Fig. 5) have been cultured for nearly two years and some are expected to reach maturity in the spring of 1979. Although the hybrids have not shown any superior aquaculture characteristics in the first generation, subsequent generations are expected to possess increased heterozygosity and may exhibit hybrid vigor or other desirable traits. The immediate advantage of hybrid crossing has been the increase in numbers of successful extrusions and hatches, infrequently accomplished in intraspecific mating of either species.

Development of artificial diets

Nutrition research at SDSU has concentrated on the development of practical diets which promote adequate growth and survival and have suitable stability in water so that they can be used in our evaluation of prototype production systems. Studies have been conducted concerning problems related to dietary deficiencies, improved processing and binding, and problems associated with storage, distribution, and waste removal. This year we developed a satisfactory method of pelletizing brine shrimp *(Artemia)* with an alginate binder to provide a maintenance diet used in studies evaluating several high-density culture system designs.

Previous results have shown that commercially available shrimp feeds reconstituted with crustacean meal from a variety of sources produce reasonable growth in lobsters fed these diets. This past year several new formulations, high in protein content and having the amount of cholesterol required by marine and freshwater shrimp, also were tested. In addition, experimental diets used in the culture of crayfish were fed to juvenile lobsters in a series of feeding trials. An experimental diet with 30% protein designed for freshwater shrimp culture gave the best results of all dry formulations tested. Lobsters fed high protein (50%) marine shrimp diets suffered significantly higher mortality. Those formulations extruded under high pressure were superior diets in terms of storage and water stability. Based on these studies a dry pelletized formulation was selected for feeding of lobsters being cultured in prototype production systems at the Ormond Beach Laboratory.

Food conversion efficiency

Recently an experiment was begun to examine the combined effects of temperature and feeding level on conversion efficiency in *H. americanus.* Accelerated growth rate at elevated temperatures is a common phenomena for many marine animals. However, changes in consumption rates and nutritional requirements associated with temperature increases are poorly defined for *H. americanus.* Several investigators have postulated that the optimum temperature for growth would decrease as the amount of food provided was reduced. Where feeding levels are restricted, the decrease in maintenance metabolism at low temperatures allows a larger percentage of the ration to be available for growth. To test this hypothesis for *H. americanus,* four groups of juvenile lobsters are being cultured at temperatures of 10, 15, 20 and 25° C. The effect of feeding level is being studied by providing several subgroups a daily ration of *Artemia* equal to 0, 1, 2 and 4% of the lobsters' live body weight. A fifth group

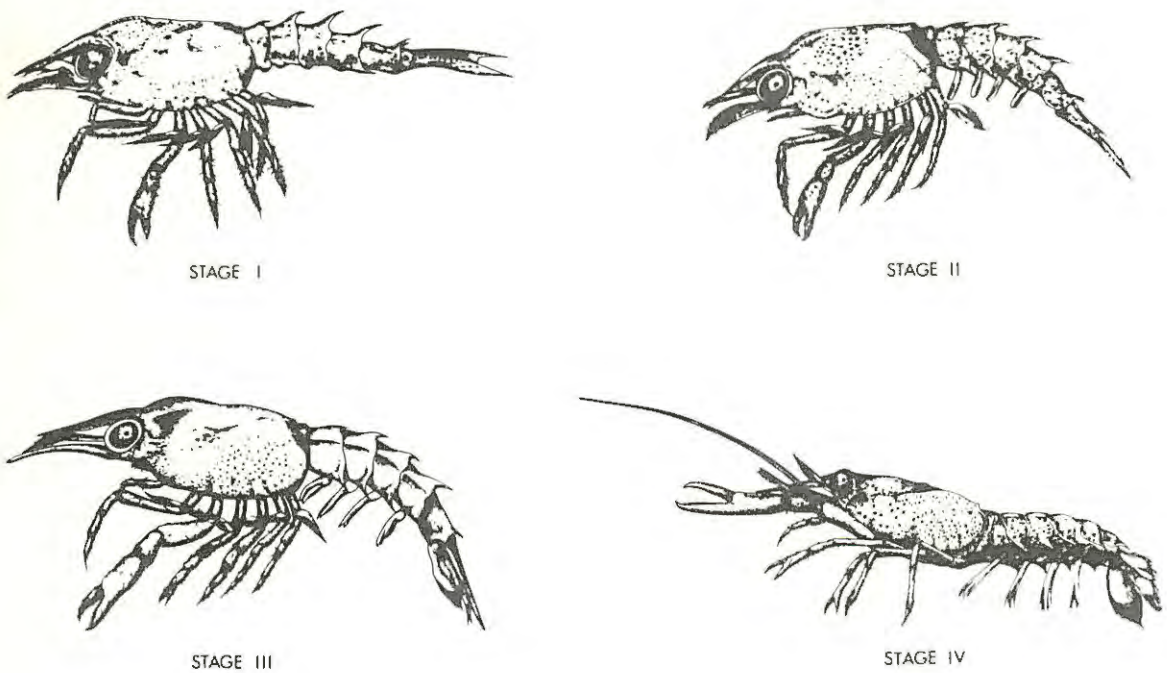


Figure 5. Four larval stages of a hybrid lobster resulting from mating a female *Homarus gammarus* with a male *Homarus americanus*.

receives an *ad libitum* feeding level. Preliminary results after 90 days of culture reveal decreased conversion efficiencies with increased feeding level. This is consistent with findings by other workers who fed varying amounts of *Artemia* to penaeid shrimp and other decapods. Also, food conversion efficiency does not appear to be strongly influenced by culture temperature. There is a slight increase in efficiency at 15° C, but it appears that it will be less expensive to rear *H. americanus* at the optimal growth temperature (20-22° C) due to the decreased production time involved. These experiments are continuing.

Water quality

Ammonia is the major excretory product of crustaceans and is toxic at relatively low concentrations. In closed, recirculating culture systems, ammonia derived from excretion and from the breakdown of unconsumed food particles may increase to toxic levels. In our previous studies of fifth stage larvae of *H. americanus,* we observed an LC_{50} value of 37 mg $[NH_3+NH_4^+]$-N/1 (total ammonia concentration). Our recent work has extended these observations to include two larger size classes of *H. americanus.* We have found LC_{50} values of 41.7 mg and 67.7 mg $[NH_3+NH_4^+]$-N/1 for lobsters of 8-9 mm carapace length and 25-30 mm carapace length, respectively. These data indicate increasing tolerance to total ammonia in the culture water with increasing animal size. The pH and temperature of culture water both modify the toxicity of a given ammonia concentration and thus all LC_{50} values were determined under optimal lobster culture conditions (pH = 8.1, T = 22° C). Knowledge of these parameters is valuable for evaluating "safe" levels of ammonia in culture water and for determining required pumping costs in a large-scale culture operation.

Flavor evaluation

A cooperative study with the Foremost Research Center in Dublin, California compared the flavor of wild-caught with cultured lobsters. The purpose of this evaluation was to determine whether the sensory properties (taste, odor, color and texture) of cultured and wild-caught lobsters are similar and would therefore have similar consumer acceptability. A limited quantity of the cultured animals was available, and therefore a descriptive panel evaluation by taste experts was selected as a logical first step prior to a consumer acceptability test requiring more animals.

In analyzing the flavor of wild-caught lobsters, the panel first noted a moderately chewy/rubbery texture. Flavor notes were, in order: sweet (threshold to slight), shellfish (slight to moderate) and salty (threshold to slight). An earthy character was noted by a minority of the panelists. In the cultured lobster, a slight chewy/rubbery texture was noted, with flavor notes, in order: shellfish (slight), sweet (slight), salty (threshold to slight) and lastly a threshold earthy flavor. The panel agreed that the cultured lobster were more moist, thus less rubbery. Both the wild-caught and cultured lobsters left a shellfish after-taste. In addition, the cultured lobster samples left a slightly salty flavor. After boiling, the shell color of the two lobster groups differed slightly; the wild-caught had a deeper red tint and the cultured lobsters had a more orange-red tone.

The panel concluded that cultured lobsters raised in captivity and fed an artificially formulated diet had aroma and flavor characteristics quite similar to that of the wild-caught animals tested. This information was very encouraging. Also, we recently conducted a preliminary consumer taste evaluation in cooperation with Ghio Seafoods of San Diego. Lobsters cultured at laboratories in San Diego and Bodega Bay were used in these tests. Several seafood experts were very favorably impressed with the flavor of these animals. Many of the cultured animals were 100-200g, which is smaller than the typical market size of 500g. The seafood representatives were convinced that a sizable market could be developed for these juveniles, which they felt could be described as a product similar to prawn and scampi. As a result of this information, we are evaluating the relative costs of producing juveniles rather than adults as a final product.

Publications

Botsford, L. W., J. C. Van Olst, J. M. Carlberg and T. W. Gossard. 1978. The use of mathematical modeling and simulation to evaluate aquaculture as a beneficial use of thermal effluent. *Proc. 1977 Computer Simulation Conference,* Chicago, Ill. 1978.

Botsford, L. W., J. C. Van Olst, J. M. Carlberg and T. W. Gossard. 1978. Economic evaluation of the use of thermal effluent in lobster culture. Power Plant Waste Heat Utilization in Aquaculture - Workshop II, New Brunswick, NJ, March 1978. Publ. by PSE&G Co., Newark, NJ.

Carlberg, J. M. and J. C. Van Olst, 1977. Development of high density culture techniques for lobsters and other crustaceans. Ann. Mtg. American Fisheries Soc., *Cal-Neva Wildlife Trans.* (Feb. 1977): 125-136.

Carlberg, J. M. and J. C. Van Olst. 1978. Methods for culturing the American lobster, *Homarus americanus.* Third Meeting of the ICES Working Group on Mariculture, Brest, France, May 1977, 4: 261-275.

Carlberg, J. M., J. C. Van Olst and R. F. Ford. 1978. Pilot-scale systems for the culture of lobsters in thermal effluent. Power Plant Waste Heat Utilization in Aquaculture - Workshop II, New Brunswick, NJ, March 1978. Publ. by PSE&G Co., Newark, NJ.

Carlberg, J. M., J. C. Van Olst and R. F. Ford. *In press.* A comparison of growth of larval and juvenile stages of the lobsters *Homarus americanus, Homarus gammarus,* and their hybrid. *Proc. 9th Ann. World Mariculture Soc. Mtg.*

Delistraty, D. A., J. M. Carlberg, J. C. Van Olst and R. F. Ford. *In press.* Ammonia toxicity in cultured larvae of the American lobster, *Homarus americanus.* Statutory Mtg. ICES, Reykjavik, Iceland, 1977.

Ford, R. F. 1977. Growth patterns of lobsters (review paper). *Proc. U.S. - Australia Workshop on Lobster and Rock Lobster Ecology and Physiology,* Perth, Australia, B. F. Phillips and J. S. Cobb (eds.): 83-102. Circular No. 7, CSIRO Division of Fisheries and Oceanography.

Van Olst, J. C. and J. M. Carlberg *In press.* The effects of container size and transparency on growth and survival of lobsters cultured in individual containers. *Proc. 9th Ann. World Mariculture Soc. Mtg.*

Van Olst, J. C., J. M. Carlberg and R. F. Ford. *In press.* Aquaculture systems utilizing thermal effluent. Statutory Mtg., ICES, Copenhagen, Denmark.

Van Olst, J. C., J. M. Carlberg and R. F. Ford. 1977. A description of intensive culture systems for the American lobster *(Homarus americanus)* and other cannibalistic crustaceans. *Proc. 8th Ann. World Mariculture Soc. Mtg.* 8: 271-292.

Van Olst, J. C., J. M. Carlberg and J. T. Hughes. *In press.* Lobster aquaculture, in *The Biology of Lobsters,* J. S. Cobb and B. F. Phillips, eds. Academic Press, New York (ms in review).

Cooperating Organizations

San Diego Gas & Electric Company

Research and Development Program, Southern California Edison Company

San Diego State University Foundation

National Marine Fisheries Service

University of California Davis and Bodega Marine Laboratory, UC Berkeley, Sea Grant Aquaculture Program

Massachusetts State Lobster Hatchery

Canada Fisheries and Marine Service, St. Andrews Biological Station

Foremost Foods, Research and Development

Ghio Seafoods

Protective Measures for Shellfish Aquaculture

James F. Steenbergen, *San Diego State University*

A number of disease problems are now recognized in crustacean aquaculture systems. These have recently been reviewed by Fisher *et al.*, (1978). Gaffkemia, a fatal bacteremia in lobsters, causes epizootics in the wild, in impoundments and in aquaculture systems. *Leucothrix*, and related epibionts, are associated with significant losses in larval and juvenile stages of lobsters and shrimp. Several types of gram negative bacteria cause septicemia in stressed lobsters. Exoskeleton lesions occur in lobsters, crabs, and shrimp held in aquaculture facilities. Fungal infections by *Fusarium*, *Lagenidium*, and *Halipthoros* have caused devastating outbreaks in both shrimp and lobsters.

During the past year, we have diagnosed major problems from gaffkemia, *Leucothrix*, *Fusarium*, and exoskeleton infections in our autopsy specimens. The potential limitations that these diseases may place on future aquaculture ventures may have been underestimated. Although it may be true that under optimal conditions (e.g. water quality, nutrition, feeding, etc.) these disease problems can be minimized, we have not yet reached that level of sophistication in our aquaculture systems. Nor are we likely to reach these goals in the near future, since economically practical aquaculture will not allow unlimited flow rates and other optimal, but costly, measures. Consequently, we predict that continual bacteriological monitoring, with antibiotic or other chemical treatments where warranted, will be necessary to avoid disastrous disease outbreaks in aquaculture projects.

Leucothrix infestations of larval and juvenile stages of crustaceans in aquaculture is one problem which we have addressed this year. In order to combat the disease, we need to know more about the mechanisms by which it spreads. Before we can study the epidemiology of the disease, we must develop techniques for detection of subtypes within the species *Leucothrix mucor*. To this end, we have developed serological and electrophoretic techniques for subtype recognition. Acrylamide gel electrophoresis of the free endotoxin fraction from *Leucothrix* strains appear most promising. Using this technique, we have established that the strains that infect crustaceans are not distinct from strains isolated as epibionts of marine algae. Consequently, we can conclude that there are no specific epibionts of crustaceans, and that the strains which make up part of the normal microflora of the nearshore waters are opportunistically infesting the aquaculture systems. We have developed antibiotic treatments that help to control epibiotic growth of *Leucothrix* and related bacteria on lobsters.

Exoskeleton lesions of cultured larvae are a continuing problem. The chitinolytic bacteria associated with these lesions are part of the normal microflora of lobster surfaces. Accumulated evidence indicates that a normal, wild-type chitin exoskeleton, overlaid by an unbroken waxy epicuticle, is rarely seriously infected. Nutritionally deficient lobsters may not produce a normal epicuticle, thereby allowing the chitin-digesting bacteria to gain access to the chitin layers. Therefore, it is reasonable to believe that better water quality and a nutritionally optimum diet will solve much of the exoskeleton problem. Until that time, antibiotics and/or chemical treatments may help to limit the problem.

Publications

Low, David. 1977. Antigenic and chemical analysis of cell walls of *Aerococcus viridans*. M.S. thesis, San Diego State University.

Steenbergen, Suzanna. 1977. Immunity and temperature effects on *in vitro* phagocytes by *Homarus americanus* hemocytes. M.S. thesis, San Diego State University.

Fisher, W. S., E. H. Nilson, J. F. Steenbergen and D. V. Lightner. 1978. Microbial diseases of cultured lobsters: a review. *Aquaculture* 14: 115-140.

Schapiro, H. C., J. F. Steenbergen and Z. Fitzgerald. 1978. Hemocytes and phagocytes in the American lobster, *Homarus americanus*. *Comp. Pathobiol.* 3: 128-133.

Steenbergen, J. F., H. S. Kimball, D. A. Low, H. C. Schapiro and L. N. Phelps. 1977. Serological grouping of virulent and avirulent strains of the lobster pathogen *Aerococcus viridans*. *J. Gen. Microbiol.* 99: 425-430.

Steenbergen, J. F., S. M. Steenbergen and H. C. Schapiro. 1978. Effects of temperature on phagocytosis in *Homarus americanus*. *Aquaculture* 14: 23-30.

Cooperating Organizations

Environmental Research Laboratory, Tucson, Arizona

KELCO Corporation, San Diego, California

San Diego State University, Sea Grant Aquaculture Research Program

Biochemical and Genetic Control of Critical Physiological Processes in Molluscan Life-Cycles: Basic Mechanisms, Water-Quality Requirements, and Sensitivities to Pollutants

Daniel E. Morse, *Marine Science Institute, University of California, Santa Barbara*

Our previous research has shown that planktonic larvae of the California red abalone *(Haliotis rufescens)* are induced in the presence of specific crustose red algae to settle and begin metamorphosis, benthic feeding, rapid development and growth (Morse 1978). From these natural algal inducers we have identified a family of homologous chemical inducers (Fig. 1) which can be used conveniently and inexpensively, in pure form, to induce behavorial and developmental metamorphosis of abalone larvae upon natural or synthetic substrates. Of these chemical inducers, the most potent and inexpensive is γ-aminobutyric acid ("GABA"), a naturally occurring amino acid and potent neurotransmitter in many species (Morse *et al.*, in press, b; Morse *et al.*, 1979).

Larvae used in the experiment were produced by our previously described technique for peroxide-induction of spawning (Morse *et al.*, 1977), followed by controlled fertilization and cultivation in 15° fresh filtered seawater. Larvae became uniformly competent for GABA-induction of settling 6-7 days following fertilization (Fig. 2). Within minutes after its addition to seawater at high concentration (10^{-3} M), GABA induces 100% of all competent abalone larvae to settle and begin benthic locomotion and feeding behavior (Fig. 3). At lower concentrations (10^{-6} M optimal), induction of settling proceeds over 1-3 hours, with $\geqslant$ 95% of all competent larvae showing developmental metamorphosis to the adult form (marked by the growth of the new, adult shell - see Fig. 4) within 2-3 days (Morse *et al.*, in press, b; Morse *et al.*, 1979).

Use of GABA or other related naturally required biochemical inducers thus provides a convenient and inexpensive means for controlling the settlement and metamorphosis of larvae of this species. Synchronous development with a high yield of survival can thus be obtained for mass production of this protein-rich and commercially valuable food species. GABA also has been found an effective inducer of settling, behavorial, and developmental metamorphosis of the planktonic larvae of certain other species of marine molluscs. Functionally related, simple transmitter substances are expected to prove useful in controlling the development of a large number of other species as well.

Use in bioassays

The physiological GABA-dependent induction of behavioral and development metamorphosis affords a convenient measure for quantitating and defining other factors which may influence (or be required for) the success of these processes. Thus, for example, the GABA-dependent induction of settling provides a rapid bioassay (Fig. 5) for the presence of interfering pollutants, including a variety of halogenated organic pesticides (Table 1) (Morse *et al.*, 1979). Results of these assays indicate that settling (and thus, reproductive success) is far more sensitive to such environmental stress than is the simple viability of the planktonic larvae. This bioassay also has proven useful in detecting and quantitating interference with natural settling (recruitment) of abalone larvae caused by industrial effluents, nitrogenous wastes, and other pollutants from urban, industrial, and agricultural sources (Morse *et al.*, in press, b). This assay will thus be useful in defining water-quality standards required for optimal hatchery and seed-production facilities, optimal sites for cost-effective reseeding of depleted coastal habitats, and marine and aquatic environmental quality assessment standards for a variety of other purposes.

Table 1

GABA-Dependent Bioassay

Detects Sensitivity to Pesticides at Sub-Lethal Concentrations

Pesticide	Mortality (%)	Interference in Settling (%)
(None)	0	0
DDT	0	100
Methoxychlor	0	100
Dieldrin	11	100
2, 4-D	0	7

Publications

Morse, D. E., H. Duncan, N. Hooker and A. Morse. 1977. Hydrogen peroxide induces spawning in molluscs, with activation of prosta-glandin endoperoxide synthetase. *Science* 196: 298.

Morse, D. E. 1978 Biochemical and genetic control applied to the critical stages in culturing abalone. *University of California Sea Grant Program Annual Report 1976-77:* 71.

Morse, D. E., N. Hooker, H. Duncan and L. Jensen. 1979. γ-aminobutyric acid, a neurotransmitter, induces planktonic abalone larvae to settle and begin metamorphosis. *Science,* **in press.**

Morse, D. E., N. Hooker and A. Morse. In press, a. Chemical control of reproduction in bivalve and gastropod molluscs, III: an inexpensive technique for mariculture of many species. *Proc. World Mariculture Soc.,* Atlanta, January, 1978.

Morse, D. E., N. Hooker, L. Jensen and H. Duncan. *In press,* b. Induction of larval abalone settling and metamorphosis by γ-aminobutyric acid and its congeners from crustose red algae, II: application to cultivation, seed-production and bioassays; principle causes of mortality and interference. *Proc. World Mariculture Soc.,* Honolulu, January, 1979.

Morse, D. E., L. Jensen, N. Hooker, A. Cameron and M. Tegner. *In prep.* Biochemical recruitment of planktonic molluscan larvae: contact-dependent signalling by algal metabolites. Accepted for publication in *Trans. New York Acad. Sci.*

Cooperating Organizations

California Department of Fish and Game

Scripps Institution of Oceanography, University of California, San Diego, Sea Grant Experimental Abalone Enhancement Program

University of California, Davis, Aquaculture Research Laboratory

Bodega Bay Marine Laboratory, University of California, Berkeley

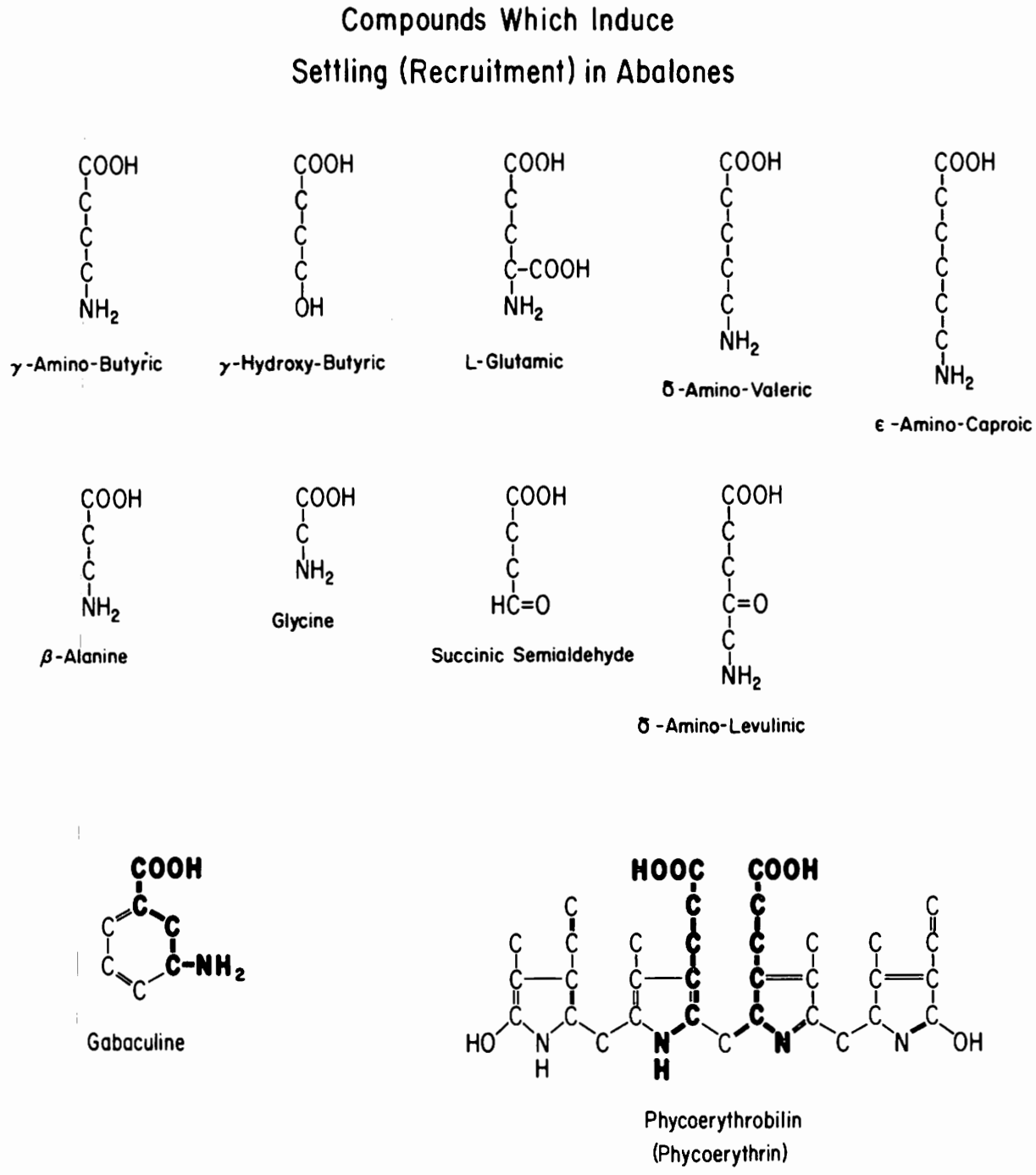


Figure 1. Compounds which induce settling of competent *H. rufescens* larvae, showing homologous relationships between active inducers. Methylene hydrogen atoms have been omitted for clarity. (Morse *et al.*, 1979).

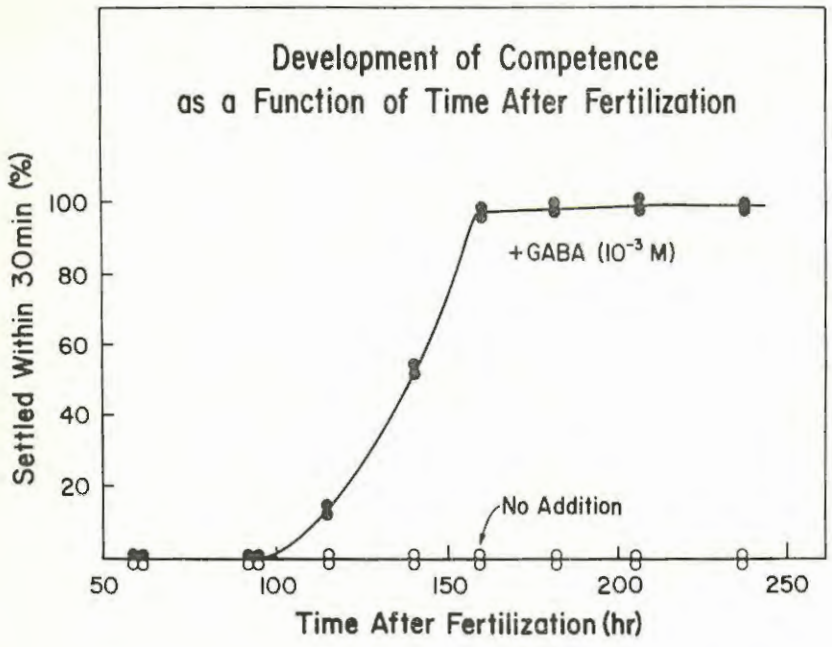


Figure 2. The development of competence for the induction of settling by GABA is followed in a population of larvae as a function of time (at 15°C) following fertilization. Aliquots of the developing larvae were withdrawn and assayed in duplicate both in the presence (filled circles) and absence (open circles) of GABA as in Fig. 3. Results are expressed as the percentage of larvae successfully settled within 30 min. after exposure to GABA, as a function of the time of development prior to testing. (Morse *et al.*, 1979).

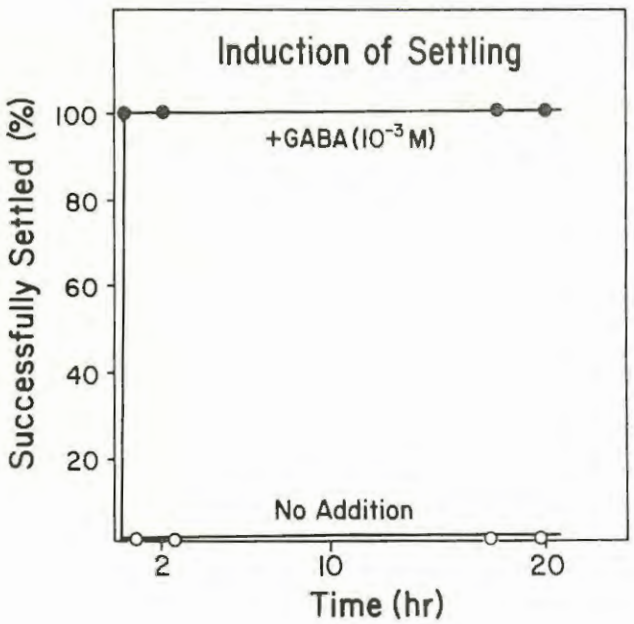


Figure 3. Kinetics of the induction of settling in a 7-day old population of larvae. Assays were performed in duplicate, both in presence (filled circles) and absence (open circles) of added GABA (10^{-3} M). The percentage of larvae in each vial exhibiting plantigrade attachment was quantitated by microscopic examination as a function of time following the addition of GABA. (Morse *et al.*, 1979).

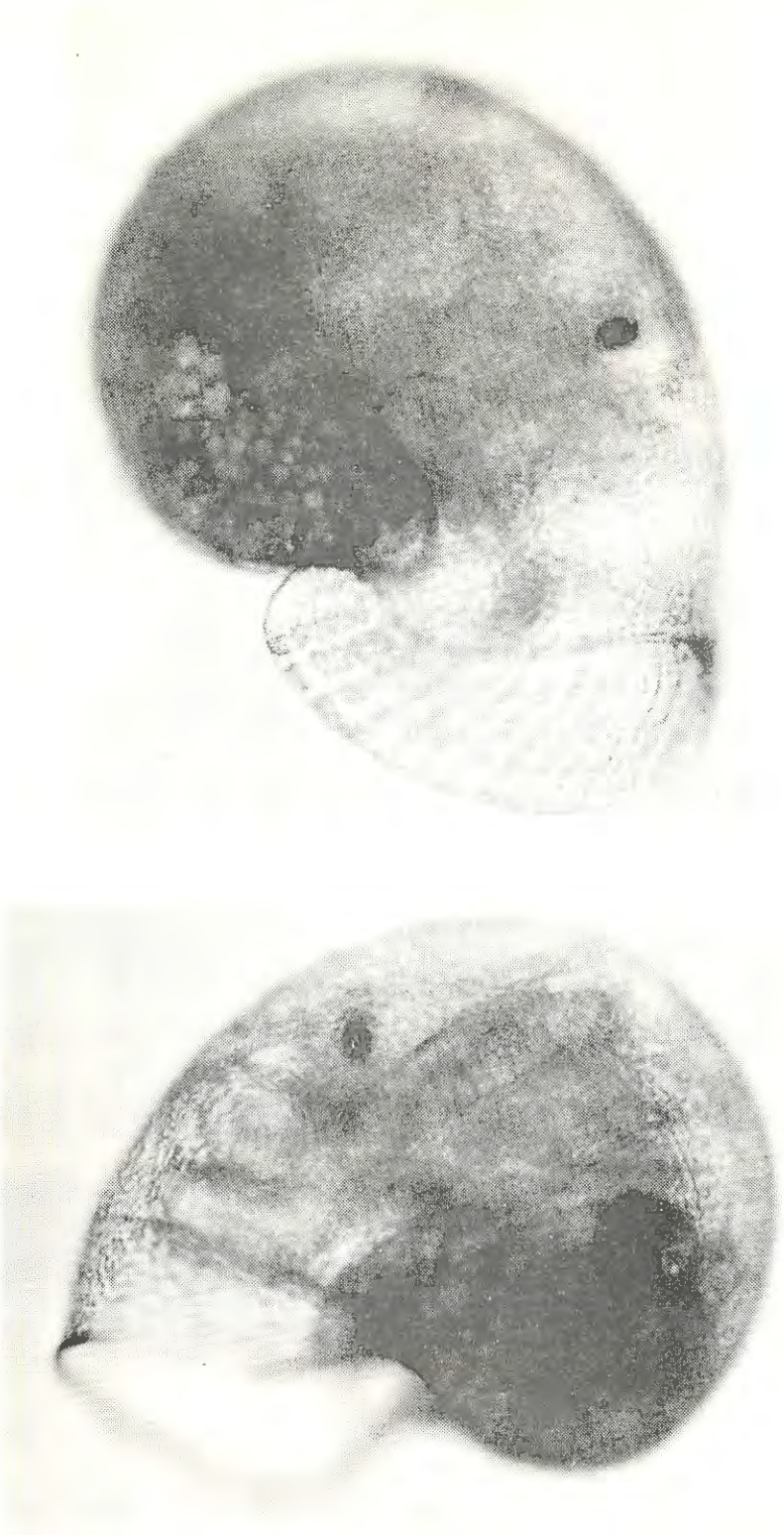


Figure 4. Developmental metamorphosis induced by GABA. Induction results in the synthesis of conspicuously rayed new shell, characteristic of the adult, as seen in the specimen above fixed in formalin 42 hr after induction by 10^{-6} M pure GABA. The sibling below treated in parallel, received no GABA. Longest dimensions ca. 210 and 180 μm, respectively. (Morse *et al.*, 1979).

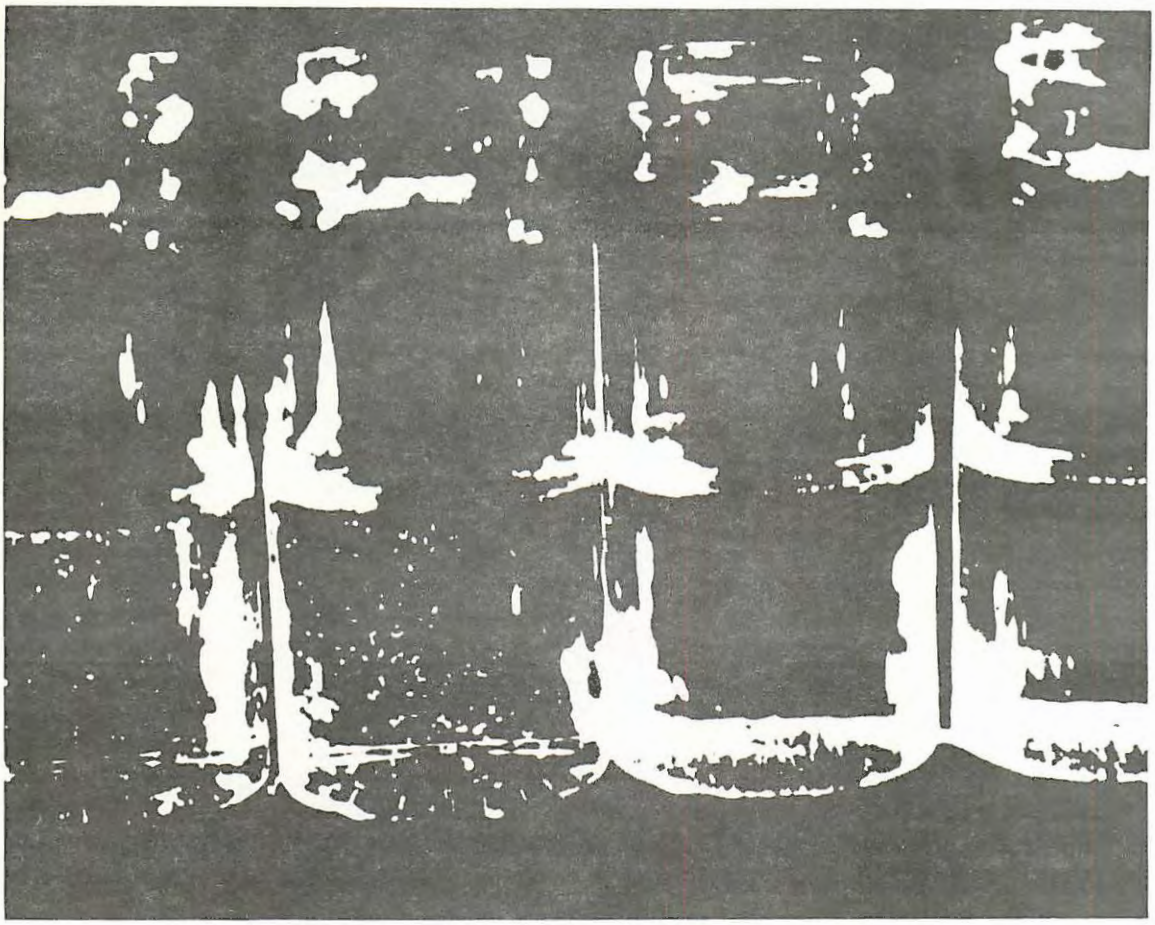


Figure 5. GABA-dependent induction of behavorial and developmental metamorphosis conveniently assayed in small glass vials (2.2 cm diam) containing aliquots of 100-300 competent, swimming larvae of *H. rufescens* (in 10 ml filtered seawater, 15°C). GABA was added to the two vials on the right (to a final concentration of 1 mM) 3 min before the photograph was taken; the two vials on the left received no additions. Microscopic examination (20-40X) shows virtually all of the larvae in the presence of GABA to have settled and assumed plantigrade attachment and locomotion on the glass; none are attached to glass in the absence of GABA. (Morse *et al.*, 1979).

Aquaculture of the Purple-Hinge Rock Scallop

Charles F. Phleger and David L. Leighton
San Diego State University

Filter-feeding molluscs (e.g., oysters, mussels, and clams) appear to offer aquaculture a level of ecological and economic efficiency yet to be reached in culture of crustaceans and fin-fish. The purple-hinge rock scallop, *Hinnites multirugosus,* is the subject of study at San Diego State University to evaluate its suitability for marine aquaculture. Characteristics of flavor, marketability, growth rate, tolerance to a broad range of physical conditions, and manipulability in hatchery and field-rearing operations combine to place *Hinnites* in a foremost position among candidates for commercial production.

Hinnites is unique among scallops in that it cements to a firm substrate after a relatively prolonged free-living or byssal-attaching juvenile stage. This behavior provides an advantage to extensive culture, since attachment to growing surfaces may be regulated and spatial distribution optimized.

This three-year study has been exploring pertinent aspects of *Hinnites* biology including reproduction, requirements for larval culture, substrate preference, natural foods, tissue chemistry, and growth rates in a wide variety of natural environments ranging from bays to the open sea, at depths from five to 130 meters.

During this last year of the project, emphasis was directed both to improvement of culture techniques to increase survival of larvae through metamorphosis, and to comparative observations on growth of scallops in ocean and in bay locations to define practical environmental limits for extensive culture of this shellfish. Other research concerned improved designs for scallop rearing structures, studies of substrate selection in juveniles, and determination of temperature and salinity tolerance of young adults.

Laboratory studies in larval culture provided very encouraging survival and growth in experiments using *Monochrysis, Isochrysis, Rhodomonas* and *Phaeodactylum* as food and in which both the medium and algae were renewed every two to three days throughout the three-week larval incubation period. Metamorphosing larvae were cultured to juvenile stages in a mesh-bottom tank constructed of black fiberglass which was immersed in a bin containing well-circulated nutrient-enriched seawater and food algae (Leighton, 1977; Leighton and Phleger, 1978). Hatchery-reared scallops from a 1976 spawning have reached market size while held for two years in Quivira Basin, Mission Bay. This group of scallops was induced to spawn last spring.

In the field, juvenile scallops were introduced to cages located at five stations within Mission Bay to compare year-long growth in fore-, mid-, and back-bay areas. Twenty individuals comprised each group. All were measured every three months to evaluate seasonal influences. At all bay locations except the back-bay, survival and growth of scallops was excellent; individuals averaging 1.2-1.6 cm at the onset reached 7.8-8.2 cm after one year. In back-bay locations, however, both slow growth and high mortality occurred. Salinity was reduced below 22 o/oo during winter periods of heavy rainfall and temperatures also were above 25° C in late summer. Both of these conditions are beyond tolerance limits for *Hinnites* in the San Diego area (Leighton and Phleger, 1978).

The U.S. Navy (NOSC) Oceanographic Platform 1.1 km off the San Diego coast served as an ocean station for scallop growth studies. There, groups of juvenile scallops were placed in cages attached to subsurface braces at depths from 3 to 18 m. Comparable groups were established in Quivira Basin. Observations on growth were made throughout one year, with measurements of shell size obtained each two months. While fouling and surge interfered with success of scallops and the cages at 3 m beneath the platform, excellent growth and survival was found for scallops at 9 and 18 m. Groups at

the ocean station grew only slightly less than those in Mission Bay over the one-year period; scallops averaging 2.2-2.4 cm reached 8.3 and 8.8 cm for the platform and Quivira Basin stations, respectively (Monical, in prep.). Additional groups of scallops were employed in experiments to evaluate the influence of density and crowding on growth. An optimal stocking density for scallops 2-8 cm was found to be $10/.1m^2$ (Monical, in prep.; Leighton and Phleger, 1978).

In another ocean location, caged scallops were held at a series of depths from 8 to 120 m on an anchored and buoyed line for a three-month period in fall 1977. The site selected was near the La Jolla Submarine Canyon, 5 km offshore from the Scripps Institution of Oceanography, over the 130 m contour. Pairs of cages with scallops distributed on asbestos board slats were secured to the line at 8, 15, 30, 60, 90 and 120 m. Average monthly shell growth ranged from 6.1 to 8.1 mm for the three uppermost positions; growth at 15 m was as good as or better than that observed for scallops in Quivira Basin during that season. Poor growth (group average 2.5-4.8 mm/mo) was found for scallops held at 60-120 m (Leighton, in press; Leighton and Phleger, 1978). These findings suggest a practical depth limit for rock scallop culture may lie between 30 and 60 m in southern California offshore waters. Since the proximity of the submarine canyon may have influenced both food availability and temperature, further study is planned of scallop growth in coastal water at depths from 30 to 90 m.

A reusable plastic panel to hold cementing juveniles in spatial distribution optimal for subsequent growth to market size was developed as an economical and easily tended and harvested structure applicable to extensive rearing of scallops in protected environments. The panels are simply stacked with separators and buoyed or anchored in place with individual panels oriented vertically. This innovation has been described and submitted for patent protection through the San Diego State University Foundation and the University of California Sea Grant College Program

Studies of substrate preference among juveniles and tests of experimental "spat collectors" have shown that adult *Hinnites* shell matter is a rather remarkable attractant for recruiting juveniles. Further research could isolate the attractant and lead to the development of artificial substrates which compete effectively with the natural substrate and could serve, then, as an alternative means of producing juveniles stock to supply aquaculture.

Publications

Jacobsen, F. R. 1977. The reproductive cycle of the purple-hinge rock scallop, *Hinnites multirugosus* Gale 1928 (Mollusca: Bivalvia). M.S. thesis, San Diego State University.

Leighton, D. L. 1977. Experimental rearing of the purple-hinge rock scallop, *Hinnites multirugosus.* Paper presented at the First Symposium of the Latin American Aquaculture Association, Maracay, Venezuela.

Leighton, D. L. *In press.* A growth profile for the rock scallop *Hinnites multirugosus,* held in cages at several depths to 120 m off La Jolla, California. *Mar. Biol.*

Leighton, D. L. and C. F. Phleger. 1977. The purple-hinge rock scallop: a new candidate for marine aquaculture. *Proc. 8th Ann. World Mariculture Soc. Mtg.:* 457-469.

Leighton, D. L. and C. F. Phleger. 1978. The suitability of the purple-hinge rock scallop to marine aquaculture. Technical Report, University of California Sea Grant Program.

Monical, J. *In prep.* Comparative studies of growth in *Hinnites multirugosus* held for one year in different environments, depths and stocking densities (tentative title). M.S. thesis, San Diego State University.

Phleger, C. F., R. B. Holtz, P. W. Grimes, D. L. Leighton and F. R. Jacobsen. 1978. Chemical and sensory analysis of the purple-hinge rock scallop, *Hinnites multirugosus* Gale. *J. Food Sci.* 43: 1793-1796.

Cooperating Organizations

U. S. Navy, Naval Ocean Systems Center, San Diego, California

National Marine Fisheries Service, Southwest Fisheries Center, La Jolla, California

Astaxanthin From the Yeast *Phaffia rhodozyma*

M. J. Lewis and E. A. Johnson (trainee)
University of California, Davis

The bright, orange-red carotenid pigment astaxanthin is a component in diets of various marine animals necessary to produce their natural coloration. Animals raised in aquaculture systems, while quite healthy, are often lacking in color and therefore less desirable on the market. Previous dietary supplements providing astaxanthin have proved to be limited and expensive. Our research has found that the easily-grown yeast Phaffia rhodozyma *is an excellent source of astaxanthin for fish and crustacean diets, and has the potential to be developed on a commercial scale.*

Physiological astaxanthin production and extraction

The physiology of astaxanthin production by the yeast *Phaffia rhodozyma* and the application of this yeast as a dietary pigment supplement for various animals were studied. Astaxanthin was found to be firmly attached in the yeast cell and not extractable by lipid solvents unless the structure of the yeast cell was first altered. Mechanical rupture of *P. rhodozyma* in a Braun homogenizer or French press followed by solvent extraction resulted in quantitative astaxanthin recovery. These methods were used routinely for estimation of astaxanthin concentration.

The need for the large scale recovery of astaxanthin (> 100 mg) led to the development of an enzymatic method of extraction. The method utilized extracellular enzymes produced by the bacterium *Bacillus circulans* WL-12, which partially digested the yeast cell wall and rendered the carotenoid pigments extractable by lipid solvents. Complete extraction of astaxanthin from heat-killed *P. rhodozyma* cells was obtained after growing *B. circulans* WL-12 on these yeast cells for 26 h and then extracting the yeast-bacterium mixture with acetone. A bacteria-free lytic system, which gave quantitative extraction of astaxanthin from *P. rhodozyma,* was obtained by concentrating the culture broth from the growth of *B. circulans* WL-12 on *P. rhodozyma* cells. The lytic system was found to work most efficiently at pH 6.5 and with low concentrations of yeast.

The enzymatic method of astaxanthin extraction revealed that the cell wall was a barrier which prevented quantitative extraction of carotenoid pigments by lipid solvents. Consequently, the lysis of cell walls was studied using the lytic enzymes produced by *B. circulans* WL-12. First, an enzyme complex which lysed whole cells and cell walls of *P. rhodozyma,* was isolated from the culture fluid of *B. circulans* WL-12 grown in a medium containing cell walls of this yeast. A number of growth substrates were tested for their ability to induce cell wall lytic hydrolases, but only the cell wall-induced enzymes caused complete lysis. When the lytic system was incubated for 12 h with log phase yeast cells, spheroplasts of *P. rhodozyma* were produced, which indicates the ability of the lytic system to lyse whole cells.

Hydrolytic activities detected in the enzyme complex included β-(1→3)-glucanase, β-(1→6)-glucanase, α-(1→3)-glucanese, xylanase and chitinase. Protease, α-amylase, cellulase and α-mananase activities were not detected. *B. circulans* WL-12 produced xylanase and α-(1→3)-glucanase only when grown on xylan or α-(1→3)-glucan, respectively, but produced chitinase, β-(1→6)-glucanase and β-(1→3)-glucanase on a number of growth substrates.

Various enzyme fractions were tested for their ability to lyse purified *P. rhodozyma* cell walls. Using a multiple regression analysis, it was concluded that β-(1→6) and β-(1→3)-glucanases accounted for most of the cell wall lysis and that α-(1→3)-glucanase had a small lytic effect. It was also found that purified *P. rhodozyma* cell walls contain 90% D-glucose, 9% D-mannose and 1% D-xylose; this supports the

evidence that the glucanases are most important in cell wall lysis.

Culturing experiments

A series of experiments was conducted that were designed to determine the optimal culture conditions for growth and pigmentation of *P. rhodozyma*. It was found that astaxanthin biosynthesis occurred maximally during the exponential phase of growth. The pigment yield in the growth medium was not solely dependent on cell concentration but was influenced by the culture conditions. The optimal pH for astaxanthin production was found to be 5.0 in shake flasks. At the other pH levels tested, however, the concentration of astaxanthin in *P. rhodozyma* remained relatively constant.

An interesting phenomenon was observed in cells grown at pH 3.5. An examination of the carotenes produced at this pH revealed a predominance of β-zeacarotene in the carotene fraction of the pigment mixture. This pigment was not isolated from yeast grown at pH 4.5. It was concluded that this pigment accumulated in cells grown under adverse conditions due to the malfunctioning of the carotenogenic enzymes present, and not to the presence or absence of different enzymes. An alternative route for β-carotene synthesis was suggested for *P. rhodozyma*.

The temperature of cultivation was found to influence the growth rate of *P. rhodozyma* but not the accumulation of astaxanthin in the yeast cell. The effects of light also did not affect carotenogenesis in *P. rhodozyma*, although the cells grown under high light intensity appeared to have a redder hue, which may have been due to different concentrations of particular carotenoids.

It was found that a low glucose concentration and high air supply were needed for efficient astaxanthin production by *P. rhodozyma*. The concentration of astaxanthin in the red yeast decreased considerably if the air supply was below 20 mmoles/liter/hour or the glucose concentration was above 4% w/v. However, astaxanthin was still the predominant pigment in yeast cultured under either of these conditions. If the effects of low air and high glucose were combined, however, then the astaxanthin concentration in *P. rhodozyma* was decreased to extremely low levels and the formation of β-zeacarotene occurred. Under these adverse conditions, again, astaxanthin was not efficiently formed from the carotenes.

It was concluded that low aeration and high glucose concentration in the growth medium promoted fermentative metabolism by *P. rhodozyma*. This hypothesis was supported by data obtained from the growth of *P. rhodozyma* on various carbon sources. When cultured on carbon compounds which promoted aerobic glycolysis in this yeast (e.g. cellobiose) the yields of astaxanthin were very high. If cultured on carbon sources which presumably repressed aerobic glycolysis (e.g. glucose) the astaxanthin yields were low. Carbon compounds metabolized via the pentose-phosphate pathway (e.g. xylose) did not promote efficient carotenogenesis.

P. rhodozyma was found to produce high yields of astaxanthin when cultured in a liquid medium supplemented with tomato wastes. The improved yield may have been due to the incorporation by the yeast cell of specific terpenoid precursors. These results suggest that a process may be developed for the commercial production of astaxanthin by *P. rhodozyma*.

P. rhodozyma as a dietary supplement

The final section of this thesis was concerned with the utilization of *P. rhodozyma* as a dietary pigment and nutrient source for various animals. The ash content was found to be low compared to other yeasts. The carbohydrate content of the whole yeast cell was slightly higher, which may be a reflection of the thick cell wall of this microorganism. The protein content determined by the Folin-Lowry assay or by total nitrogen was only 25-30% (w/w). This value is significantly lower than found in other yeasts and suggests that *P. rhodozyma* is inferior to them as a source of protein. Its amino acid content was fairly well balanced but was low in methionine. *P. rhodozyma* contains a high proportion of lipids (= 20%) and is high in the fatty acids oleic and linoleic. The high fat content of this yeast

suggests its possible use in high energy animal diets.

An evaluation of the nutrient value of *P. rhodozyma* by using an insect bioassay (*Tribolium*, flour beetle) showed that this yeast supported less growth than *S. cerevisiae*. Slightly less growth was also observed in lobsters fed *P. rhodozyma* than in those fed *S. cerevisiae*. However, rainbow trout showed higher growth on diets supplemented with the red-yeast than on a diet supplemented with the same level of brewer's yeast. It is evident that a more thorough nutritional evaluation of *P. rhodozyma* is needed.

The yeast proved to be a superb source of pigment for rainbow trout or chicken eggs provided that the cell wall of *P. rhodozyma* was first altered to allow pigment deposition in the animal tissues. Lobster did not accumulate astaxanthin from *P. rhodozyma* to any significant degree.

The deposition of astaxanthin in the flesh of rainbow trout was dependent on the proper preparation of the yeast cells before their inclusion into the diet. No astaxanthin was available from intact yeast cells. If *P. rhodozyma* was mechanically ruptured its pigments could be transferred to the bodies of rainbow trout. Visual examination of the flesh revealed a beautiful salmon-pink color. The most efficient deposition of astaxanthin in the salmonids occurred when much of the cell wall of *P. rhodozyma* was removed by enzymatic digestion.

Carotenoids from mechanically-fractured yeast were incorporated into quail or chicken egg yolks. A wide range of colors was achieved in chicken egg yolks by the feeding of different combinations of yeast, marigold and corn pigments. Astaxanthin was most efficient in imparting pigment.

In conclusion, the evidence presented predicts the commercial use of the yeast *P. rhodozyma* as an animal feed supplement. The application awaits the development of fermentation methods for the production of astaxanthin and a method for processing the yeast to liberate but not destroy the carotenoids.

Publications

Johnson, E. A., D. E. Conklin and M. J. Lewis. 1977. The yeast *Phaffia rhodozyma* as a dietary pigment source for salmonids and crustaceans. *J. Fish. Res. Bd. Canada* 34: 2417-2421.

Johnson, E. A., T. G. Villa, M. J. Lewis and H. J. Phaff. 1978. Simple method for the isolation of astaxanthin from the basidiomycetous yeast *Phaffia rhodozyma*. *Appl. Microbiol.* 35: 1155-1159.

Johnson, E. A. 1977. The yeast *Phaffia rhodozyma* as a potential source of astaxanthin for the salmonoid industry. Paper presented at the Northern California Institute of Food Technologists Meeting, November, 1977.

Lewis, M. J. 1978. The yeast *Phaffia rhodozyma* as a dietary pigment source for salmonids and crustaceans. Paper presented at the Pacific Fisheries Technologists Meeting, February, 1978.

Johnson, E. A. 1978. Astaxanthin production by the yeast *Phaffia rhodozyma* and its use as a pigment source in animal feeding. M.S. thesis, University of California, Davis.

Cooperating Organizations

University of California, Davis, Department of Avian Sciences

California Department of Fish and Game, Mad River Hatchery and Nimbus Hatchery

Bodega Marine Laboratory, University of California, Berkeley

Experimental Abalone Enhancement Program

Mia J. Tegner, *Scripps Institution of Oceanography, University of California, San Diego*

California populations of abalones, succulent molluscs sought after by both commercial and sport fishermen, have declined considerably in recent years. The objectives of this project are to develop an understanding of the natural history and ecology of the major species of abalones in southern California and to use this knowledge to determine the scientific and economic feasibilities of different methods for enhancing stocks of this valuable shellfish.

This joint University of California Sea Grant College and California Department of Fish and Game program was guided by a steering committee, composed of representatives of the academic, industrial and management communities, with the first meeting held on September 27, 1977.

One of our major objectives for this year was to learn as much as possible about the ecology of the poorly-known juvenile abalones. Joint cruises were made to the Channel Islands with Department of Fish and Game biologists to study areas with healthy abalone populations. Juveniles were found to occupy different habitat types than adult abalones, specifically the undersides of rocks with less than 0.1 m^2 bottom surface area, the bottom underneath adult red sea urchins, or occasionally *Macrocystis* holdfasts. Medium and large abalones were found on larger, rocky surfaces: boulders, under ledges, in crevices or on vertical faces - habitats which do not appear to offer adequate protection from predation for juveniles. When both types of habitat were present, we observed both size classes; we generally saw only one size class in areas where only one of the habitat types was present.

We used these data to design our first seeding experiment which was conducted on Santa Rosa Island in December. One thousand red abalones were seeded into four different habitats, two natural ones based on the field studies, one artificial habitat of cinder blocks, and one mixture of boulders. While the series of storms we experienced last winter prevented complete evaluation of this experiment, the survival rate of the seed planted in a field of small boulders (the natural nursery habitat) was about twice that we found on the cinder blocks. These data suggest that the use of natural abalone nursery habitat will eliminate the need for artificial structures which are costly in terms of both time and material expenditures.

In July we began our life table studies to determine growth rates and size-specific mortality at Johnson's Lee, Santa Rosa Island, a site with a healthy red abalone population and some protection from prevailing winds. Five hundred animals were measured, tagged, and replaced for growth studies. A comprehensive survey was undertaken to analyze abalone densities, size-frequency distributions, and habitat preferences and to consider abalone food, competitors, and predators as well.

Some of the more important results of this survey concerned habitat preferences. Fifty-eight percent of the emergent (larger animals visible without turning rocks) and 71% of the nonemergent (smaller, hidden) abalones were found in habitats categorized as rock/sand, i.e., substrate consisting of 25 to 75% sand. Forty-one percent of the emergent and 29% of the nonemergent abalones were found in habitat consisting of greater than 75% rock. The rock/sand category comprised 27% of the total habitat surveyed and the rock category 28%, therefore being roughly equally available habitats. These data therefore indicate a strong preference of juvenile abalones for the rock/sand habitat whether due to settlement preference or survival rate or both. This pattern held for both the first and second year classes.

Further small scale experimental plants were conducted at Point Loma in August and September to test the survivorship of seed in different natural habitats. Our Santa

Rosa observations of better survival of juveniles in rock/sand habitat were demonstrated experimentally. Based on the collection of dead animals, the mortality rate of seed planted in boulders set in sand was 7% compared with 34% for boulders set on pavement rock. Final evaluation of these experiments will be based on the collection of surviving seed this winter. We are currently conducting field and laboratory studies to determine whether this differential mortality is due to some aspect of abalone behavior or to different predator effectiveness in the two habitat types.

Cooperating Organizations

California Department of Fish and Game, Long Beach and San Diego.

Control of Reproduction in the Lobster

Prudence Talbot, *University of California, Riverside*

It would be highly beneficial to the development of the aquaculture of crustaceans to be able to control reproductive events in lobsters, crabs, and shrimp. This would facilitate certain laboratory procedures (such as controlled hybrid crosses). By closing the life cycle in captivity, it would also reduce costs to aquaculturists.

The longterm objective of this project is to acquire an understanding of and thereby gain control of reproductive events in decapods. This year, we initiated studies related to fertilization in the lobster. The structure of sperm from 2 lobsters *(Panuliris* and *Homarus)* was analyzed using light and electron microscopy. These sperm are atypically structured (e.g. *Homarus* sperm are immobile and have an uncondensed nucleus). The mechanism by which these sperm interact with eggs is at present only speculative. In general, sperm undergo an exocytotic event referred to as the acrosome reaction, as a necessary preliminary to fertilization. We were successful in inducing acrosome reactions in *Homarus* sperm using the calcium transporting ionophore A23187. The morphological details of this reaction are presently being examined with electron microscopy.

A second goal for the past year was to induce extrusion of sperm from living male lobsters. Although the injection of several muscle contacts was without positive effect, two males did extrude sperm spontaneously during handling. These sperm were fixed for electron microscopy and will be analyzed this year to determine how sperm in natural extrusions are packaged.

The results from the past year will aid in future analysis of fertilization in *Homarus* and will be helpful in the development of an *in vitro* fertilization technique for decapod gametes.

Publications

Talbot, P. and R. G. Summers. 1978. The structure of sperm from *Panuliris,* the spiny lobster, with special regard to the acrosome. *J. Ultrastructural Res.* 64: 114-124.

Talbot, P. and P. Chanmanon. 1978. The acrosome reaction of sperm from the lobster, *Homarus americanus. J. Cell. Biol.* 79: 158a.

Cooperating Organizations

Bodega Marine Laboratory, University of California, Berkeley

Colloids from Certain Seaweeds and their Application in Microbiological Media as Agar Substitutes

Isabella A. Abbott and Faylla A. Chapman
Hopkins Marine Station, Stanford University

In the first year of this study (1976), 16 species of marine red algae in central California were collected seasonally. A variation in abundance of some species and a constant availability of others was demonstrated. Spectro-photometric characteristics and gel strengths of the carrageenans, agars and other colloids present in these species, as well as percent yield of colloid for each gametophytic life stage was determined.

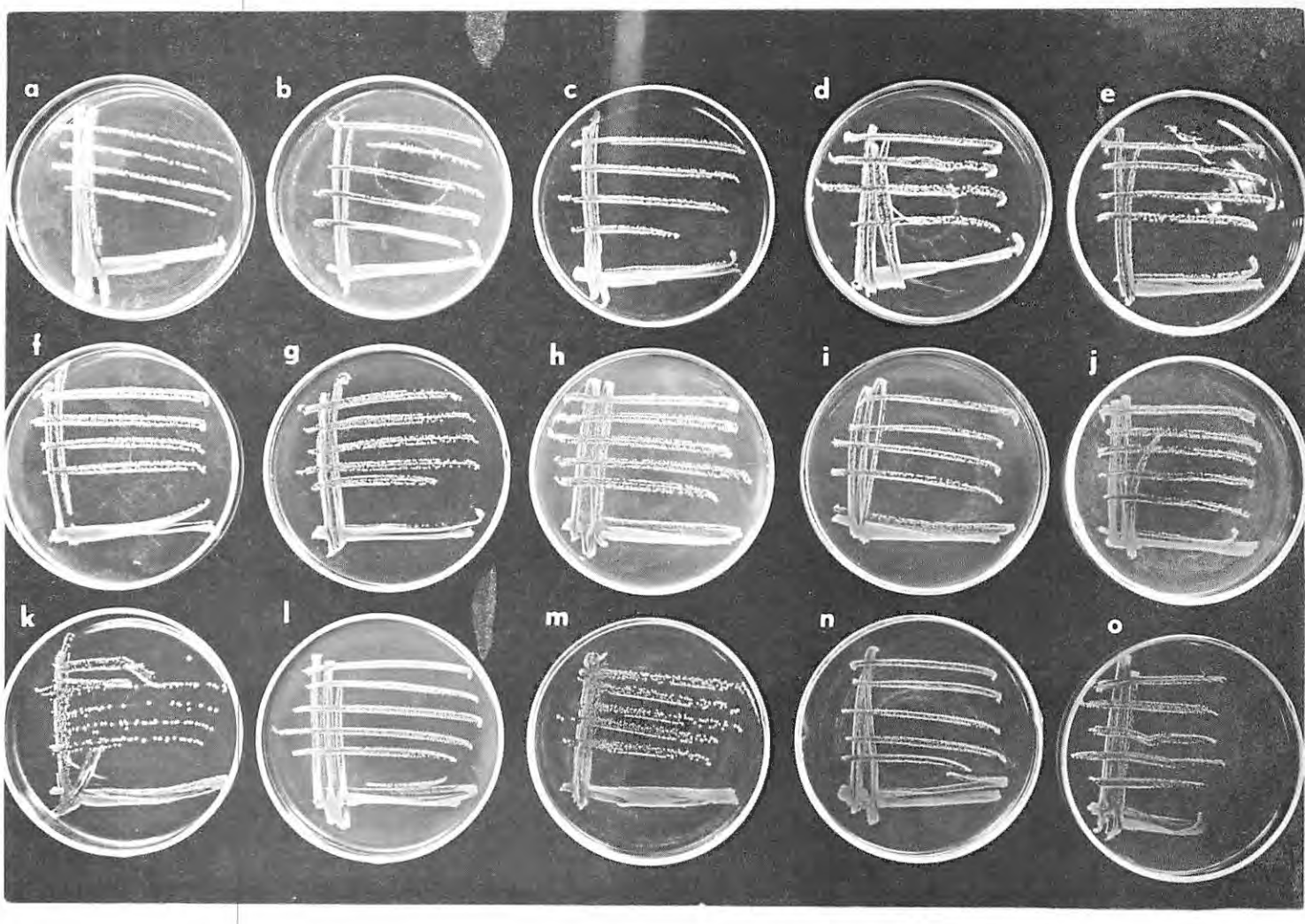
Seven algal species, 5 producing kappa-carrageenans, 1 an iota-carrageenan, and 1 an agar, were collected seasonally in the second year (1977) in order to assess the standing crop. Biomass/m^2 of each life stage (gametophytic and sporophytic) was determined after sampling 5 m^2 quadrats each season. The quadrat selection was biased by choosing areas where each species occurred, but not biased as to life stages present. Quadrats were scraped of the chosen alga and data were taken on other species present and their relative abundances. The scraped algae were sorted to life stage, dried and weighed. The greatest total biomass for all seven species was in the summer. Standing crop of each life stage varied but the gametophytic and sterile stages were most commonly encountered in the summer. The two algal species producing the best carrageenans as an agar substitute *(Gigartina leptorhynchos* and *Rhodoglossum affine)* displayed comparatively low biomass throughout the seasons.

Kappa carrageenans from 6 to 8 algal species were extracted in our laboratory from the seasonal collections of 1976-1977. The colloid from each gametophytic life stage (female and male/sterile), by season, was incorporated into a dextrose-yeast extract medium. Colloid solutions of 1.5%, 2%, 2.5%, 3% and 4% were tested for sol/gel properties, slant retention, clarity, surface strength and bacterial growth at temperatures between 28° C and 55° C. Bacto agar, Oxoid agar #3 and three commercially-produced kappa-carrageenans were tested in the same manner. In addition, all media were made with and without the addition of 0.2% potassium chloride (KCl).

General conclusions about kappa-carrageenans versus agar in microbiological media can be made irrespective of the algal species, seasonal variation, or method of extraction. Kappa carrageenan goes into solution at a significantly lower temperature (roughly 30-40° C lower) than agar and sets or gels at a lower temperature also. Syneresis, the formation of droplets of water as the colloid gels, is less in kappa-carrageenans than agar. These properties are advantageous in the speed of media preparation and use, especially where temperature of the media is important. The addition of KCl, even at the low 0.2% concentration, increased the gel strength of all the kappa-carrageenans but did not appear to affect the agar gel strengths. Tests with 0.5% KCl showed the maximum amount needed for best gel characteristics was somewhere between 0.2% and 0.5%. Also, the addition of KCl increased the syneresis in the carrageenans but not in the agars.

Seasonal variation in the carrageenans of the central California species was demonstrated in 2 ways: 1) gel strength at 25° C of a 2% colloid solution with 0.2% KCl added, and 2) a pass/fail series of tests culminating in a plate streak test. Gel strengths varied from a low of 20 grams pressure/cm^2 to break the gel to a high of 320 grams. Generally, a gel strength above 290 was needed for a good to very good rating in the plate streak test. This test was very subjective, dependent on thickness of the gel, the pressure used and also the tool used in streaking.

A seasonal breakdown of the numbers of good and very good gels is as follows, expressed as a % of total preparations:



Escherichia coli grown on a dextrose-yeast extract medium containing 0.2% KCl and the following colloids (% solution):

a) Bacto agar (2%)
b) Oxoid agar #3 (2%)
c) K-4 *(Chondrus crispus,* Sigma Chemicals) (2%)
d) K-7 *Eucheuma cottonii,* Marine Colloids) (2%)
e) K-13 *(Eucheuma cottonii,* Stauffer Chemical Company) (2%)
f) *Gigartina canaliculata* (2.5%)
g) *Gigartina canaliculata* (2.5%)
h) *Gigartina corymbifera* (2.5%)
i) *Gigartina leptorhynchos* (3%)
j) *Gigartina leptorhynchos* (2.5%)
k) *Gigartina harveyana* (2%)
l) *Gigartina volans* (1.5%)
m) *Iridaea flaccida* (4%)
n) *Rhodoglossum affine* (3%)
o) *Rhodoglossum californicum* (2.5%)

Note the clarity of the various media and also the individual colony growth $_{(k,m)}$ on those media which had a poorer streaking surface.

	Good	Very Good	Total pass
Fall 1976	12.0%	2.0%	14.0%
Winter 1976	8.3%	1.6%	9.9%
Spring 1977	10.0%	4.0%	14.0%
Summer 1977	7.3%	1.8%	9.1%
Commercial preparations	20.0%	26.0%	46.0%
Bacto agar	20.0%	80.0%	100.0%

Three percent of all California carrageenans were rated good without added KCl, none were very good. Without KCl, 23% of the commercial preparations rated good or very good. Bacto agar rated equally with or without KCl. *Gigartina leptorhynchos* and *Rhodoglossum affine* produced the greatest number of good and very good gels throughout the entire year (Gl = 20%, Ra = 30%).

Qualitative comparison tests for bacterial growth between the agars and carrageenans were routinely conducted using *Escherichia coli* (Fig. 1), *Proteus vulgaris, Lactobacillus casei* and *Pseudomonas fluorescens.* In all cases there seemed to be little difference in growth on any of the colloid media. Other organisms grown on the colloids were *Streptococcus thermophilus, S. diacetylactis, Acetobacter suboxydans, Saccharomyces cerevisiae, Lactobacillus acidophilus, Cytophaga marinoflava, C. flavensis* (both marine), *Neurospora* sp., as well as several unknown species kept in culture for their easily recognizable colony morphologies.

Cooperating Organizations

University of Hawaii, Department of Botany

McGill University, Department of Microbiology and Immunology, Montreal, Canada

McMaster University, Ontario, Canada

Marine Colloids, Rockland, Maine

Stauffer Chemical Company, Dobbs Ferry, New York

Iridaea Population Dynamics and Cultivation

William T. Doyle and Judith E. Hansen
University of California, Santa Cruz

The red alga *Iridaea cordata* (Turner) Bory is from a family of plants known to produce carrageenans. These phycocolloids are used as gelling, stabilizing and thickening agents in the food, textile, biomedical, cosmetic and pharmaceutical industries. The overall goal of this project has been to explore the potential of *I. cordata* as a domestic carrageenan resource. With Sea Grant support we have studied *Iridaea* carrageenan biochemistry (McCandless, *et al.*, 1975), population biology (Hansen and Doyle, 1976; Hansen, 1976; Packard, 1978; Hansen, in press), growth (Hansen, 1977a) and aspects of physiology (Hansen, 1977b).

The major results of these studies show that: a) *Iridaea* carrageenans (kappa and lambda) differ according to life history stage, similarly to *Chondrus* and *Gigartina*. b) Peak standing crops on the California open coast are comparable to commercial *Chondrus* crops on the Atlantic coast; however, *Iridaea* growth rates are considerably higher. c) *Iridaea* blades are true spring annuals with a perennial holdfast. d) *In situ* populations are dominated by the tetrasporangial stage and would therefore, produce predominately lambda carrageenan.

Subsequently, physiological and cultivation experiments were initiated to explore the feasibility of growing specifically male and female plants for kappa carrageenan. Results of the physiological studies indicate a difference in net photosynthetic rate between developmental stages of *I. cordata*, with sterile plants $\bar{X} = 2.49 \pm .08$ mgC/gm dry wt/hr, and reproductive plants in all stages $\bar{X} = 1.49 \pm .10$ mgC/gm dry wt./hr. Additionally, saturating irradiance is approximately 200 microeinsteins/m^{-2}/sec^{-1}.

Doubling time of *I. cordata* varies seasonally (11 to 59 days) and growth appears to be limited by irradiance/daylength during winter-early spring. NH_4-N is the "preferred" inorganic nitrogen source and is taken up when external seawater concentrations far exceed ambient coastal levels. These latter results specified the conditions necessary for offshore cultivation of this species, which was the object of our studies in the past 12 months.

Aquaculture/Field Cultivation

A nearshore experimental aquaculture system was developed for *Iridaea* employing nets as an artificial substrate. Nylon seine nets are sporulated with tetraspores in a circulating seawater tank system. Spores attach within 2 days and grow to 5 mm before outplanting nets on an offshore structure. Once the nets are outplanted, initial "fouling" by other algal species (primarily by green algae) presents a major problem. The cultured thalli outplanted in autumn, winter and summer have grown to approximately 8 cm, but to date have not reached maturity. These experiments are continuing.

Field experiments on *Iridaea* blade harvesting were concluded. Removal of the large, dominant blades during a favorable growth period (spring) stimulates outgrowth, but not initiation of juvenile, subordinate blades; blade removal during summer resulted in no outgrowth. Overall results indicate that internal control (possibly hormonal or a circadian mechanism) is integral in maintaining the integrity and seasonal growth of this species.

California *Iridaea cordata* is a good source of carrageenan for industry. *In situ* populations are dominated by diploid plants and are adequate only as a source of lambda carrageenan; additionally, they would be difficult to harvest. Aquaculture of this species, selecting for male/female plants, is a potential alternative. Techniques have been developed to successfully sporulate nets throughout the year. Outplanting on an offshore structure has been accomplished and harvesting experiments indicate that multiple crops could be grown in a year. The major problem is competition among

Figure 1. Experimental net culture of the carrageenophyte *Iridaea cordata*

other algal species. Selective "weeding" is currently in progress. We are attempting, in present experiments, to reduce the irradiance by placing the nets below the compensation depth for most green algae, which may give *Iridaea* a competitive advantage over "fouling" organisms. Presently, planning for large-scale aquaculture of *Iridaea cordata* is impeded by this problem of algal competition. Experiments concentrating on this will be continued at Hopkins Marine Station (Stanford University).

The concluding results of this project are described in Hansen (in prep.) and Hansen, *et al.* (in prep.).

Publications

Hansen, J. E. 1976. Population biology of *Iridaea cordata* (Rhodophyta; Gigartinaceae). Ph.D. thesis, University of California, Santa Cruz, 343 pp.

Hansen, J. E. 1977a. Ecology and natural history of *Iridaea cordata* (Rhodophyta; Gigartinaceae): growth. *J. Phycol.* 13: 395-402.

Hansen, J. E. 1977b. Productivity of *Iridaea cordata. J. Phycol. Suppl.* 13: 27.

Hansen, J. E. *In press.* Studies on the population dynamics of *Iridaea cordata* (Rhodophyta; Gigartinaceae). Proc. Int. Seaweed Symp., Wales, 8.

Hansen, J. E. *In prep.* Productivity of *Iridaea cordata:* photosynthesis versus growth.

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

Hansen, J. E., W. T. Doyle and J. E. Packard. *In prep.* Prospectus on red algal mariculture. Coastal Marine Studies, University of California, Santa Cruz/Sea Grant Special Report No. 10.

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

Packard, J. E. 1977. Field studies on the perennial crust/blade complex of *Iridaea cordata* (Gigartinaceae; Rhodophyta). *J. Phycol. Suppl.* 13: 52.

Cooperating Organizations

Marine Colloids, Inc., Rockland, Maine

Dr. I. A. Abbott, Hopkins Marine Station, Stanford University

Dr. T. Mumford, Washington Department of Natural Resources

Genetic Program for Improvement of Carrageenan Production in *Gigartina*

John A. West, *University of California, Berkeley*

The marine red alga Gigartina *is potentially a major source of the phycocolloid carrageenan which is widely used in commercial food products and some industries. Genetic selection of strains with higher yield and superior quality carrageenans appears probable through controlled laboratory breeding. We have continued this year investigations of the life history, hybridization and carrageenan production of species of*

Life history studies

Cultured carpospores from field collected plants of *Gigartina agardhii* Setchell and Gardner gave rise to either *Petrocelis*-like crustose plants, or basal discs with erect *Gigartina*-type blades. Blade tips excised from field-collected female plants and cultures in the laboratory also showed two patterns of reproduction: procarpic papillae that only produced cystocarps in the presence of the male plants with spermatia, or cystocarpic papillae that formed and released carpospores in the absence of male plants. The first pattern in each case above is evidence for a sexual life history and the second for an apomictic type similar to those noted previously for *G. papillata* (C. Agardh) J. Agardh.

The resorcinol test for kappa-carrageenan was negative for *Petrocelis*-like plants and positive for foliose plants providing additional evidence that the former are haploid and the latter diploid as is characteristic for the Gigartinaceae. Crossing experiments between sexual male and female isolates of *G. agardhii* from several locations indicated that free interbreeding occurs. All crosses between *G. agardhii* and *Gigartina*-phase gametophytes cultured from tetraspores of *Petrocelis middendorffii* (Ruprecht) Kjellman were negative demonstrating that *G. agardhii* is reproductively isolated from *G. papillata/P. middendorffii* and represents a distinct species. The tetrasporophytic phase of *G. agardhii* in nature is still not known.

On the basis of nomenclatural priority *G. agardhii* Setchell and Gardner 1933 is placed in synonomy under *G. jardinii* J. Agardh 1876.

We are continuing our investigation of the life histories of other *Gigartina* species from California and Mexico to determine their potential for mariculture or carrageenan resources.

G. johnstonii Dawson, presently known only from the Gulf of California, has a very rapid life history and growth in culture (24-52 weeks for a completed cycle). The manner in which plants readily regenerate indicates a potential use in mariculture. Two complete cycles were observed in culture without deviation from an isomorphic dioecious gametophyte-tetrasporophyte alternation. In a third cycle, however, one female plant became monoecious and self-fertile and one male plant produced spermatangia and tetrasporangia. Viable tetraspores from the male plant germinated to form male and female plants. Field-collected tetrasporophytes had a 47% yield of lambda carrageenan and gametophytes had a 46% yield of kappa carrageenan.

Life history investigation are also underway on other species of *Gigartina* from central California (*G. canaliculata* - 4 isolates, *G. leptorhynchos* - 3 isolates, *G. spinosa* - 2 isolates) and *Rhodoglossum* (*R. californicum* - 2 isolates, *R. affine* - 2 isolates).

The cycle has not been completed yet for these but most appear to have typical sexual reproduction with the exception of one isolate of *G. canaliculata* which is apomeiotic. Generally 6-8 months are required in culture for one phase to reach reproductive maturity in all these species.

Hybridization experiments

In addition to our studies on hybridization between isolates of *G. papillata* from the Pacific Coast of North America reported last year, we have begun a series of crosses between Japanese isolates of *G. pacifica* and *G. ochotensis* as well as isolates of *G. stellata* from numerous countries in the North Atlantic (Ireland, Scotland, Wales, England, France, Portugal and Spain). There is a high degree of interfertility among isolates within a single geographic locality although surprisingly as many as 4 distinct breeding groups are present among the isolates of *G. papillata* along Pacific North America. Crosses between Japanese isolates and American isolates generally have been negative. It is remarkable that a few crosses between European and Japanese or Pacific American isolates are positive. The *Petrocelis*-like plants derived from several of these are growing well, but others are not, indicating that the genetic affinity is rather low.

New investigations on Phyllophoraceae

Two red algal genera *(Gymnogongrus* and *Ahnfeltia)* in the Phyllophoraceae are commercially utilized as sources of carrageenan and agar. In order to determine the potential cultivation of these in aquaculture systems we have initiated life history studies under controlled environmental conditions. The species under investigation here have not been analyzed completely with regard to carrageenan type or yield but this will be finished next year. Preliminary analyses show that the gametophytes yield kappa-type and the tetrasporophytes a lambda-type.

Tetraspores of the crustose red alga *Erythrodermis* sp. from Oshoro Bay, Hokkaido, Japan gave rise to upright plants, morphologically and anatomically similar to *Gymnogongrus flabelliformis* Harvey, in unialgal culture. Sexual reproductive structures did not develop on these plants. Carpospores of *G. flabelliformis* from Muroran, Hokkaido germinated in culture to form crustose plants anatomically similar to *Erythrodermis.* Transfer of these crusts from full strength enriched seawater medium to unenriched seawater resulted in the formation of seriate intercalary tetrasporangia. Tetraspores germinated to form *Gymnogongrus* plants. The specific determination of the crustose tetrasporophyte *(Erythrodermis)* awaits further comparison with species from other geographic areas. A similar life history pattern was observed in plants collected near Pusan, Korea. On the basis of our studies it is evident that *Gymnogongrus flabelliformis* exhibits an alternation of independent, heteromorphic gametophytes and tetrasporophytes.

Carpospores of *Gymnogongrus leptophyllus* J. Agardh from Duxbury Reef and Yankee Point, California gave rise to crustose plants similar to *Erythrodermis haematis.* Tetrasporangia developed on these plants following dehydration and abrasion. The tetraspores germinated to form basal discs with dichotomously branched blades identical to the original field-collected plants.

Tetraspores derived from field-collected crusts of *Petrocelis anastomosans* Dawson (type locality Salina Cruz, Mexico) gave rise in culture to upright male and female plants similar to *Gymnogongrus martinensis,* carpospores derived from cystocarps differentiated into crustose plants identical to *Petrocelis anastomosans.*

Gymnogongrus furcellatus from Chile has been isolated in culture and also shows a similar life history. It grows very well in culture and is currently field-harvested as a carrageenan resource in Chile.

Gymnogongrus linearis and *G. platyphyllus* obtained in California are also being investigated to determine the life history patterns but information is not complete.

Carpospores of *Ahnfeltia gigartinoides* J. Agardh from Puerto Escondido, Mexico, formed crustose tetrasporophytes *(Erythrodermis)* that released tetraspores. These spores germinated and developed into upright gametophytes identical to *A. gigartinoides.*

Publications

Masuda, M., T. C. DeCew and J. A. West. 1979. The tetrasporophyte of *Gymnogongrus flabelliformis* Harvey (Gigartinales, Phyllophoraceae). *Jap. J. Phycol.* 27: (in press).

West, J. A., A. R. Polanshek and D. E. Shevlin. 1978. Field and culture studies on *Gigartina agardhii* (Rhodophyta). *J. Phycol.* 14: 416-426.

West, J. A., M. D. Guiry and D. J. Stancioff. 1980. A life history of *Gigartina johnstonii* from the Gulf of California. *Bot. Mar.* 22: (in press).

Cooperating Organizations

Marine Colloids, Inc., Rockland, Maine

Toward Seawater-Based Crop Production

Emanuel Epstein, *University of California, Davis*

For the first time, wheat was included in field tests at Bodega Marine Laboratory and was irrigated with undiluted seawater. Plants of some wheat selections completed their life cycle and produced grain. Tomatoes grown at 70% seawater salinity had very high concentrations (up to 15%) total dissolved solids - a quality feature prized by tomato processors.

Field experimentation

Unlike the two preceding years, the 1977-78 season was unusually wet. The severe and late rains delayed planting of selected lines of the grains (barley and wheat) until March 14, 1978. Growth of the plants, including tillering, was adversely affected by the late planting and yields were low.

Furthermore, performance of plants in different parts of the seawater-irrigated plots was uneven. This was traced to differences in salt concentration in the soil (sand) water. Probably physical heterogeneity of the sand profile was responsible for these spatial differences in salinity. This experience emphasizes the need for attention to the physical condition of the sand substrate in seawater culture, in addition to the genetic make-up of the plants.

Tomatoes were again grown in plastic greenhouse shelters at the Bodega site. Figure 1 shows tomatoes from progeny of an initial cross between the commercial *Lycopersicon esculentum* (salt sensitive) and the wild *L. cheesmanii* from the Galapagos Islands (salt tolerant - see previous Annual Reports). The tomato on the right came from a plant grown under control (fresh water) conditions; the two tomatoes on the left are still attached to a plant of the same genotype irrigated with 70% seawater. These tomatoes are the size of cherry tomatoes. They were found to have very high concentrations of total dissolved solids, up to 15%, as compared to 5%, approximately, for the same tomatoes grown under control conditions (fresh water irrigation). High total solids are a feature much prized by tomato processors because of the superior flavor the dissolved solids impart to tomatoes.

The salt tolerance of these plants may be gauged by the fact that the salinity causing a 50% reduction in yield was 10 times higher than that producing a similar yield decrement in the domestic cultivar.

Work at Davis

The list of entries in the world collection of barley was sorted on the basis of country of origin. Of the total of 22,000, six thousand were put on high priority for screening because they came from countries with salinity problems. So far, 600 lines have been screened at 90% seawater salinity; 24 were able to germinate and establish seedlings - 11 from India, 1 from Algeria and 12 from Egypt. Of these 24 lines only 9 had been given names; the rest were wild accessions not in agricultural use.

In that wheat project, selections were done in salinized solution culture. Forty lines of the world collection have been identified that can germinate and establish seedlings at 85% seawater salinity and can complete their entire life cycle at 50% sea water salinity. Screening of the world collection of wheat continues.

Recognition

The project continues to generate great interest from government agencies, research institutes, and various business enterprises from around the world - evidence of the high potential this novel scheme of seawater-based crop production is believed to have.

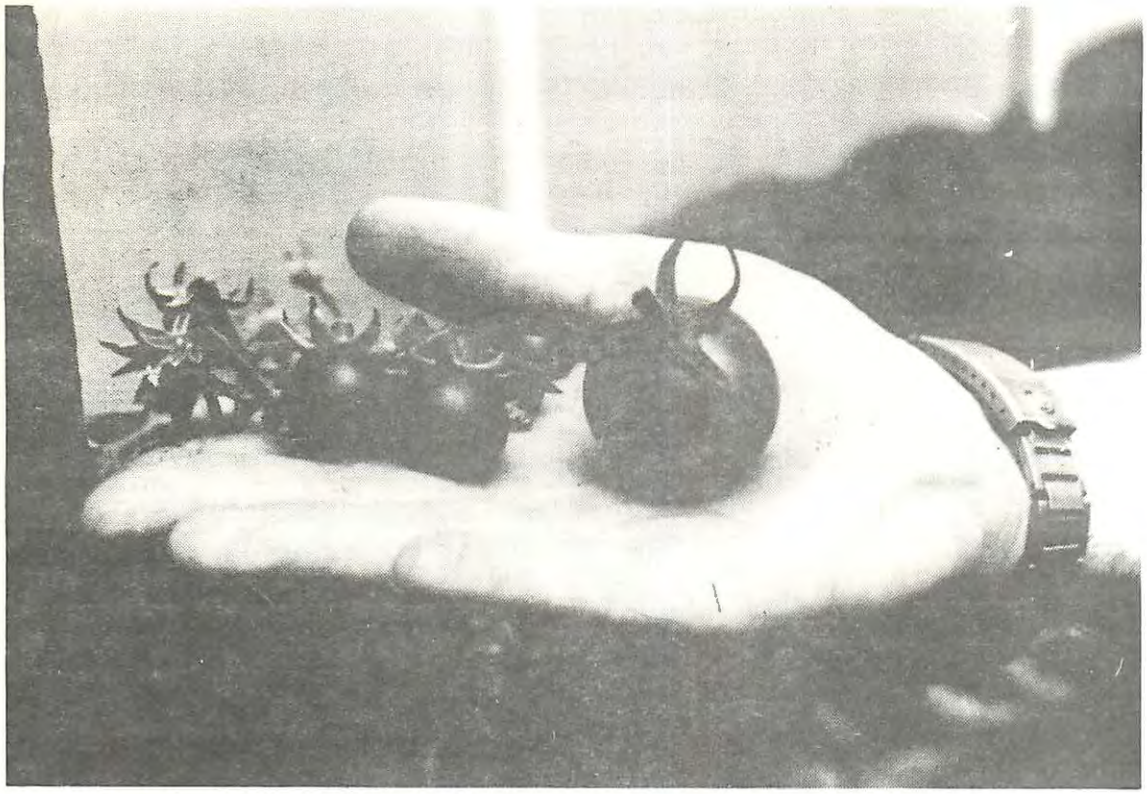


Figure 1. Fruit of progeny of a cross between the commercial tomato, *Lycopersicon esculentum*, and the wild *L. cheesmanii*. The two fruits on the left are still attached to a plant irrigated with 70% seawater. The fruit on the right was taken from a plant of identical genetic makeup irrigated with fresh water.

Publications

Epstein, E. 1977. Genetic potentials for solving problems of soil mineral stress: adaptation of crops to salinity. *Proceedings of Workshop on Plant Adaptation to Mineral Stress in Problem Soils.* M. J. Wright, ed.: 73-82. A special publication of Cornell University Agricultural Experiment Station, Ithaca, New York.

Epstein, E., R. W. Kingsbury, J. D. Norlyn and D. W. Rush. *In press.* Production of food crops and other biomass by seawater culture. *In: The Biosaline Concept: An Approach to the Utilization of Underexploited Resources,* A. Hollaender, ed. New York: Plenum.

Kelley, D. B., J. D. Norlyn and E. Epstein. *In press.* Salt tolerant crops and saline waters: resources for arid lands. *Proceedings of the International Conference on Plant Resources,* J. R. Goodin and D. K. Northington, eds., Texas Tech University, Lubbock, Texas.

Cooperating Organizations

University of California, Davis, Department of Agronomy and Range Science

University of California, Davis, and Bodega Marine Laboratory, UC Berkeley, Sea Grant Aquaculture Research Program

California Aquaculture Law

G. Bowden, *University of California, Santa Cruz*

The purpose of this project has been to examine the principle laws governing or influencing marine aquaculture on the California coast. This program year marks the final stage of a project which has taken four years to complete. The operating hypothesis has been that these laws have the synergistic effect of retarding the growth of a vigorous aquaculture industry. Unfortunately this hypothesis remains largely as we found it since the bulk of our work has been devoted to describing the law and its application to aquaculture rather than assessing the impact of public regulation on the industry.

The product of this project is a book-length report comprising twelve chapters. Each chapter has been written to stand on its own in order that the disparate audiences interested in this complex field can be furnished with a summary of the law addressing their particular subareas. The separate monographic chapters are as follows.

1. The California Aquaculture Industry. This section is a description of the marine aquaculture industry with special attention to 1) overall problems and potential growth, 2) shellfish culture techniques, 3) anadromous fish culture, and 4) the status of crustacean culture programs.

2. Bureaucracy and Administration. In this chapter the major institutional problems confronting the aquaculture industry are described along with some of the remedial measures which may be taken to lessen their impact. These problems include: 1) a large number of regulatory agencies, 2) voluminous and complex regulations, 3) conflicting public policies and programs, 4) lack of a coherent set of policies to guide aquaculture. The remedial proposals discussed include 1) the creation of a permit register, 2) the designation of a lead agency, 3) the initiation of a multi-agency permit hearing procedure, and 4) the creation of an administrative advisor.

3. The Role of the Department of Fish and Game. Since the Department of Fish and Game is the primary agency regulating all forms of aquaculture in California, it has been given separate treatment. The major spheres of Fish and Game jurisdiction discussed in this chapter are 1) mariculture, 2) oyster allotments, 3) fish breeding, 4) kelp harvesting, and 5) plant and animal importation.

4. Marine Plant Aquaculture. The law governing the harvest of naturally occurring seaweed is meshed with the law governing its culture. This chapter describes both sets of statutes and administrative regulations. This chapter also describes the current uses of seaweed and projects designed to make use of its energy through biomass conversion. The legal consequences of culturing seaweed are also discussed and proposals are advanced for statutory change to accommodate and encourage marine plant aquaculture.

5. The Role of the California Coastal Commission. Under the California Coastal Act local and state agencies are at work planning the entire coast of California. The product of this work will have a decisive effect on whether aquaculture will become a commercially important industry. This chapter analyzes the Coastal Act and describes its impact on coastal aquaculture.

6. The Role of the State Lands Commission and the Department of Parks and Recreation. These two departments are the major owners of coastal land in California. The Lands Commission leases land to some operators and the Parks Department is influential in deciding whether aquaculture will be permitted off the shore of state park lands. The law and policy of these two agencies is analyzed to determine its effect on the aquaculture industry's growth potential.

7. The Role of the Army Corps of Engineers. The Corps of Engineers is responsible for permitting the erection of structures in the navigable waters of the United States. It is, therefore, an important

force to be reckoned with. The regulatory jurisdiction of the Corps is described in this chapter along with its impact on the industry.

8. Boundary Law and its Effect on Aquaculture. The question of where one agency's power ends and another's commences is the subject of boundary law. Knowing how to separate state and federal waters and submerged land can be vital in predicting the permissible use of land and water for aquaculture. This chapter discusses boundaries based on tidal criteria, mileage from shore, depth from surface, and other boundary doctrines as well as the legal doctrines applying to these areas.

9. Aquaculture as a Common Property Resource Problem. One of the most difficult public policy issues raised by aquaculture is whether individuals should be permitted to derive private economic gain from the use of a common property resource such as the sea. This chapter discusses this problem by examining the major arguments against allowing private gain from common property.

10. Economic Analysis of the Permit Process. This chapter attempts to assess the economic impact of gathering the permits necessary to commence or expand an aquaculture operation. This is done by examining the case histories of several different forms of aquaculture.

11. Conclusions and Recommendations. Findings and recommendations drawn from the first ten chapters are synthesized in this rather brief and plotless chapter.

FISHERIES

Joanne Silberner

Protective Immunization of Anadromous Salmonids Against *Aeromonas salmonicida* and *Vibrio anguillarum*

Theodore H. Kerstetter, *Humboldt State University*

Vibriosis, caused by the marine bacterial species Vibrio anguillarum, *has caused mortalitites as high as 90 per cent in marine pen-culture of coho salmon. But it is not known whether significant losses from vibriosis infection occur among young salmon and steelhead trout migrating into the open ocean. This project is the second year of a program to test the hypothesis that mass immunization of juvenile salmonids against vibriosis will significantly increase ocean survival.*

Forty-three thousand coho salmon *(Oncorhyncus kisutch)* and *34,000 steelhead trout (Salmo gairdneri)* were immunized by the immersion method against *Vibrio anguillarum,* marked appropriately, and released at the time of their downstream migration in the spring of 1977. Forty-five thousand coho salmon controls and 26,000 steelhead controls were also differentially marked and released at the same time. The vaccine was a *Vibrio* bacterin produced by Tavolek Laboratories, Inc., Redmond, Wisconsin, and supplied as a part of their contribution to this project.

One hundred forty-seven precociously mature coho salmon (jacks) returned to the Mad River hatchery in fall 1977. Sixty-six (45%) were from the immunized group, compared to 48.8% immunized fish in the original release. The difference is not statistically significant. Returns of mature adult salmon to the hatchery in fall 1978 and the return to date of coded wire nose tags from the ocean fishery have both been far too low to give useful data.

Mature steelhead trout from the marked populations returned to Mad River hatchery in excellent numbers in winter, 1979. By March 8, 1979, 946 fish, or 1.6% of the original release of 60,076 had been tallied. Table 1 summarizes the results.

The increase in the percent of immunized steelhead in the returning population is statistically significant at the 0.01 level and reflects an actual increase of 19.3%. The estimate of the increase in survival is based on an expected return of 481 immunized steelhead *had there been no effect from the treatment.* We tentatively conclude, therefore, that vibriosis immunization by the immersion method is a potentially useful means of increasing the return of reproductively mature steelhead to their natal streams.

In 1978 chinook salmon were to be used for additional tests of vibriosis immunization and for immunization against furunculosis, but poor returns of mature chinook salmon the preceding fall resulted in a sharp reduction in the egg take, and the juvenile chinooks needed for the project were not available. A further complication was a lack of furunculosis *(Aeromonas salmonicida)* vaccine suitable for the immersion method. Research on that problem is continuing at Tavolek Laboratories and elsewhere.

Cooperating Organizations

Tavolek Laboratories, Inc., Redmond, Washington

California Department of Fish and Game

Table 1
Differential Returns of Immunized and Non-immunized Steelhead Trout to Mad River Hatchery

	Number Released	Percent	Number Returned	Percent of Returning Population
Immunized	33,881	56.4	574	60.7
Control	26,195	43.6	372	39.3

Endocrinology of Salmon Smoltification and Adaptation to Seawater

H. A. Bern, R. S. Nishioka, K. Aida, C. Paoletti, Y. Nagahama and J. N. Fryer
University of California, Berkeley

Before seaward migration some salmonid species must undergo certain morphological and physiological changes (identified together as smoltification) before becoming properly adapted to the seawater environment. We are investigating the endocrine mechanisms that are involved in this transformation in an attempt to reduce the mortality and growth-stunting which often occur when coho salmon, Oncorhynchus kisutch, *are tranferred prematurely to sea-pens for growth enhancement prior to harvest or release. Stunted coho are generally pan-hypoendocrine, except for the pituitary growth hormone cells and the corpuscles of Stannius. The ability of stunt tissues to bind growth hormone is significantly decreased. The secretory activity of the Stannius corpuscles is directly responsive to calcium ion concentration (the higher the calcium concentration, the greater the depletion of secretory material). Histology of the skin has not proven to be usefully predictive of degree of smoltification, but body weight and plasma magnesium concentration shortly after transfer of fish to seawater are being investigated as possible sensitive indicators of smoltification.*

Many salmonid species undergo substantial physiological and morphological changes when migrating to and from sea water. Of critical concern is the ability of the young, relatively fragile, freshwater parr stage to transform into the seawater-adaptable smolt stage through a process known as smoltification. Little is known of the conditions that trigger this transformation. Photoperiod, temperature, and water quality have all been suggested as factors, but definitive evidence is still lacking. Although it is obvious that the neuroendocrine apparatus plays a major role in the adaptation to this drastic environmental change, little is known about the relative importance of the several possible endocrine mechanisms involved and about their interaction. When young salmon that have not or are not ready to undergo smoltification are transferred to seawater in an aquaculture or fish husbandry operation, high mortality, and/or drastic stunting (parr-reversal) occurs. A thorough understanding of the endocrinological basis of stunting may provide a method of reducing this economic loss. Our study is particularly concerned with attempts to reduce or eliminate stunting or parr-reversal when young silver or coho salmon *(Oncorhynchus kisutch)* are transferred to seawater pens for further growth and subsequent release or harvest.

Comparison of endocrine glands from different stages in coho development (H. A. Bern, R. S. Nishioka, Y. Nagahama, K. Aida)

In a series of light and electron microscope comparisons of the endocrine organs of parr, freshwater smolt, seawater smolt and stunt, we are attempting to determine the primary endocrine "lesion" that results in stunting. To date, the stunt shows evidence of reduced activity of thyroid, interrenal, pancreatic islets, ultimobranchials and urophysis. The thyrotropes of the pituitary gland also appear less active. Blood levels of insulin are lower in the stunt than in the smolt, correlating with the observed histology of the endocrine pancreas. However, the stunt is apparently not totally "pan-hypoendocrine" (i.e. the reduction of all endocrine secretions), inasmuch as the growth hormone cells of the pituitary show evidence of activity, despite the failure of the stunt to grow normally. The Stannius corpuscle is another endocrine gland that showed evidence of activity in the stunt.

The interrenal gland cells in the seawater smolt do not appear significantly larger (indicating higher activity) than in the freshwater smolt and the seawater stunt by light microscopy. However, as seen with the electron microscope the mitochondria of the seawater smolt are generally small and uniform in size and are distributed uniformly in cytoplasm packed with smooth and rough endoplasmic reticulum. On the other hand, some of the mitochondria of the seawater

stunt are several times larger, irregular in shape and unevenly distributed in the cytoplasm among sparse amounts of endoplasmic reticulum. In addition there are many more membrane infoldings adjacent to the capillaries in the seawater smolt than in the stunt. The membrane infoldings and higher density of endoplasmic reticulum may be indicative of higher secretory activity. In the freshwater smolt, there are considerably fewer mitochondria as well as fewer membrane infoldings.

By light microscopy the ultimobranchial glands appear similar in various stages of fish, varying in size in relation to the size of the fish. However, as judged by electron microscopy, the seawater smolt glands contain a much higher proportion of "empty" and pale granules compared with stunts or freshwater smolts, possibly indicating a higher level of secretion in the former.

The urophysis in different stages of smoltification was assayed for hormone content, and in addition the caudal neurosecretory system was examined by electron microscopy. The young freshwater stage (parr) urophysis contained the lowest concentration of UII and lowest content of granules. The seawater stunt contained much less activity and fewer granules when compared with the seawater smolt. Correlation between the degree of smoltification and urophysial granule content and neurohormonal activity will be examined further.

Ability of coho tissues from different developmental stages to bind growth hormone (J. N. Fryer, H. A. Bern)

In view of the cytological evidence for growth hormone (GH) cell activity in the stunt, growth hormone-binding studies were conducted to determine why such a major difference in growth was evident between the normal and the stunted fish in seawater. (Presently no method is available for measuring circulating levels of growth hormone in salmon.) *Tilapia* GH demonstrated specific binding to membrane preparations from coho salmon liver, kidney and gill but not muscle. Specificity studies with the coho liver GH receptor indicated that up to 45% of the iodinated *Tilapia* GH bound may be displaced by unlabelled *Tilapia* GH at a concentration of 1 μg/ml. Both ovine GH and bovine GH at a concentration of 10 μg/ml are equally as effective as *Tilapia* GH in saturating the GH-binding site in coho salmon liver. Other peptide hormones such as ovine FSH, ovine LH, bovine MSH and bovine insulin at concentrations of 2 μg/ml do not inhibit the binding of iodinated *Tilipia* GH to coho liver membrane preparations.

Membrane preparations of both liver and gill from stunted salmon obtained from stocks in California, Washington state and British Columbia bound significantly less iodinated *Tilapia* GH than normal smolts. Kidney membrane preparations from stunted salmon in California also bound significantly less GH than normal smolts. However, no specific binding of the iodinated *Tilapia* GH was observed with kidney membrane preparations prepared from fish collected in either British Columbia or Washington.

These results indicate that the stunted coho salmon have a decreased ability to bind GH which may be reflected in a deficiency in GH-mediated processes.

Functional analysis of the corpuscles of Stannius in relation to calcium metabolism in the coho (K. Aida, R. S. Nishioka, H. A. Bern)

The Stannius corpuscles, although composed of smaller cells in the stunt, may in fact be more active than in the normal seawater smolt, as judged by granule depletion in the predominant cell type. In view of the importance of calcium in survival and growth of teleosts and the proposed contributions of the Stannius corpuscles to calcium metabolism (by the secretion of hypocalcin), we have focused attention on ultrastructural changes occurring in this organ before and after smoltification and seawater adaptation of coho salmon.

Two types of endocrine cells, Type 1 (large granules) and Type 2 (small granules), were found. Parr, freshwater smolt and seawater smolt had granulated Type 1 cells, whereas most of the stunted fish had highly degranulated Type 1 cells. It is conceivable that calcium deficiency may

be related to incomplete smoltification, and we have begun experiments to determine the effects of calcium supplementation on smoltification, on responses to seawater challenge (see below), and on endocrine tissues *in vivo* including the Stannius corpuscles, pituitary prolactin cells and ultimobranchials.

In addition, we have begun to study the response of the Stannius corpuscles *in vitro*. Corpuscles are organ-cultured in a defined medium in the presence of high (3 mM) and standard (1.5 mM) concentrations of calcium. High calcium medium induced degranulation of Type 1 cells. The Type 2 cells remained unchanged. This result suggests that Type 1 and 2 cells have a different function, and that Type 1 cells are the likely source of hypocalcin. The effects of K, Na, Mg and Cl concentrations on Type 2 cells as well as on Type 1 cells are being studied currently.

Changes in the skin during coho development
(K. Aida, C. Paoletti, R. S. Nishioka)

Our initial observations indicated a correlation between the number of "white cells" in the subopercular epithelium (skin underlying the operculum) and the ability of the smolt to withstand seawater challenge. These cells were assumed to be possible chloride cells (mitochondria-rich ionocytes). Further analysis of integumentary histology makes it evident that these cells are not chloride cells and that their utility in "diagnosing" degree of smoltification (or preparation for seawater transfer) is dubious. Chloride cells are found in the subopercular membrane of freshwater and seawater smolts as well as the seawater stunt but they are few in number. The chloride cells of the freshwater smolt appear undeveloped when compared with those of the seawater smolt and stunt.

Undeveloped chloride cells are found in the intralamellar region and respiratory epithelium in parr and freshwater smolt, whereas well-developed cells were found only in the intralamellar region in both seawater smolt and stunt. No morphological difference was recognized between smolt and stunt chloride cells in seawater.

Responses of freshwater coho to seawater challenge as a measure of degree of smoltification
(C. Paoletti, K. Aida)

Inasmuch as smoltification is considered to be a process that prepares a freshwater salmon for seawater, one way to assess the extent of smoltification in a fish is to examine how it regulates its plasma ion levels and body water following abrupt transfer to seawater. We have found that young salmon respond to seawater transfer in a variety of ways.

Although most presmolts that are transferred to seawater survive, the majority suffer a high rise in plasma magnesium (approximately 2 to 3 times the freshwater levels), a slight rise in plasma sodium and chloride, and a loss of body weight which is due to water loss during the first 24 hours after transfer. In some fish and in fish pretreated with growth hormone, the large changes in body weight and plasma ion concentrations upon transfer to seawater appear to be reduced.

Amount of weight loss and extent of increase in ion concentrations (especially magnesium) after 24 hours in seawater may provide a measure of degree of smoltification. Studies are now in progress to determine if this method of defining state of smoltification is meaningful in terms of predicting growth in seawater (and hence in predicting the risk of stunting).

In summary, the stunt can be described as a basically "pan-hypoendocrine" organism with the ability to survive in seawater and maintain itself in a *status quo* condition. However, it is sufficiently physiologically "crippled" so that normal growth is severely retarded. Consequently, if the stunt were not protected within the confines of a sea-pen, it could not be expected to survive natural predation and environmental challenges.

Publications

Bern, H. A. and R. S. Nishioka. 1978. The caudal neurosecretory system and osmoregulation. *Proc. 16th Gunma Symposium on Endocrinology,* Institute of Endocrinology, Gunma University, May 31 - June 1, 1978, p. 2 (abstract).

Bern, H. A. 1978. Endocrinological studies on normal and abnormal salmon smoltification. *VIII International Symposium on Comparative Endocrinology,* Amsterdam, June 19-23, 1978, p. 17. (abstract).

Bern, H. A. 1978. Endocrinological studies on normal and abnormal salmon smoltification. *In: Comparative Endocrinology,* P. J. Gaillard and H. H. Boer, eds.: 97-100. Elsevier/North Holland, Amsterdam.

Woo, N. Y. S. and H. A. Bern. 1978. Vasoactive property of urotensins I and II in birds. *Proc. the 16th Gunma Symposium on Endocrinology,* Institute of Endocrinology, Gunma University, May 31 - June 1, 1978, p. 4. (abstract).

Woo, N. Y. S. and H. A. Bern. 1978. Vasoactive properties of urotensins I and II in a columbian and three galliform birds, and a bioassay for urotensin I. *J. Comp. Physiol.* B 126: 193-202.

Woo, N. Y. S., H. A. Bern and R. S. Nishioka. 1978. Changes in body composition associated with smoltification and premature transfer to seawater in coho salmon *(Oncorhynchus kisutch* Walbaum) and king salmon *(O. tschawytscha* Walbaum). *J. Fish. Biol.* 13: 421-428.

Cooperating Organizations

National Marine Fisheries Service, Tiburon Laboratory, California

Tyee Club, Tiburon, California

University of California Cooperative Extension, Sonoma County, California

California Department of Fish and Game, Redding and Arcata, California

Pacific Biological Station, Nanaimo, British Columbia, Canada

University of Washington, Seattle, Washington, Department of Zoology

University of Montana, Missoula, Montana, Department of Zoology

Development of Multispecies Management For Kelpbed Resources with an Emphasis on Sea Urchins

Mia J. Tegner, *Scripps Institution of Oceanography*

Wise management of our nearshore resources requires that we base fishery regulations not only on the population dynamics of an exploited species, but on its interactions with other members of the community in which it lives as well.

Sea urchins are functionally important to the structure of kelpbed communities in southern California. Associated with episodes of destructive overgrazing in the past, sea urchins are now the object of a rapidly growing fishery. The goals of this project are to complete our data base on the natural history and population dynamics of the red sea urchin, *Strongylocentrotus franciscanus,* so that management plans can be developed to ensure a sustained yield fishery. Secondly, we are studying urchin interactions with other species, especially those whose populations we have reduced by fishing, to determine the biological controls of urchin population size and how other species and the kelpbed community as a whole will be affected by urchin harvesting.

This year we have moved the focus of our efforts to the Channel Islands, where most of the fishery is taking place. Our studies of red urchin size-frequency distributions, based on samples collected over the past two years, have illustrated two basic population structures. The northern islands (our most extensive data are from Santa Rosa and San Miguel) exhibit a pattern of low recruitment rates to benthic populations but relatively high survival into the second year class. In contrast, the southern islands (Santa Barbara and San Clemente) show very high recruitment rates but very poor survival into the second year class. We are currently analyzing these patterns in terms of competition and predation differences between these two regions and how they each will be affected by harvesting. Two urchin predators, the California sheephead, *Pimelometopon pulchrum,* and the spiny lobster, *Panulirus interruptus,* are both common on the southern islands and may be preying heavily on juvenile urchins as they leave the protection of the spine canopy.

This spine canopy association, where juvenile red urchins spend much of their first year underneath conspecific adults, is a major reason why this fishery cannot be managed in a classical manner; harvesting not only removes reproductive potential from the population but also nursery grounds as well. When discussions with the Department of Fish and Game suggested that a size limit may be the best approach to management, we undertook a sampling program to determine what the contribution of various size adults is to the nursery association. Figure 1 illustrates that the number of recruits per adult increases significantly with the size of the adult. Although significant numbers of juveniles are found under adult urchins as small as 60 mm, the larger the adult, the more space it has under it and the longer a recruit can utilize the protection of the spine canopy. The fate of juveniles exposed by the fishing of adults depends upon the topography, whether there are available crevices for hiding, and predator densities. Sheephead are known to follow urchin divers.

Studies of sea urchin and abalone interactions were conducted in the field and laboratory. One of our first steps was to identify the preferred habitat of red *(Haliotis rufescens)* and pink *(H. corrugata)* abalones of all size classes so that we could determine where to expect interactions. Large numbers of small red abalones are found under the spine canopies of adult red urchins. Based on the work of Daniel Morse of University of California, Santa Barbara, which experimentally defined the role of a settlement-inducing substance from encrusting coralline algae we have been able to identify two advantages which the juvenile abalones derive from the urchins. Not only do the small abalones enjoy the protection of the spine canopy, the sea

urchins maintain patches of encrusting corallines under and around themselves from overgrowth by other encrusting organisms. The juvenile abalones apparently feed off the encrusting corallines after they have settled there. Studies are being conducted in the laboratory to evaluate hypothesized competition for food by the two herbivores. Different mixes of urchins and abalones are competing for a limited amount of food, and growth rates are being monitored. Red urchins and red abalones have similar resistance to food deprivation, but the urchins appear to have the behavioral advantage of a more aggressive foraging strategy when food supply is low.

Cooperating Organizations

California Department of Fish and Game, Long Beach and San Diego, California

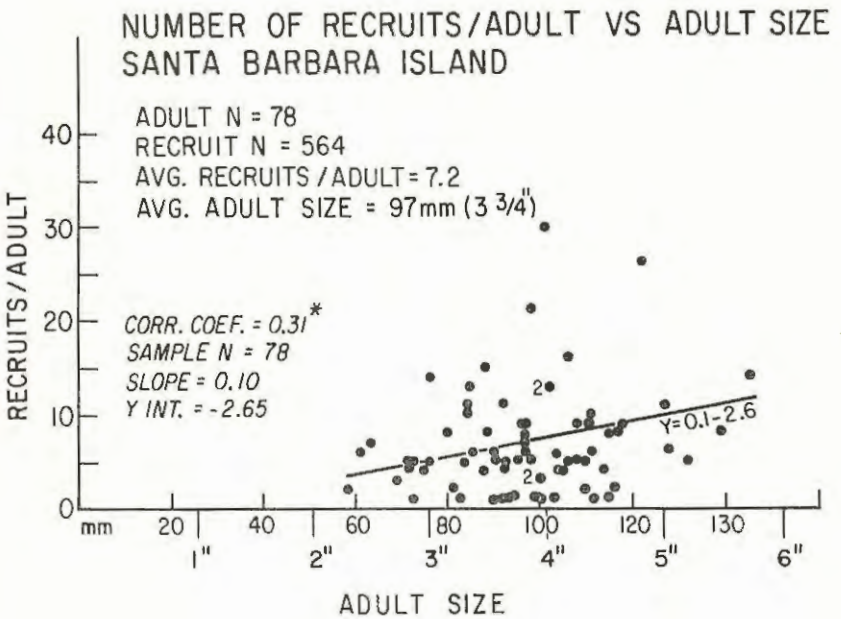


Figure 1. The number of recruits per adult red sea urchin increases significantly with the size of the adult.

The California Market Squid Fishery

C. Recksiek and H. Frey, *University of California, Santa Barbara*

During the 1977-78 year, the first draft of a manuscript reporting the results of the previous three years of Sea Grant supported research on market squid was completed. This will be published as California Department of Fish and Game Fish Bulletion 169, entitled *Biological, Oceanographic, and Acoustic Aspects of the Market Squid, Loligo opalescens, Berry.* Its contents will be as follows:

Background of market squid research program, basic life history, and the fishery. Conrad W. Recksiek and Herbert W. Frey.

A study of spermatogenesis in the spawning population of the squid, *Loligo opalescens.* Thomas M. Grieb and Robert D. Beeman.

Histological observations on oogenesis in *Loligo opalescens.* James H. Knipe and Robert D. Beeman.

Age and growth of the market squid, *Loligo opalescens,* **Berry, in Monterey Bay from statoliths.** Jerome D. Spratt.

Feeding dynamics of *Loligo opalescens.* Konstantin A. Karpov and Gregor M. Cailliet.

Marine fish, bird and mammal predation of *Loligo opalescens* **in Monterey Bay.** C. Victor Morejohn, James T. Harvey and Lynne T. Krasnow.

Possible morphological indicators of population structure in the market squid, *Loligo opalescens.* Jerry Kashiwada and Conrad W. Recksiek.

A biochemical-genetics population structure study of market squid, *Loligo opalescens,* **along the California coast.** J. R. Raymond Ally and Scott A. Keck.

An electrophoretic study of select proteins from the market squid, *Loligo opalescens,* **Berry.** J. P. Christofferson, A. Foss, W. E. Lambert and B. Welge.

An acoustic investigation of market squid, *Loligo opalescens.* Douglas Lee Vaughan and Conrad W. Recksiek.

The target strength of individual market squid, *Loligo opalescens.* Douglas Lee Vaughan.

Correlations between squid catches and oceanographic conditions in Monterey Bay, California. Rodney R. McInnis and William W. Broenkow.

Santa Barbara Inshore Partyboat Fishery: Emphasis on the Olive Rockfish

Milton S. Love
Faculty sponsor: Alfred W. Ebeling
University of California, Santa Barbara

Rockfishes *(Sebastes* spp.) and kelp bass *(Paralabrax clathratus)* form the bulk of the catch in the inshore partyboat sportfishery off Santa Barbara (Table 1). Olive rockfish *(Sebastes serranoides)* formed about 24% of all fish sampled, followed by kelp bass (19.1%), blue rockfish *(S. mystinus)* 11.6% and Pacific mackerel *(Scomber japonicus)* 7.1%. Popular species landed farther south, such as yellowtail *(Seriola dorsalis),* white seabass *(Cynoscion nobilis)* and barracuda *(Sphyraena argentea)* were rarely taken. Though Pacific mackerel ranked fourth in numbers taken during the two-year study, the species fluctuates widely in abundance off Santa Barbara. In the previous 15 years, few were taken in the sport catch. Similarly, bonito *(Sarda chiliensis),* commonly taken in the past, were relatively rare during the sample period.

Both rockfish and kelp bass were caught throughout the year, though spring and fall months were peak periods for kelp bass catches. Other species showed more seasonality. Pacific mackerel were most abundant in catches during summer and fall; white seabass - fall; barracuda - fall; chinook salmon - spring; halibut - spring.

Of special interest is the importance of the olive rockfish to the sportfishery. This streamlined, bass-shaped species aggregates over hard or rocky substrate in waters 5-80 m deep. The species ranked first in both numbers and frequency of occurrence. At least one was taken during 85% of the trips sampled. Perhaps 80% of all olive rockfish taken were immature. Mature individuals are rare in the Santa Barbara vicinity. Only lightly fished or unfished reefs harbor substantial numbers of mature fish. Thus, continuous fishing pressure by partyboats and private vessels remove subadults.

Most fishing effort occurred over only a few habitats of shallow (5-50 m), rocky and hard substrate (Table 2). Four-mile Reef, offshore oil platforms and One-mile Reef received almost 37% of the fishing effort. Large rockfish aggregations, particularly of *S. serranoides, S. mystinus, S. entomelas* and *S. paucispinis* were found around these sites. Of special interest is the extensive sportfishery about offshore oil platforms in the Santa Barbara Channel. The platforms support very large rockfish populations; an estimated 10,000 rockfish were taken from a single platform during one year. Rockfish are easily caught, and so are sought after by partyboat operators when large numbers of unskilled fishermen are on board. Oil platforms are readily identifiable on radar, thus easily found during rain or fog. Naples Reef was another important fishing site, and received about 17% of total fishing effort. Though it is located about two hours from Santa Barbara, Naples Reef is popular because it supports a large population of kelp bass.

Off Santa Barbara, olive rockfish mature at 4-10 years of age (total length 29-37 cm) although fish to the north, off Avila, mature earlier (2-7 years, 28-38 cm). Avila individuals grew at a faster rate than Santa Barbara fish. Females spawn from December through March, once per year. Juveniles ate mostly plankton and other small fish; adults shifted to larger prey, squid and octopus. Artificial and biological (parasite-mix) tagging indicated that olive rockfish move but little in shallow water, and somewhat more over deeper reefs.

Results of this study apply to fisheries management. Even though olive rockfish and kelp bass resemble each other superficially and have similar lifestyles, their movements are quite different. Olive rockfish are residential; they usually grow to maturity on the same reef where they first settled as tiny young. Therefore, intense fishing may soon remove all adults and subadults from the reef so that the local

Table 1
Sportfish catch from off Santa Barbara, California, during the year 1977-78, in order of absolute (N) and relative (%) abundance of fish per species.

Species	N	%	Frequency of Occurence (%)
Sebastes serranoides	3033	23.7	85
Paralabrax clathratus	2448	19.1	61
Sebastes mystinus	1486	11.6	61
Scomber japonicus	917	7.1	39
Sebastes entomelas	864	6.7	27
Sebastes paucispinis	642	5.0	45
Sebastes hopkinsi	627	4.9	34
Sebastes auriculatus	432	3.3	53
Sebastes miniatus	372	2.9	43
Sebastes pinniger	223	1.7	20
Paralabrax nebulifer	169	1.3	34
Sebastes caurinus	160	11.2	56
Genyonemus lineatus	119	.9	28
Sebastes chlorostictus	118	.9	13
Sebastes carnatus	102	.8	37
Sebastes goodei	99	.8	3
Sebastes rubrivinctus	94	.7	25
Sebastes rosaceus	78	.6	23
Sebastes flavidus	75	.6	19
Sebastes constellatus	73	.6	24
Ophiodon elongatus	71	.5	42
Sarda chiliensis	64	.5	17
Squalus acanthias	63	.5	10
Sebastes atrovirens	59	.5	17
Sebastes dallii	58	.5	26
Cynoscion nobilis	48	.4	13
Sebastes umbrosus	43	.3	17
Sebastes elongatus	35	.3	6
Paralichthys californicus	29	.2	13
Sebastes chrysomelas	25	.2	11
Trachurus symmetrichus	20	.2	11
Anoplopoma fimbria	16	.1	2
Medialuna californiensis	15	.1	4
Chromis punctipinnis	13	.1	7
Scorpaena californica	13	.1	9
Caulolatilus princeps	13	.1	12
Pimelometopon pulchrum	11	tr	10
Scorpaenichthys marmoratus	8	tr	5
Oxyjulis californica	6	tr	2
Sebastes rastrelliger	6	tr	5
Sphryna argentea		6	tr
Synodus lucioceps	6	tr	1
Oncorhynchus tshawytscha	5	tr	4
Cephaloscylliumm ventriosum	5	tr	4

Species	N	%	Frequency of Occurence (%)
Sebastes levis	4	tr	2
Amphistichus argenteus	4	tr	2
Sebastes serriceps	4	tr	4
Alopias vulpinus	4	tr	2
Sebastes rufus	3	tr	3
Cheilotrema saturnum	3	tr	3
Mustelus californicus	3	tr	2
Citharichthys sordius	2	tr	2
Eopsetta jordani	2	tr	1
Galeorhinus zyopterus	2	tr	2
Rhachochilus toxotes	2	tr	1
Platyrhinoides triseriata	2	tr	2
Hydrolagus colliei	2	tr	2
Rhinobatos productus	2	tr	1
Sebastes eos	1	tr	1
Sebastes saxicola	1	tr	1
Sebastes ruberrimus	1	tr	1
Heterostichus rostratus	1	tr	1
Oncorhynchus kisutch	1	tr	1
Atherinopsis californiensis	1	tr	1
Hexagrammos decagrammus	1	tr	1
Eptatretus stoutii	1	tr	1
Seriphus politus	1	tr	1
Squatina californica	1	tr	1

Table 2
Sportfishing measured by absolute hours and relative time (%) spent at different sites off Santa Barbara, California during 1977-78

Sites	Hours	%
4-Mile Reef	613.2	18.4
Oil Platforms	607.6	18.2
Naples Reef	565.0	16.9
1-Mile Reef	501.6	15.0
Horseshoe Reef	291.5	8.7
18 Fathom Spot	136.5	4.1
12-Mile Reef	136.0	4.1
6-Mile Reef	78.5	2.4
Other sites (15)*	409.0	12.2

*Goleta Point, Coal Oil Point, Canby's Reef, El Capitan Point, Tejiguas, Ellwood Pier, 42 Fathom Spot, 50 Fathom Spot, Isla Vista, 3-Mile Reef, Rincon Point, Hope Ranch, Ledbetter Beach, Carpenteria Reef, Salmon trolling.

resident catchable population is decimated.

Because rockfish are slow-growing, it takes many years for recruitment to repopulate the reef with catchable fish. On the other hand, kelp bass move from reef to reef within an area of square miles, so immigrants soon take the place of angled adults. Consequently bag limits may preserve kelp bass populations, whereas preserves should be set aside for many years to repopulate decimated reefs with olive rockfish. But since both fish are caught together, it is impossible to insure the preservation of the olive rockfish population as long as kelp bass are being caught in the area.

Publications

Love, Milton S. 1978. Movements of the olive rockfish, *Sebastes serranoides.* Paper presented at the conference of the American Society of Ichthylogists and Herpetologists, Tempe, Arizona, June 1978.

Love, Milton S. 1978. Aspects of the life history of the olive rockfish, *Sebastes serranoides.* Ph.D. thesis, University of California, Santa Barbara. Accepted for publication in *Fishery Bulletin.*

Cooperating Organizations

Environment Canada, Fisheries and Marine

Sea Landing Sportfishing

Re-establishment of Anadromous Fishes in Southern California

Jon C. Van Olst and James M. Carlberg
San Diego State University

The objective of this project has been to assess the feasibility of a periodic stocking program for the re-establishment of anadromous fish in Mission Bay and San Diego Bay. The native anadromous species of southern California have been victims of rapid industrial and agricultural development which has effectively eliminated almost all freshwater runoff, disrupted natural spawning grounds, and made freshwater spawning impossible. Prior to 1950, coho salmon *(Oncorhynchus kisutch),* steelhead rainbow trout *(Salmo gairdneri)* and several other salmonid species were endemic to this area. Steelhead runs were observed in the in the San Diego River until approximately 1954 (Hubbs, pers. comm.). One method of compensating for these decreases in fishery resources caused by habitat destruction--as well as decreases attributed to increased fishing pressure--is to develop a program for periodic release of hatchery-reared juveniles. Coho salmon and stripped bass *(Morone saxatilis)* fingerlings for this purpose are available from the California Department of Fish and Game (CFG).

Our research has been very successful in stimulating a cooperative effort involving several groups which will continue beyond the end of this one-year project. CFG has funded two ongoing projects at the Hubbs-Sea World Research Institute in San Diego to study the feasibility of planting coho salmon and striped bass. A trial plant of 1,000 striped bass juveniles was conducted recently and the ecological effects of this introduction are being monitored. Everingham Bros. Bait Company has agreed to permit us to use several of their large bait receivers in San Diego Bay in a cage-release study scheduled for February 1979. Several local groups have expressed interest in continuing the project if this test planting involving 20,000 coho salmon is successful.

We also were assisted in this research by scientists from the National Marine Fisheries Service in Tiburon, California and UC Sea Grant Advisory Agents who participated in a similar cage-release study in San Francisco Bay. Several groups of coho salmon and striped bass were brought to San Diego by CFG tanker truck and used in studies of temperature and seawater acclimation. Striped bass adapted extremely well to conditions in Mission Bay and grew from 70 g to almost 1.0 kg in less than one year. Seafood experts at Ghio Seafood Products prepared and tasted these fish and were very impressed with their flavor. Considerable interest has developed locally in the mariculture potential of this species.

Several groups of coho salmon were acclimated to seawater, with variable results. Hatchery officials believe that the drought and subsequent flood and silting conditions during 1977-78 stressed the fish and caused an outbreak of kidney disease in the hatchery. This was confirmed by observation of retarded renal development in the fingerlings brought to San Diego. Dr. H. Bern of UC Berkeley cooperated in assessing these problems related to smoltification. Groups of coho salmon that did acclimate successfully survived well until bay temperatures increased to 23-24° C. Infection by *Vibrio* sp. caused considerable mortalities, as confirmed by Dr. F. Steenbergen of SDSU. Several companies produce vaccines for *Vibrio* but their products are rather expensive. With the cooperation of Dr. J. Fryer of Oregon State University and Dr. F. Steenbergen we were successful in preparing large quantities of vaccine at low cost. This vaccine will be used during subsequent planting attempts.

Publications

Van Olst, J. C., J. M. Carlberg and D. B. Kent. 1978. Effects of introductions of coho salmon in San Diego. Semiannual Report to California Department of Fish and Game. Hubbs-Sea World Research Institute.

Van Olst, J. C., J. M. Carlberg, C. Foe and P. Dygert. 1978. Effects of introductions of striped bass in the San Diego River Flood Control Channel, Semiannual Report to California Department of Fish and Game. Hubbs-Sea World Research Institute.

Cooperating Organizations

San Diego Gas and Electric Company

Southern California Edison Company, Research and Development Program

San Diego State University Foundation

National Marine Fisheries Service

Sea Grant Aquaculture Program, University of California, Davis and Bodega Marine Laboratory

Massachusetts State Lobster Hatchery

Canada Fisheries and Marine Service, St. Andrews Biological Station

Foremost Research Center

Ghio Seafoods

A Multispecies Bioeconomic Fisheries Model Under Uncertainty

Richard E. Just, *University of California, Berkeley*

This report covers the modeling effort which has thus far been directed at developing an empirically tractable set of relationships describing biological and economic interactions in fisheries. Much of the recent focus in fishery research has been on modeling of multispecies aspects of the particular systems under investigation. This report discusses first a specific biological growth model of a multispecies ecosystem originally proposed by Coutlee and Jennrich (1968) (the CJ model). Secondly, we formulate an econometric model for a description of the shortrun determination of effort, ex-vessel price, and quantity landed.

The CJ Model

The general form of description for an n-species ecosystem can be expressed by the differential equation system

$$\dot{X}_i = X_i f_i(X) \qquad (1)$$
$$i=1,\ldots,n$$

where X_i is a component of the vector of population sizes X, $\dot{X}_i$ is the rate of change of the i th population, and $f_i(\cdot)$ is the relative growth function of the i th population. CJ argue that, if the interaction between and within species are modeled by Gompertz-type--$X_i \ln X_j$-- for all i and j, then the relative growth function for each species can be modeled as linear in logarithms. This permits the n equations in (1) to be expressed as a linear differential equation system in the variables $Y_i \equiv \ln X_i$. That is, in vector form, the system becomes

$$\dot{Y} = AY \qquad (2)$$

where $\dot{Y}$ and Y are n μu 1, and A is a constant n × n matrix. It is interesting to note that Eq. 2 is essentially a generalization of the Gompertz model which has been supported in the fisheries literature by Silliman.

The continuous linear model in Eq. 2 permits straight-forward discretization and a possible rationale for formulating similar discrete-time linear models of fishery systems. A linear formulation of a fishery system could prove to be of value because it would allow one to dispense with the *ad hoc* assumption of equilibrium required by other approaches (for example, see Agnello and Anderson 1977). Moreover, the most complete set of results pertaining to the properties of dynamic systems (such as stability, controllability, etc.) exist for the linear case. A linear model also allows the most flexibility in the choice of an optimal policy evaluation technique since deterministic, stochastic, and adaptive control procedures are farthest advanced for the case of linear systems.

To be sure, assuming any specific functional form implies certain restrictions. For a discussion of the implications of this model, the original paper by Coutlee and Jennrich (1968) should be consulted. The papers by Gomatam (1974) are also helpful. Whether the biological description in Eq. 2 will lead to expanded possibilities for fishery system description and policy evaluation remains a question for future research.

Short-run, effort, price and quantity

Bockstael (1976) has suggested that supply response of a fishery involves long-run decisions by fishermen to establish the capital stock and short-run decisions on effort conditional on the existing capital stock. Hence, short-run supply of fish from a single species fleet depends primarily upon exogenous short-run factors such as weather and perhaps abundance. Short-run supply of fish in this case would not depend upon price. Evidence in support of this conjecture has been found by Doll (1972) and by Storey and Willis (1978). However, for the case of fleets capable of fishing more than one species in a single time period, it has been admitted that alternative prices would affect short-run supply.

Anderson (1976) has suggested that individual fishermen are actually suppliers of

effort not fish and that they take their supply decisions based upon an implied "price of effort" (which depends upon the ex-vessel price and catch per unit of effort). From this, it can be inferred that the aggregate behavior of fishermen determines industry effort which in turn determines fish supplied through a technical relationship relating abundance and industry effort to quantity caught. This scenario can be represented by the following simultaneous equations model.

Ex-vessel demand is specified by

$$p=f(Q,X_1) \tag{3}$$

where p is the ex-vessel price, Q is the quantity of fish landed, and X_1 is a vector of exogenous demand shifters. (The subscript for time is suppressed throughout). At a minimum, the vector X_1 should reflect alternatives to the processing sector via ex-vessel prices of other species and the impact of final demand through some index of consumer income.

Ex-vessel supply is given by

$$Q=g(E,X_2) \tag{4}$$

where E is industry effort and X_2 is a vector of exogenous variables including at a minimum the abundance of the fish stock or some index for it. This is a technological relationship. (Note that a simple form often used in the past is Q = qEA where A is abundance, and q is the catchability coefficient. A Cobb-Douglas function would be a generalization).

The demand for effort equation is

$$P_E=h(E^d,X_3) \tag{5}$$

where P_E is the implied price of effort, E^d is the industry demand for effort, and X_3 is a vector of exogenous variables affecting the demand for effort. It must be noted that there might be a problem in discriminating between X_1 and X_3.

The supply of effort is given by

$$E^s=k(p_E,X_4) \tag{6}$$

where E_s is the industry supply, and X_4 is a vector of exogenous variables including a measure of the capital stock upon which the short-run decision is conditioned, the implied price of effort of alternative species if appropriate, and weather or other short-run influences on the supply of effort.

The model is closed by specifying industry effort to be the equilibrium outcome of the effort market.

$$E^d = E^s = E \tag{7}$$

Unfortunately, an independent measure of the endogenous variable P_E is not available. It must be constructed from the other data of the problem, implying an additional restriction on the system. The only recource is to "solve out" P_E which is equivalent to solving for the reduced form of E as a function of X_3 and X_4. (Note that constructing the implied price of effort for the exogenous variables does not pose a similar problem.)

Assuming functional specifications that allow linear-in-parameters representations of the ex-vessel demand, ex-vessel supply, and reduced form for effort equations, the resulting system in the three endogenous variables--p, Q, and E--is a linear, recursive system for which estimation is especially simple if the error terms are uncorrelated between equations. The system would then appear as

$$p=\alpha_1 Q+\beta_1' X_1+u_1 \tag{8}$$

$$Q=\alpha_2 E+\beta_2' X_2+u_2 \tag{9}$$

$$E=\pi_1' X_3+\pi_2' X_4+u_3 \tag{10}$$

where, again, the time subscript is suppressed.

It must be pointed out that, if effort is not observed and includes an error (for example, if the data consists of "number of pots used" rather than "pot days fished"), the simple estimation procedure associated with linear recursive systems would break down if these errors in observation are in the exogenous variables. For this situation, the econometric literature on errors in variables may be employed. For example, see Geraci (1977), Hsiao (1977), and Levi (1977).

References

Agnello, Richard J. and L. G. Anderson. 1977. Production relationships among inter-related fisheries. *In: Economic impacts of extended fisheries jurisdiction,* edited by Lee G. Anderson. Ann Arbor: Ann Arbor Science Publishers, Inc.

Anderson, Lee G. 1976. The relationship between firm and fishery in common property fisheries. *Land Econ.* 52(2): 179-191.

Bockstael, Nancy E. 1976. Analysis of investment behavior and price determination: analytical input for the formation of policy in the fisheries. Ph.D. dissertation, University of Rhode Island.

Coutlee, E. L. and R. I. Jennrich. 1968. The relevance of logarithmic models for population interaction. *American Naturalist* 102: 307.

Doll, John P. 1972. An econometric analysis of shrimp ex-vessel prices, 1950-1968. *Amer. J. Agricul. Econ.* 54: 431-440.

Geraci, Vincent J. 1976. Identification of simultaneous equation models with measurement error. *J. Econometrics* 4(3): 263-283.

Geraci, Vincent J. 1977. Estimation of simultaneous equation models with measurement error. *Econometrica* 45(5): 1243-1255.

Gomatam, J. 1974. A new model for interacting populations--I: two species systems. *Bull. Math. Biol.* 36: 347-353.

Gomatam, J. 1974. A new model for interacting populations--II: principle of competitive exclusion. *Bull. Math. Biol.* 36: 355-364.

Hsiao, Cheng. 1977. Identification for a linear dynamic simultaneous error-shock model. *International Economic Review* 18(1): 181-194.

Levi, Maurice D. 1977. Measurement errors and bounded OLS estimates. *J. Econometrics* 6(2): 165-171.

Silliman, R. P. 1971. Advantages and limitations of 'simple' fishery models in light of laboratory experiments. *J. Fish. Res. Bd. Canada* 28(8): 1211-1214.

Storey, David A. and Cleve E. Willis. 1978. Econometric analysis of Atlantic sea scallop markets. Report submitted to the New England Regional Fishery Management Council, February, 1978.

Cooperating Organizations

New England Regional Fisheries Management Council

National Marine Fisheries Service, Northeast Center

University of Texas, Project on Control in Economics and the Center for Economic Research

National Marine Fisheries Service, Tiburon Laboratory

The Effects of Food Availability on the Growth and Survival of Jack Mackerel Larvae

F. K. Devonald (M. M. Mullin and R. Lasker, sponsors)
Scripps Institution of Oceanography, University of California, San Diego

The management of commercial fisheries to optimize production while preventing overfishing requires an understanding of the relationship between the abundance of fish in one generation and the size of the next generation. This relationship depends on the survival and growth rates of young fish. The objective of this project is to determine whether the larvae of the California jack mackerel can survive, and if so, how fast they can grow, when feeding on low densities of plankton such as the average densities found in the sea. It has commonly been found that most first-feeding fish larvae raised in the laboratory require very high concentrations of food to survive, much higher concentrations than are found on the average in the open sea. It is not clear whether larvae in the sea achieve higher survival rates at lower food densities than do those in the laboratory, or whether the only larvae which survive in the sea are those which encounter patches of water with higher-than-average densities of prey organisms, or whether larvae in the sea are actually experiencing very slow growth rates and high rates of mortality due to starvation.

Jack mackerel are one of the most abundant types of fish larvae found by the biannual CalCOFI egg and larva surveys of the California Current. The estimated biomass of the species is from 2 to 5 million tons, which represents a sizable and currently underutilized resource for sports and commercial fishing. While considerable work has been done in California and around the world to study the feeding requirements of the larvae of anchovies, sardines, herring and their relatives, far less is known about the requirements of mackerel and similar, moderately-sized pelagic fishes. Jack mackerel larvae are larger and more active than anchovy or sardine larvae, and they can eat larger food particles. These differences may permit mackerel larvae to survive in plankton conditions that would be insufficient to support anchovy or sardine larvae.

During the first year of the project, laboratory experiments were done to determine how well mackerel larvae survive and grow when exposed to mean natural densities of natural prey organisms. Larvae were reared from eggs caught at sea. Methods were developed for capturing and transporting large numbers of wild zooplankton from nearshore waters into the laboratory and keeping them alive for several weeks to serve as food for the larvae.

The results of these experiments were that some larvae were able to survive at the mean natural densities, but survival rates were low, and growth rates were markedly less than those of larvae fed at higher than these "natural" densities. The surviving larvae had thinner bodies, less muscle mass, smaller eyes, and less well-developed mouths than wild-caught larvae of corresponding lengths. They also had, on the average, only about 40-50% as many prey items in their stomachs as had the wild-caught larvae.

These results support the hypothesis that larvae in the sea are encountering prey densities higher than the "average natural densities" measured by standard plankton sampling procedures. It is known that planktonic organisms in the sea are not uniformly distributed. However, plankton ecologists are only beginning to describe the sizes and shapes and distributions of patches of higher-than-average plankton densities, and most investigations have considered only the larger organisms (especially adults and copepodites of larger species of copepods). The lab experiments and analyses of the gut contents of field-caught larvae, show that young fish larvae can feed only on the smaller zooplankton: primarily the nauplius larvae of copepods, as well as some copepodites and adults of the smaller

species of copepods (especially certain cyclopoids and harpacticoids). There is almost no information available on the patchiness of these small zooplankton in the sea. In order to determine the likelihood of fish larvae in the sea finding sufficient food, we need to know something about the patchiness of their prey organisms on a spatial scale comparable to the scale of movements of the larvae through their environment.

We are conducting a field-sampling program by which we can measure the horizontal and vertical variations in density of prey organisms within areas where the fish larvae are feeding. A large capacity pump is used to sample plankton densities over a spatial scale of a few meters. Opening-closing bongo nets are used to collect fish larvae from various depths in the study area. During the 1978 spawning season, one-day pump and net sampling surveys were conducted on each of three cruises into different portions of the California Current. Sorting of fish larvae, their measurement and gut contents analysis, and counting of the plankton samples is currently underway.

One or two additional cruises are planned for the 1979 spawning season. Additional laboratory experiments will be performed in the spring or summer of 1979 to determine the lower limit of prey density at which larvae obtain enough food for normal morphological development.

Cooperating Organizations

National Marine Fisheries Service, Southwest Center

Development of a Mechanism to Allow Release of Dungeness Crabs from Lost or Abandoned Pots

Frank Jolly, *Humboldt State University*

An extensive trap fishery for Dungeness crab exists along the northern coast of California and north through Oregon and Washington. The traps, or pots, are circular structures with a steel frame and stainless steel webbing--a "tunnel" in the side allows crabs to enter the baited traps, but spring-operated barriers (triggers) prevent their exit. Typically, the pots are set out in depths of 200 feet or less and are checked for crabs every 2 to 5 days. One of the problems with this type of fishery is abandonment of pots, often because storms have partially buried them or moved them from their original location, or because floats attached to the pots are lost. These pots, even though unbaited, continue to catch crabs, albeit not as effectively as do baited traps.

This project was instituted to devise and test devices which, when placed on crab traps, would break up in a predictable time, allowing the crabs within to escape and preventing capture of additional crabs. Since crabs can live for many weeks inside a trap, a device which would fail in 2 to 6 months was sought in order to minimize the expense of replacement.

Preliminary tests led to the conclusion that electrolytic corrosion caused by two unlike metals in contact with one another in sea water offered the best solution for a time-predictable failure device. Aluminum-steel combinations were quickly discarded due to the growth of fouling organisms on the failure device and the consequent uncertainity of failure time. Copper-steel combination had the obvious advantage of being non-fouling because of the toxicity of copper. A steel pop-rivet with a copper washer combined the necessary electrolytic properties with economy, ready availability, and ease of installation.

Figure 1 illustrates the way in which the failure device was made and fitted to the traps. The rivet-washer pairs were used to fasten two plastic (polypropylene or polyethylene) bars to form one longer bar, and this in turn was wired to the crab pot so as to obstruct an opening in the wire fabric of the trap. This configuration was easily attached to the pots, and--importantly--the plastic material isolated the rivet-washer pairs from the metal framework of the traps. Also importantly, polypropylene did not support the growth of fouling organisms, therefore the two plastic pieces of each unit separated readily when the rivet corroded through. Failure devices placed on the lid tie-down straps were less effective since the lids did not necessarily open automatically when the devices failed. The escape ports were most effective when located on the top of the pots above the entrance tunnel. Ports placed on the pot sides tended to become buried on pots which were sanded in.

In the 1977-78 crab fishing season, a total of 2,000 escape devices--three rivet sizes combined with 4 copper rivet-burr sizes--were distributed to crab fishermen for testing. Ocean conditions were generally turbulent, and pot locations ranged from protected bay waters to both shallow and deep open ocean waters. The water turbulence and the variety of environments in which tests were conducted combined to produce longer time spreads for failure than were encountered under more stable conditions and more similar environments the previous year. Rivet and burr size combinations, and the number of each for which failure times were reported, are summarized in Table 1.

As expected, failure times were inversely related to the copper burr surface area exposed to sea water and the diameter of the steel rivets. Uncertainity of failure times, reflected in relatively long time spans between first and last failures of a set, were probably related to temperature changes during the trial period (9° - 12° C) and to differences in water turbulence. This uncertainity can be used to good advantage in limiting the loss of crabs due to unexpected

failure of a device during the fishing season. The strategy is to use two devices to block one escape port, and since it is highly unlikely that both will fail at the same time, the one which fails first can be replaced before the escape port opens.

In Table 1, code numbers 2 and 3 appear to best fit the requirements if two escape devices are used together, as described above. The mean time to failure, 3.5 months, is long enough so that, at most, only two changes would be necessary during the crab season. In addition, the 60-day failure span which we observed indicates there would be only a slight probability of simultaneous failure if two were used together.

Cooperating Organizations

California Department of Fish and Game

Table 1
Summary of tests of crab trap escape devices in the 1977-78 fishing season

Code No.	Number Tested	Plastic Material*	Copper Burr size	Steel rivet Diameter in.	Failure Time
1	106**	PP	6	3/16	2.5 months ±14 days
2	325**	PP	7	5/32	3.5 months ±30 days
3	100***	PP	7	5/32	not significantly different from 2
4	116**	PP	8	5/32	4.0 months ±21 days
5	100***	PP	8	5/32	not significantly different from 4
6	98**	PE	9	1/8	2.5 months ±35 days

* PP-polypropylene; PE-polyethylene
** Mandrels (rivet heads) removed
*** Mandrels not removed. (Presence of mandrel had little effect.)

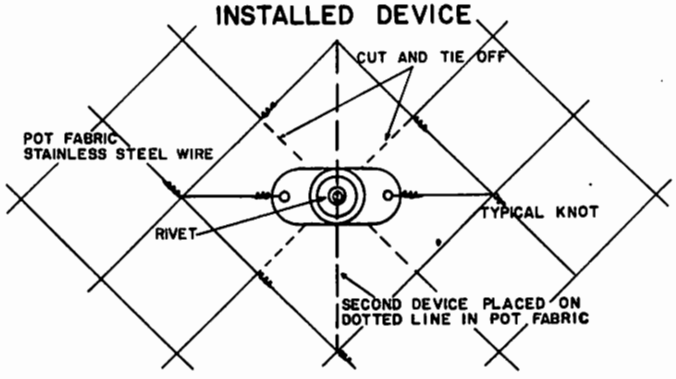


Figure 1

Improved Marine Food Products and Marine Food Technology

W. D. Brown, *University of California, Davis*

The primary objective of this project is that of providing improved methods of packaging and handling a variety of seafood products. During the first year's work, emphasis has been placed on investigations of the use of modified atmospheres for the storage and shipment of fish, and on evaluation of the potential for the use of edible coatings for frozen seafood products. Related work dealing with associated technological problems has been in the area of histamine toxicity from fish products, and that dealing with the chemistry of myoglobin pigments of fish, which are important in determining color in a variety of seafoods.

Modified atmosphere studies

In a series of tests, fresh rockfish fillets were held either in air (controls) or in modified atmospheres containing a mixture of 80% carbon dioxide and 20% air for up to 14 days in refrigerated storage. Samples of six fillets from each treatment group were removed at intervals of 3, 7, 10 and 14 days and subjected to chemical and microbial analyses. Microbial growth was drastically inhibited in the modified atmosphere samples, with the lag phase of growth being extended over the entire 14 day period, i.e. microbial counts were the same at 14 days as initially. In contrast, samples stored in air showed marked growth at 7 days (increase of 3 log cycles), continuing upwards throughout the 14 day period. Slime formation and a decaying odor were very perceptible for the control samples after 10 days of storage; no slime or off odor was associated with the samples stored in modified atmospheres after 14 days.

Results of various chemical analyses were as follows. Surface pH increased from initial values of about 6.7 to around 7.5 in the control samples during the storage period, while the treatment group showed values decreasing from 6.7 to just under 6.3. This change in pH may account for some of the antimicrobial effects produced by storage in carbon dioxide. Samples held in modified atmospheres also displayed significantly less accumulation of trimethylamine and maintained higher surface oxidation-reduction potentials than did the control samples. Concern had been expressed by some potential users over rumors of increased weight loss (drip) during storage of fish in modified atmospheres. No weight losses were notable in this study. We believe earlier observations by others were due to inattention to proper humidity control when gassing samples from cylinders containing very dry carbon dioxide.

We had an opportunity this year to conduct field studies under commercial conditions. With the cooperation of the TransFresh Corporation, one of our trainees (Kirk Parkin) spent several weeks in a fish processing plant in Anchorage, Alaska. This facility dresses and packages fish for shipment by steamship from Anchorage to the lower 48 states. Studies were made of the effectiveness of modified atmosphere systems in retarding spoilage of dressed gray cod, gray cod fillets, Alaskan spot shrimp and halibut steaks. Atmospheres mainly employed 60% carbon dioxide, with high (25%) levels of oxygen, or with low (less than 5%) levels of oxygen. All products were studied as fresh samples and were analyzed and evaluated at time intervals during the treatment period, as well as post-treatment (i.e. after removal from atmosphere storage) for periods of up to 28 days. Very good preservation quality was found for fresh shrimp, halibut and cod fillets. All were acceptable for at least 21 days of refrigerated storage when held in modified atmospheres.

Results from actual commercial shipments of salmon held under modified atmospheres were equally promising. During the summer about 2,250,000 pounds of dressed salmon were shipped from Anchorage to Seattle by steamship in Sea-Land vans gassed by TransFresh to contain 65% carbon dioxide. No losses occurred due to spoilage. Present economic considerations appear promising as indicated by Table 1.

Costs for refrigerated shipment, Anchorage to Seattle	
Mode of transportation	Costs, cents per pound
Air freight	15 to 40
Steamship, unmodified atmosphere	3.05 to 4.00
Steamship, modified atmosphere	4.30 to 5.25

These costs are based on capacity loads of 36,000 pounds per van. It is imperative that attention be given to proper refrigeration at point of shipment and the work of TransFresh, our own, and that of others indicates clearly that parameters must be established for each product shipped. However, with all due restraint, there appears to be great promise for commercial application.

The use of edible coatings

Problems encountered during frozen storage of fish include lipid oxidation, dehydration, changes in texture and water binding capacity and flavor, color and odor changes. A recent development in the protection of frozen foods is the use of edible alginate films. One such product is called "Flavor-Tex" and has been employed in our initial studies using red snapper fillets and salmon steaks held in frozen storage. A series of samples were prepared as follows: (1) Flavor-Tex coated, (2) glazed with ice containing ascorbate as an antioxidant and (3) untreated.

Evaluation of the effectiveness of the film was based on results of testing for lipid oxidation, moisture loss, microbial growth, and hypoxanthine and trimethylamine formation. The results of testing for hypoxanthine, trimethylamine, and aerobic plate counts showed no differences among the treatment groups. There was significantly more moisture loss in control samples than in either of the other two groups. Flavor-Tex treatment may have an advantage over glazing in that it remains intact after thawing so that drip loss is decreased. Control samples showed pronounced lipid oxidation (based on thiobarbituric acid assay) while the Flavor-Tex and glazed samples were moderate and low, respectively. Advantages from the use of Flavor-Tex in certain industrial applications appear to warrant its use. A reduction in labor might be facilitated by eliminating the repeated dippings necessary for glaze formation and the expense of reglazing during extended storage. Flavor-Tex could also provide protection in situations where the use of ice glazes is impractical, such as foods to be fried. Organoleptic evaluation of frozen products coated with Flavor-Tex is necessary, but tests completed to this point indicate that its protective capabilities and the advantages derived from its use justify further experimentation for use in the food industry.

Histamine toxicity from fish

This project assumed the responsibility of completing earlier work in histamine toxicity. A number of papers were prepared dealing with the development of various bioassays for histamine. Newly hatched Japanese quail are sensitive to the addition of histamine to chick starter meal (depressed weight gain) and to toxic tuna (freeze-dried and incorporated into a ration). It appears that quail might be useful bioassay animals for toxic factors in spoiled scombroid fish products. The small crustacean *Daphnia magna* was also found to be sensitive to histamine and the ease of assay with this organisms suggests potential for its use in quality control testing. Larger animals studied included pigs, cats, dogs and rabbits. Young pigs were the only animals showing a reaction to toxic fish (regurgitation); Durocs were more sensitive than other breeds tested. The review article prepared some time ago on this topic has not yet appeared, but will be published in the 1978 edition of *Advances in Food Research.*

Myoglobin pigment studies

Amino acid sequences of the soluble tryptic peptides of yellowfin tuna myoglobin have been determined. It was found that the amino terminus is acetylated as shown by Fourier transform nuclear magnetic resonance spectroscopy of an N-terminal dipeptide. Comparison of peptide sequences from yellowfin tuna myoglobin with corresponding regions of mammalian myoglobins show obvious homology around the heme-attachment site and the carboxyl terminus, but marked dissimilarity is evident at other locations, such as the amino terminal region.

Detailed knowledge of the primary structure of this protein may enable us to understand better some of the characteristics, such as its relative sensitivity to denaturing agents, that have bearing on its pigment function, i.e. off colors in a variety of fish products.

Publications

Blonz, E. R. and H. S. Olcott. 1978. *Daphnia magna* as a bioassay system for histamine in tuna extracts. *Bull. Jap. Soc. Sci. Fish.* 44: 517-519.

Blonz, E. R. and H. S. Olcott. 1978. Effects of orally ingested histamine and/or commercially canned spoiled shipjack tuna on pigs, cats, dogs and rabbits. *Comp. Biochem. Physiol.* 61C: 161-163.

Blonz, E. R. and H. S. Olcott. 1978. Effects of histamine, putrescine and of canned spoiled tuna on growth in young Japanese quail. *J. Food Sci.* 43: 1390-1392.

Blonz, E. R. 1978. Histamine toxicity from fish: bioassay. Paper presented at the 175th American Chemical Society National Meeting, Anaheim, California, March 1978, Symposium on "Chemistry of Marine Organisms" (organized by the project leader, W. D. Brown).

Ijichi, K. 1978. Evaluation of an alginate coating during frozen storage of red snapper and silver salmon. M. S. thesis, Food Science, University of California, Davis.

Olcott, H. S. 1978. Histamine toxicity from fish: overview and chemical assay. Paper presented at the 175th American Chemical Society National Meeting, Anaheim, California, March 1978 Symposium on "Chemistry of Marine Organisms" (organized by the project leader, W. D. Brown).

Omura, Y. R., J. Proce and H. S. Olcott. 1978. Histamine-forming bacteria isolated from spoiled skipjack tuna and jack mackerel. *J. Food Sci.* 43: 1779-1781.

Rice, R. H., D. A. Watts and W. D. Brown. *In press.* Sequences of the soluble tryptic peptides from myoglobin of yellowfin tuna *(Thunnus albacares). Comp. Biochem. Physiol.*

Wolfe, S. K., D. A. Watts and W. D. Brown. 1978. Analysis of myoglobin derivatives in meat or fish samples using absorption spectrophotometry. *J. Agric. Food Chem.* 26: 217-219.

Cooperating Organizations

TransFresh Corporation

California Seafood Institute, Research Committee

Massachusetts Institute of Technology, Department of Nutrition and Food Science

Amine Toxicity of Fish Products

L. F. Bjeldanes, *University of California, Berkeley*

Chemicals in addition to histamine may be involved in the cause of scombroid fish poisoning. Practical and reliable methods are required for the analysis of these substances in fish. The method we have developed is a relatively simple and inexpensive technique which is sensitive enough for routine analysis of many samples. The method was used to determine levels of important chemicals (amines) in canned samples of wholesome tuna and in tuna implicated in an outbreak of human poisoning. Levels of certain of these chemicals (cadaverine, putrescine and histamine) are greater in toxic tuna than in wholesome tuna. These chemicals may act together in producing the toxic effects characteristic of scombroid poisoning.

The effects of the chemical cadaverine on histamine metabolism were also studied with sections of guinea-pig gut in efforts to understand how cadaverine increases the toxicity of histamine in this animal. Cadaverine was observed to affect only the rate at which histamine crosses the gut wall. Cadaverine does not affect histamine metabolism. These findings suggest that although cadaverine has a much stronger effect than other amines on histamine toxicity, cadaverine and other amines may increase histamine toxicity by similar mechanisms. This supports further the hypothesis that the levels of several amines in addition to histamine may be important in the cause of scombroid poisoning.

Histamine formation and degradation by bacteria isolated from spoiled skipjack tuna (Cheu-Hsia Chu)

One strain of *Proteus morganii* isolated from spoiled jackmackerel was used to study histamine formation and degradation over a week in the nutrient broth with 0.5%, 1%, and 2% histidine. A simple rapid method described by Lin *et al.* was modified to analyse histamine content in the culture. At 25° C histamine production increased with the rise of histidine level, reaching a maximum around the 5th or 6th day, then decreasing slightly. While at 37° C, histamine formation had the same tendency as at 25° C except that the maximum was reached on the 2nd day in 0.5% histidine nutrient broth and the concentration of histamine seemed lower than that at 25° C. The high level of histamine formed in the culture was indicated by the color changing from yellow to pale orange.

Tuna infusion broth with pH = 5.7 was prepared to observe the histamine formation of three strains of *Proteus morganii* (one of them being the same as above) and one strain of *Proteus vulgaris* at 30° C. All the *Proteus morganii* cultures rapidly produced elevated levels of histamine, followed by a slight decrease, and then another rise. The final concentration exceeded the previous maximum level. As to *Proteus vulgaris* culture, histamine formation continually increased over a period of 7 days. The result of the rapid degradation of about of the formed histamine could not be reproduced in this experiment. This indicated that the degradation enzyme system of histamine might not exist in the same bacteria as histidine decarboxylase. Even if present, the activity should be very low. So a further search for spoilage with a high activity of histamine degradation is needed.

In comparison with the control sample, bacteria culture showed two extra spots on two dimensional chromatograph development CC_{41} cellulose TLC plate (first dimensional developing solvent system, t-butanol : fromic acid : water = 7:15:15; second one, methanol : chloroform : ammonia = 4:4:1). One was determined to be histamine; the other had the same Rf value as histamine on the first dimension and a higher Rf value than histamine on the second dimension. It may be histamine, due to the phenomena of histamine separation on CC_{41} cellulose plate, or it may be a metabolite of other enzyme activity. This also needs to be further identified.

Publications

Bjeldanes, L. F., D. E. Schutz and M. M. Morris. 1978. On the etiology of scombroid poisoning: cadaverine potentiation of histamine toxicity in the guinea pig. *Food and Cosmetics Toxicology* 16: 157.

Jung-Paik, H. Y. and L. F. Bjeldanes. Effects of cadaverine on histamine absorption and metabolism in isolated gut sections. Submitted to *J. Food and Cosmetics Toxicology.*

Kim, I. S. 1977. Analysis of amines in canned tuna. M. S. thesis, Food Science, UC Berkeley.

Kim, I. S. and L. F. Bjeldanes. Thin-layer chromatographic-spectrophotometric analysis of amines in tuna. Submitted to *J. of Food Science.*

Paik, H. Y. 1978. Studies *in vitro* of cadaverine effects on histamine metabolism in isolated gut segments of guinea pig. M. S. thesis, Food Science, UC Berkeley.

Design and Development of a Squid Processing System

R. Paul Singh, *University of California, Davis*

Squid is an important food item in many countries, particularly in Mediterranean Europe and the Orient. It is a nutritious seafood high in protein and low in fat, and it is abundantly available. The current world catch exceeds one half million tons, and it is estimated that this could be increased to a sustainable fishery of over one hundred million tons annually (Kato 1975). Squid is potentially the single largest source of animal protein in the marine environment.

One species, *Loligo opalescens* Berry (commonly referred to as market squid) abounds off the western coast of the United States. The California squid catch averages 10,000 tons worth 1.2 million (McAllister 1976). It is estimated that this tonnage could increase to over one half million tons annually if demand would allow (Voss 1973).

In spite of its excellent food value and delicate flavor, squid is unpopular in North America. Not only does it appear unappetizing to many, but the task of cleaning squid is also laborious and unpleasant. However, prepared fish products such as snack foods, breaded patties, and cocktail sauces are quite popular. Prepared foods made from squid meat have been well received in preliminary tests (Berk 1974), and this shows that a potential market exists for squid meat products in this country. These products require that whole squid should be cleaned economically and at a high processing rate.

Currently there are no commercial squid processing facilities in the United States. Hand cleaning of squid is both time-consuming and expensive, and no mechanical systems are available for cleaning (Ghio 1977). If a system could be developed to economically clean squid, new products could be developed. Coupled with consumer education and product promotion, increased use of squid would result. Thus, automation of all or a portion of the squid cleaning process indicates a feasible way to increase squid utilization. Knowledge of the physical properties of squid is necessary to develop new food products using squid and mechanical devices for cleaning raw squid.

The major objective of the research reported in this paper was to determine physical properties of *Loligo opalescens* important in the cleaning and handling processes.

Physical properties

The squid of the *Loligo* species have been extensively examined with respect to taxonomy, natural history, structure and reproduction by Fields (1965). Squid are mollusks of the Class Cephalopoda, which contain the octopus and cuttlefish as well. In a typical *Loligo opalescens,* eight sessile arms and two tentacular arms are attached at the head end. The mantle surrounds the visceral mass and the chitinous "pen" or backbone. The fins extend to half the length of the mantle. The mantle and tentacles are the parts normally eaten. The mantle is covered by a thin, pigmented epidermal layer which changes color depending upon the physical and emotional environment of the squid.

Loligo opalescens is smaller than most other common squids, for example the eastern variety *Loligo pealii* and *Illex* species (Berk 1974) are much smaller than *Ommastrephus sloani pacificus,* which are up to a half meter long and make up the bulk of the Japanese squid fishery. Berk (1974) gives a breakdown by weight of various squid species. It is noted that the yield from whole *Loligo opalescens* (49%) is somewhat lower than the east coast variety (68-70%).

The development of a cleaning system requires information on the morphological characteristics and physical forces required to separate edible from non-edible parts. According to Takahaski (1965), squid meat contains considerable fibrous protein and little fat. It is not made up of bundles like muscle, yet it is not tissue-like soft due to the presence of fibers. Mohsenin (1970)

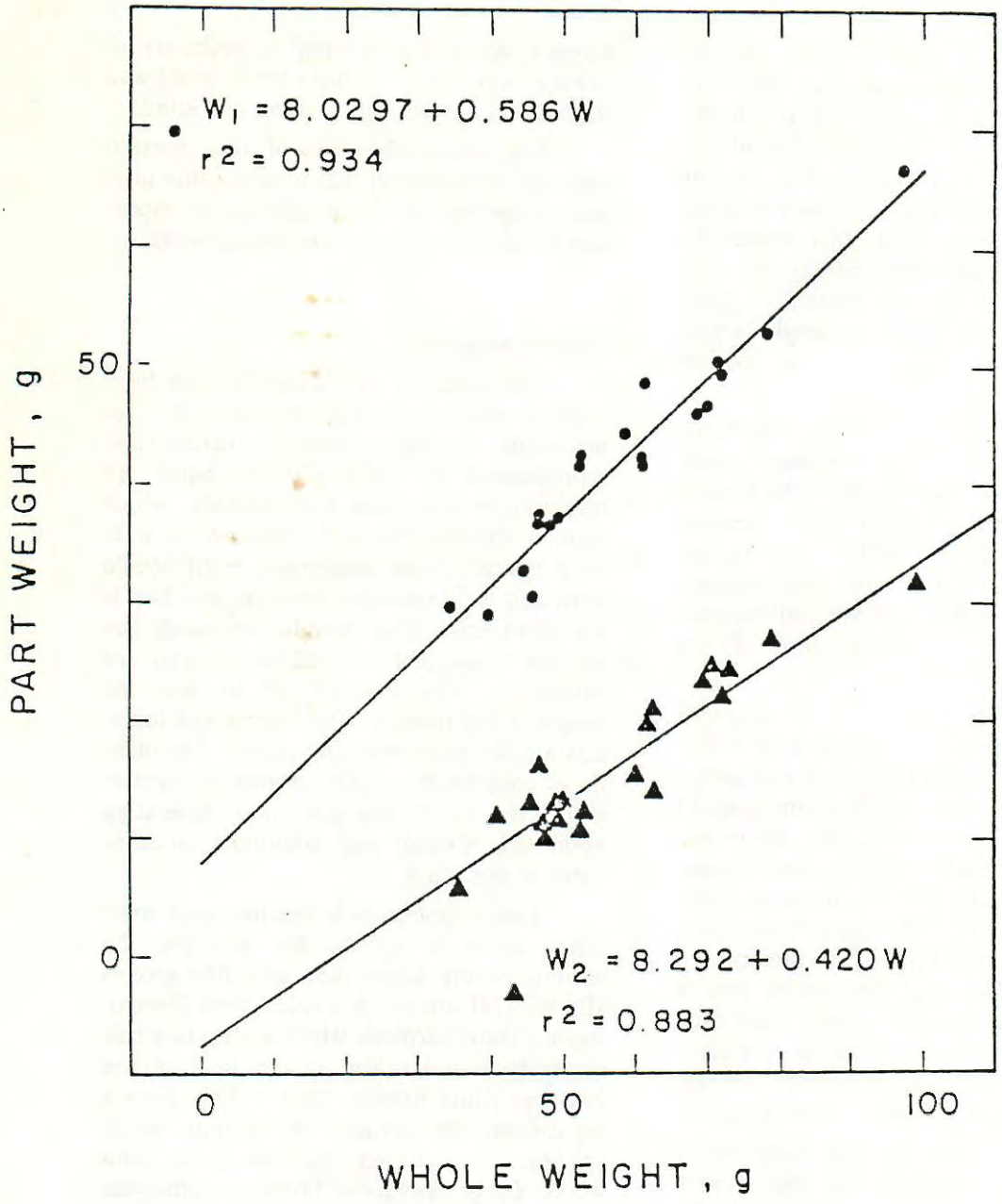


Figure 1. Weight of whole mantle, and weight of head-arms-tentacles vs. whole body weight of *Loligo opalescens*. Combined male and female population.

suggests that, due to the lack of uniformity in biological materials, caused by temperature, humidity, food supply and internal factors such as age and physiological condition, empirical approaches to the determination of rheological and mechanical properties are necessary.

General characteristics

The squid body is covered with a thin, gelatinous layer. The dark mottling of the skin on the dorsal side varies from light to very dark. The mottling extends to the ventral portion, but is not as pronounced. The mantle approximates a right circular cone, with the circumference approximately equal to one-half the mantle length (as measured from the tail tip to pen tip).

The areas where the skin, fins and viscera are strongly attached to the mantle flesh are identified as follows. The pallial cartilage connects the siphon to the body and provides support for this organ which enables the squid to swim. The skin extends around the rim of the collar and attaches at the inner rim. Invariably, pulling the skin from the mantle leaves behind a small portion attached to this point. It was qualitatively determined that initial tearing of the skin is more difficult than peeling the skin back once it is torn. Thus, skin removal is facilitated by cutting through the mantle just behind the collar. The fins are connected to the mantle by a rough, transparent membrane extending the length of the fins. The skin covering the fins is removable along with the rest of the skin.

The results of weight, dorsal mantle length, mantle thickness and bulk density measurements are presented in Table 1. The squid sample was obtained from a truncated distribution (those selected for sale) as compared to the samples of Evans (1976) and Fields (1965), who took their samples directly from the boats. This fact may account for the difference in the mean weights and lengths between the results in Table 1 and data reported by Evans. There is less variance in the size distribution of the frozen squid as compared to those freshly caught. A Kolmogorov-Smirnoff test for goodness of fit showed that the individual and combined population of males and females could be taken as normally distributed. An estimate of the percent yield was computed as follows:

$$\%\,Yield = \frac{whole\ wt. - cleaned\ wt.}{whole\ wt.} x100$$

A relationship between the weight of the whole mantle (including skin, viscera and fins) W_1 and the total weight, W, may be statistically estimated as:

$$W_1 = 8.0297 + 0.586\,W,\ r^2 = 0.93$$

which is valid for the range of total weights between 35 and 100 grams.

A statistical estimate of the relationship between the weight of the head, arms, and tentacles (W_2) without regard to sex is:

$$W_2 = 8.2920 + 0.420\ W,\ r_2 = 0.88$$

valid for squid weighing between 35 and 100 grams (Fig. 1). The longitudinal center of mass is located in the body about one-fifth of the length of the mantle back from the collar. Although the mass of the arms of the male make up a larger percentage of its weight than that of a female does, the center of mass lies at the same point for both male and female. Distribution of the mantle thickness, the visceral mass, and the mass of the fins may account for this phenomenon.

Surface friction characteristics

A study of surface frictin characteristics was made using a sliding sheet metal ramp with samples of squid that had been previously frozen and thawed. Results of the surface friction study are presented in Table 2. The friction coefficient of each part was plotted as a function of whole weight. No simple correlation, however, was found. This result would be expected for a dry friction model. The wide range of the friction coefficient data could be due to variabilities in the slimy coating on the body or the way in which the arms contact the surface, e.g., the number of suckers contacting the slide. In addition, the amount of moisture on the surface has most likely a significant effect on the friction characteristic.

It was observed that virtually all of the squid could be made to orient mantle-end down if the ramp angle was properly adjusted. This factor could be incorporated

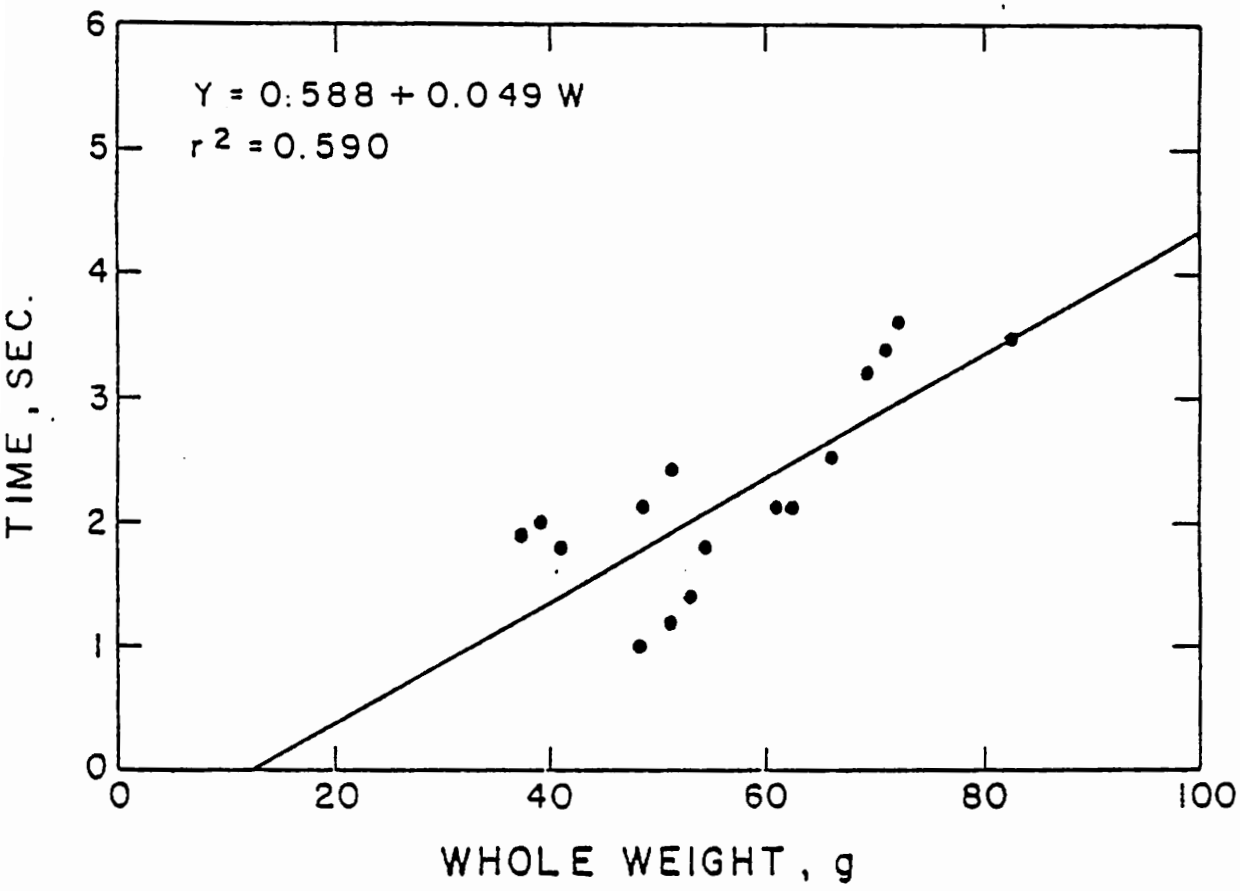


Figure 2. Water spray application time to separate viscera from mantle of *Loligo opalescens* using water jet.
Pressure = 1.93×10^5 Pa
Flow rate = $1.2 \times 10^{-4} / m^3 / sec$
Area = $7.92 \times 10^{-6} m^2$

into an automatic handling system. The design parameters include the ramp angle, ramp length, and time for the squid to reach the bottom of the ramp. For the 20 squid which were dropped onto the ramp and oriented within the 120 cm ramp length the ramp angle varied from 14° to 30° with a mean of 22.6°. These were not necessarily the minimum or maximum angles at which the squid would orient in 120 cm, since the determination would take repeated tests with the same squid. The squid surface changes with repeated handling (slime layer comes off, skin tears) and prohibits replications. However, a mimimum orientation angle of about 14° and a maximum of about 30° are indicted. One estimate of the mimimum angle to orient the average size squid could be to use the mean overall friction coefficient and its corresponding angle:

$$\mu = \tan \theta = 0.42$$

$$\theta = 22.78$$

The minimum and maximum angles required for orientation were the following:

$$\theta_{min} = 19.7°$$

$$\theta_{max} = 30.1°$$

Forces to remove viscera and fins

Results of the Instron tensile tests on the viscera and fins, and the force gauge test of the head, pen, siphon and fins are listed in Table 3. Fins were harder to remove by pulling than the viscera. The strongest point on the viscera was at the pallial cartilage. Comparison of the forces required to pull the viscera and fins away from the mantle by pulling from the head end confirms these relationships. Stress determinations were not made due to the difficulty in measuring the size of the connective cross-sectional area. The deformation includes stretching of the siphon as well as the cartilage, therefore the total deformation is not a true deformation of the connection point. Plots of the forces required to remove the various parts from the mantle and the head from the body suggests that there may be an increase in force required for increasing body weight, although the computed correlation coefficients were small. The variability of the data could be due to intrinsic biological considerations such as age, vigor, etc., of the animal and size of the attachment area which may not be a linear function of body weight. An increase in strength of connective tissue with body weight is in keeping with the findings of Bouton (1965).

The preceding discussion indicates that efforts to mechanically clean *Loligo opalescens* should be directed at separating the siphon and fins from the mantle, since these are the areas of strongest attachment.

Separation of the viscera, fins and skin from the mantle using a water spray. The water pressure at the laboratory jet nozzle which would effect removal of the viscera, skin and fins without damaging the mantle flesh was found to be 1.93×10^5 Pa (28 psi). This gave a flow rate of 1.2×10^{-4} m^3/sec. The average times and energies for the spray to cause visible separation at the points in contact with the spray are given in Table 4. The time for the mantle was noted when evidence of damage to the flesh was visible. It can be seen that the fins are the most difficult to remove, followed by the viscera at the pallial cartilage, then the skin. This could be expected from the results of previous force tests. It was noted that the mantle flesh would be damaged at almost the same time as the fins were removed. Figure 2 shows that there is a tendency towards increased resistance for higher total weights, which occurs with the results of tensile tests. Minimum cleaning times at the given conditions can be estimated from the figures. It was found that the nozzle pressure of 1.93×10^5 Pa exceeds the minimum necessary to loosen the skin. The variability in the data is most likely due to inability to detect the exact separation time, which is less than 1 sec. The variability in the time to remove the fins is also due to the difficulty in observing exactly when separation occurs and, in addition, the fins would at times move and hide the contact area of separation. However, a mimimum time for fin removal of about 3 seconds is indicated, though in five cases out of 17 the fins did not separate at this water pressure. The mimimum nozzle pressure which cause separation of the skin when applied continuously was 1.5×10^5 Pa (psig).

Conclusions

1. *Loligo opalescens* squid taken from the wholesale market averaged 58.01 grams for males, 42.78 grams for females and a combined average of 52.67 grams. The weight of the combined population was normally distributed with a standard deviation of 15.64 grams. These squid averaged 13.72 cm dorsal mantle length.
2. Product yield of arms, tentacles, and mantle was 49% of the total body weight.
3. The friction coefficient of squid on wet sheet metal may be characterized by a dry friction model. The mean overall friction coefficient was 0.42.
4. Of a twenty squid sample tested, all were oriented tail first within 120 cm when placed on an inclined sheet metal ramp perpendicular to the direction of travel at a ramp angle of 30°.
5. Through repeated experiments, it was found that it is easier to separate the skin and soft body parts from the mantle; the fins are more difficult to separate.
6. A nozzle pressure of 1.93×10^5 Pa and flow rate of $1.2 \times 10^{-4} m^3$/sec caused separation of the skin in less than one second, siphon at the pallial cartilage in 2.25 seconds, and fins in more than 3.7 seconds. The mantle flesh was damaged in 3.5 seconds.

References

Berk, Zeki. 1974. Processing squid for food. MIT Sea Grant Program. Rept. No. MITSG 74-13.

Boolootian, R. A. and D. Hagneman. 1969. *An illustrated laboratory text in zoology,* 2nd ed. Holt, Rinehart, Winston.

Bouton, P. E., *et al.* 1965. Possible relationships between shear, tensile, and adhesion properties. *J. Texture Studies* 6(3).

Evans, R. G. 1976. Aspects of the population biology of the California market squid. M.A. thesis, California State University, Hayward.

Fields, W. G. 1965. The structure, development, food relations, reproduction and life history of the squid *Loligo opalescens* Berry. *Fish. Bull.* 131, Calif. Dept. of Fish and Game.

Ghio, Todd. Personal communication. Ghio Seafood Products, Inc., San Diego, Calif., February 4, 1977.

Kato, S. and J. E. Hardwick. 1975. The California squid fishery, from expert consultation of fishery for squid and other Cephalopods. FAO Fishery Report 170, suppl. 1.

McAllister. 1976. *Fish. Bull.* 164. Calif. Dept. of Fish and Game.

Mohsenin, Nuri N. 1970. An engineering approach to evaluation of texture of solid food materials. *J. Texture Studies* 1(2).

Voss, G. G. 1973. Cephalopod resource of the world. FAO Fishery Circular 149.

Publications

Brooks, L. A. and R. P. Singh. 1977. Design of a squid cleaning machine. *ASAE Paper* No. 77-6525.

Brooks, L. A. and R. P. Singh. *In press.* Properties of squid useful in designing of cleaning and handling systems. Paper accepted for publication in *Transactions of American Society of Agricultural Engineers.*

Brooks, L. A. 1977. Development and testing of a device to automatically clean California market squid *(Loligo opalescens).* M.S. thesis, University of California, Davis.

Cooperating Organizations

University of California Cooperative Extension, Davis, California

Table 1
Morphological Data of Frozen, Packed *Loligo opalescens* Berry
Purchased at Wholesale

Parameter	Units	No. in Sample	Mean	S.D	95% CI-T test τ unknown	Max. difference for K-S test for goodness of fit
Whole wt, male	g	39	58.01 *70.1	15.15 *22.4	±4.0 *±6.8	0.0964
Whole wt, female	g	21	42.78 49.3	11.25 13.4	±5.10 ±4.2	0.1712
Whole wt, combined sexes	g	60	52.67	15.64	±3.33	0.0852
Dorsal, Mantle length, male	cm	39	14.1 14.6	12.80 13.90	±3.38 ±4.2	
Dorsal, Mantle length, female	cm	21	13.0 13.4	9.41 10.1	±4.26 ±3.2	
Dorsal, Mantle length, combined sexes	cm	60	13.72	13.12	±3.34	
Body wt, combined sexes	g	37	41.7	8.93	±2.87	
Head, arm, tentacle wt combined	g	37	15.6	9.10	±1.44	Paired T-test 95% CI on difference between whole and cleaned weight $\mu d = 23.62 \pm 2.00$
Cleaned weight (head, arms, tentacles of combined sexes)	g	37	29.6	8.92		
% YIELD = 49.0%						
Density of whole squid, g/cc		22	1.10	0.004	±0.0013	

*The second figure is data collected by Evans (1976)

Table 2
Friction Characteristics of *Loligo opalescens* on Wet Sheet Metal. (Sample Size = 21)

Parameter	$\bar{X}$ Mean	S Stand. Dev.	Standard error of the mean = $S/\sqrt{n}$
Whole weight, g	57.1	14.7	3.14
Whole mantle (incl. viscera and fins, skin), g	41.56	8.93	1.95
Head, arms, tentacles, g	15.57	6.63	1.48
Slide angle θ_1°	13.19	3.04	0.66
Slide angle θ_2 °	24.43	3.97	0.87
Mantle friction coefficient μ_1	0.234	0.055	0.012
Head-arm friction coefficient μ_2	1.03	0.232	0.051
Overall friction coefficient $\mu = \tan\tau_2$	0.46	0.087	0.019
Orientation test: (n=20)			
Whole wt, g	56.25	13.52	3.02
*θ,°	22.65	4.68	1.05
$\mu = \tan\theta$	0.42		

* θ = angle of ramp for each squid that oriented within 120 cm ramp distance.

Table 3
Tensile Tests on *Loligo opalescens* to Determine Peak Tensile Force to Separate Various Parts From the Mantle Flesh

		Peak Force to Separate, N		
	12 Samples Part Separated from Mantle	Sample Mean	Sample S.D.	Standard Error of Mean
Instron-	Viscera-pallial cartilage attachment	0.31	0.10	0.0304
	Fins	0.39	0.118	0.036
	Sample whole weight, g	65.43	18.51	5.58
	14 Samples			
Force-Gauge	Head	0.474	0.134	0.036
	Pen	0.284	0.048	0.013
	Siphon	0.407	0.128	0.034
	Fins	0.824	0.122	0.033
	Sample whole wt, g	57.68	11.89	3.18

Table 4

Time and Energy for Separating Various Body Parts From Whole *Loligo opalescens* Using Laboratory Jet Type Water Nozzle Delivering Rod-Shaped Spray.

Pressure = 1.93×10^5 Pa (gauge)
Flow rate = $1.2 \times 10^{-4} m^3/sec$
Spray area = $7.92 \times 10^{-6} m^2$ (0.3175 cm dia.)
Energy = $1/2\ PQ\ \Delta = 11.58\ \Delta T$ Joules

Body Part	Time for Separation, sec		Energy of Spray for Separation, Joules	
	Mean	Range	Mean	Range
Viscera at pallial cartilage	2.25	1.0-3.5	26.05	11.58-40.53
Skin	0.94	0.8-1.2	10.88	9.26-13.90
Fins	3.68*	2.4->10	42.61	27.79->115.8
Mantle Flesh	3.44**	2.1-4.6	39.82**	24.38-53.27

*In five out of 17 cases, fins were not removed in 10 sec. Test discontinued.
**Mean time and energy to cause visable flesh damage.

Bioconversion of Chitin Wastes

P. Carroad, *University of California, Davis*

This project concerns design of a process to treat shellfish wastes. The disposal of shellfish wastes, and particularly their chitin fraction, is a severe environmental problem. Conversion to a single-cell protein, usable in such products as animal and aquaculture feed, would facilitiate waste disposal as well as develop a a beneficial byproduct industry.

Objectives

The objectives of this project are to determine experimentally the necessary data for a preliminary design of a process to convert shellfish chitin wastes into single-cell protein, to complete such a design, and to assess its economic feasibility. A process is desired which can be associated with a large shellfish processor or a shellfish-processing community, but which does not depend upon a national market for sale of the product. Figure 1 illustrates a process concept in which chitin shellfish wastes are pretreated and divided. A minor fraction of the waste is diverted to an enzyme production step in which chitin serves as substrate for a microorganism and as inducer for a chitinase enzyme system. The chitinase, filtered free of microbial cells and undigested chitin, is added to the bulk of the chitin waste, hydrolyzing the accessible chitin to a sugar solution. This hydrolysate can then be fed to a yeast for bioconversion to single-cell protein.

The specific goals of the first year were to: 1) select the microorganism which secretes the most active chitinase, 2) obtain rate data on enzymatic chitin hydrolysis, and 3) initiate optimization of enzyme production.

Progress on first year objectives

After compiling a suitable screening program, the microorganism selected for the project was a strain of *Serratia marcescens* designated as QM B1466 and obtained from the U.S. Army Natick Research and Development Center. This organism not only produces the most active extracellular chitinase enzyme system tested on chitin wastes, but also it may be susceptible to genetic engineering to enhance its properties.

Preliminary hydrolysis studies indicated a need for more detailed data for design of the enzymatic chitin hydrolyzer. The parameters of temperature, enzyme concentration, and substrate concentration have been studied. The pH optimum of the *S. marcescens* system is available in the literature. Hydrolyses were conducted for 48 hours and were followed by measuring the increase in reducing sugar concentration in solution. A trade-off between enzymatic reaction rate and enzyme stability exists, and 30° C has been adopted as the best hydrolysis temperature. Experiments are currently underway to test the effect of chitin particle size, and this objective will be completed with controlled hydrolyses conducted in suitably equipped reaction vessels whose results can be scaled up directly.

The production of chitinase by *Serratia marcescens* has been studied in an agitated, aerated fermentor under conditions of controlled pH and temperature. Optimum conditions are pH 8 and a temperature of 30 ° C. The year has seen the determination of maximum specific rates of growth and substrate yield coefficients in media with glucose and with N-acetylglucosamine, the chitin monomer. The microbial oxygen demand was determined with media of N-acetylglucosamine and chitin. Further data will be determined as needed to allow design of the process step in which chitinase is produced.

Further progress

A projected second year goal was to initiate study of yeast single-cell protein production on the chitin hydrolysate. This was begun in the first year. Yeasts were selected for screening based on their precedent as food and feed microorganisms and their suitability for inexpensive recovery in industrial

processing. Fifty yeasts are being screened for their ability to metabolize N-acetylglucosamine, which has been reported in the literature to be the main hydrolysis product, as well as the crude hydrolysate itself. Already, several suitable species have been identified. The organism of choice will be further studied for growth rate characteristics and for amino acid distribution.

Publications

Carroad, P. A. and R. A. Tom. 1978. Bioconversion of shellfish chitin wastes: process conception and selection of microorganisms. *J. Food Sci.* 43: 1158-1161.

Carroad, P. A. 1978. Utilization of the chitin-chitinase system for the treatment of shellfish wastes. Paper presented at the 175th American Chemical Society National Meeting, Agricultural and Food Chemistry Division.

Cooperating Organizations

University of California Cooperative Extension, Dr. Robert Price

National Science Foundation, Engineering Section

PROCESS CONCEPT FOR BIOCONVERSION OF CHITIN DEGRADATION PRODUCTS

(HYDROLYSIS OCCURRING IN CELL-FREE ENZYME)

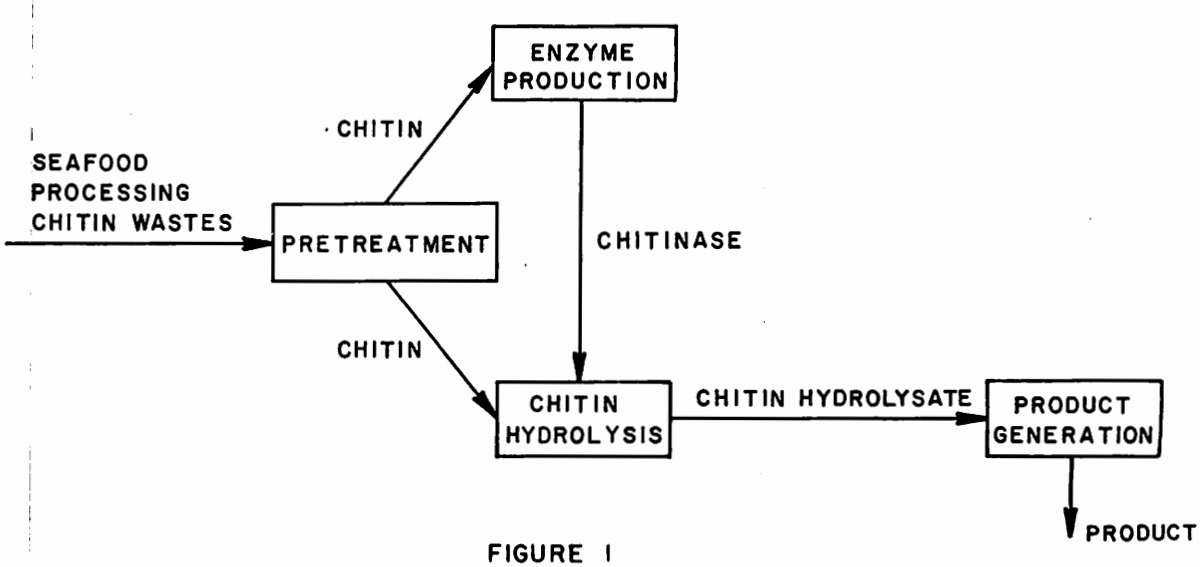


FIGURE 1

Coordinated Management of the Pacific Coast Salmon Fisheries and the Implications of Extended Jurisdiction

John E. Moore, Alan J. Wyner and Biliana Cicin-Sain
University of California, Santa Barbara

The research for this project has proceeded along two converging lines -- the first concerned with management planning for the Pacific troll salmon fishery, the second concerned with implementation of the Fisheries Conservation and Management Act (FCMA).

In connection with the first line of research, we have examined the options available for managing the salmon fishery, and sought to assess them, using evaluative criteria that include biological preservation, economic efficiency, legal feasibility, social equity, political feasibility and administrative feasibility. In view of our interests and training as political scientists, we have concentrated on the latter three criteria -- social equity, political feasibility, and administrative feasibility.

These criteria are closely connected with one another: broadly construed, political feasibility may be the ultimate test of social equity -- if the decision-making structure represents all affected interests in proportion to their stake in the outcome, then a politically feasible plan should represent social equity. But given the difficulty of assuring the equity of fisheries policy in the decision-making structure, political feasibility is likely to be the ultimate *constraint* on realizing social equity, reflecting what is acceptable to the most influential interests, rather than what is most equitable for all affected interests. Where this is the case, politics affects administration. Depending upon the decision-making structure, it may be possible to obtain the agreement of certain groups required to adopt a given management plan, but not necessarily to obtain the agreement of other groups who may forestall its effective implementation. In addition to requiring an assessment of the level of anticipated cooperation, consideration of the administrative feasibility of a given management plan entails an assessment of the practicality and cost of enforcing the plan, and of the equity with which administrative costs can be shared.

The impact of decision-making structures on management planning for the salmon troll fishery marks the point of convergence between our first and second lines of research. Adoption of the FCMA represents a deliberate effort to restructure the decision-making process for marine fisheries. It mandates a regional approach to fisheries management, and effects a varied input through the composition of the regional management councils that it establishes. These changes influence the process of decision-making through analysis provided by the council's scientific and statistical committees, advisory panels representing a variety of interests, and general public input through public hearings and informal communications with council members.

Management planning for the Pacific troll salmon fishery has thus served as a focal point for assessing the potential of the FCMA for enhancing political and administrative processess to increase social equity. To this end we have examined pre-FCMA policies in the states of Washington, Oregon, and California, and we have looked at efforts to facilitate coordinated management through the Pacific Marine Fisheries Commission. The objectives and representation of both the most directly affected interests -- commercial fishermen, sports fishermen, resource managers -- and of broader publics including coastal communities, consumers, and the general public have been considered.

We have simultaneously monitored the organization and activities of the Pacific Fisheries Management Council through observation of all relevant meetings and personal interviews with the principal participants. We have also monitored the formulation of management plans for the troll salmon fishery from their inception in a preliminary management plan prepared by the

National Marine Fisheries Service, through two interim plans adopted by the Pacific Council and approved by the Secretary of Commerce, to the specification of objectives for a comprehensive plan to be implemented by 1980.

In order to provide some comparative perspectives on the management options considered by the Pacific Council, interviews were also conducted with members of the North Pacific Council and officials of relevant agencies in the state of Alaska. While the adoption and implementation of management plans for the troll salmon fishery is clearly an ongoing process, we are satisfied that we have sufficient data for an initial assessment of that process, and of the ways in which it has been affected by decisions reached within the new framework established by the FCMA. We are presently drafting a book-length manuscript that analyzes implementation of the FCMA with specific reference to the commercial troll salmon fishery, and -- to the extent possible within a limited time perspective -- assesses the emerging policy outcomes.

Publications

Cicin-Sain, Biliana, John E. Moore and Alan J. Wyner. 1978. Limiting entry to commercial fisheries: some worldwide comparisons. *Ocean Management* 4.

Cicin-Sain Biliana. 1978. Evaluative criteria in making limited entry decisions: an overview. Paper presented at the National Conference to Consider Limited Entry as a Tool in Fishery Management, July, 1978, Denver, Colorado.

Hibbeln, Kenneth H. 1978. Marine fisheries policy in a federal system. Ph.D. dissertation, Political Science, University of California, Santa Barbara.

Cooperating Organizations

Pacific and North Pacific Fishery Management Councils

National Marine Fisheries Service

Pacific Marine Fisheries Commission

Alaska Department of Fish and Game

Washington Department of Fisheries

California Department of Fish and Game

Oregon Department of Fish and Wildlife

Treaty Indian organizations of California, Oregon, Washington and Alaska

Optimal Leasing Arrangements for Marine Resource Development

Tracy R. Lewis
Faculty sponsor: James P. Quirk
California Institute of Technology

The recent passage of Extended Jurisdiction legislation by numerous countries has prompted us and other researchers to reevaluate current fishery management programs. The legislation provides the legal framework for the United States and other countries where it has been adopted to retain exclusive control over the use of their marine resources. Because of it, the United States can now attend to certain problems that have historically plagued management programs. The first of these involves the common property status of ocean fisheries that has led to over-exploitation of fishery resources and excessive capitalization in the fishing industry. The second stems from the lack of public institutions to share the risks of fishing with the boat owners and crewmen. Despite the government's superior capability to minimize risk costs, the adverse impacts of economic uncertainty in the fishery now fall entirely on the fishermen.

We have proposed and evaluated a two-part certificate-leasing program designed to alleviate both these problems. The program is intended for use in managing the Northern Anchovy Fishery.

Publications

Lewis, Tracy R. and Steven Matthews. 1978. A certificate-leasing program for marine resource development. *EQL Report,* California Institute of Technology.

Lewis, Tracy R. 1977. Information and optimal incentive contracts. Presented at the Winter *Econometrica Society* Meetings, New York, December 1977.

Cooperating Organizations

University of California, Davis, Department of Avian Sciences

California Department of Fish and Game, Mad River Hatchery and Nimbus Hatchery

Bodega Marine Laboratory, University of California, Berkeley

An Economic Survey of the U.S. Pacific Albacore Jigboat Fishery

Suzanne Holt, *University of California, Santa Cruz*

Although the albacore jig boat fleet on the West Coast is extensive (numbering about 3,000 vessels), relatively little is known about the economic conditions of these vessels or the varieties of fish species pursued by them throughout the year. At some time in the future it is likely that fishing on the highly migratory albacore tuna stocks will be regulated by an international body. Consequently, U.S. representatives to this body will need such information.

The first stage of research involved characterizing the population of vessels. The fish and game agencies of Washington, Oregon and California identified vessels that landed albacore in their state by owner's name and address and vessel characteristics. These vessels were then stratified according to major homeports and vessel characteristics and a profile of the fleet as a whole was developed. A random sample was drawn for field survey based on the 1977 season.

In the second stage of the research, a survey was designed to gather data on individual vessel economic conditions, fishery participation rates (fish species pursued), and fisher attitudes during the 1977 season. Parallel to the process of survey design, a theoretical model was developed to estimate the extent of nonmonetary benefits (i.e. psychedelic income, e.g. independence, pride in productivity) fishers derive from commercial fishing. It was hypothesized that nonmonetary benefits are positively related to effort, costs, years of experience, and positive fishing attitudes, and negatively related to alternative skill and occupation levels and negative fishing attitudes. Other related factors were assumed to be family size, extent of nonfishing income, net income, and species landed. Drawing from recreational economics literature, the sum of nonmonetary benefits plus net income was measured as the difference between actual gross income and minimum acceptable gross income. Appropriate questions related to the model's data needs were made part of the survey.

In the third stage of the research, personal surveys were conducted with 60 albacore trollers along the West Coast based on their 1977 fishing experiences. It was originally hoped that the sample size would be 100, but 1977 proved to be a very bad albacore year. Consequently, when the 1978 season proved to be a good season, it was decided to extend the project five months to facilitate additional winter surveys of the fleet based on 1978 experience. The project will be completed in February 1979. As of October 1978, data from the completed questionnaires have been edited and placed on file for computer access. Preliminary testing of the benefit model is proceeding.

The output of the research will consist of cost, earnings, and participation rate profiles of representative trollers in various fisheries combinations, and an econometric test of the nonmonetary benefit model. These outputs will compose a technical report as well as more specific individual journal publications.

It is hoped that the research will prove useful to members of the fleet, resource managers dealing with the albacore stocks and other fisheries, and policy makers concerned with the less tangible aspects of optimum yield.

Cooperating Organizations

Washington Department of Fisheries

Oregon Department of Fish and Wildlife

California Department of Fish and Game

National Marine Fisheries Service

Western Fishboat Owners' Association

All Coast Fishermen's Marketing Association

University of California Cooperative Extension

Oregon State University Cooperative Extension

Washington State University Cooperative Extension

The Social and Political Systems of the Tuna Fleets of San Diego and Ensenada

John S. Petterson
Faculty sponsor: F. G. Bailey
University of California, San Diego

The principal concern of this two-year project has been to obtain social and political data relevant to the tuna fleet of Ensenada. An initial concern was to define the elements that contribute to the establishment of restrictive fishing regulations concerning the access of foreign nationals to the territorial waters of Mexico.

The primary objective of the last twelve months has been to complete the collection of data on (1) the ownership and management patterns of the Mexican fleet out of Ensenada, B.C., Mexico, (2) the labor and cooperative organizations of the fishermen of Ensenada and (3) the relationship between these organizations and government agencies charged with determination of fishery policy for Mexico.

The data collection phase of the research has been completed and early analysis of the data indicates a significant difference between the ownership and management pattern of the Mexican fleet and that of the U.S. fleet, and between the potential inputs of the fishermen of each fleet into government policy determination.

In the U.S. fleet the majority of the vessels are either owned by their captains or by small corporations. Within the Mexican fleet, on the other hand, roughly half the high-seas vessels are owned and managed by cooperative organizations, while one quarter are owned and operated by the Mexican government, and the remaining quarter are controlled by small corporations and individual owners.

In the United States the interests of the crewman are represented by fishermen's unions while those of the owners are represented by an association of boat owners. Fisherman input into government policy formation is usually channeled through one of these two conduits, usually after the policy has been formed and usually ineffectively. Fishermen in Mexico are organized into either into one of three unions or into cooperatives. One of the unions operates exclusively with the government fishery while the other two provide fishermen to privately owned domestic and foreign vessels. These unions are principally concerned with protecting the individual fisherman's rights and safety on foreign and domestic vessels and have had relatively little impact on government policy. The cooperatives are organized into a federation which, as a result of recent personnel and structural changes--a shift from elite bargaining and accomodation toward democratic representation--has been able to exert pressure on the Mexican government for policy decisions favorable to cooperatives in particular and to Mexican fishermen in general, often providing input into the policy determining process itself.

An Ethnography of the San Pedro Wetfish Fishing Fleet

Carlos G. Velez-I., *University of California, Los Angeles*

The investigation on this project was limited to the two-month period of July-August, 1978. During this period analysis was focused on the following specific socio-cultural areas: 1. the main interrelated social sectors which make-up the wetfish fleet, 2. the manner in which these sectors compete and/or cooperate in extracting the fisheries, 3. the major constraints, technical and social, which structure the limits of this fleet, and 4. the likely projective status of the fleet as a dependable source of natural resource extraction.

Interrelated social sectors which make-up the wetfish fleet

The wetfish fleet of San Pedro must be understood as not merely being comprised of the technical and material apparatus used in extracting a natural resource, but also as a material apparatus of largely over-age vessels made up of the following social sectors: owners, skipper-owners, crew, cannery, market-owners, unions, vessel-owner's cooperative, and the material suppliers for the operation of the fleet. All of these social sectors overlap and constitute the ethnic-social networks that comprise one part of the community of San Pedro. All of these sectors compete and/or cooperate through various mechanisms of exchange which the following section articulates.

Competitive and cooperative mechanisms of exchange

Between owners and/or skippers of the fleet the basic competition for natural resources is an obvious focus of activities. Each vessel is seemingly a self-reliant platform used to extract a resource, and certainly the competition is intense, rivalrous, and at times reaches extra-legal dimensions. There have been cases in which the skippers of various vessels have "corked" each others nets in order to win a catch. Yet more often owners and vessel skippers are forced by other contexts to cooperate with each other.

One central mechanism of cooperation is the local Fishermen's Cooperative which acts as a political and social agent of exchange between the various owners. While these men are competitors in one context--the actual setting of nets for a natural resource--they cooperate as a group against other sectors of the industry--cannery, unions, crew, markets, material suppliers and governmental agencies. Self-interest and skipper-owner goals of maximizing profits and minimizing risks are undertaken through the information cleared within the boundaries of the Fishermen's Cooperative. While it serves as an important political mechanism which articulates these goals in relation to local, State, and national legislative and regulatory agencies, nevertheless the key function of the Cooperative is to ensure the proper allocation of quotas set by the cannery to a proportion of the fleet. The mechanism utilized to ensure this allocation and its actual fulfillment is the mechanism of the "Central Patrol."

The Central Patrol is one other key mechanism of cooperation between the vessel-owners, crew-members, union, and canneries. This mechanism consists of a "head patrolman" and two assistants who maintain vigilance over the allocation of the quotas set by the canneries and their distribution to the vessels. Secondly, they supervise the weighing in by the cannery or occasionally by one of the local markets on the pier. The functions fulfilled by this mechanism are crucial to the articulation of prices, allotments, and the meeting of size standards of the species caught. It also maintains clear communication channels between the various sectors that in fact fund this mechanism: the canneries, the unions, and the fisherman's cooperative. While the functions of the Central Patrol seem to pit each sector against the other, it serves as the impartial facilitator for prices, information, and continued quality control of the species

caught. At times, this mechanism is at odds with all of the sectors which it represents, but the honesty and integrity of the Central Patrolman is such that the impartiality of the mechanism is rarely questioned by any sector.

Between crew and vessel owners the basis of competition lies in the sharing of the monies earned in the extraction of the natural resource. For the most part, although contractural agreements between the vessel owners/skippers and the two unions which represent the interest of the crew establish the basis of sharing, the actual relation that defines whether the crew member will receive a "full share, half-share, or quarter-share" is the agreement made between skipper and crew member and not the union and the skipper. Thus intense competition exists among crew members as to their various agreements with the vessel-owners/skippers. Longevity and ethnicity are factors that will determine the content of these agreements, but nevertheless most of the agreements are based on negotiation between the individual crew member and the skipper.

Since the crew members do not negotiate directly with the institutions that set prices for fish, and which therefore control the periodicity of income for fish caught, crew members' unions strike the vessels themselves. The owners must then negotiate with the canneries for higher prices on the tonnage of the wetfish which in turn will be shared with the crew. This indirect method of conflict with the vessel-owners in fact forces both unions and vessel-owners into cooperative pressures upon the canneries for higher prices.

Competition between crew and vessel owners is often mitigated against by kinship relations, ethnic group membership, and the common goals of extracting as much as possible in order to gain a stable income. Between canneries and vessel owners, the competition over prices, allocations, and quality control is incessant, and in fact the greatest source of conflict and discord lies at this crucial juncture. The conflict between skippers/owners and unions seems to rank second. For the most part such conflict between canneries and vessel owners occurs 1) as attempts by the cannery to reject the species caught for the price indicated because of size and quality differentials, and 2) as attempts on the part of the vessel to introduce more fish caught than the quota originally solicited by the cannery. Such conflicts are in fact the outcome of intense competition on a daily basis, and therefore are the most frequent source of conflict among all sectors. On the other hand such conflicts are crosscut by loans provided by the cannery to some vessels for equipment, repairs, and fuel. In some cases canneries may become part-owners, due to extension of loans during periods of extreme income fluctuation.

Unions that represent the interests of the crew members have both antagonistic and cooperative relations with all the other sectors of the industry. While they are the single most important agents representing the crews aboard the thirty-one wetfish boats, they also are among the single most important agents in the allocation of prices to both the vessel crew and to the owners. Any gain that the unions accrue in their negotiations with the various skippers automatically pressures the vessel-owners to re-negotiate the price for tonnage paid by the canneries. Therefore the vessel-owners gain a higher price, not only for the crew, but also for themselves, once the canneries have agreed to a higher price.

Aboard the vessels, disputes occur among the crew and many times between the crew and the skippers. In such cases the unions intercede on the behalf of their constituents and usually follow a three-step process. First an informal gathering of three crew members, three members of the fishermen's cooperative, and the union director or chair meet to discuss the dispute and settle the outstanding issues. Second, if this fails, a formal board of arbitration is solicited, and upon failure a final mediator is requested. The third part of the process is a binding arbitration process and the crew members and/or the skippers must conform to the decisions handed down. However such conflicts are often complicated by the fact that most skippers have been union members themselves, and in fact many maintain welfare and retirement rights within the union, so that total division between unions and members of the

fishermen's cooperative is impossible. In addition, ethnic and kinship relations often cross such divisions, and while the union and vessel-organization maintain antagonistic relations in one context, they cooperate in others.

The most intense competition is that existing between the market owners on the pier and the vessels that extract the various species. While the markets on the pier utilize only about 20% of the wetfish fleet production, the prices gained by the vessels vary widely according to ethnic group membership, kinship relations, "deals" worked out beforehand, and world market prices. There is seldom any single agreed market price since the negotiation is so singularly entrepreneurial between market-owner and skippers. In fact much conflict is generated between the Central Patrol and the vessel owners who often try to avoid the patrol's presence and claim fewer fish unloaded that that actually delivered. They then split the difference between themselves and the market owners. This in fact short-changes the crew of the total share caught.

These various mechanisms of exchange among the various sectors are then exhibited in a host of kinship networks, friendship networks, and voluntary associations, both civic and ethnic. Some manifestations are in church activities, in betting pools, in investments in real estate in Palm Springs or in apartment houses in San Pedro, and in various formal political organizations in San Pedro. Thus the community itself is dependent on the framework of the fishermen society, both cooperative and competitive, to form the cultural and social organizational patterns that are an integral part of the stability of the community of San Pedro. When these begin to fail, one important cohesive part of the community also begins to fail. When the fleet and its various sectors can no longer mesh, San Pedro as a fishing community will also be selected out of existence and in its a different community will be generated.

Technical and social constraints

Of the 161 vessels devoted to wetfish species that were part of the fleet in 1952, only 31 remained in 1978. At a loss rate at sea of 3 vessels per year since 1946, and with a replacement of only four boats of those lost between 1966 and 1978, the numbers are steadily declining. It would appear that old age, non-replacements and continued losses at sea will irreversably select out the wetfish fleet of San Pedro for extinction.

Technical constraints contribute to reduce the capacity of the local fleet to extract the traditional fisheries. Since most of the shipboard platforms used for equipment are not suited to such modern machinery as aluminum winches, real buoyancy problems crop up constantly at sea. While the kinetic energy created by aluminum winches is equal to that created by the older cast-iron winches, the former do not stabilize the platform by their weight as did the latter.

In addition, weather is one variable factor for this largely over-age fleet, constraining the most efficient use of equipment. Inefficient equipment, coupled with inclement weather, and the insecurity of the correct catch limits per fish species, do not make for optimum utilization of a fishery.

Catch limitations are constraints employed to protect a species and a fishery from overfishing. However, they can contribute as well to the economic inefficiency of the fleet at sea. From the point of view of the wetfish fishermen such regulations seem unwarranted, and seem to fluctuate arbitrarily. Those regulations that limit the amount or percentage of Spanish versus blue mackerel seem to shift and change at such frequent rates that it allows little time for the development of adaptive techniques. In addition, the wetfish fishermen perceive State regulatory agencies especially as responsible for what they see as minor deviations from regulatory norms.

These constraints are frequently also coupled with fish population dynamics, such as the consumption of anchovies by the protected blue mackerel which leads to a reduced anchovy biomass and then a cut in the anchovy reduction quota available to the wetfish fleet. This slice into the species available to an already reduced fleet further exacerbates the decline in marginal returns and increases the uncertainty of the fishermen.

The projective status of the fleet

It is most doubtful that the present fleet will continue to fulfill important functions due to all the factors illustrated. In addition, the reduction of highly-skilled labor due to the acute reduction of the fleet further increases the likelihood of a soon-to-be extinct fleet. While other vessels such as "combination" boats may continue to extract both tuna and the various wetfish species, a wetfish fleet as such is due to extinction.

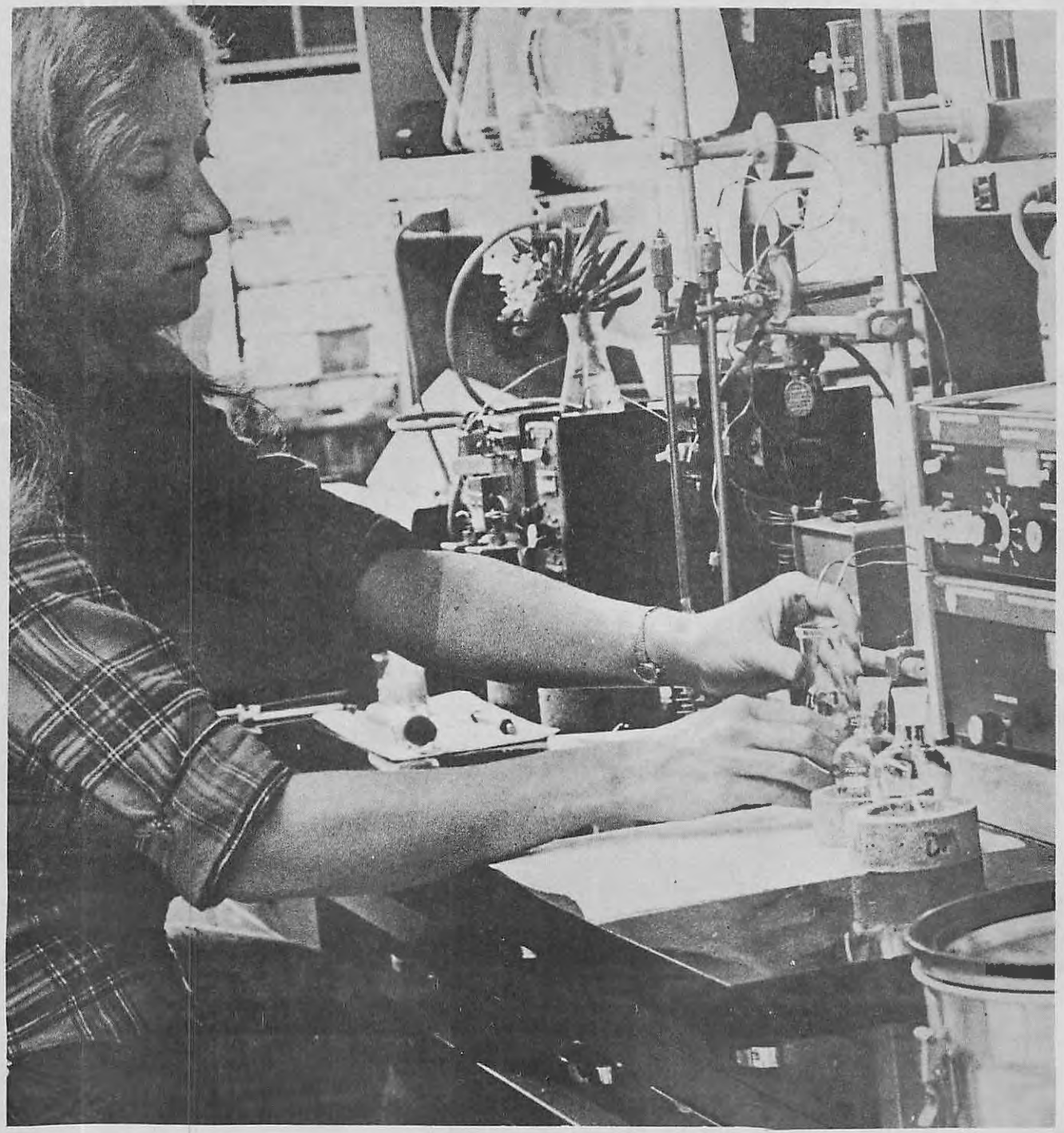
Cooperating Organizations

Harbor Occupational Center, Commercial Fishermen Class, San Pedro, California

San Pedro Fishermen's Cooperative Association, San Pedro, California

University of California, Los Angeles, Chicano Studies Center

NEW MARINE PRODUCTS



Joanne Silberner

Pharmacological Evaluation Program

Robert S. Jacobs, *University of California, Santa Barbara*

Biologically active substances isolated by Drs. W. Fenical, D. J. Faulkner and P. Crews from a variety of marine organisms are currently being evaluated from a pharmacological point of view.

The test systems utilized in our research are capable of detecting marine products that antagonize histamine, epinephrine, acetylcholine, norepinephrine, and other chemicals that occur naturally in the human and are implicated in diseases or in control of organ function. We also use test systems capable of detecting the effects of marine products on blood pressure, heart rate and heart force of contraction, and others that detect central nervous stimulation, depression, local anesthesia, analgesia and neurotoxicity. A special test utilizing the fertilized sea urchin egg detects substances that inhibit cell division.

Since the program's inception on July 1, 1977, we have studied 74 different marine products. As of October 1, 1978, we have identified 21 compounds possessing interesting biological activity.

The general categories of interest include the following: (1) inhibitors of cell division, (2) compounds that appear to have diuretic activity, (3) a substance that improves muscle strength (4) substances that appear to alter either glucose transport or metabolism.

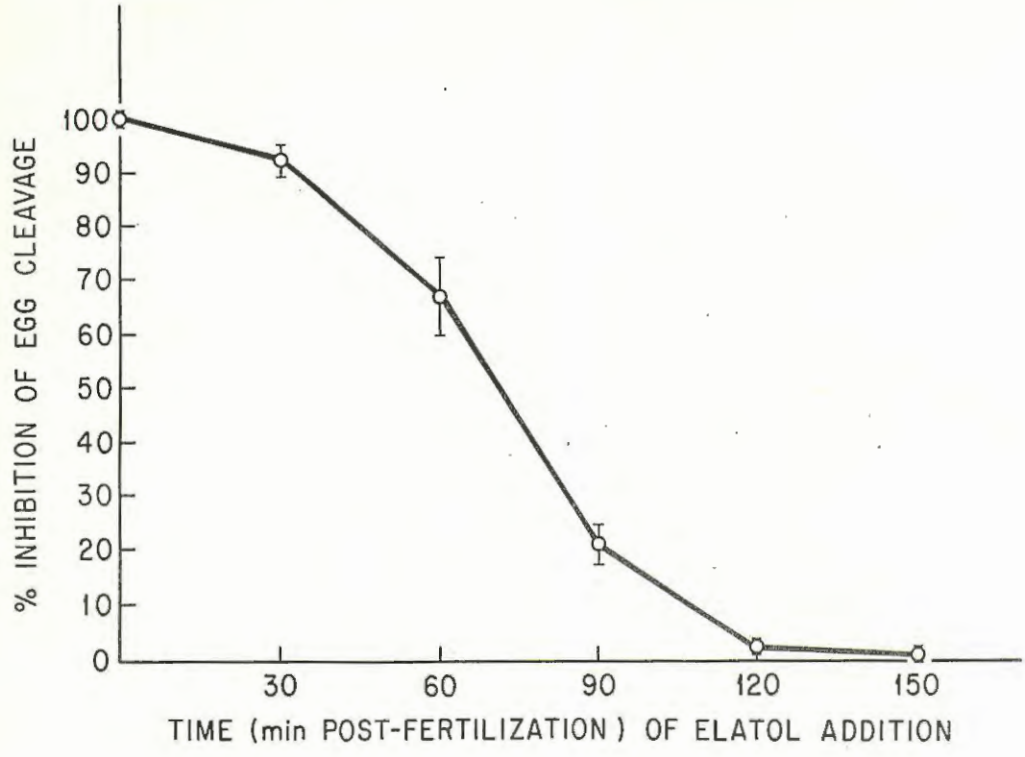
Simply stated, a compound that inhibits cell division may prove useful in studying the process of growth and cell differentiation. A compound that affects the kidney may prove useful in studying ion transport mechanisms. A compound that improves muscle strength may prove useful in understanding either neuromuscular function or perhaps muscle metabolism. Finally, a compound that affects glucose metabolism or transport may prove useful in studying mechanisms by which energy is supplied to various organs and cells.

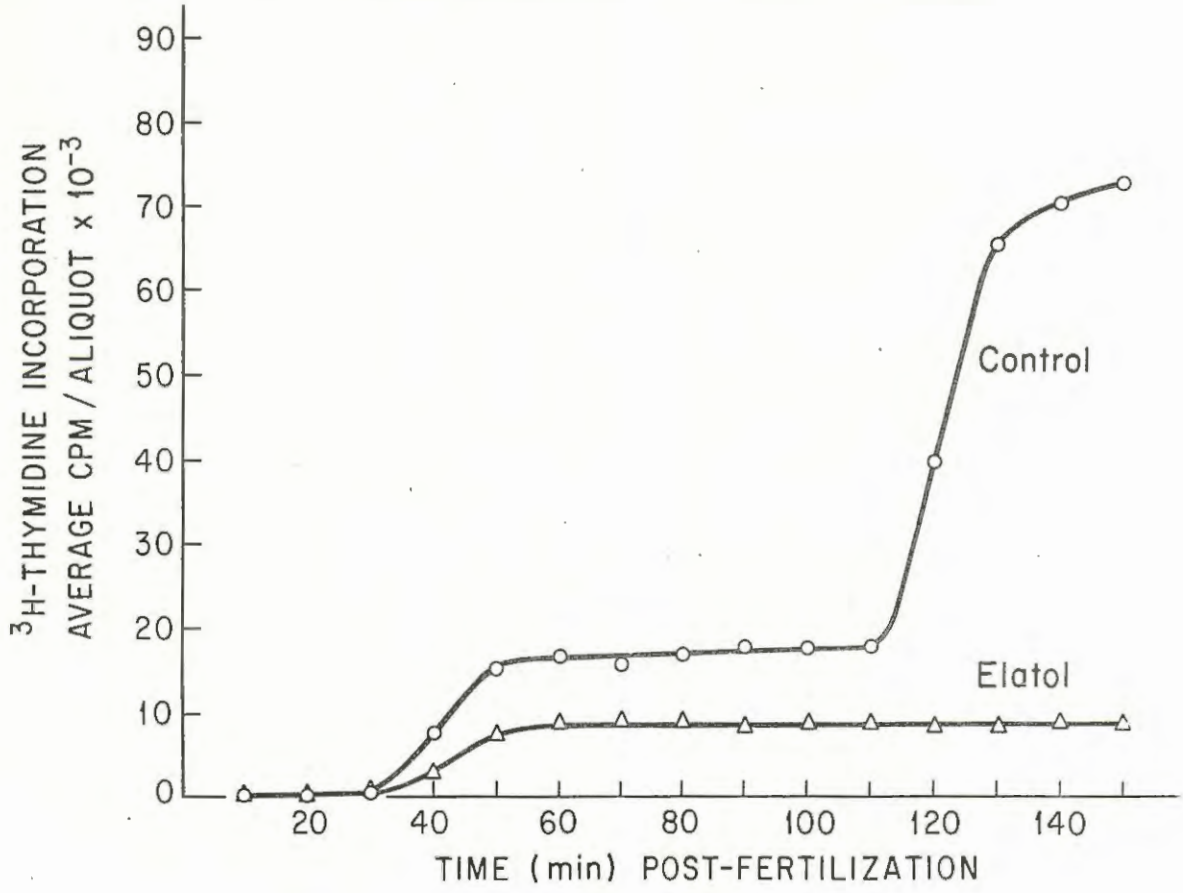
The therapeutic potential of any of these substances is a distant objective that can only be speculated upon at this very early stage of the work. What must be done next is to assess the novelty of each substance's action against known chemicals. That is, does this substance derived from marine organisms represent something new in terms of its site of action or mechanism of action? The way we have approached this problem has been to institute special studies utilizing our Sea Grant trainees. An example of their efforts is the following study of one of the inhibitors of cell division, Elatol, isolated by Dr. Fenical from a red alga *Laurencia elata.*

After finding Elatol to be active against fertilized sea urchin eggs the following observations were made: 1) the effect on cell division appears to be time dependent. That is, Elatol must be added to the test system within the first 30 minutes of the 2 hours it takes for each division to take place. If it is added later its activity declines (Fig. 1). 2) Amino acid incorporation into DNA is also blocked by Elatol (Fig, 2). DNA is a substance involved in the transfer of genetic information from one cell to another.

The question of the novelty of action of Elatol is still unanswered. Studies are planned to explore the mechanism of action of this substance at the biochemical level. The other substances we have discovered that inhibit cell division will be studied in a similar manner.

Like the studies of Elatol we have also undertaken follow-up studies with other active compounds. A study is currently under way examining the site of action of a substance that increases muscle force of contraction. This substance appears to act on the muscle contractile mechanism itself. Currently we are assessing its potency. In another study we are establishing dose response curves for a compound that appears to have diuretic activity, and we have been developing methods to evaluate some agents which appear to affect blood glucose levels.


% INHIBITION OF EGG CLEAVAGE
100
90
80
70
60
50
40
30
20
10
0
30
60
90
120
150
TIME (min POST-FERTILIZATION) OF ELATOL ADDITION


^{3}H-THYMIDINE INCORPORATION
AVERAGE CPM / ALIQUOT x 10^{-3}
90
80
70
60
50
40
30
20
10
0
Control
Elatol
20
40
60
80
100
120
140
TIME (min) POST-FERTILIZATION

Publications

Jacobs, Robert. 1978. Pharmacological properties of substances derived from marine organisms. Paper presented at Symposium of American Chemical Society, March 1978.

White, Steven J., Ryk Tanalski, William Fenical and Robert S. Jacobs. 1978. Inhibition of cell cleavage by a halogenated sesquiterpene (Elatol) and the 9-ketone synthetic derivative (Elatol Ketone). *The Pharmacologist* 20: 210.

Cooperating Organizations

Bristol Myers Corporation

Merck, Sharp and Dome Laboratories, Dr. Charles Winter

Marine Natural Products for Pharmacological Evaluation

D. John Faulkner, *Scripps Institution of Oceanography, University of California, San Diego*

During the past year we have been working on sponges obtained during a research cruise on R/V *Alpha Helix* sponsored by the National Science Foundation. The samples obtained have been divided among three projects according to the requirements of the sponsoring agencies. Whenever pure compounds were obtained, the material remaining after structural elucidation and related chemical studies was submitted for screening for pharmacological activity.

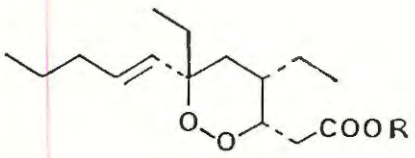
Our research on cyclic peroxides from sponges has continued. Most of the sponges which contained cyclic peroxides have been identified as *Plakortis* species; three samples are considered to be *P. halichondrioides* (K. Ruetzler, pers. comm.), despite the fact that they could be differentiated by texture and appearance in the field. We found one sponge, *Chondrosia collectrix,* which contained cyclic peroxides when freshly collected but not after storage in ethanol. The cyclic peroxides obtained from a frozen sample of the sponge were a 1:1 mixture of the acids **1** and **2** and a 4:1 mixture of the corresponding methyl esters **3** and **4.** A sample of the same sponge which had been stored in aqueous ethanol for two months gave the hemiketal **5** and the diol **6** as major products and the ketal **7,** hemiketal **8,** and α, β-unsaturated ester **9** as minor products. Since the peroxides **1** and **2** inhibited the growth of selected microorganisms *in vitro* while the hemiketal **5** and associated metabolites were inactive, we have for this sponge explained the phenomenon of "disappearing activity."

Research on other samples of *Plakortis* species have yielded 3-epi-plakortin **(10),** a $^4\Delta$-peroxide **11,** the ester **12,** and the lactone **13.** Surprisingly, a sample identified as *P. halichondrioides* gave a series of compounds which appeared to be unrelated to the peroxides. We have isolated a total of eight aromatic compounds of which the δ-lactone **14,** the γ-lactone **15,** and the β-hydroxy ester **16** were the major constituents. These compounds may be interrelated through two homo-allylic, alcohol-cyclopropyl carbinol rearrangements. After questioning the taxonomic identification, we were relieved to find two aromatic peroxides **17** and **18** which provide a link between the two groups of compounds.

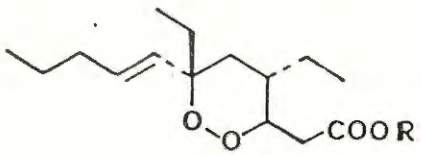
We have also continued to study *Stylatula* sp., a sea pen which was shown to produce a toxin, Stylatulide **19.** The minor metabolites in *Stylatula* sp. have been shown to be 17-epistylatulide **20** and three related metabolites **21-23** which lacked chlorine. Plans to submit the minor compounds for screening have been dropped since Stylatulide **19** is inactive except as a toxin toward copepod larvae. We have studied some related compounds from *Briareum asbestinum.* Since we and others have found good antimicrobial activity in crude extracts, this research will be continued.

Among the interesting compounds isolated from marine sponges were the brominated amines **24** and **25** which were isolated from *Smenospongia aurea* and *Smenospongia echina.* These compounds are brominated derivatives of dimethyl tryptamine, a known halucinogenic compound, and have been submitted for evaluation. We have also submitted the indole derivative **26** for evaluation but have recently learned that this compound has been evaluated by Roche Laboratories.

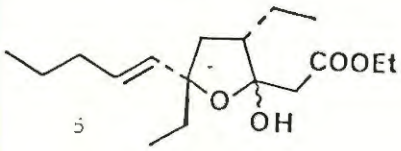
We have encountered a series of interesting sesquiterpene quinones which are related to ilimaquinone **27,** previously described by Scheuer and Clardy. The quinones are closely related to ilimaquinone but contain amine and amide functional groups. The only other naturally occurring amino-quinone is Rhodoquinone, a derivative of ubiquinone-10. Since these appear to be relatively unusual compounds, we will pursue the structures, although we do not have enough material for an extensive evaluation. If possible, we will prepare the aminoquinones from ilimaquinone in order to provide sufficient material for evaluation.



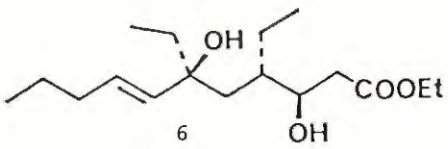
1 R=H
3 R=Me



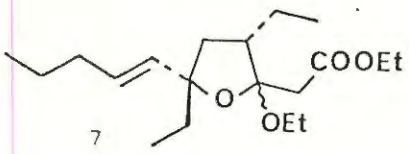
2 R=H
4 R=Me



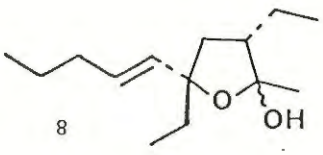
5



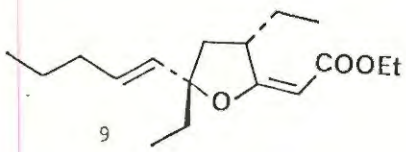
6



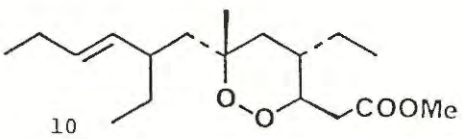
7



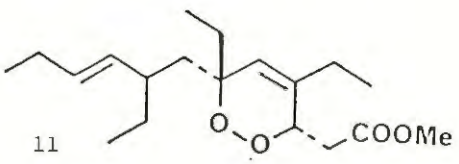
8



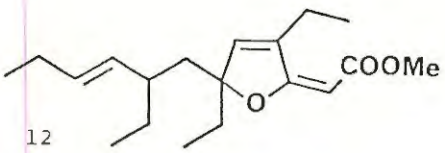
9



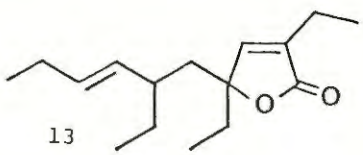
10



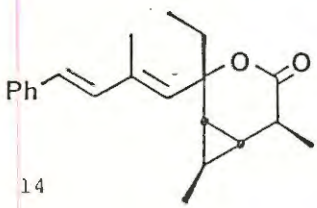
11



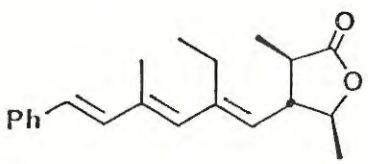
12



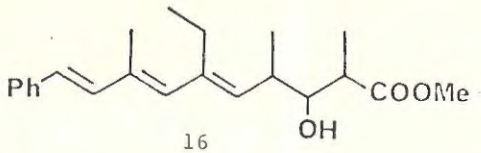
13



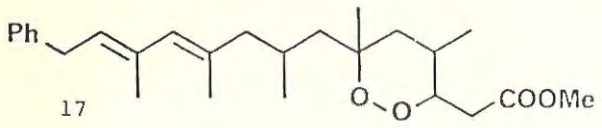
14



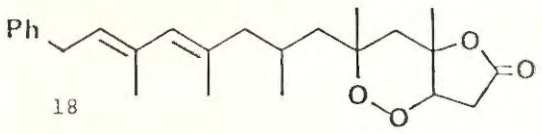
15



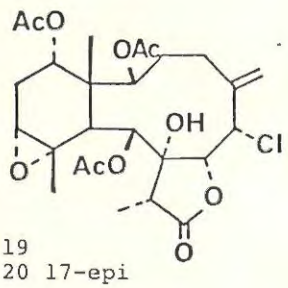
16



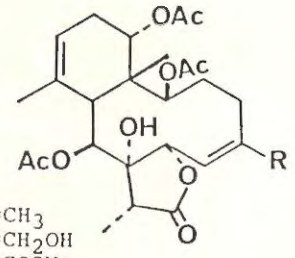
17



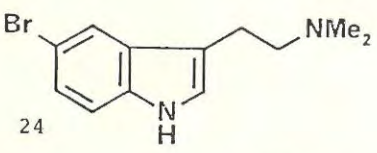
18



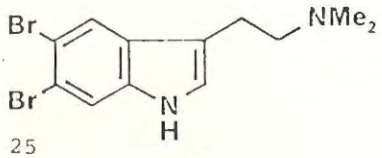
19
20 17-epi



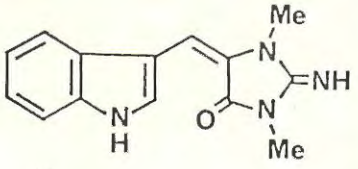
21 R=CH_3
22 R=CH_2OH
23 R=COOMe



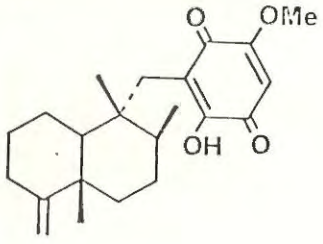
24



25



26



27

The materials submitted for evaluation have produced some interesting results. When we began this research, we predicted that we would get a better return by screening pure compounds as opposed to crude extracts. This prediction has been substantiated by the evaluation results. Of 18 pure compounds evaluated, 10 (55%) have interesting pharmacological activity which requires continued investigation. In comparison, only 6 of 24 (25%) crude extracts showed sufficient activity to warrant fractionation of the extracts and further screening (for details see previous annual report). Some of the ten compounds required for further evaluation can only be obtained by recollection of the organism, but at least six are available in good supply. We are currently generating about ten new compounds and twenty extracts every four months. We have started fractionation of the active extracts.

Publications

Higgs, M. D. and D. J. Faulkner. 1977. 5α-Pregna-1, 20-dien-3-one and related compounds from a soft coral. *Steroids* 30: 379.

Higgs, M. D., D. J. Vanderah and D. J. Faulkner. 1977. Polyhalogenated monoterpenes from *Plocamium cartilagineum* from the British Coast. *Tetrahedron* 33: 2775.

Higgs, M. D. and D. J. Faulkner. 1978. Plakortin, an antibiotic from *Plakortis halichondrioides*. *J. Org. Chem.* 43: 3454.

Mynderse, J. S. and D. J. Faulkner. 1978. Variations in the halogenated monoterpene metabolites of *Plocamium cartilagineum* and *Plocamium violaceum*. *Phytochemistry* 17: 237.

Ravi, B. N. and D. J. Faulkner. 1978. Cembranoid diterpenes from a South Pacific soft coral. *J. Org. Chem.* 43: 2127.

Van Engen, D. J., J. Clardy, E. Kho-Wiseman, P. Crews, M. D. Higgs and D. J. Faulkner. 1978. Violacene: a reassignment of structure. *Tetrahedron Letters* 29.

New Agricultural Chemicals from Marine Organisms

William Fenical, *Scripps Institution of Oceanography, University of California, San Diego*

The long term objectives of this project are the development of new and environmentally-safe (biodegradable) herbicides and insecticides which are fashioned from natural products found in the marine environment. To attain these goals, a close working relationship has been developed with Zoecon Corporation in Palo Alto, California. Zoecon has provided matching funds as well as the guarantee of complete insecticidal biotesting.

Our initial approach was to isolate and biotest pure compounds which were isolated from noxious and toxic marine organisms well known to be avoided by prospective predators. This approach has been highly successful, and a variety of unique organisms have been investigated in this last year. Our field studies have proven to be a key in our success, in that poor collecting practices have led to failure in the past. We have largely shifted our collecting to more tropical marine plants and invertebrates, and in doing so we have tripled our output. In 1978 we made shore collections at Carrie Bow Cay, Belize, and also utilized R/V *Alpha Helix* along tropical Pacific Mexico. Onboard *Alpha Helix,* Dr. Robert Jacobs provided five pharmacological bioassays which greatly influenced the efficiency of our collections. Only *active* species were mass collected, and a variety of interesting algae and sea fans were discovered which show antimicrobial, cytotoxic and other bioactivities.

The fruits of this year's collecting and chemical work have been the isolation and biotesting of 75 purified compounds. Fifty-five pure compounds were submitted to Zoecon Corporation, and another 20 or so were provided to Dr. Jacobs. Of the 55 compounds provided Zoecon, 24 have shown at least one form of insecticide activity. Positive results have been obtained most frequently with the *Manduca sexta* (tobacco hornworm), *Musca domestica* (common house fly), and *Oncopeltus fasciatus* (milkweed bug) bioassays. Positive results in the insecticide assays were found to repeat within several specific groups of metabolites, common to certain marine organisms. To further pursue this lead, we have emphasized the collection of biologically-related species, and we have been able to obtain related compounds which show activity. This approach is important in selecting new organisms for study.

The insecticidal chamigrene derivative previously isolated from the red seaweed *Laurencia* is still undergoing modification to provide analogs for testing. It is still too early to assess the developmental progress of this insecticide.

Of the 20 purified substances submitted to the Jacobs pharmacology program, 14 have survived the initial screening process. This indicates that sufficient bioactivity was observed to warrant more detailed follow-up testing, and it further means that more compound is required. Five of our compounds, WF-5, WF-6, WF-13 and WF-17, show strong activity in the fertilized sea uchin egg cell division bioassay. Activity in this test indicates cytotoxicity, and this form of activity may be useful in the treatment of various forms of cancer. A University patent disclosure has been filed for compound WF-17, and disclosures for the remaining four cytotoxins will be filed shortly.

Another one of our compounds, WF-3, shows activity in lowering blood sugar levels in rats. Compounds of this type are of possible use in the treatment of hyperglycemia in mammals. Another compound, WF-21, shows marked diuretic activity in rats. We have recently re-isolated WF-21 and provided 1.5 grams of this compound for thorough biotesting.

Two trainees, William Gerick and Maury Banduragga, and a lab helper, Roy Okuda, were associated with this project during 1977-78. William Gerick was responsible for the isolation and structure elucidation of the diuretic, WF-21, and Maury Bandurraga has been involved in the isolation of

some unusual lactones from sea fans. Roy Okuda has isolated a variety of compounds in this study.

Publications

Gerwick, W. H. and W. Fenical. *In press.* Stypotriol and stypoldione, ichthyotoxins of mixed biogenesis from the marine alga *Stypopodium zonale. Tetrahedron Letters.*

Fenical, W., O. J. McConnell and Anne Stone. *In press.* Antibiotics and antiseptic compounds from red seaweeds of the family Bonnemaisonaceae. *Proceedings of the 9th International Seaweed Symposium,* Santa Barbara, California, 1979.

McConnell, O. J. 1978. Chemical and biochemical studies of the halogenating red algae *Asparagopsis* and *Bonnemaisonia.* Ph.D. thesis, University of California, San Diego.

Cooperating Organizations

Zoecon Corporation, Palo Alto, California

Marine Products as a Source of Insect Growth Inhibitors

Phillip Crews, *University of California, Santa Cruz*

The continuing goal of this project is to explore the potential of seaweeds as a source of new insect control chemicals. Our focus is upon the isolation and identification of unique natural products from red seaweeds of the order Gigartinales whose crude extracts inhibit the development of four common insect pests. Several new halogenated terpenes and non-halogenated compounds were purified and characterized. They were also evaluated for their anti-insect activity during the grant year period.

The management of destructive insects continues to be a challenging problem in aquaculture. Even at this writing the tobacco budworm is making a comeback and is destroying crops in southern California.

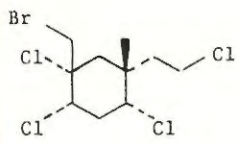
The first phase of our evaluation of seaweed extracts and isolated natural compounds for anti-insect activity is essentially complete. It has and will continue to be facilitated by cooperation with the Zoecon Corporation whose assays are designed to discover "bio-rational" agents as opposed to broad spectrum biocides.

A major part of our effort during the past year has been upon four seaweeds from the Gigartinales because their extracts were extremely active in initial tests. We have pinpointed the maximum activity that can be expected from each and we have discovered that it is not only species dependent but also location dependent. Results in each of five assay categories are summarized in Table 1. It should be noted that positive activity indicates potent action because of the low dose threshold consideration. These results are extremely significant when it is realized that very few leads of comparable promise have come from the testing of a large number of terrestrial plant extracts carried out during the last several decades.

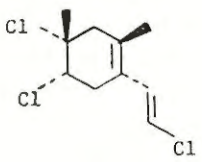
In following up the above positive results we focused upon both purified compounds and purified extract fractions, some of which contained three or more components. This second stage of our work is still largely on-going. Table 2 presents in generalized form results accumulated to date. Because further development work is in progress on some compounds of promise we are deferring a report of the results on a compound-by-compound basis. Inspection of Table 2 will show that the summary activity noted from *Plocamium* products is well within the range of activity level observable for commercial insect agents. Finally, the results in the *Plocamium* entry were actually derived from more than thirty different experiments.

A significant amount of our effort involved total structural analysis. First, the structure of a major active *Plocamium* metabolite, violacene **1**, was revised and the results have been published. Another published structure, plocamene B **(2)** was found to be quite active. Other new compounds that were characterized and which are in various stages of testing include **3-5, 7-10** from *Plocamium*, kylenone **6** from *Laurencia* and **11** from *Dictyota*. Two additional synthetic derivatives of violacene **(1), 12** and **13** are also being evaluated to pinpoint the effect of various structural elements on quantitative activity.

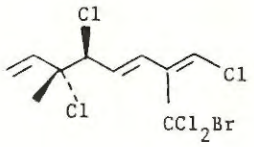
During the last grant year we have disseminated information related to our research in the form of: several publications to the technical literature (see below), participation in an American Chemical Society national meeting (3 papers and Chair of one session), participation in a regional American Chemical Society meeting (Session Chairman), and presentation of five invited seminars to various university and industry groups.



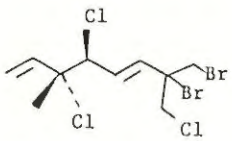
1



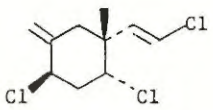
2



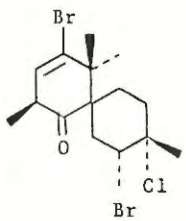
3



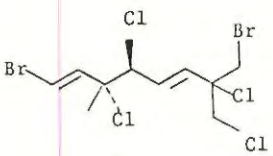
4



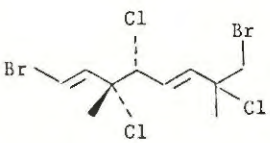
5



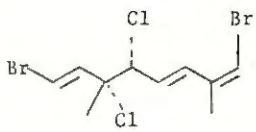
6



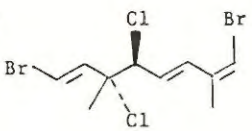
7



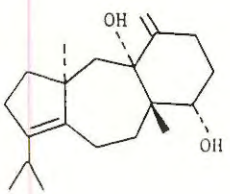
8



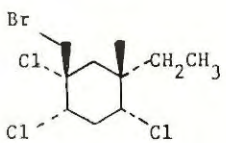
9



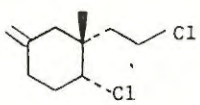
10



11



12



13

Publications

Crews, P. 1977. Monoterpene halogenation by the red alga *Plocamium oregonum. J. Org. Chem.* 42: 2634-2636.

Crews, P., E. Kho-Wiseman and P. Montana. 1978. Halogenated alicyclic monoterpenes from the red alga *Plocamium. J. Org. Chem.* 43: 116-120.

Crews, P and E. Kho-Wiseman. 1978. Stereochemical assignments in marine natural products by ^{13}C NMRγ effects. *Tetrahedron Letters* 28: 2483-2486.

Kho-Wiseman, E. 1978. Natural products chemistry of the red marine algae *Plocamium violaceum* and *Plocamium cartilagineum.* Ph.D. thesis, University of California, Santa Cruz.

Van Engen, D., J. Clardy, E. Kho-Wiseman, P. Crews, M. D. Higgs and D. J. Faulkner. 1978. Violacene: a reassignment of structure. *Tetrahedron Letters* 1: 29-32.

Cooperating Organizations

Zoecon Corporation, Palo Alto, California

Table 1
Anti-insect activity from red seaweed extracts

Gigartinales	*Manduca* Tobacco Hornworm	*Musca* Fly Adult	*Aedes* Mosquito Larvae	*Musca* Fly Larvae	*Heliothis* Tobacco Budworm
Callophylus sp.	*0*		+	*0*	
Plocamium oregonum	*0*		*0*	*0*	
Plocamium cartilagineum			+	*0*	
Ploamium violaceum	+	+	*0*	+	+
Threshold	5μ/L	50μ/L	1 ppm	100μ/L	50μ/L

Table 2
Plocamium Products vs. Standards

	Manduca Tobacco hornworm larvae (μg/L)	*Musca* Fly adult (μg/female)	*Aedes* Mosquito larvae (ppm)	*Musca* Fly larvae (μg/L)	*Heliothis* Tobacco budworm (μg/L)
Plocamium (composite)	1.8	3.2	.0054	92	4.8
Padan	22.0	-	3.2	-	-
Peramethrin	.029	.029	-	.35	.018
Methroprene	>100	>1000	.0002	.004	>1000
Precocene II	>1000	-	-	-	-
Taxophene	32	10	-	1	>100
BHC	>100	.062	.14	-	4.3

Antileukemia Compounds from the Brown Seaweed *Dictyota*

William Fenical, *Scripps Institution of Oceanography, University of California, San Diego*

Brown seaweeds of the family Dictyotaceae have been known for several years to possess cytotoxic, antiviral and antibiotic propertites. Our investigations of the natural products chemistry of this group have revealed an interesting array of exceptional diterpenoids to be produced by this family. While it had not been unambiguously shown, it had been predicted that these diterpenoids were responsible for the biological activity associated with the Dictyotaceae. The purpose of this project was to explore several "activity" leads in existing collections of these plants, and to expand our studies to other readily available species. Particular emphasis was placed upon biotesting these pure compounds and extracts in leukemia and solid tumor inhibition assays.

Eight species of *Dictyota, Glossophora galapagensis,* and two species of *Spatoglossum* were investigated in this project. Chloroform-methanol extracts were produced, and the extracts were biotested at the University of Hawaii in their P-388 lymphocytic leukemia and Erhlich ascites (EA) tumor assays. Two of the *Dictyota* species from the Gulf of California showed slight survival enhancement. All these extracts showed toxicity in the Ehrlich ascites tumor assay. The results are summarized in Table 1.

Results from the two *Spatoglossum* species have not yet been obtained.

Following several prior "activity" leads, we have isolated and determined the structures of eight unique diterpenoids. In a collaborative effort with L. Minale in Naples, J. Clardy at Cornell University, and R. E. Moore at the University of Hawaii, we have determined the structures of dictyodial **(1)**, and dictyolactone **(2)**. These compounds were found active in preliminary testing, but were found inactive when purified. Compounds **1** and **2** do show antibacterial activity, and they are currently undergoing thorough testing

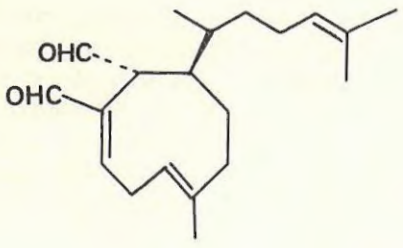
Investigations of several additional algal species in this family have yielded other compounds for study. From *Dictyota masonii* we have isolated the monocyclic diterpenoid, hydroxydilophol **(3)**, and from *Glossophora galapagensis* we have obtained the diterpenoids **4-8.** The latter compounds were originally isolated from extracts of the Pacific sea hare *Dolabella californica,* which were known to exhibit cytotoxic properties. It appears that the molluscs obtain these diterpenoids by grazing algae of the family Dictyotaceae.

Publications

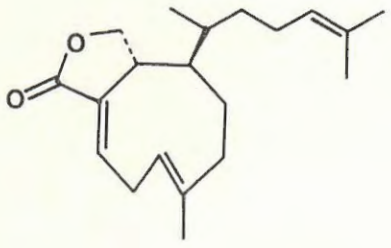
Finer, J., J. Clardy, W. Fenical, L. Minale, R. Riccio, J. Battaile, M. Kirkup and R. E. Moore. 1978. The structures of dictyodial and dictyolactone, unusual marine diterpenoids. Submitted to *J. Am. Chem. Soc.*

Sun, H. H. and W. Fenical *In press.* Diterpenoids of the brown seaweed *Glossophora galapagensis. Phytochemistry* 1978.

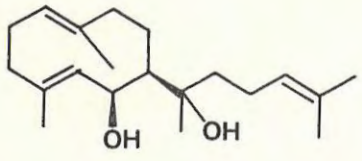
Sun, H. H. and W. Fenical. 1978. Hydroxydilophol, a new monocyclic diterpenoid from the brown alga *Dictyota masonii.* Submitted to *J. Org. Chem.*



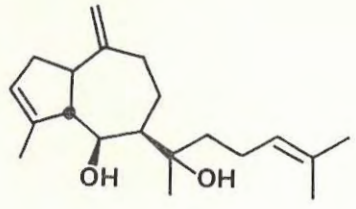
1



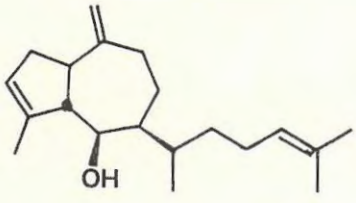
2



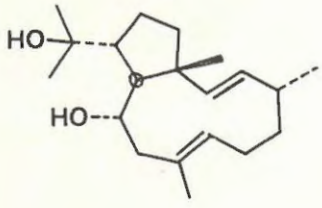
3



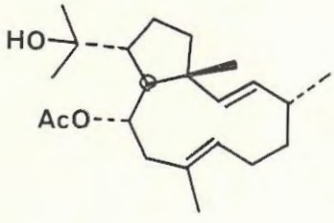
4



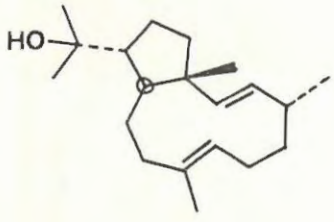
5



6



7



8

P-388 Lymphocytic Leukemia Assay			
Algal extract			dose mg/Kg
Dictyota sp.	8982	103.5	104
		414	108
Dictyota flabellata	8983	188.5	104
		566	115
Dictyota crenulata	8984	232.5	106
		697	toxic
Dictyota sp.	8985	184.0	118
		548	toxic
Dictyota sp.	8986	232.5	118
		623	125
Dictyota sp.	8987	195	94
		589	110
Dictyota sp.	8988	219.5	106
		1242	toxic
Dictyota sp.	8989	414	94
		659	105
Glossophora galapagensis	8990	242.5	115
		728	toxic

Erlich Ascites Tumor Assay			
Algal extract			dose mg/Kg
Dictyota sp.	8982	82.8	negligible
		331.2	negligible
Dictyota sp.	8983	105.8	negligible
		452.8	negligible
Dictyota sp.	8984	186.0	negligible
		557.6	negligible
Dictyota sp.	8985	147.2	negligible
		438.4	negligible
Dictyota sp.	8986	186.0	negligible
		498.4	negligible
Dictyota sp.	8987	157.2	toxic
		471.2	toxic
Dictyota sp.	8988	175.6	toxic
		993.6	toxic
Dictyota sp.	8989	331.2	negligible
		527.2	negligible
Glossophora galapagensis	8990	194.0	negligible
		582.4	toxic

Antiviral Compounds from Algae

M. T. Hatch, E. F. Deig and N. A. Vedros
University of California, Berkeley

Extracts from 8 closely related species of marine red algae have previously been shown to contain active antiherpes virus substances in cell culture. The current study is a further attempt to find additional sources of this natural product, formerly limited only to species in the family Dumontiaceae. It should be noted that the systematics within the Cryptonemiales has recently changed such that our most active genera in the past, *Constantinea* and *Farlowia,* are now in separate families, namely Weeksiaceae and Dumontiaceae, respectively.

Pronounced antiviral activity has now been found in the Nemaliales and the Ceramiales in addition to the Cryptonemiales. Several specimens, belonging to six different genera, were collected from coastal areas of northern California and from the Puget Sound area near Seattle, Washington. Criteria for collection of given specimens were: (1) plant mass and availability, (2) relationships of morphological features and life histories to algal species previously shown to contain the active viral inhibitor or (3) relative polysaccharide content.

Crude extracts or partially purified and lyophilized material were tested for antiviral activity in cultures of human embryonic lung cells infected with herpes simplex virus (HSV) type 1 strain MacIntyre. Extracts from *Weeksia reticulata* Setchell elicited a highly toxic response from cultured cells. Thus, antiherpes-viral activity could not be observed. However, recent preliminary experiments have shown that when toxic extracts of *W. reticulata* are diluted 1000-fold before use, they demonstrate significant antiviral activity but no toxic effects in cell culture. Extracts from *Cumagloia andersonii* (Farlow) Setchell and Gardner and *Dilsea californica* (J. Agardh) Kuntze both showed pronounced antiviral activity against HSV, but also exhibited moderate to extensive toxicity towards the cultured cells. Extracts of *Gliosiphonia verticillaris* Farlow specimens collected from different coastal sites showed high antiviral activity, with only one specimen eliciting a slight toxic reaction in cell cultures. In contrast, extracts from *Constantinea subulifera* Setchell and *Polyneura latissima* (Harvey) Kylin showed comparatively high antiviral activity *in vitro* and no toxicity to cell cultures.

A number of methods have been examined to determine optimal procedures for disruption of algal plant tissues, extraction, isolation and purification of active antiviral substances under conditions which minimize inhibitor degradation and denaturation. Specific questions need to be resolved before large-scale extractions are possible. These involve the integrity of active inhibitor molecules during extraction and purification procedures, including (1) drying of plant material before extraction, (2) freezing-thawing-freezing cycles on whole plants, (3) leaching of active substances in wash fluids, (4) varying total ionic strength of aqueous extracts, (5) heating of active material in crude aqueous extracts, (6) extracting in aqueous buffered (pH 4 to 10) versus unbuffered solutions, (7) dehydrating of crude or purified material by oven-heating up to 60° C or by lyophilization and (8) binding effects of various precipitating agents. Of the many procedures examined, a total of 25 samples representing various crude extracts or fractions thereof were prepared and processed to the dehydrated state, then evaluated for antiviral activity in cell cultures. In some instances, however, the mouse encephalitis model was also used.

In the *in vitro* system, the index of protection (IOP) (defined as the $\log_{10}$ difference between $TCID^{50}$ titers of HSV in treated and untreated control cells) varied from 0.7 to 4.0. These results indicate the possibility of preparing reasonably purified material with demonstrated significant activity in cell culture. However, when these highly active fractions were evaluated

in the *in vivo* model, antiviral activity decreased to an IOP of 1.8 for extracts of *Constantinea simplex* Setchell and an IOP of 0.5 for *C. subulifera* derived material. Only a single dose of 0.03 ml (150 μg dry weight) per infant mouse was injected via the intraperitoneal route, followed within 2 hours by virus challenge. One explanation for this unexpected finding is that crude extracts contain more than one antiherpes virus substance, one of which is demonstrable in cell culture and the other in the animal model system. The latter appears more labile than the former or is lost during separation procedures. Experiments are in progress to resolve this question.

In a previous report (Hatch, *et al.*, 1977), we outlined preliminary evidence suggesting that antiherpes virus substances from *C. simplex* were composed of sulfated polysaccharides complexed with lesser amounts of protein molecules. The "inside" and "outside" of the dried frond on *C. subulifera,* which tends to peel and divide, and purified anionic polysaccharides from *C. simplex* and *C. subulifer* were analyzed for sugar composition by Dr. Elizabeth Percival. Her preliminary results (unpublished) indicated that the following sugars were present in the anionic polysaccharides from both weeds: Xylose, galactose, glucose and arabinose in the approximate molar proportions of 0.75:4.1:1.0:0.22, for *C. subulifera,* and 4.0:7.3:0.3:0.7 for *C. simplex.* In addition, the polysaccharide from *C. simplex* also contained a 3- and/or 4-0-methylhexose (1.0) and a 3,4-di-0-methylhexose (0.23). Traces of the monomethyl hexose were also found in the polysaccharide from *C. subulifera.* Paper chromatograms of both hydrolysates indicated the presence of a small proportion of aldobiouronic acid.

Treatment of hydrolysates from each of the two polysaccharides with glucose and galactose oxidase showed that *D*- glucose and *L*- galactose were present. About 18% of half ester sulphate was present in each polysaccharide. Methylation of both polysaccharides by a single Hakomori followed by hydrolysis and characterization of the sugars as the derived alditol acetates, showed that the major product was 2,3,6-tri-0-methyl hexose. In view of the relative proportions of galactose and glucose in the polysaccharide, it is reasonable to assume that this is the galactose derivative, consequently, 1,4-linked galactose must be a major structural unit in both polysaccharides. 2,3,4-tri-0-methylxylose, 2,3,4,6-tetra-0-methyl glucose and galactose were also characterized indicating that all three sugars were present as end groups. 2,3-di-0-methylhexose was also found to be present.

An unusual feature in both polysaccharides was the presence of a relatively large proportion of unmethylated galactose and xylose (greater in *C. simplex).* Although the polysaccharides had been subjected to only one Hakomori methylation this is unusual and might indicate that these two sugars were carrying an unidentified substituent. This is the only unusual feature detected in the polysaccharides which might explain the antiviral properties of the two red algae.

In an earlier study by Hatch, *et al.,* (in press), it was found that occurrence of herpes virus encephalitis in infant mice could be significantly reduced by a single treatment with extracts from marine red algae, provided the drug was administered at the challenge site and prior to or simultaneously with HSV-1 or HSV-2 viruses. Results of a collaborative study with investigators of the Antiviral Testing Program, National Institute of Health, confirmed our initial *in vivo* finding and indicated that the prophylactic administration of extracts from *C. simplex* and *Farlowia mollis* was effective in reducing final mortality or prolonging the mean day of death of animals innoculated by the intraperitoneal, intracerebral or intranasal routes with HSV-2. These extracts were also shown to possess low levels of antiviral activity against two additional viruses, namely vaccinia viruses and vesicular stomatitis
viruses, in infected confluent mouse embryo fibroblast cell monolayers.

In the previous annual progress report, we reported preliminary results of a separate study relative to the successful treatment of herpes virus lesions in adult mice by topical application of algal extracts in suitable solvents. However it was evident that further development of this model was required because scarification and infection of the

skin all too frequently progressed to acute encephalitis and death in untreated control animals. Factors examined in the recent report period include: (1) age of mice, (2) sex, (3) virus challenge strain and concentration and (4) method of skin scarification. At the present time, we can reproducibly induce dermal lesions in 80% of infected untreated animals. However, we have been unable to completely suppress the encephalitogenic trait of this virus. Regardless, results to date with this improved model further substantiate our earlier finding and indicate that algal extracts active in infant mice also prevent the development of skin lesions by herpes viruses, provided treatment is initiated with or prior to infection. It is concluded that more efficient ways to deliver active antiviral material to specific sites, where viruses are replicating, must be sought before the true potential application of these substances in herpes virus infections in man can be fully evaluated.

Publications

Deig, E. F., D. J. Riedlinger, D. W. Ehresmann and M. T. Hatch. 1977. Evaluation of extracts of marine algae for antiviral activity in experimental herpes simplex infections of infant mice. 52nd Technical Progress Report, Naval Biosciences Laboratory, University of California, Berkeley, California: 11 pages.

Ehresmann, D. W., E. F. Deig, M. T. Hatch, L. H. DiSalvo and N. A. Vedros. 1977. Antiviral substances from California marine algae. *J. Phycol.* 13: 37-40.

Hatch, M. T., D. W. Ehresmann, E. F Deig and N. A. Vedros. 1977. Further studies on the chemical composition and an initial *in vivo* evaluation of antiviral material in extracts of macroscopic marine algae. Paper presented at the 9th International Seaweed Symposium, Santa Barbara, California, August 20-27, 1977.

Richards, J. T., E. R. Kern, L. A. Glasgow, J. C. Overall, Jr., E. F. Deig and M. T. Hatch. 1978. Antiviral activity of extracts from marine algae: *Antimicrobial Agents and Chemotherapy* 14: 24-30.

Cooperating Organizations

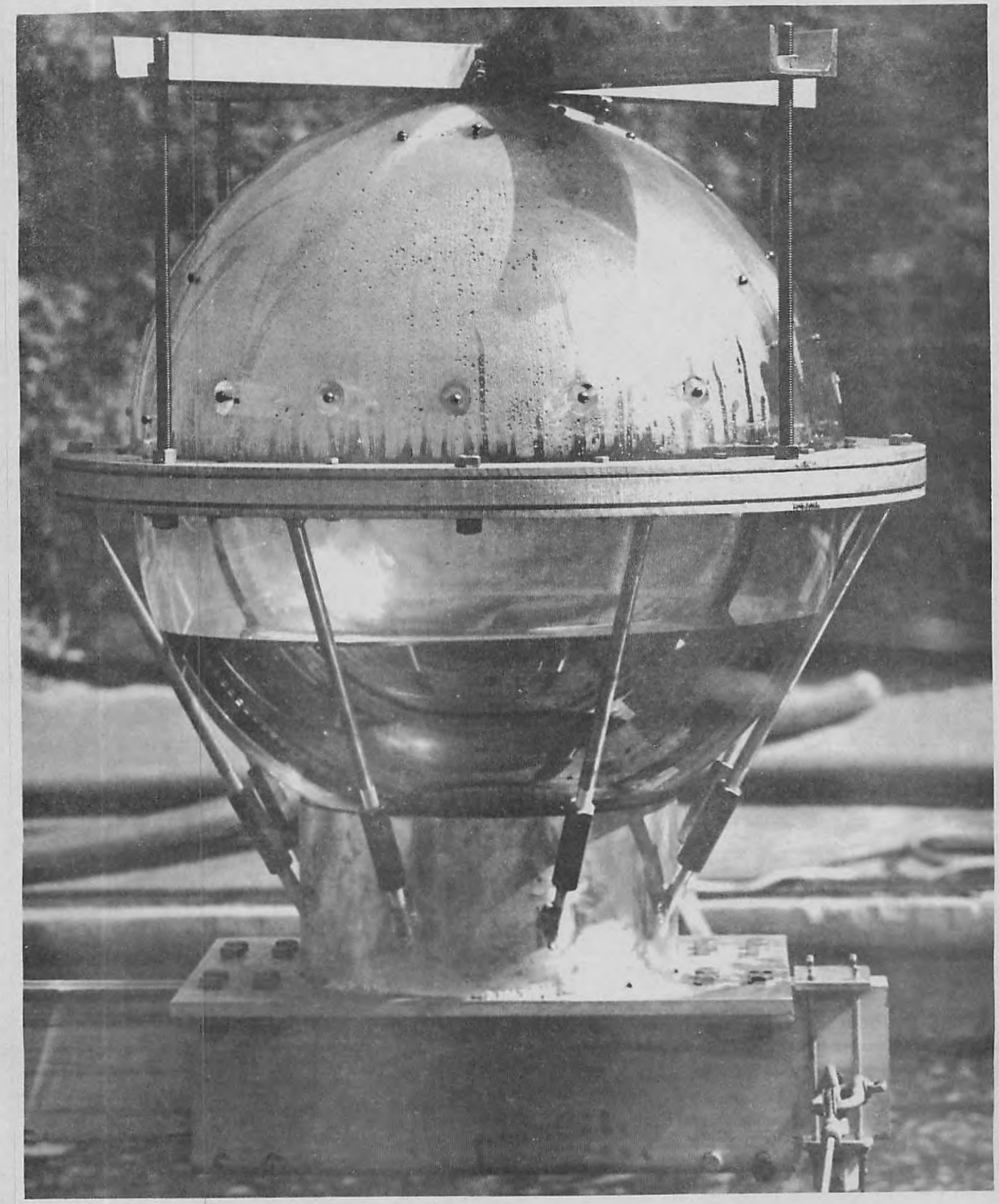
Marine Colloids, Inc., Rockland, Maine, Drs. Kenneth B. Guisley and Donald W. Renn

U.S. Navy, Naval Biosciences Laboratory

National Institute of Health, Antiviral Testing Program

University of California, Berkeley, Department of Botany, Dr. John A. West

ENERGY RESOURCES RESEARCH AND DEVELOPMENT



Effect of Stray Electrical Current on the Corrosion of Prestressed Concrete in Sea Water

Yimsan Gau
Faculty sponsor: I. Cornet
University of California, Berkeley

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. Stray currents may be generated from cathodic protection of adjacent structures, ships, pipelines, etc. These currents can be picked up by prestressed concrete structures and result in the corrosion of embedded metal wires. The extent of damage and structural weakening that may result is being examined in this project.

This is a continuation of an experimental investigation of the effect of stray electric direct current on the corrosion of steel in prestressed concrete in sea water. Beams 2.5 x 2.5 x 48" were prestressed with a single 0.172"-diameter wire, prestressed to 175,000 psi. They were then exposed to sea water and maintained anodic to a copper cathode with applied densities of 2.5 to 85 mA/ft^2.

Monitoring included a weekly potential measurement with current on, relative to a silver/silver chloride reference electrode, a biweekly potential with current off, and resistance measurement. Beams were examined biweekly, and the presence of rust spots and cracks were noted.

Time to change in potential, which was taken as the time of onset of corrosion, and time to visible corrosions were recorded. As the monitoring method used in this experiment does not tell quantitatively the extent of corrosion damage, rusted or cracked beams were subjected to tension testing to failure to determine the strength left in the wire. After the tension testing, beams were notched lengthwise and split open, and the prestressing wire was examined to determine the distribution and extent of corrosion.

Eleven beams were tested to failure this year. Four beams, two of which were without current (73 weeks exposure), are still under test with time of exposure ranging from 94 weeks for a beam at 5 mA/ft^2 to 63 weeks for a beam at 2.5 mA/ft^2.

Results of beam tests have been reported at the Offshore Technology Conference in Houston, Texas, in May, 1978 and published in the proceedings (see below).

A theoretical analysis of the time to change of potential and beginning of steel corrosion requires knowledge of the rate of diffusion of chloride ions into concrete. The threshold concentration of chloride ion required to depassivate steel in concrete is unknown. To obtain the diffusion coefficient for chloride ion in concrete, experiments are being run on cylindrical concrete specimens 2.5" in diameter and 1.164 and 3" thick, cast against a 1/8" steel plate, exposed on the other end to sea water with the end steelplate maintained anodic to a copper plate, with current densities from 0.0 to 20 mA/ft^2. When the steel changes potential to indicate corrosion, 1/16" thick slices are cut from the specimens at various depths and analyzed for chloride content using a wet chemical analysis. Data are being obtained at the present.

Publications

Cornet, I., D. Pirtz, M. Polivka, Y. Gau and A. Shimizu. 1978. Effect of stray electric current on the corrosion of prestressed concrete in sea water. Paper presented at the 10th Annual Offshore Technology Conference, Houston, Texas, May 1978. OTC 3195: 1251-1256.

Earthquake Loading on Large Offshore Structures in Deep Water
A Study for the Correlation of Analytic and Physical Models

Robert L. Wiegel, Ben C. Gerwick, Jr., Joseph Penzien, Robert C. Byrd and Fukij Nilrat
University of California, Berkeley

The trend in recent years for offshore development has been to larger structures in deeper water. While a large body of data has begun to accumulate concerning the response of these structures to ocean wave conditions, very little is available concerning the response of these structures to severe earthquakes. It is likely that offshore oil storage tanks, LNG terminals, or other large volume structures of a similar nature will be desirable in this region in the future. Preliminary studies have shown that earthquake forces may dominate the design of characteristics of such structures in many seismically active areas off the West Coast.

This program was formulated to assist in evaluating earthquake effects on large offshore structures. Actual measurements of these effects were made on a scale model under laboratory conditions and these results were compared with those of typical analytic methods. This study is being directed by Professors Ben C. Gerwick, Jr., Joseph Penzien and Robert L. Wiegel of the Civil Engineering Department, Berkeley campus. Planning and structure design of the model began in September 1976, with the analysis being conducted by Sea Grant trainee and doctoral students Robert C. Bryd and Fukij Nilrat. The experiments are being conducted at the UC Earthquake Engineering Research Center (EERC) at Richmond.

Preliminary considerations

The dynamic interaction of a large submerged tank with the surrounding fluid and an elastic bottom of varying characteristics is a very complex phenomenon, necessitating some simplifying assumptions before being dealt with in a physical model. A preliminary consideration of the problem showed that of all the forces exerted on structures by water in an earthquake, those related to the acceleration of the structure were by far the most important for large structures. The effect in this case is to cause an apparent increase in the mass of the structure due to the fact that the structure is moving some of the surrounding water when it attempts to move with its foundation in an earthquake. This increase in the mass of the structure is generally related to the mass of displaced water by what is commonly called an "inertia" coefficient.

The displaced volume of water for large offshore structures is measured in hundreds of thousands of tons, and errors in the inertia coefficients can lead to serious error in the calculation of foundation and structural forces under some circumstances, possible leading to slippage or other types of failure. For these reasons the initial model design and test series were devoted to defining these inertia coefficients under realistic earthquake conditions.

A careful consideration of the nature of the foundation of a large gravity type structure leads to the conclusion that the foundation cannot be properly modeled by use of anything approaching real soils, since all the characteristics must be scaled to conform to the reduced size of the model and some relate to geometric constraints which cannot be satisfied. However, since this study is concerned with accurately describing fluid-structure interaction and not internal foundation stresses, it was possible to design a model foundation that sufficiently represents the stiffness characteristics of the sediments to allow proper response in the model.

Foundation damping was not included in the model design because it was felt it would be an unnecessary complication and would tend to mask the effects of hydrodynamic damping. Foundation load cells were designed such that they represented

the range of stiffness one might expect to encounter in siting an offshore structure, taking into consideration the degradation of sediment shear strength with strain due to earthquake excitation. The foundation stiffnesses actually used were those derived from an elastic half-space representation of homologous soils having shear moduli ranging from 1.0×10^7 N/m^2 to 1.5×10^8 N/m^2. Consideration was given in the model design to maintaining the proper relationships between horizontal, vertical, and rotational stiffness in the plan of motion.

The structure of the model itself was designed to be essentially rigid body, since the study was not involved in consideration of structural deformations. The model was manufactured from an aluminum cylinder with one-inch thick walls and was heavily braced internally.

There were several questions concerning the hydrodynamic inertia coefficients which were considered in this study. The major one was magnitude of the coefficients relating to the principle nodes of motion (i. e., horizontal, vertical, rotational) and whether or not they varied with the frequency of the foundation excitation. A second matter of interest was whether or not significant interference, or coupling, exists between the various modes of motion where the hydrodynamic coefficients are concerned. This latter consideration imposed the additional constraint on the model design that the three modes be uncoupled elastically in dry model conditions so that hydrodynamic coupling could be readily detected.

A final consideration in the model design was the size of the prototype system for which the model was to be tested. It was considered desirable to be able to model a structure of at least 200,000 tons and to simulate water depths of approximately 100 meters. The load carrying capacity of the earthquake simulator on which the experiments were to be performed allowed for flooding to a depth of approximately one meter. These and the other factors involved led to a model which represents a structure of approximately 34 meters height and 80 meters diameter on a scale of 1:100. This would be the approximate size of a structure of about 250,000 tons.

Careful consideration was given to instrumentation requirements in the model design. The basic information necessary was model displacement and foundation acceleration time histories for the various conditions tested. It was considered highly desirable, however, to include the capacity to measure model acceleration, foundation forces, and fluid pressure distributions directly. This allowed sufficient redundancy so that results could be cross-checked, and allowed for better comparisons of response with analytic techniques.

Construction and testing of the model

The model with accompanying instrumentation and the portable basin required to flood the earthquake simulator table were completed in June, and the first series of tests were conducted during July. The first tests were concerned with verifying the dry response of the model and determining the submerged response at the maximum water depth. Tests were conducted with three different foundation conditions covering the entire range of stiffness conditions. In each case tests were conducted with harmonic excitation corresponding to a range of frequencies from 0.1 Hz to 1.5 Hz and accelerations up to about 40% of gravity, depending on physical constraints. Reproductions of actual earthquake excitations were also used in each case, with maximum accelerations as high as 50% of gravity.

The July tests yielded over 200 individual data files, each consisting of 15 response time histories relating to various aspects of the system dynamics. The analysis of these results continued into the second year of this study. A second test series was conducted during December 1977. It was concerned with the effects of water depth change on the various response characteristics.

Test results

The experimental study comparing the results of measurements of forces on a submerged tank model due to
earthquake excitation was presented in detail in the thesis dissertation of Dr. Robert C. Byrd. A paper covering some aspects of the

study was presented at the 1978 Offshore Technology Conference, Houston, Texas, in May 1978. The experimental results were compared with analytic solutions for the case where the model was submerged in water of depth equal to 2.5 times the tank height and for the case where the depth exactly equalled the height.

Details were presented for the design of a 1 to 100 scale model of a circular cylindrical structure which is 34 meters in height with a mass of approximately 250,000 tons. The model included a foundation system which simulates elastic half-space soil stiffness in three degrees of freedom.

The experimental results were presented in the form of inertia coefficients measured in harmonic motion at varying amplitudes and over a frequency range of 0.3 Hz to 2 Hz in prototype scale. Coefficients were presented for horizontal, vertical, rotational, and horizontal-rotational coupling. The relationship between these coefficients and the physics of the fluid-structure interaction was examined in detail.

The study leads to the following conclusions concerning earthquake-induced forces on large submerged gravity-type structures:

1. Available analytical techniques provide good estimates of hydrodynamic inertia force coefficients for submerged structures of simple form.
2. A correct estimate of foundation dampening is likely to be the most critical point in calculating the hydrodynamic forces on a submerged gravity structure.
3. Foundation stiffness only influences the hydrodynamic force by changing the resonant frequency.
4. Frequency dependence in the inertia coefficients is not likely to be an important consideration.
5. Coupling in the hydrodynamic inertia forces between the horizontal and rotational modes is not likely to be an important consideration in structural design.
6. Hydrodynamic dampening will not be an important factor for deeply submerged structures but may be significant in near-surface and surface-piercing structures.

Analytical and numerical model studies

A computer program was developed for computing the hydrodynamic pressure and added mass of a rigid submerged caisson subjected to horizontal, harmonic ground excitation by using the finite element method. The fluid was assumed to be incompressible and inviscid, and the governing equation of small amplitude irrotational motion of fluid was written in the form of partial differential equation, with the hydrodynamic pressure as an unknown in cylindrical coordinates. By taking advantage of the axisymmetry of the caisson, the toroid elements were used in the discretization. The transmitting boundary was used as an outside boundary of the fluid domain where the acceleration of fluid particles could be expressed in terms of unknown hydrodynamic pressure at that boundary. This transmitting boundary permits energy radiation into the far-field. Presently, the computer program is being debugged. We plan to modify the program for the vertical harmonic excitation and compare the results of the two cases with those of the experiment. These studies are a part of the Ph.D. thesis work of Mr. Fukij Nilrat.

Design modifications

Originally, it was planned that four surface-piercing vertical circular cylinders ("towers" or "legs") would be mounted on top of the existing instrumented model. The effect of these structural members on the characteristics of the added mass was to be studied by means of tests on the earthquake simulator. However, experience with the first model, together with new calculations, showed that a new approach was needed. A new model had to be designed and constructed. This consisted of four vertical circular cylinders, of a larger size than originally planned, to be mounted directly on the earthquake simulator, as an array. The configuration of tbe array and tbe spacing of the individual members could be varied. This required a modification to

the surface of the earthquake simulator, as well as the design and construction of a new model. This new model will permit the study of interactions of the fluid and the array.

After Dr. Byrd finished his Ph.D. thesis and left the University, a new trainee, Mr. Farhad Safaie, started to work on the above-mentioned phase of the project, starting on 1 June 1978. He has been engaged in the detail analysis of the new model (four-cylinder array) of an offshore structure. He participated with Fukij Nilrat in the consideration of the relative magnitude of inertia and hydrodynamic forces acting on the models in a harmonic ground excitation. A load cell was designed which can measure the shear and overturning moment at the base of the model in two perpendicular directions. The locations of pressure transducers were chosen so that pressure can be measured at three different elevations for three different water depths around the column. In addition, it will be possible to measure the acceleration at the top and bottom of the column for two perpendicular directions. The new model has been constructed. Calibration of the new model and a preliminary set of experiments have begun.

Publications

Byrd, Robert Clark. 1978. A laboratory study of the fluid-structure interaction of submerged tanks and caissons in earthquakes. Ph.D. thesis, Dept. of Civil Engineering, University of California, Berkeley. Report No. UCB/EERC-78/08, Earthquake Research Center, University of California, Berkeley, May 1978, 150 pp.

Byrd, R. C. and F. Nilrat. 1978. Earthquake excitation of submerged tanks and caissons: a correlation study for physical and analytic models. OTC 3110, *Proc. Offshore Tech. Conf.*, Houston, Texas, May 8-11, 1978.

Byrd, R. C. Earthquake loading on offshore gravity structures. *Forefront,* research in the College of Engineering, University of California, Berkeley, 76/77: 100-103.

Seymour, Richard J. 1977. Report on earthquake loading on large offshore structures in deep water - a study for the correlation of analytic and physical models. *Proc. U.S.-Japan National Resources Panel: Marine Facilities Panel,* 1 June 1977, Tokyo, Japan, (in Japanese), pp. 116-117.

Cooperating Organizations

University of California, Earthquake Engineering Research Center, Richmond

Seismic Hazards to the Development of Offshore Oil Resources

William A. Prothero, *University of California, Santa Barbara*

The purpose of this project is to study earthquake occurrence in the southern California coastal zone and offshore regions. By accurately locating seismic activity, we are also locating active faults which could pose particular hazards to manmade structures. In order to perform these studies, 3 ocean bottom seismometer (OBS) capsules have been constructed. The new OBS capsules can be launched from smaller boats and can be programmed for more optimum recording criteria than older versions.

This year we completed the 3 capsules and field tested them extensively; we performed over 15 deployments and conducted or participated in 5 separate experiments. The Santa Barbara earthquake of August 13, 1978, provided us with a good opportunity to use our equipment for an aftershock study. We deployed 5 portable instruments on land within 24 hours of the main event and 2 OBS capsules within 48 hours. The earthquake was located 3 to 5 km south of Santa Barbara in a fault zone where offshore oil production activities are taking place. The combination of land and sea bottom stations was ideal. These data are being worked up by Barbara Bogaert for her master's degree and will accurately locate the zone and direction of fault slip.

Microearthquake data are also being processed from a 2-week deployment west of Lompoc. The purpose of this was to study the seismicity of the southern Hosgri fault zone. During the third year, we plan further microseismicity studies of the Santa Barbara Channel and the region west of Point Conception.

This year the 3 capsules were completed and field tested during more than 15 deployments. Our activity this year is summarized in the following:

1. 7 Feb. - 7 Mar.

   Test 3 OBS capsules and leave 1 in Santa Barbara Channel for 1 month. (Sea Grant, National Science Foundation (NSF)).

2. 6 May - 19 May

   Deploy 3 OBS capsules in refraction experiment (NSF).

3. 14 June - 1 July

   Participate in OBS intercomparison tests at Lopez Island (Office of Naval Research (ONR)).

4. 13 July - 19 July

   Deploy 3 OBS in refraction experiment (NSF).

5. 20 July - 4 Aug.

   Deploy 3 OBS west of Lompoc for seismicity measurements (Sea Grant, NSF).

6. 15 Aug. - 6 Sept.

   Deploy 2 OBS south of Santa Barbara for aftershocks of August 13 earthquake (Sea Grant, NSF, U.S. Geological Survey (USGS)).

Funding sources for these experiments are indicated in parentheses, with Sea Grant providing the core support. Figure 1 is a map showing the location of stations for studies 2, 4 and 6. Figure 2 shows the locations of the OBS capsules and 2 land stations for experiment 5. The plotted epicenters are from historic data recorded on land. The data from this experiment have not been fully processed yet.

The OBS capsules made the transition from a prototype instrument to an operational tool during this year. Capsule reliability is very good. Operations beginning at item 3, produced good data except from one capsule which had a bad microprocessor chip. Several important capsule design approaches were proven during this testing. First, the microprocessor controller is reli-

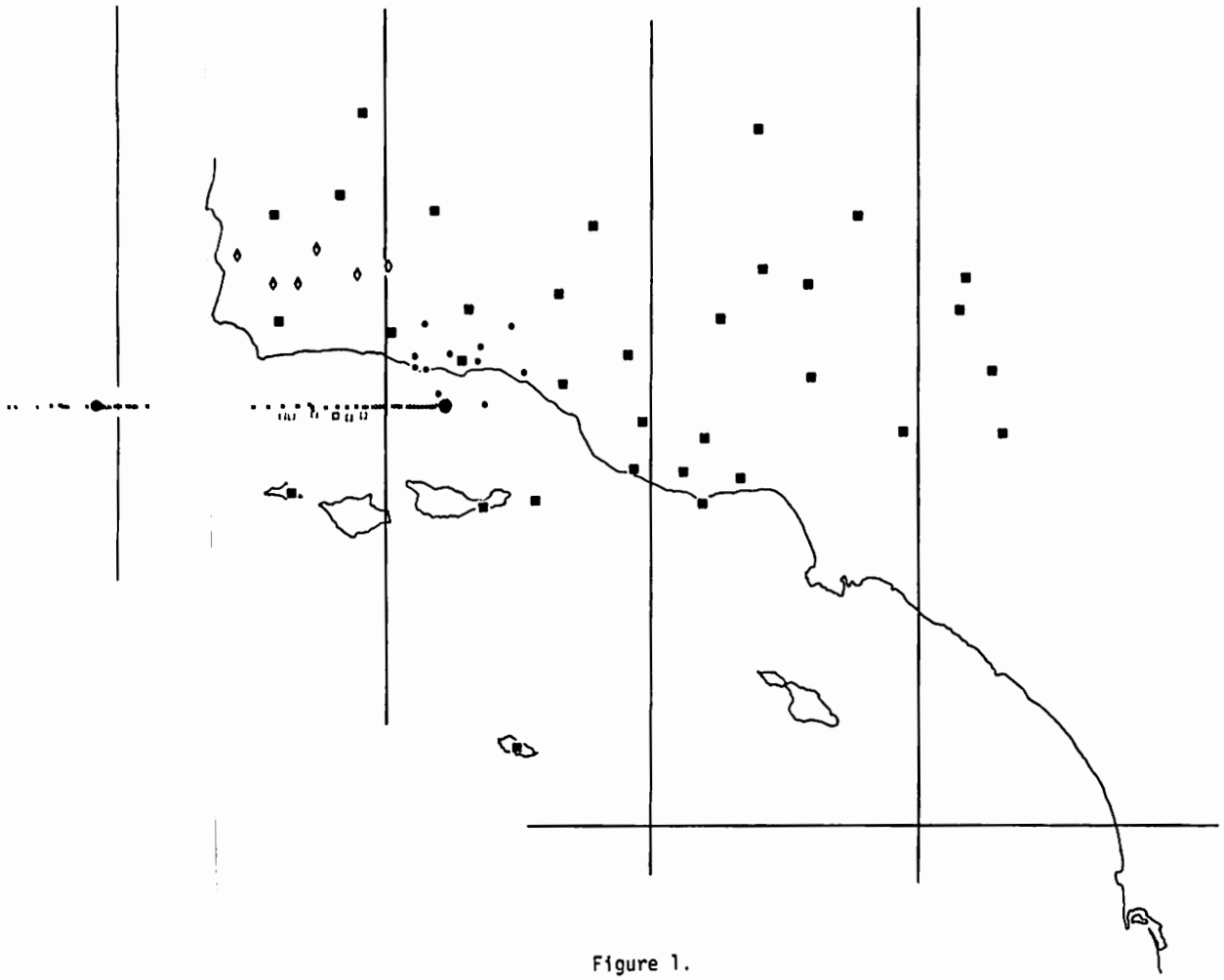


Figure 1.

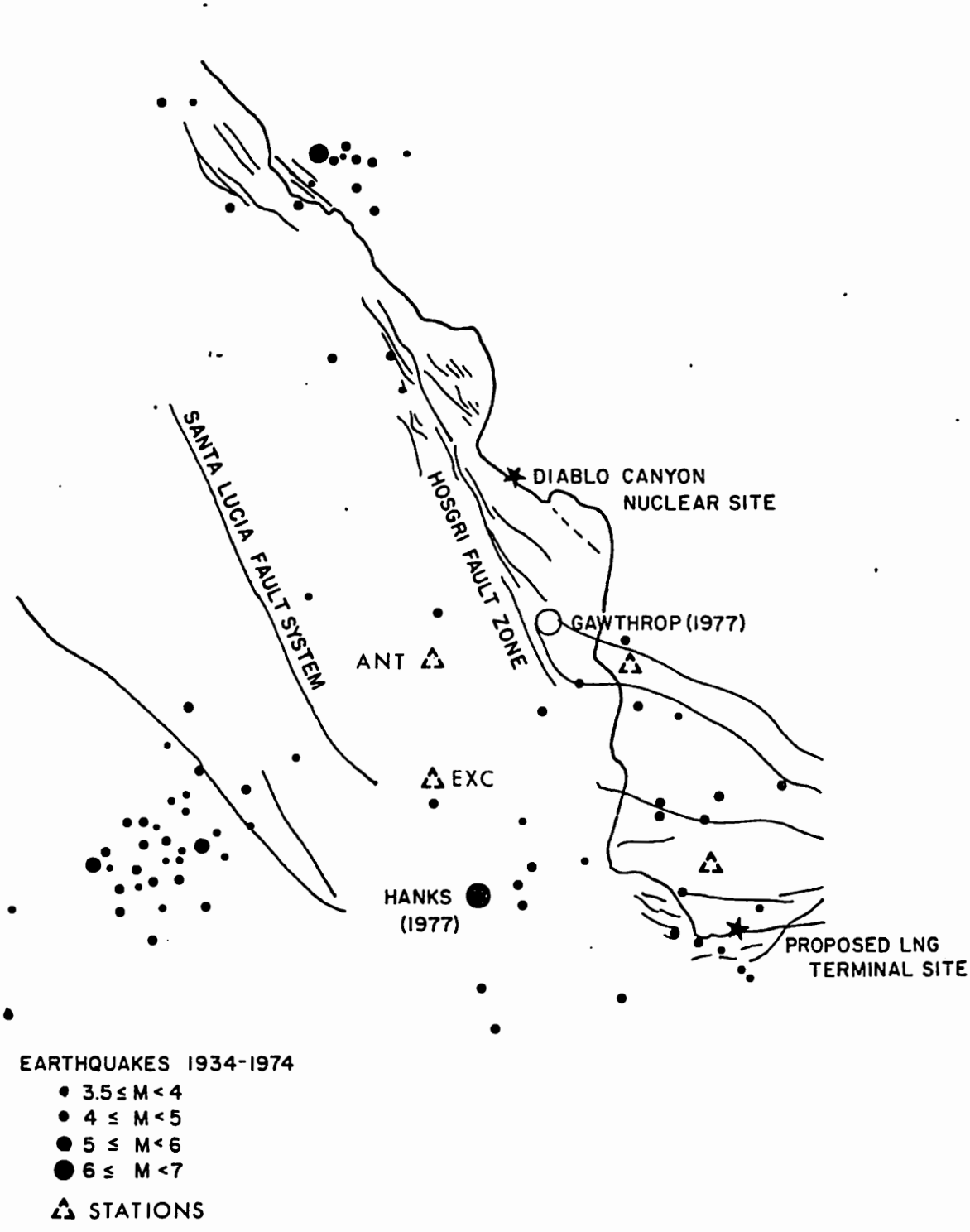
■ PERMANENT SEISMIC STATIONS (USGS & CAL TECH)

• PORTABLE SEISMIC STATIONS INSTALLED FOR AFTERSHOCKS OF 13 AUGUST 1978 EARTHQUAKE

◊ PORTABLE SEISMIC STATIONS OPERATING DURING JULY REFRACTION STUDY

⊠, × EXPLOSIONS SET OFF DURING MAY, JULY, 1978

● OCEAN BOTTOM SEISMOGRAPH OPERATING DURING JULY REFRACTION STUDY


SANTA LUCIA FAULT SYSTEM
HOSGRI FAULT ZONE
DIABLO CANYON
NUCLEAR SITE
GAWTHROP (1977)
ANT
EXC
HANKS
(1977)
PROPOSED LNG
TERMINAL SITE
EARTHQUAKES 1934-1974
3.5 ≤ M < 4
4 ≤ M < 5
5 ≤ M < 6
6 ≤ M < 7
STATIONS

able and the operating programs can be stored in write-protected random access memory for indefinite periods of time without system failures. Second, the power consumption at the microcomputer is lower than expected (10 ma at 6 v), allowing a longer deployment time with our existing battery pack than previously expected. Third, the tubular (rather than spherical) design of the instrument pressure housing considerably eases handling and assembly at sea. Also, self-test programs simplify and speed prelaunch checkouts, a considerable advantage when performing complex experiments in difficult conditions.

On the other hand, we have had unexpectedly severe problems with impulsive ground noise which triggers the capsule (looking like an earthquake) and expends a great deal of our available magnetic tape for data recording. These impulsive sources are thought to come from fish bumps, reflection profiling ships, and drilling activity. Fortunately, since the OBS is controlled by a microcomputer, and event detection algorithms are reprogrammable without hardware modifications, we have a good possibility of discriminating against these noise sources.

An event is triggered on the basis of a short term signal average exceeding the long term average, and the number of slope reversals occurring during a certain time interval. The short term-long term average criterion requires a signal jump above ambient, and the slope reversals criterion requires a signal with a certain degree of complexity. We must be careful not to be so restrictive in our criteria that we exclude earthquakes. We are now attempting to optimize our trigger algorithm based on seismograms we have acquired to date.

Our most exciting research opportunity this year occurred as a result of the August 13 Santa Barbara earthquake (magnitude 5.1). This event was unusually damaging (for its size) to Santa Barbara and Goleta. The University alone sustained 9 million dollars worth of damage. The earthquake occurred offshore in a fault in close proximity to oil platforms and drilling activity, so its accurate location is of considerable interest from a hazards point of view. We deployed 5 portable land stations and 2 OBS capsules within 48 hours of the main shock (see Fig. 1). Hundreds of aftershocks were recorded on our stations, with the OBS capsules providing important seaward control.

Another contributor to this effort was the refraction work we are performing in the Santa Barbara Channel under NSF support. This work studies the velocity structure of the region using OBS capsules in the Channel and temporary and permanent land stations. Since the unknown velocity structure in this area leads to major uncertainities in locating earthquakes, the refraction data has been crucial in getting the best hypocentral locations. We will complete the refraction work in spring 1979, and optimize the land array to provide the best station corrections for the Santa Barbara earthquake aftershock study.

The earthquake locations, focal plane solutions, and geologic interpretations will form the major part of the master's thesis of Barbara Bogaert, a Sea Grant trainee. From this data, we hope to learn the location of the zone of rupture, the causative fault, the direction of slip, and its tectonic significance.

The 2-week deployment west of Lompoc (Fig. 2) was the beginning of a detailed seismicity study of the southern Hosgri fault zone. Historic seismicity has been rather high with an earthquake of magnitude 7.4 occurring in the region in 1927. Residual microseismicity could point to possible locations for this event, which has caused so much controversy regarding the safety of the Diablo Canyon nuclear reactor site. The data from this deployment are only now being processed. We will study this region in detail during the third year of this project.

Publications

Prothero, W. *In press.* An operationally optimized ocean bottom seismometer capsule. *Phys. Earth and Plant. Int.*

Prothero, W. 1977. An operationally optimized ocean bottom seismometer capsule. Paper presented at IA SPEI/IAVCEI Assembly, Durham, England, August, 1977.

Prothero, W. 1978. A new operationally optimized ocean bottom seismometer capsule. Paper presented at the spring meeting of the Seismological Society of America, Reno, Nevada, 1978.

Lopez, R. 1978. A microprocessor controller for an ocean bottom seismometer capsule. M.S. thesis, University of California, Santa Barbara.

Cooperating Organizations

National Science Foundation, Geophysics and Marine Geophysics

U.S. Geological Survey

U.S. Navy, Office of Naval Research

Side-scan Sonar Mapping and Computer-aided Interpretation of the Geology of the Santa Barbara Channel

B. P. Luyendyk and D. S. Simonett
University of California, Santa Barbara

Objectives

Our overall objectives are to map the sea-floor geology in the Santa Barbara Channel and environs with particular attention to possible geological hazards. The Channel is a region of high seismicity as evidenced by the 5.9 RM earthquake on August 13, 1978. This natural fact comes in direct confrontation with the socio-economic uses of the Channel region which include oil well drilling and production, fisheries, aquaculture, and recreation.

Geological sea-bed features of interest include offset sea-floor due to faulting, areas of sediment movement and instability, sea-floor erosion due to currents and mass movement, and regions of differing sediment types.

We are conducting our sea-bed mapping program using a towed 100 kHz side-scan sonar system. This is usually supplemented with a 3.5 kHz seismic reflection system.

An objective of our mapping program is to develop and optimize computer image processing of the side-scan data. We plan to be able to digitally process the sonar data to aid in feature detection and recognition, sonar mosaicing, and sonar stereoscopy.

Progress during period September 1, 1977 to September 30, 1978 - field operations

Procurement and implementation of a survey system. Our sonar mapping system includes an Edo-Western 606-603 side-scan sonar. This unit was custom built to our specifications for a 2000 meter depth limit, which would if needed allow the entire depth range of the California Borderland to be surveyed. The sonar transducers are enclosed in an oversized tow fish (Fig. 1) which includes space for the addition of other instruments such as a 3.5 kHz profiler and a digital depth sensor, the latter of which we will install this year. The side-scan fish is towed at the end of 150 meters of double armored conducting cable which is wound on a heavy hand winch which has 8 conductor slip rings.

Another system, component is an ORE-136 sub-bottom profiling system which we usually operate at 3.5 kHz. This profiler uses a 10 kw ORE-140 sonar transceiver and a Hydroproducts 4000 T recorder.

We have navigated our operations with a Micrologic ML-1000 LORAN-C which has proven remarkably precise. At present we are interfacing this receiver to a North Star Horizon 32 k microcomputer which will log LORAN fixes every 21 seconds and keyboard entries at will, plus output a real-time navigation plot on a Tektronix interactive plotter. The 3.5 system, LORAN, and a computer were funded by UCSB's Marine Science Institute.

Survey operations in the Santa Barbara Channel. We conducted three survey cruises in the Santa Barbara Channel in November 1977, and June and July 1978. Each cruise was about 4 to 5 days in length. Ship time was provided by the R/V Ellen B. Scripps of the Scripps Institution of Oceanography. This time was funded through an NSF grant to W. Prothero (UCSB) for offshore seismicity studies using ocean bottom seismometers and sonar mapping.

The survey operating areas (Fig. 2) include Anacapa Passage, Santa Cruz Channel, Santa Rosa ridge, the Point Conception LNG site, offshore Coal Oil Point, and offshore Santa Barbara-Ventura.

Development of navigation processing software. During survey operations we recorded LORAN-C and Radar fixes at equal

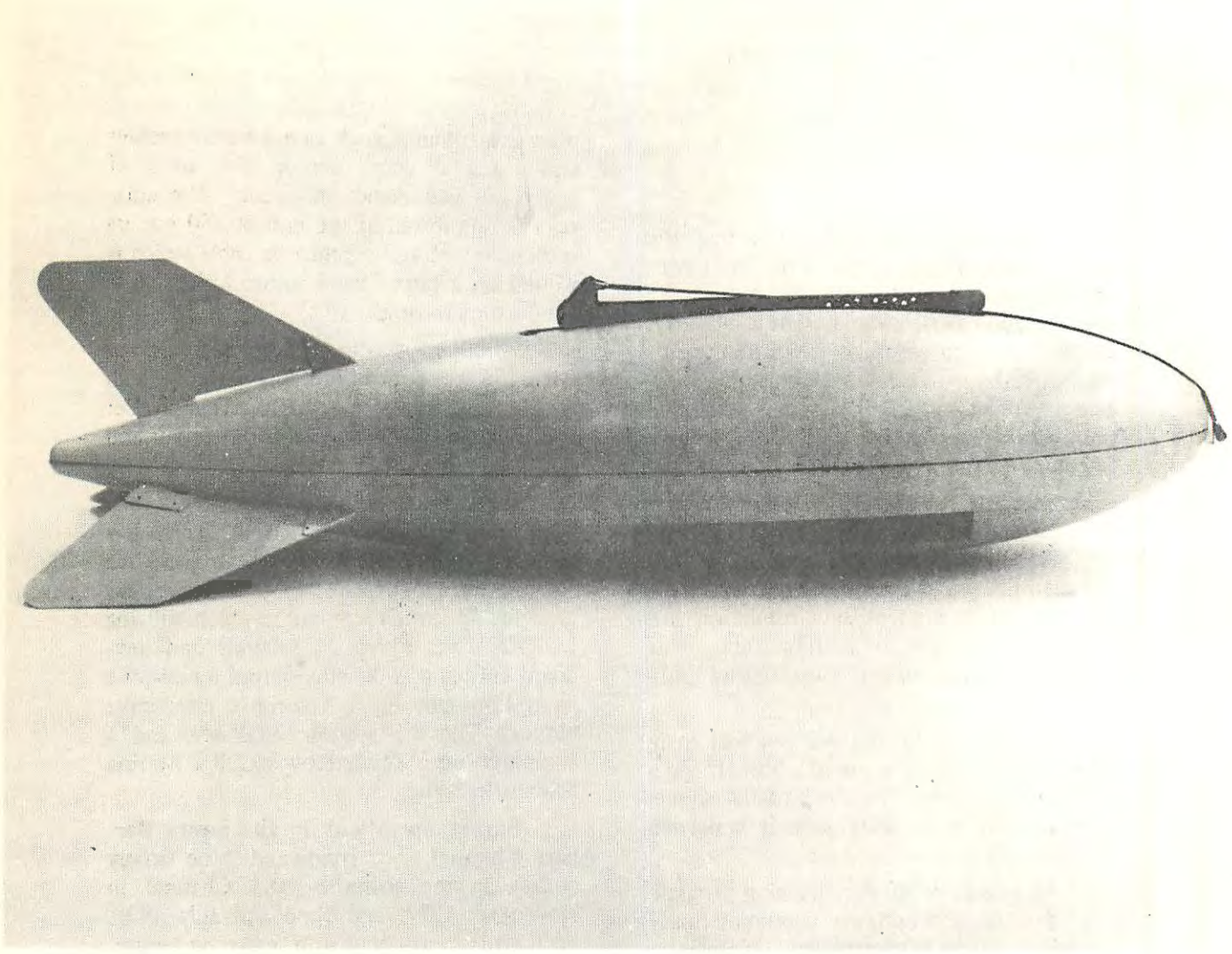


Figure 1. The Edo-Western 603 side-scan sonar tow fish. Black stripes are transducer exposures.

time intervals - usually 5 minutes for LORAN and 15 minutes for Radar. We noted that although the LORAN navigation data was as precise or more so than the Radar, systematic errors were apparent with the LORAN fixes. Program OFFSET was written to calibrate the systematic differences between the two data sets. In most operating areas these offsets are small (Table 1).

Prior to calibration of the LORAN fixes these and the Radar fixes were checked for errors by two methods. Program DEADREK was written to calculate speeds, course changes, and time differences between fix pairs. These parameters are compared against upper limits initialized in the program, and fix pairs which exceed any of the limits are flagged. Program TRACKS was written to produce Mercator track charts of the fix series both to identify navigational errors and to produce finalized navigational track plots.

We have finalized the navigation from all operating areas and plotted the data on 1:20,000 sheets. The navigation for the June cruise in Anacapa Passage is shown in Figure 3.

Maps of bottom features on 1:100,000 scale. Reflection data from the November 1977 cruise and one in May 1977 were analyzed for fault traces, mass movement, sea-floor erosion and folding. These data were compiled on three sheets of 1:100,000 scale (Fig. 2). This study delineated several faults which are either more active or more definite than some postulated by Ziony *et al.* (1974). In particular the Santa Cruz Island fault was traced and connected to the Malibu Coast system through the Anacapa Passage. Also the Rincon fault (?) was traced west to Santa Barbara where it prominently offsets the sea-floor. This fault is near but not on the epicenter of the August 13, 1978 earthquake. Surveys south of Coal Oil Point mapped out the extent of a fairly recent submarine slide which covers over 100 sq km.

Photo albums of paired side-scan and 3.5 kHz data.
One problem in viewing side-scan and 3.5 kHz data record is that they are bulky and unwieldy. Also, the side-scan records are covered with burnt paper soot. We built a roller viewing box to overcome this problem. Photos were taken of geologic features recorded on side-scan and reflection records for matching time intervals. About 100 frames were taken and mounted in triplicate albums, one of which is kept by the image processing group (see below). These albums are useful in preliminary interpretations of data, in keying interesting areas for image processing, and in displaying data to visiting investigators.

Analysis of sonar data from Anacapa Passage. Our surveys in Anacapa revealed a particularly spectacular set of sonar features. Generally the Passage contains a set of truncated east-west trending anticlines and synclines, plus left-lateral east-west faults and conjugate northeast-southwest faults (Fig. 4).

The truncated folds are particularly evident in the southern half of the passage (Fig. 4) where resistant beds appear as elongate ridges up to 5 meters high. These beds form spectacular sonar targets (Fig. 5). When the side-scan sonar data is combined with 3.5 kHz profiler data these sinuous ridges are shown to be truncated anticlines and synclines.

Just as the profile data discriminates between anticlines and synclines on the side-scan records, the side-scan data can show whether a fault seen to have vertical offset on the profile record also has horizontal offset. For example, a fault with vertical offset at 0740 in Figure 6 is also seen to have left offset on the side-scan record (Fig. 5). Left-lateral faults trending northeast are quite frequent in this region (Fig. 7 and Fig. 4).

Our goal for this upcoming year is to produce a sonar mosaic of the Anacapa Passage. This approach is explained in the following section in some detail.

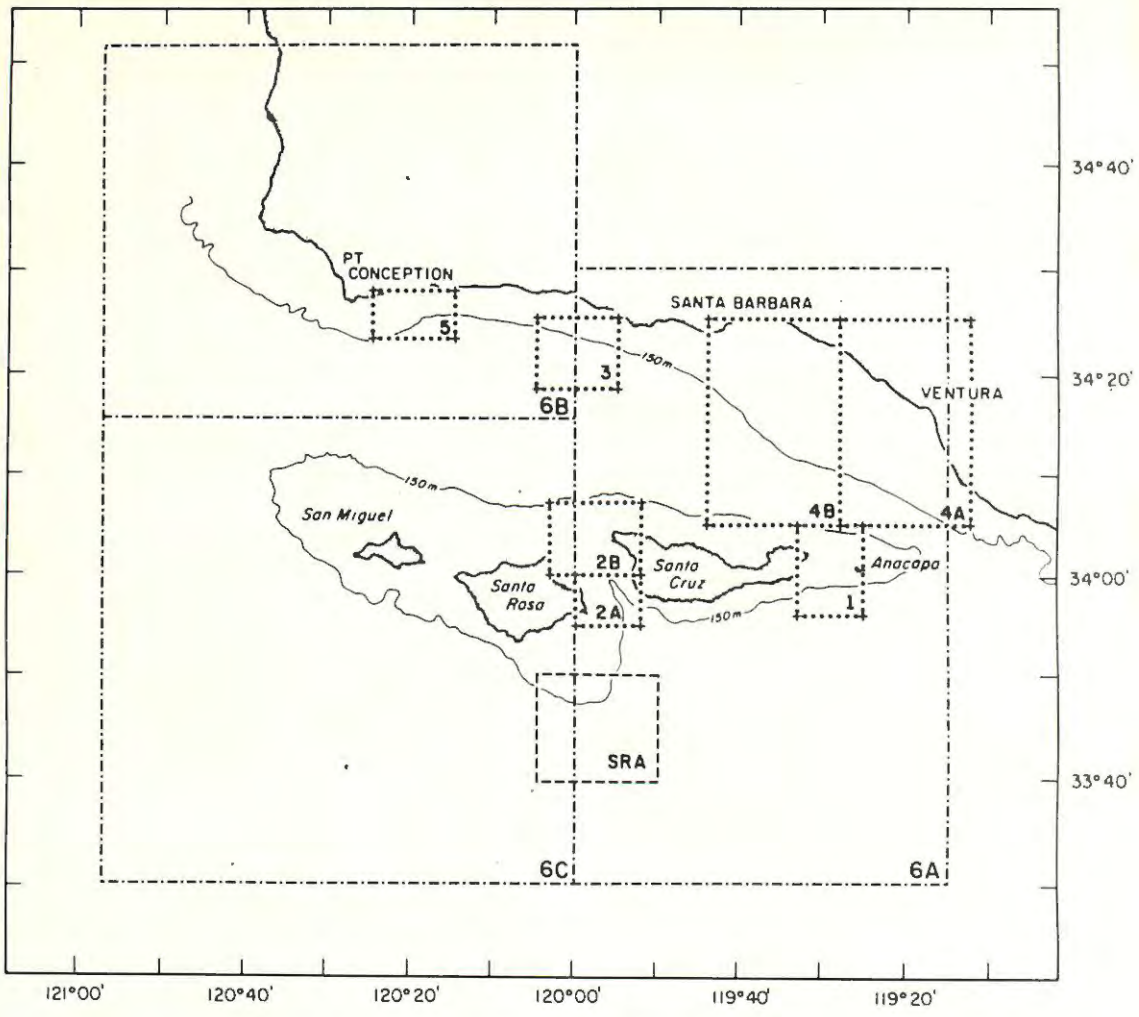


Figure 2. Project operating areas. Data are compiled at 1:20,000 or 1:40,000 in the dotted regions and 1:100,000 in the dash-dot regions.

Table 1
Calibration of LORAN-C fixes to Radar navigation nets

Area	latitude* offset (min.)	std. dev.	longitude* offset (min.)	std. dev.
Cruise SSS-77-1 - November 1977				
1. Anacapa	0.37	0.212	0.12	0.624
4B. North Channel	0.38	0.235	0.17	0.482
5. LNG Site	0.41	0.290	0.23	0.258
Cruise SSS-78-1 - June 1978				
1. Anacapa	0.32	0.263	0.07	0.154
2A. Santa Cruz	3	0.189	0.10	0.166
2B. Santa Cruz	0.57	0.277	0.27	0.150
3. Coal Oil Point	0.35	0.141	0.32	0.183
4A. Ventura	0.45	0.126	-0.06	0.701
Cruise SSS-78-2 - July 1978				
5. LNG Site	0.37	0.087	0.31	0.165

* These values are added to original LORAN-C fixes.

Sonar image processing, September 1, 1977 to September 30, 1978

The following text gives a sense of the direction and intent of our image processing activities. Given sonar chart displays similar to Figure 7 (location C in Fig. 3), we noted the general restricted range of grays and lack of features in the mid-to-far range (of the starboard channel) and the often saturated near-to-mid ranges. Separately, the cross and along track scale ratio (of about 1:7) is useful for some feature interpretation but difficult for direct feature mapping. Our efforts are to geometrically rectify such images - demonstrated herein - and expose and enhance features. The latter aspect we have only begun to pursue.

Sonar image data-related activities have been data collection, analogue-to-digital conversion, test processing and image mosaicing and software implementation. The general processing flow is shown in Figures 8 and 9.

Data collection. Initial tape recording at sea of sonar data used an Ampex PR-2200 double FM, 12-channel recorder. Equipment problems and high lease cost, coupled with a desire to use a newly-acquired in-house capability, prompted use of a TEAC 3400S. Detected 100 kHz carrier data was analog recorded on 3 of the available 4 tracks at 7½ ips. These were the port, starboard and synch pulse channels. Approximate frequency response was 15 hz to 30 kHz.

A/D conversion (Figure 8). Data digitalization was at a 12 kHz sample rate for a dual-channel pass. The effective rate was thus 6 kHz per data and synch channels. Test digitalization runs used low-pass filters of 3000, 2000, 1000, 500 and 50 hz. Subjective examination of trial printouts selected the highest filter frequency for data production, pending tests of digital processing trade-offs for improving feature/noise ratios.

Initial data storage on two RKO5 disks of a PDP 11/05 limited the data capacity per A/D "pass" to 5 M words (5 M pixels) prior to storage on the 300 M bytes PDP 11/45 disks. This limited digitized data to about 3½ min of data collection time and prompted changes in the synch-pulse recognition program (see Software section) to permit simultaneous port-starboard digitization. The synch-pulse recognition programs were used to image-format the raw data. Test images were printed on a Printronix printer using a 2 x 3 dot matrix. A second data pass rescaled the 12-bit, signed data (± 2047 signal levels/DN-digital numbers) to an 8-bit (0 to 255) range and determined signal-level distributions (histograms) for VICAR processing.

VICAR digital signal processing (Figure 9)

Contrast stretch. Input data (Fig. 7) was contrast stretched to a uniform distribution throughout a 0-255 range.

Sample averaging. A processing test case (dark flow lines on Fig. 9) pixel-averaged data in the cross track direction (image lines) by a uniformly weighted 7-sample window. This reduced the cross track image dimension and data volume by a factor of 7 and reduced both high frequency image and noise signals. Later, alternate processing sequences will examine the use of structure passes to effect a weighted averaging window for improved feature/noise ratios.

Signal rectification. Much of the present data preserved the effects of apparent multi-path signal interference - with the second ray reflected from the water surface. This Lloyd's Mirror effect (Fig. 10) can enhance interpretation of bottom contour changes but it may also confuse general feature interpretation because strong reflections from rock outcrops may appear in an image as alternate bands of extremely dark and light densities. Background noise is medium gray. An alternate and compatible explanation is that the recorded signal was only the rectified 100 kHz carrier. Hence, the modulation components needed rectification.

Signal rectification (Fig. 11) was effected by a linear contrast stretch which "folded" all DN values about the central (DN = 127) value. In the stretch, 127

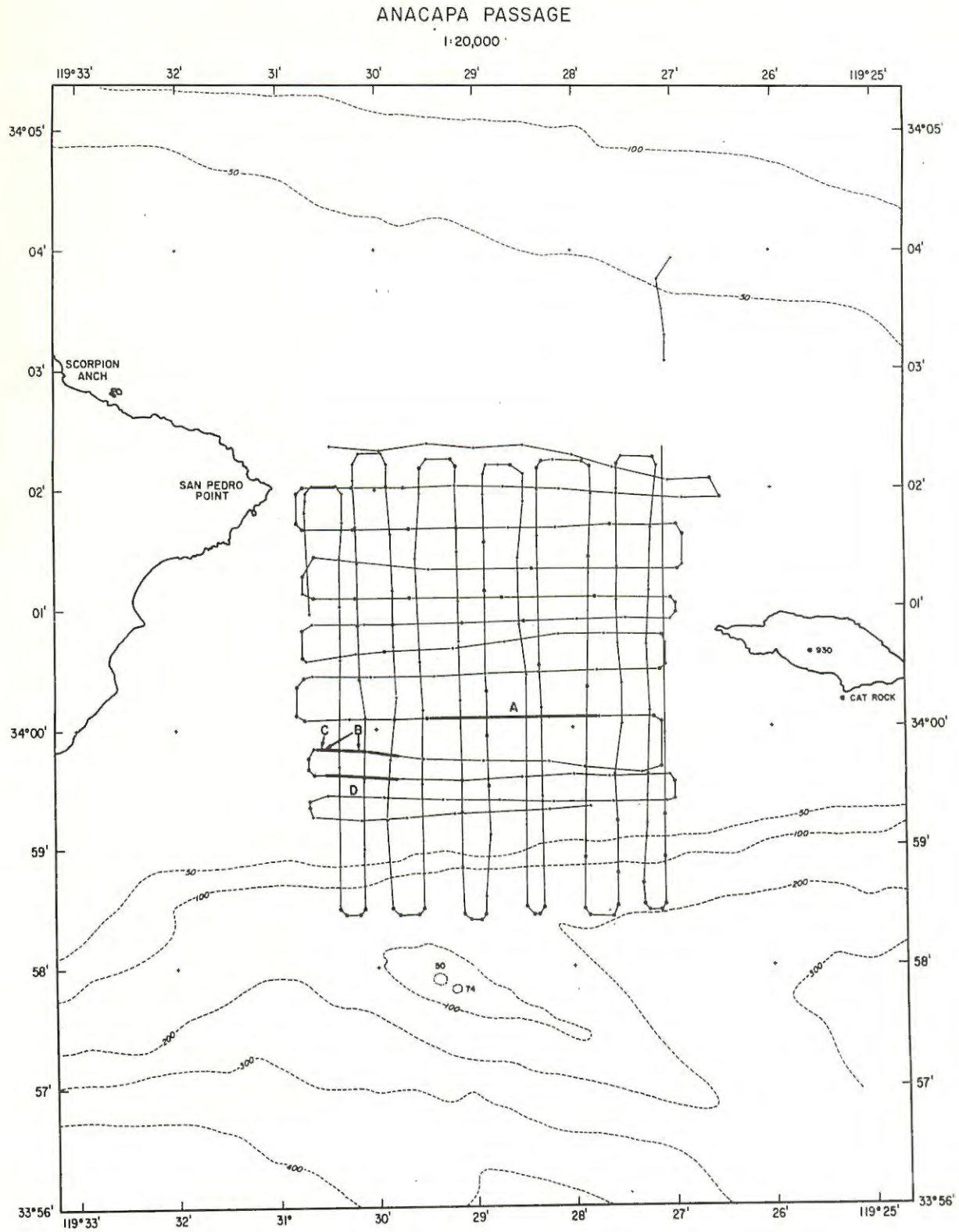


Figure 3. Track of the R/V Ellen B. Scripps in the Anacapa Passage for side-scan sonar and 3.5 kHz profiling study in June 1978 (SSS-78-1). Map scale, not photo scale, is 1:20,000. A, B, C, D are locations of data shown in Figures 5 and 6, 17 and 18, 7, and 14-15-16.

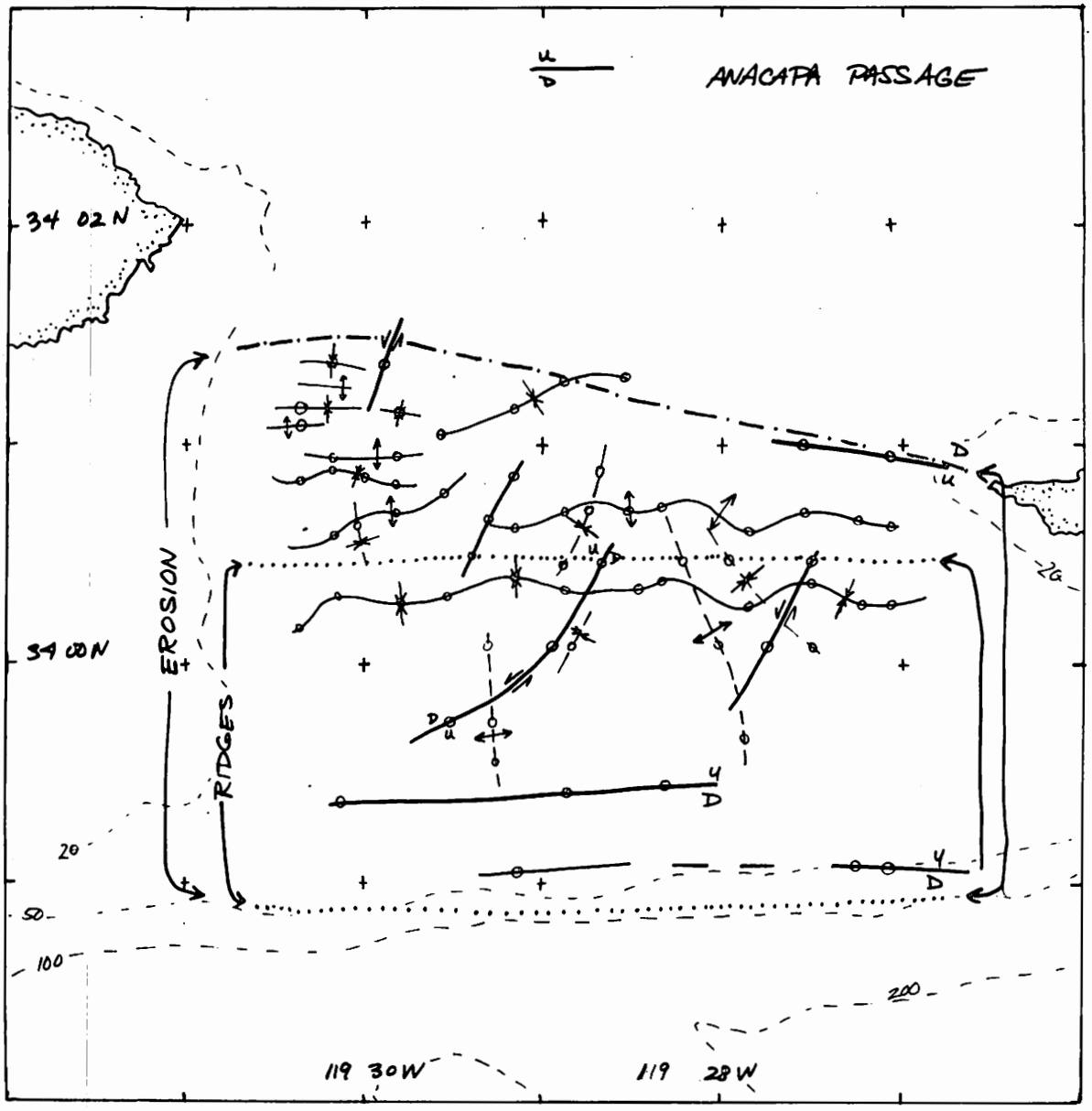


Figure 4. Structure interpretation of side-scan and reflection data taken on the tracks shown in Figure 3.

became 0 and the previous 0 and 255 values became 255. Thus background noise becomes 0 (black in a sonar *negative* image) but the previous crossover region (through DN = 127) now produces a thin black band along the high reflection features.

Geometric rectification. Slant range to plan range correction (cross track) and variable ship speed and course (along track) were corrected via a 30 control-point grid (Fig. 12) encompassing each 3½ minutes ship time image. The slant range correction assumed relatively flat terrain and minimal fish roll, and was parametric in fish depth. The nearest slant range return was assumed to come from features about 60° below the fish horizon. Control point columns were most closely spaced in the near range. Variable ship speed was corrected via non-uniform expansion-compression of the grid in the along-track direction. Multiple common control points produce triangular rectification regions for improved mapping. The geometric rectification additionally "pre-distorted" the image element spacing to give an output scale of 1:1000 (before photo reduction) using a 3 x 5 dot matrix in 10 gray scale densities. Figure 13 is the rectified image of Figures 10 and 11, all of which are a sub-image of Figure 7 - port side. The printer output trade-offs are the limited gray scale range of a 2 x 3 matrix and a photo reduction requirement of the larger printouts for larger matrices with greater gray scale range. Within several months an alternate output format will use an Optronics film writer.

Test output imagery. A relatively severe test of geometric correction and mosaicing fidelity was provided by determining the registration error of two overlapping starboard channel images from parallel, opposite ship courses (Band D, Fig. 3). The separate data sets (Figs. 14-18) were mosaiced into the west track (images numbered 2, 3, 4) and the east track (5, 6). Cursory examination showed relatively small registration errors for rather extensively separated control features. Ship speed was relatively constant on the west course at 5 kt and increased from about 5.1 to 5.8 kt on the east course and was incrementally corrected via 5 compensating grid spacings. Notice that in this region the starboard channel has generally poorer signal levels than the port channel (Fig. 7).

Feature enhancement. Initial tests of alternate methods of feature enhancement included high pass and Weiner-inverse filtering. Improvement in feature signal/noise ratio was sought. High pass filtering, high pass boost, or Laplacian processes will enhance edges and generally improve subjective interpretation. Current tests (in the image space domain) are parametric in window size and weighting. In contrast, Weiner-filter image restoration (in the image frequency domain) is based on some *a priori* knowledge of image blurring caused by the sonar system image transfer characteristics, the turbulent media and fish motion. Only preliminary estimates with variable rectangular and Gaussian point spread functions (the *a priori* blur information) have been tried. Figure 19 is an "enhanced" sub-image of Figure 11 using a stepped spread function. Figure 20 is an "enhanced" sub-image of Figure 15 using the Gaussian point spread function. This VICAR program (OFT2) additionally estimates image noise and compensation. Both of these (256 line by 256 column) sub-images appear blurred due to non-optimum spread functions and over-compensation for noise. (Note: dot-matrix printer problems on both figures produced the interfering light and dark lines).

Determination of the spread function is by analytical estimates and/or image data. In the latter case, a sharp step or edge-like feature is examined. One such test used the leading edge of the synch pulse (in the image data) as this edge. The spread and related transfer functions for both the original and averaged images (3346 and 478 range elements - pixels per line) were determined (Fig. 21). That determined from system noise is compared in the figure.

Software implementation. Software tasks have included the implementation and checkout of the extensive set of VICAR programs - a very time-consuming project. Two synch pulse recognition methods were programmed. the preferred one cross-correlates the synch pulse in the image data with a template. This method doubles our data handling rate. Driver software for the Printronix printer was written to permit gray scale combinations and dot matrix sizes.

Image histogram and density slicing programs as well as improved tape I/O routines and data set labelling were rewritten in the C language for significant reductions in raw image handling time.

Cooperating Organizations

University of California, Santa Barbara, Department of Geological Sciences

Scripps Institution of Oceanography, University of California, San Diego

University of Caifornia, Santa Barbara, Computer Systems Laboratory

University of California, Santa Barbara, Department of Geography

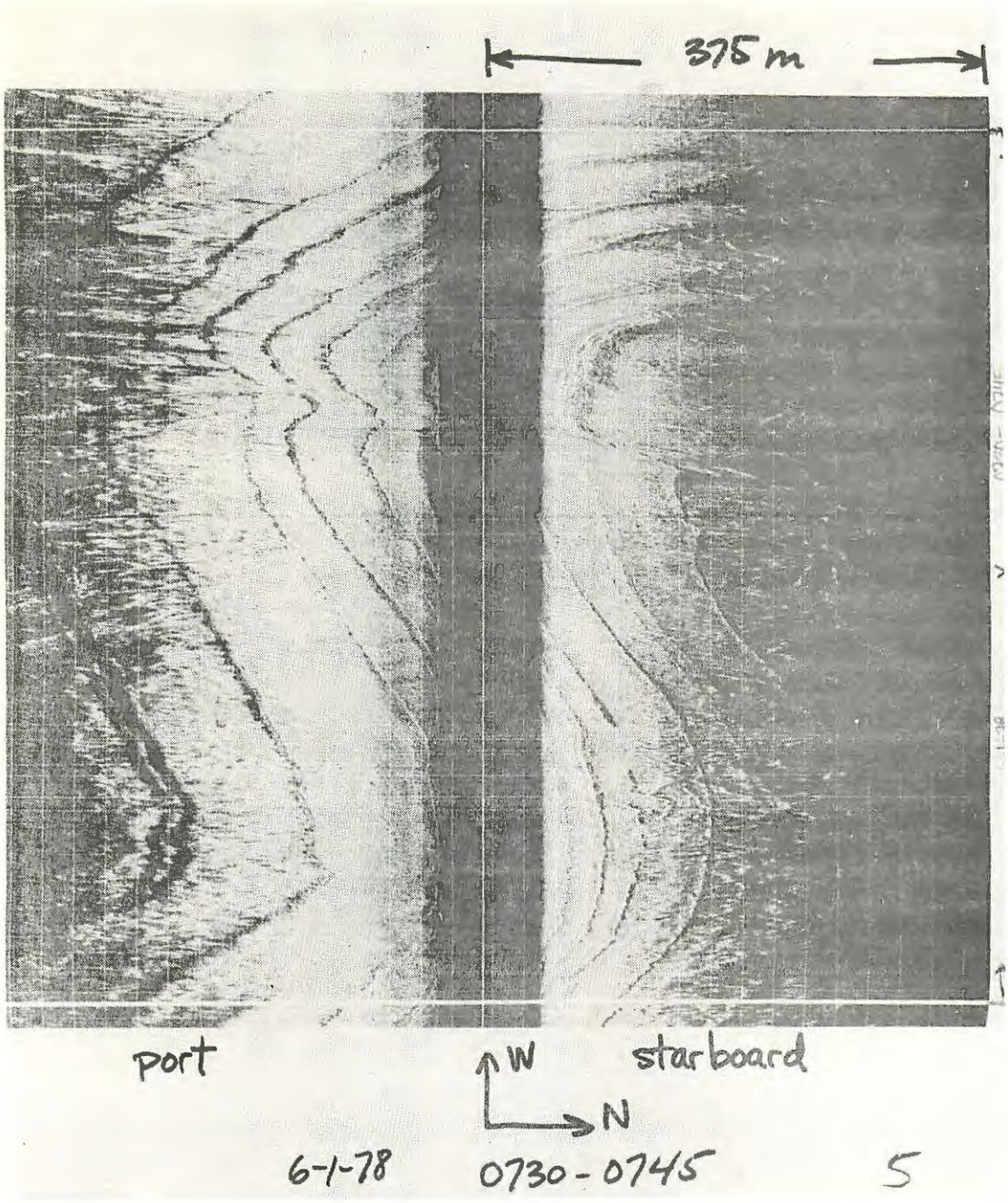


Figure 5. Side-scan sonar record from Track A in Figure 3. Sonar reflections are white and shadows are black.

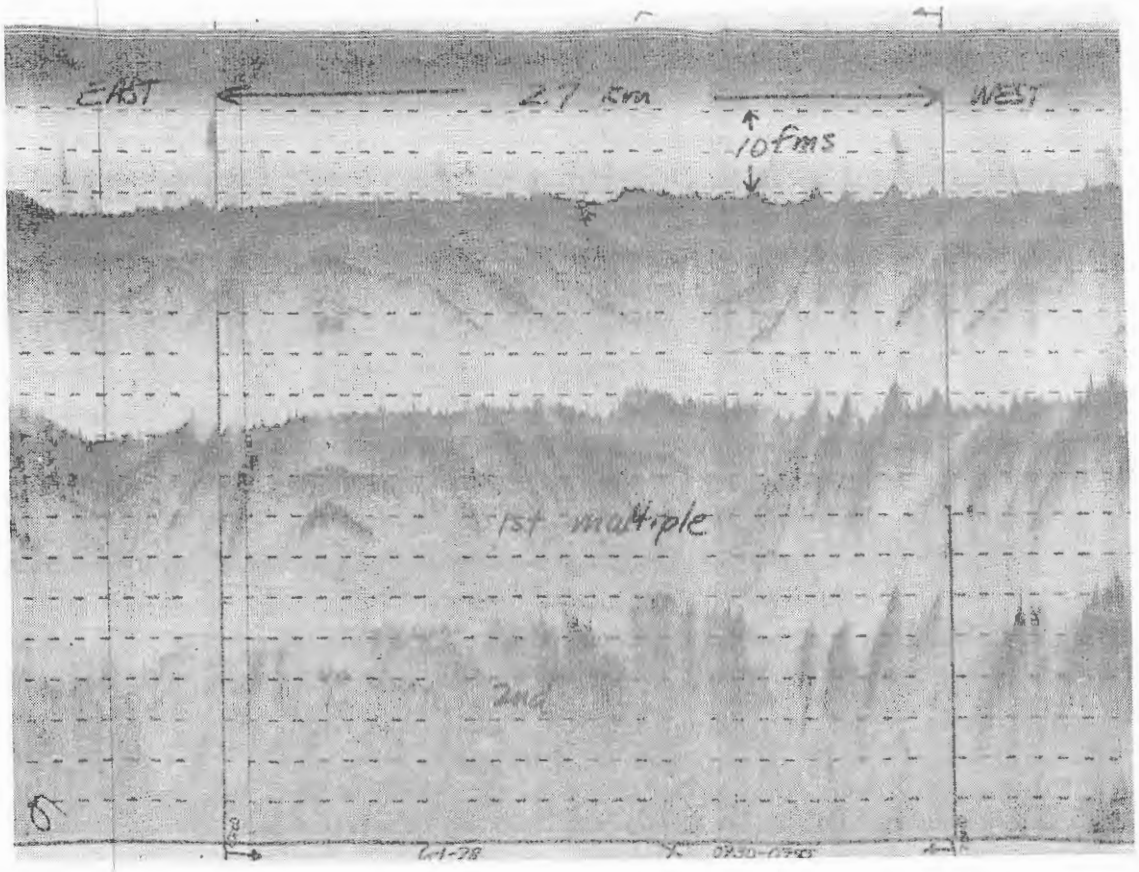


Figure 6. Reflection profile (3.5 kHz) taken on track A in Figure 3. Both Figures 5 and 6 are at the same along-track scale. Fifteen minutes between vertical lines.

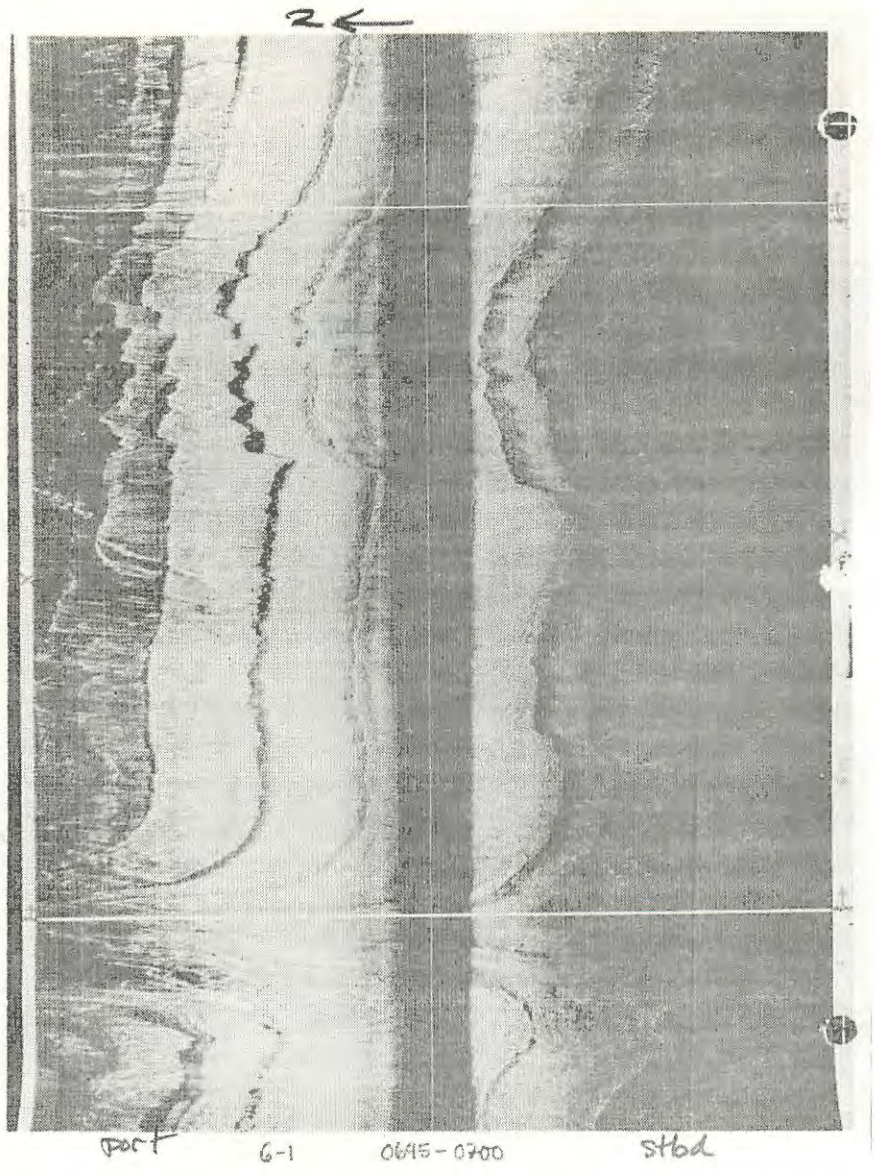


Figure 7. Side-scan sonar record taken from track C in Figure 3. Sonar reflections are white. A left offset fault cuts the sea-floor in the center of the photo. Test data for Figures 10, 11, 13 and 19 are from the port channel for the time frame 0645:00 to 0648:20 (approximately). Time 0645 is the western white line mark and 0700 is the eastern.

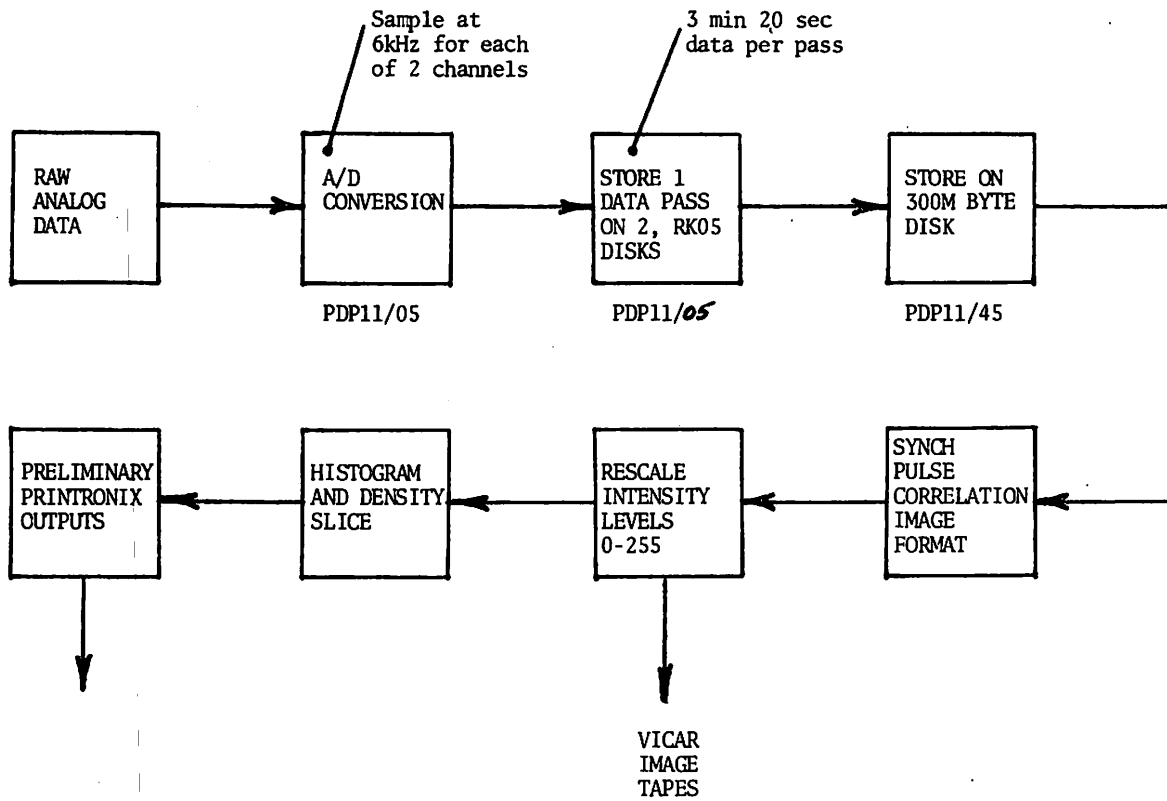


Figure 8. Sonar data conversion and image formating flow chart.

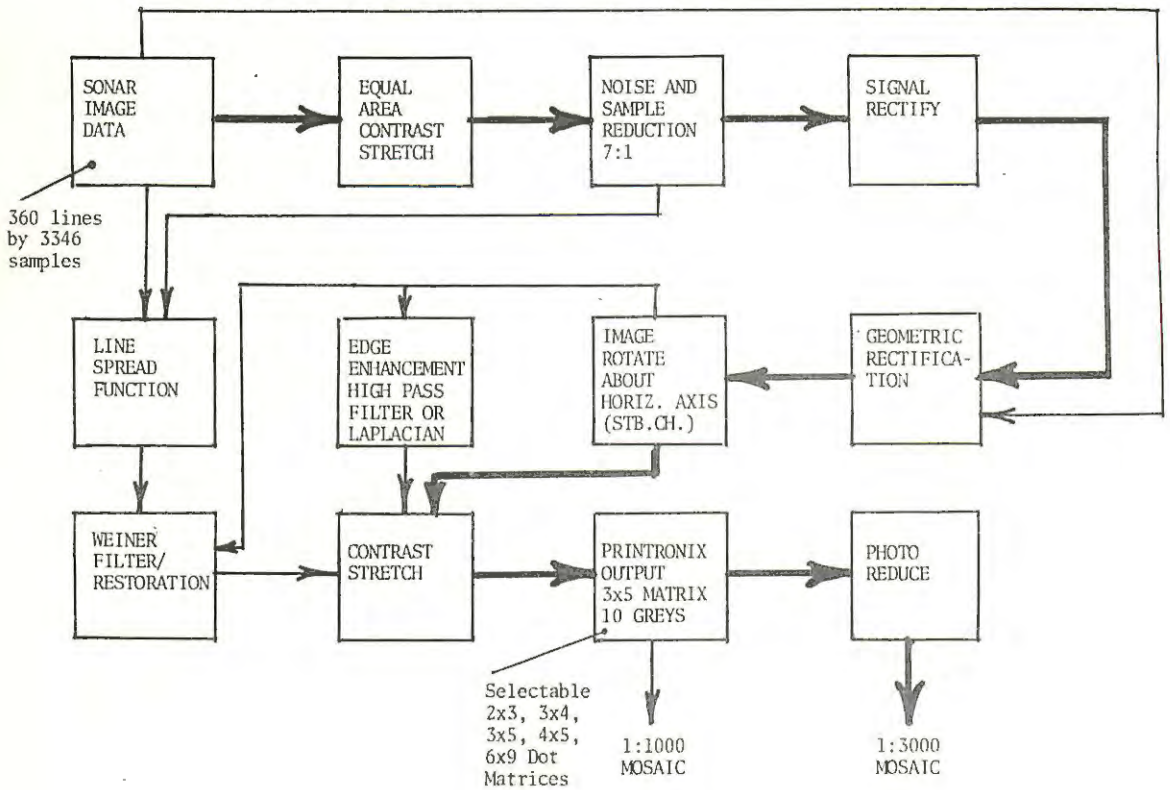


Figure 9. Sonar data digital image processing flow chart.

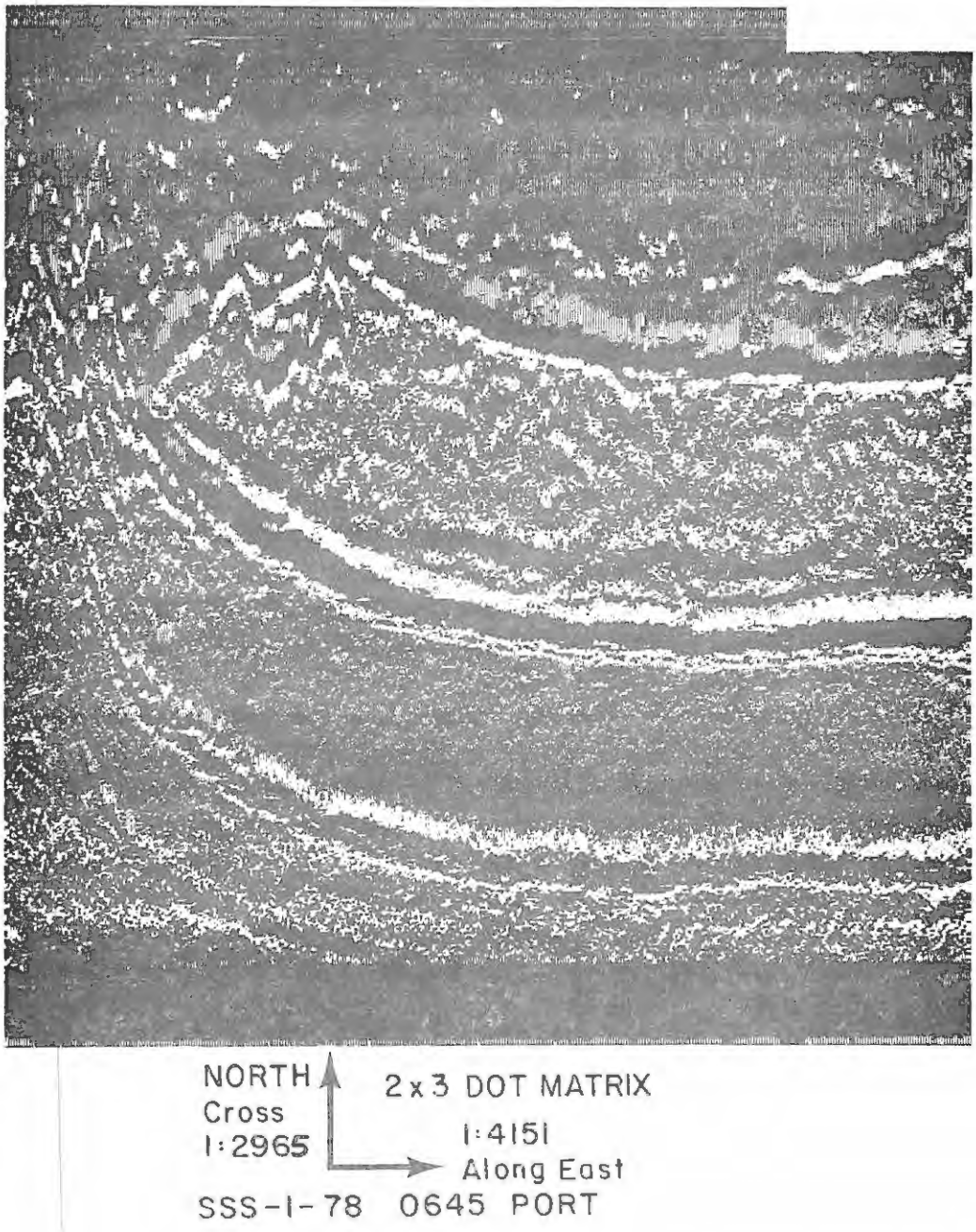


Figure 10. Test data subimage of Figure 7 (0645-0645:20, port) after contrast stretch showing light-dark bands or Lloyd's Mirror effect.

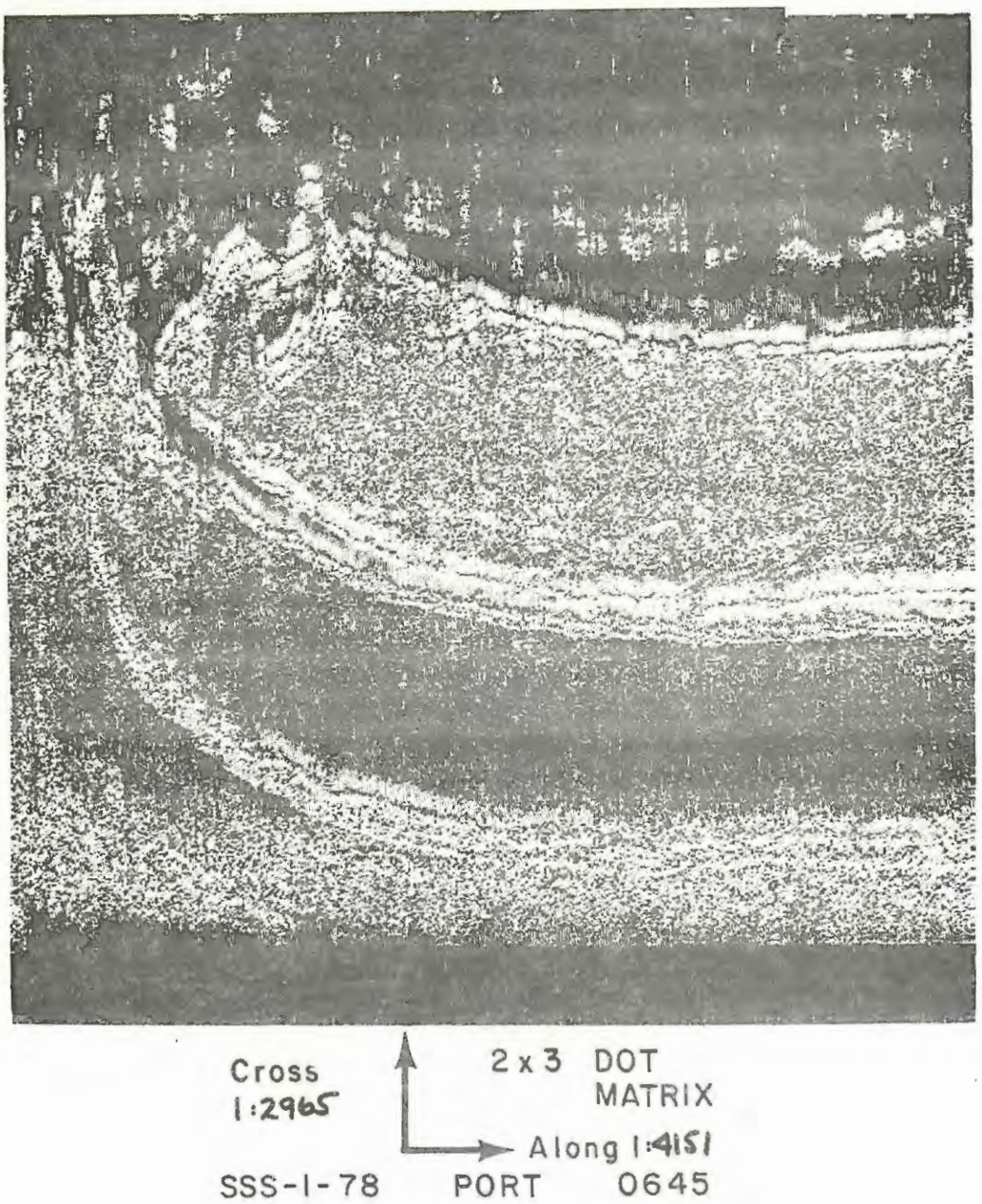


Figure 11. Signal rectified image of data set from Figure 7.

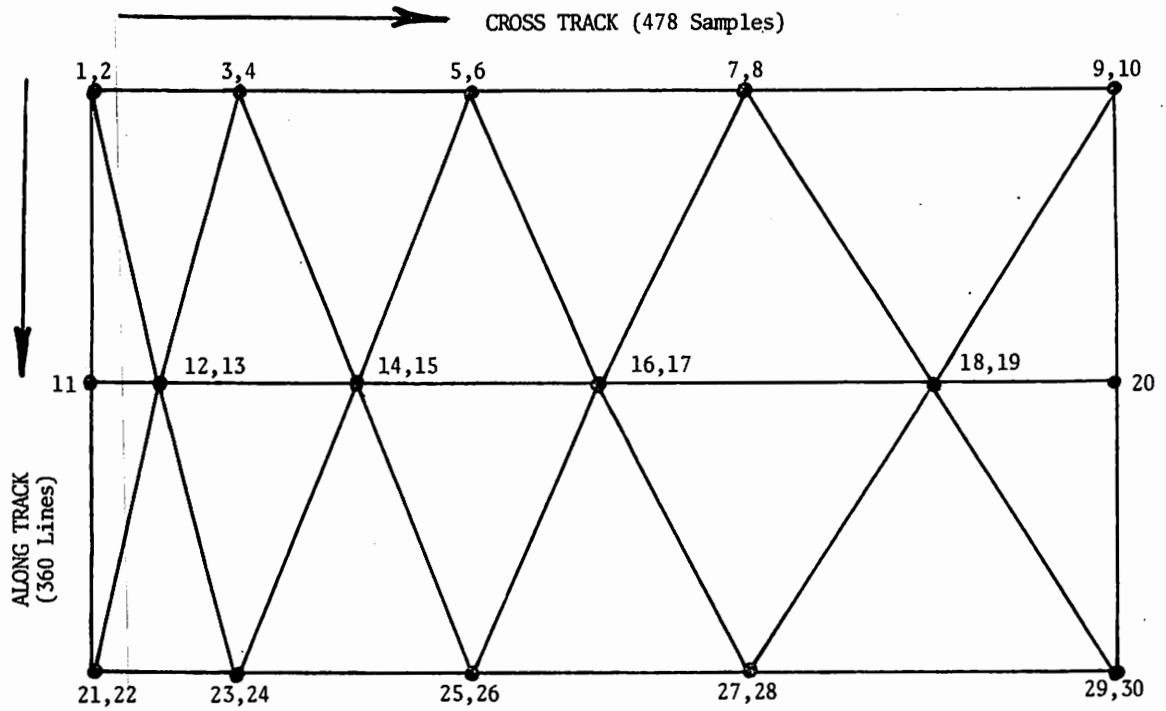


Figure 12. Geometric rectification grid used to produce image in Figure 13.

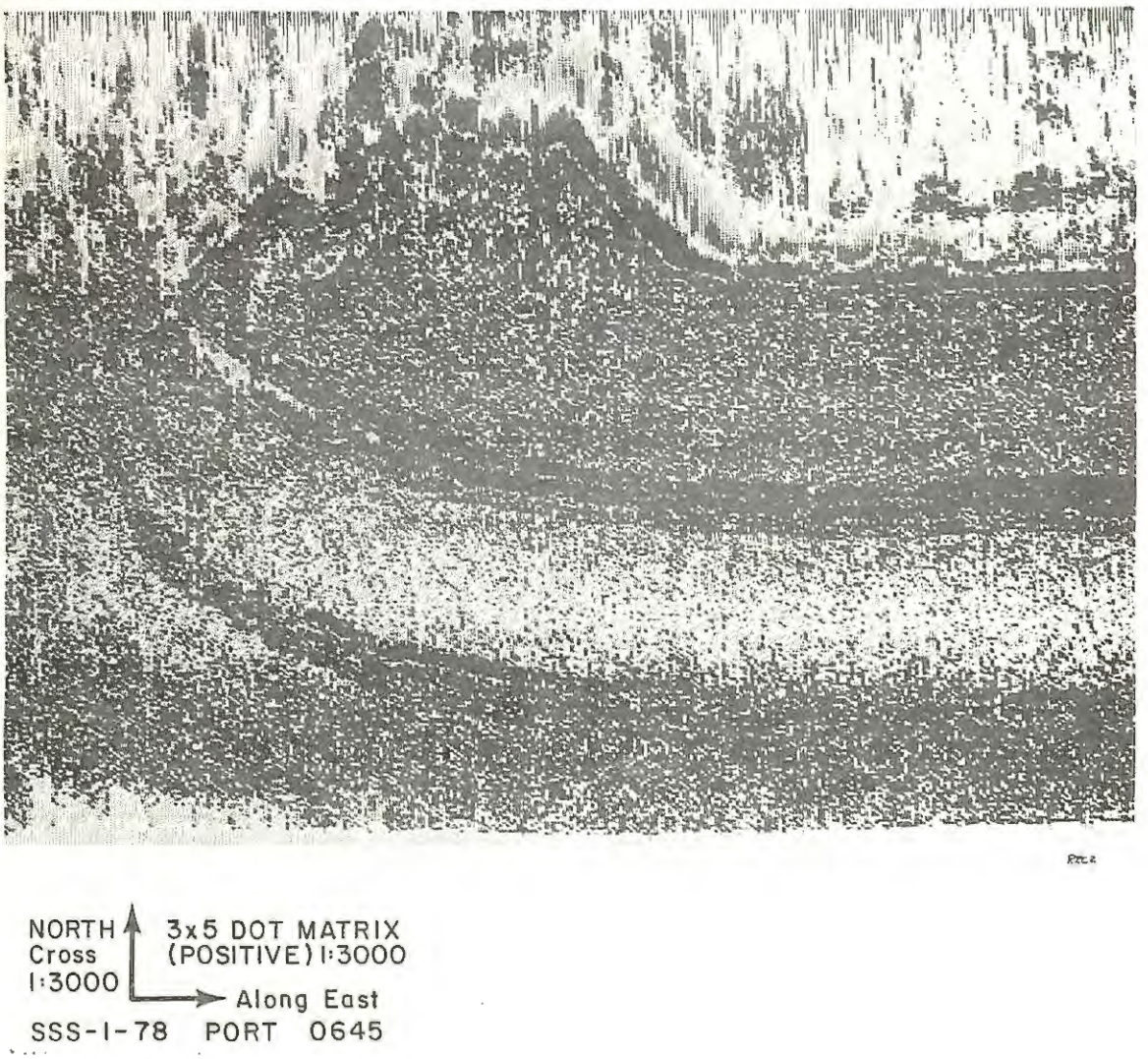


Figure 13. Geometrically rectified image. The polarity of this image is reversed relative to Figures 7, 10 and 11 in that sonar reflections appear black instead of white.

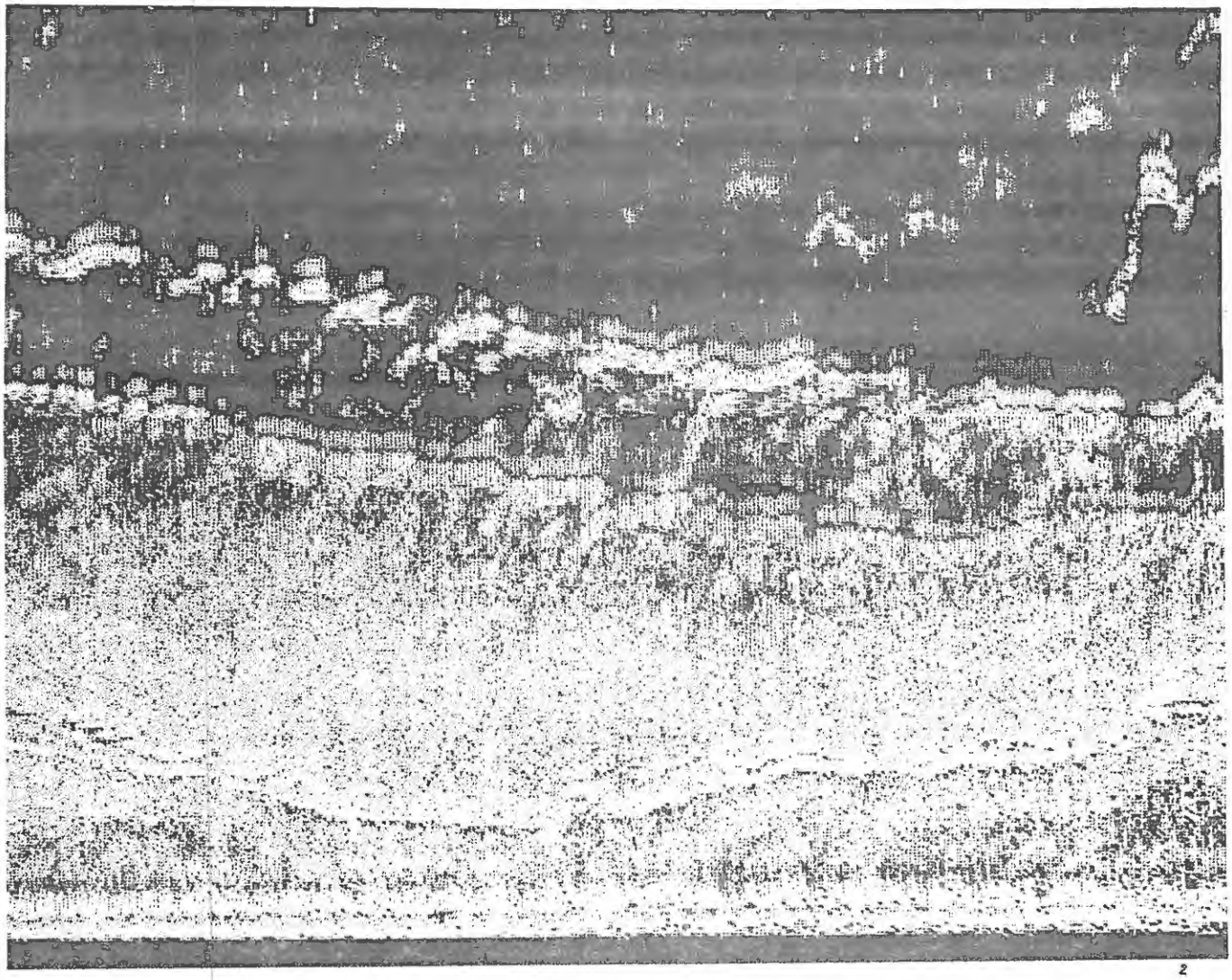


Figure 14. Rectified image from the east end of D in Figure 3.

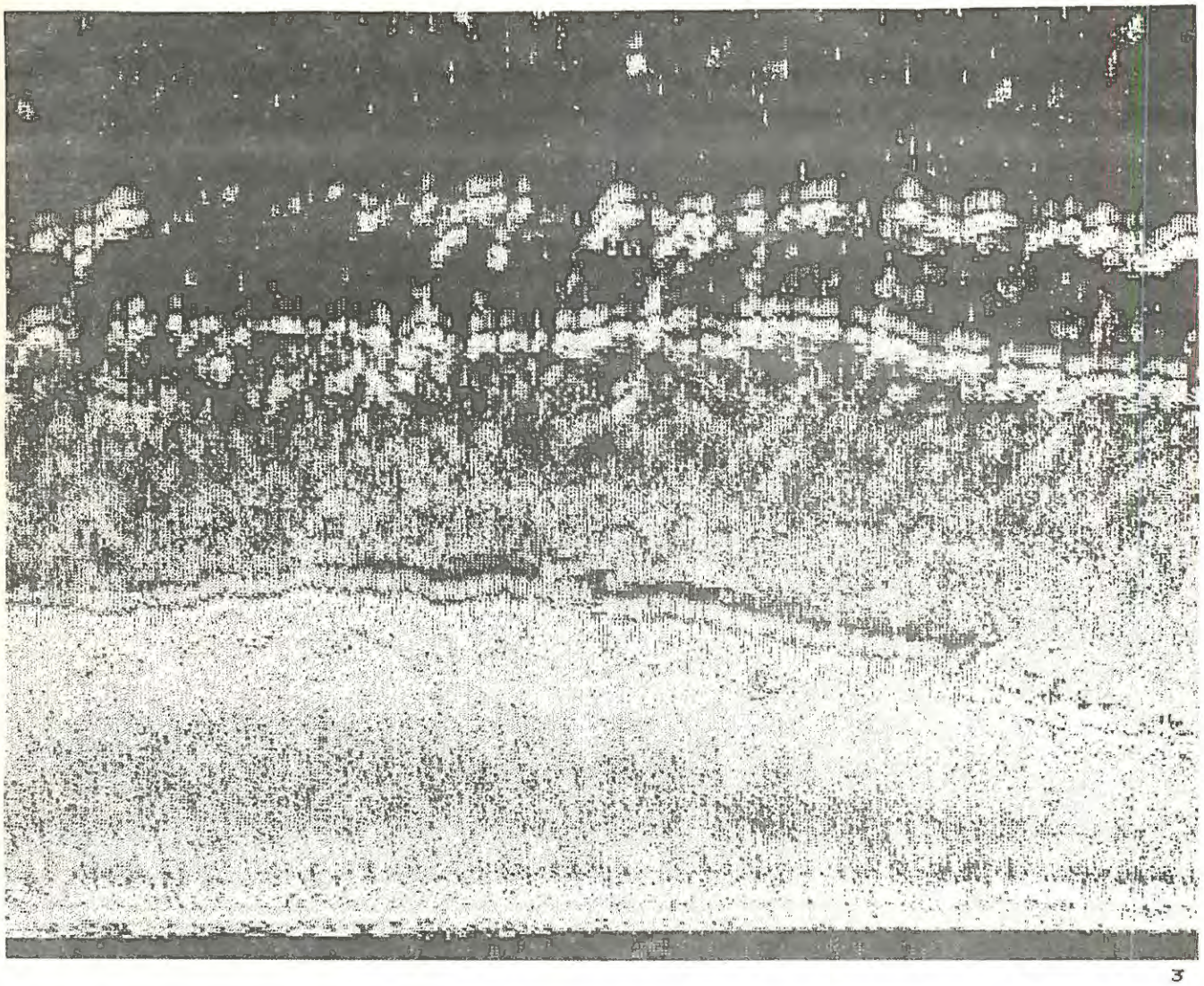


Figure 15. Rectified image from the center of D in Figure 3.

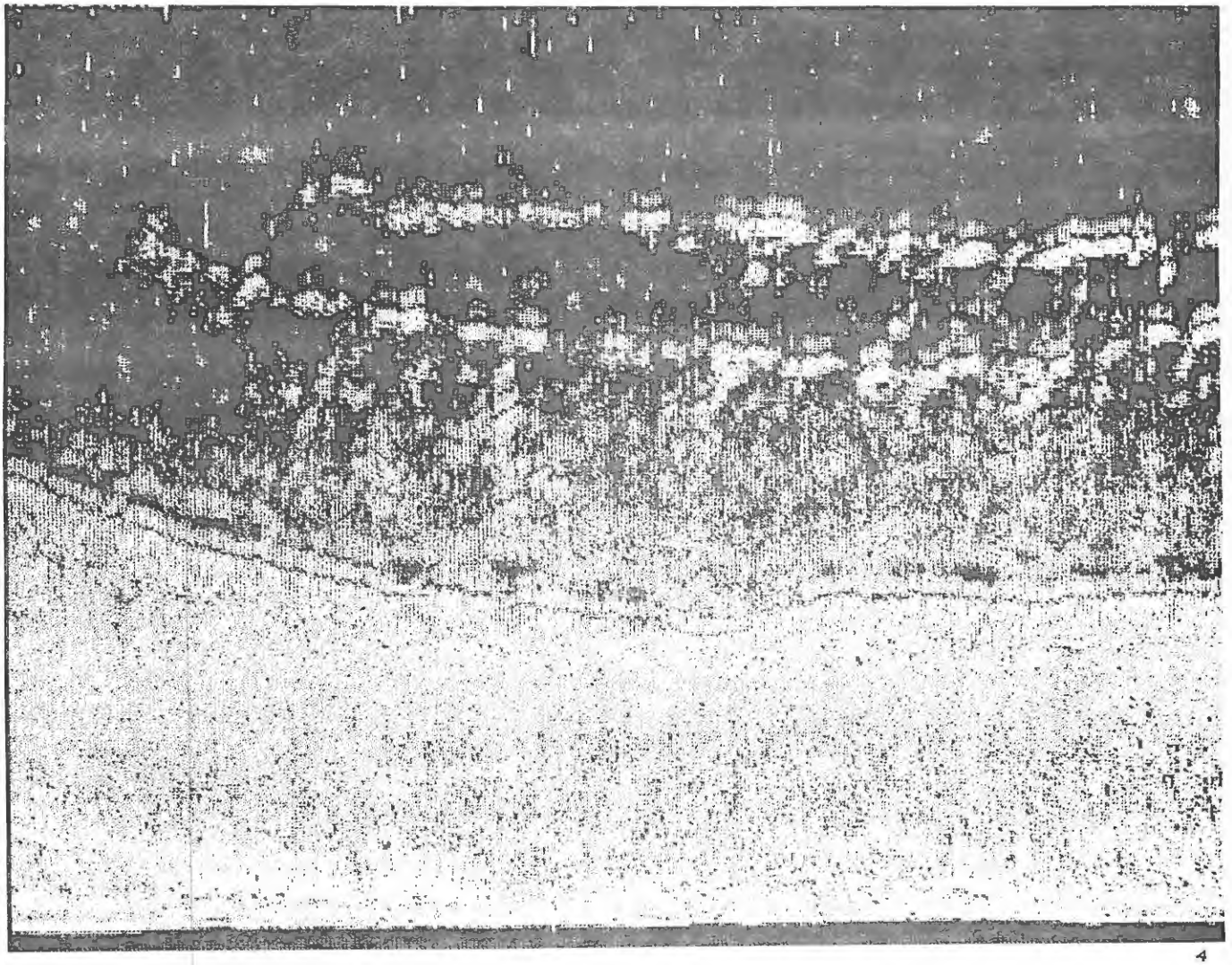


Figure 16. Rectified image from the west end of D in Figure 3.

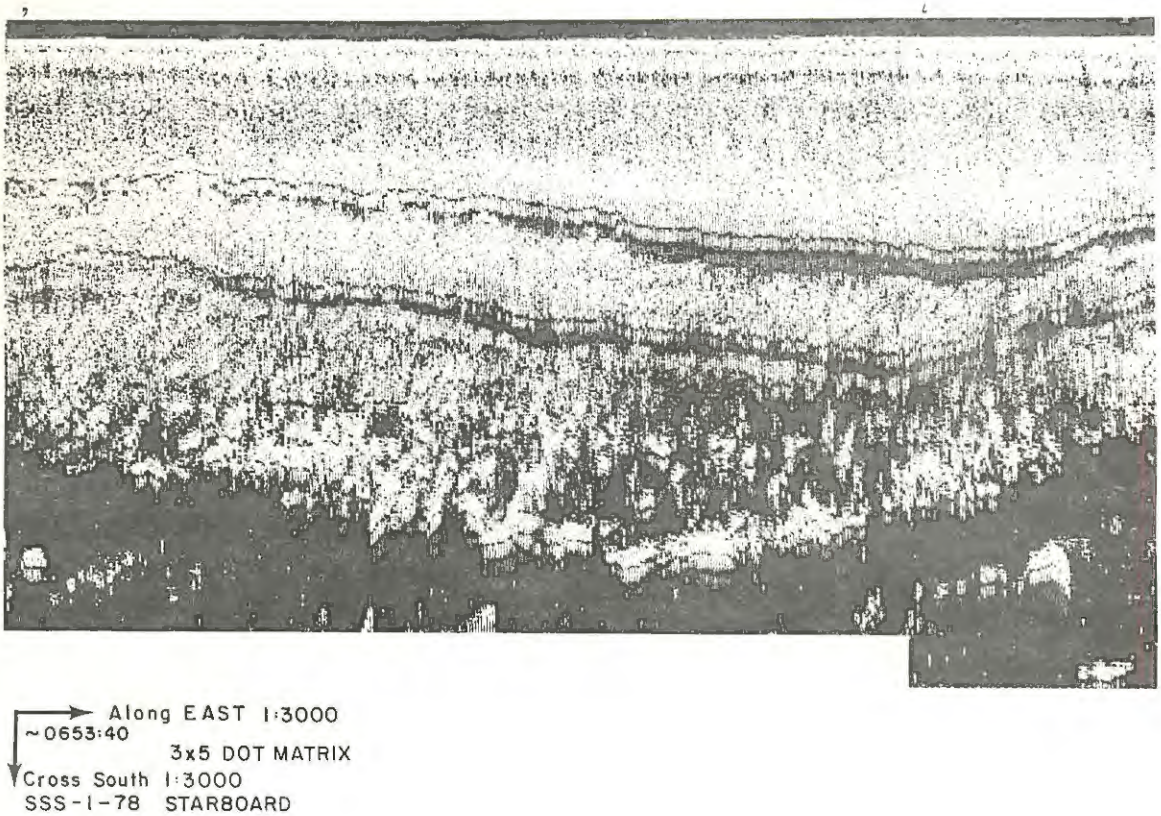


Figure 17. Rectified image from the west end of B in Figure 3. Compare with starboard channel of Figure 7 near 0647.

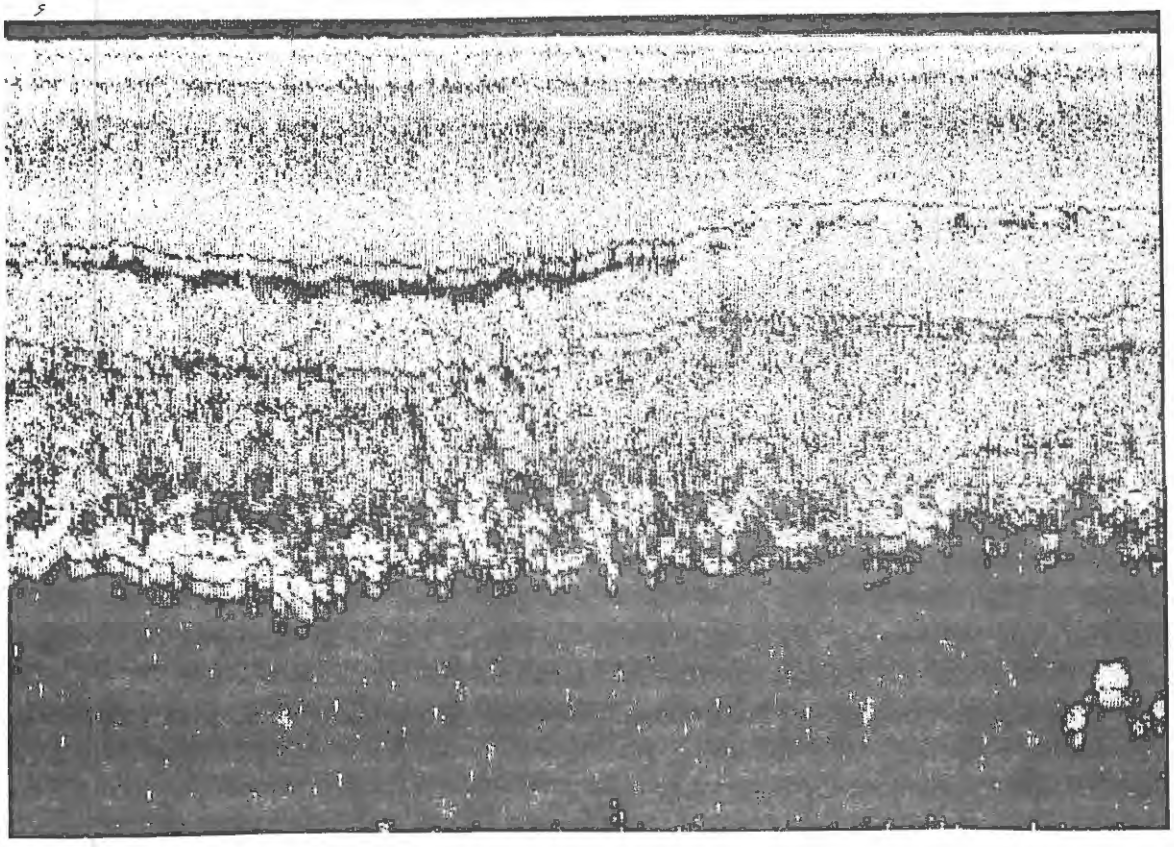


Figure 18. Rectified image from the east end of B in Figure 3. Compare with starboard channel of Figure 7 near 0654.

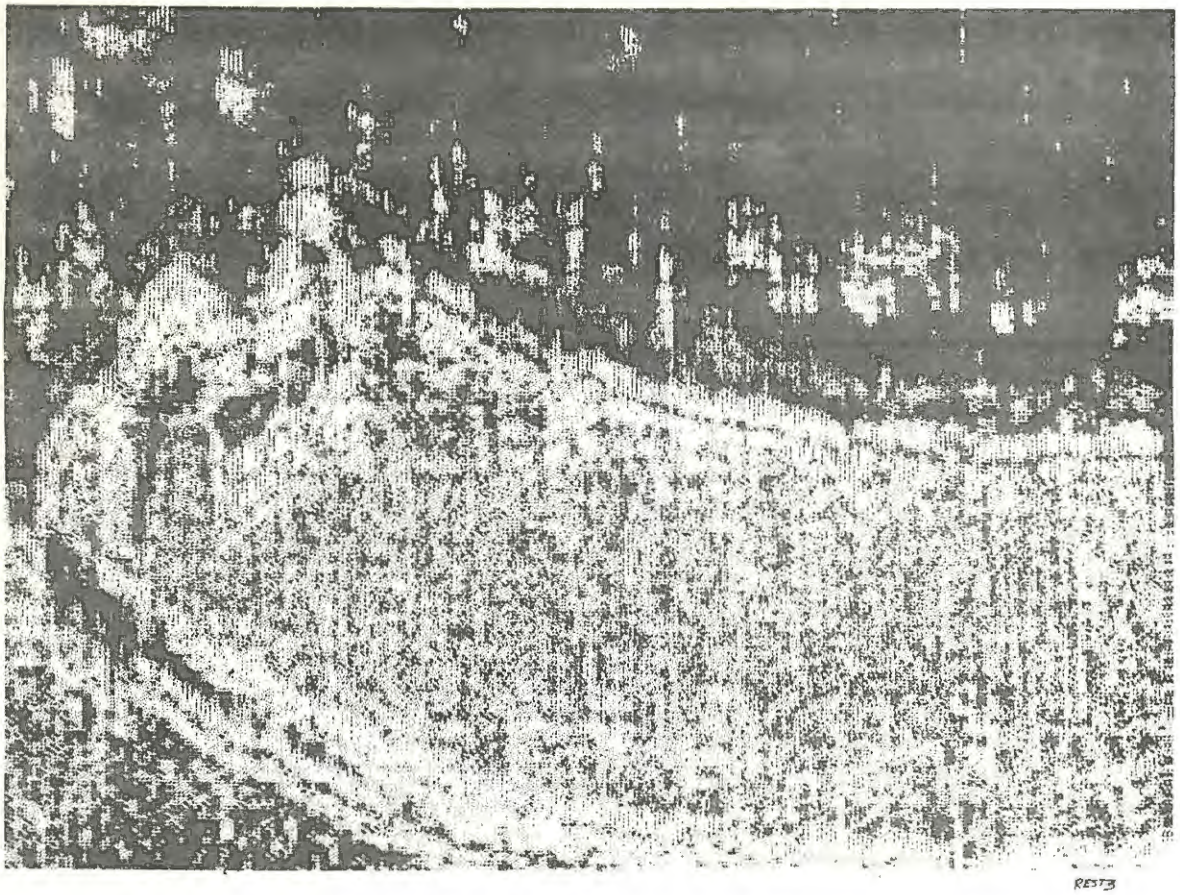


Figure 19. Test of Weiner - inverse filter to subimage of Figure 11 using a stepped point-spread function.

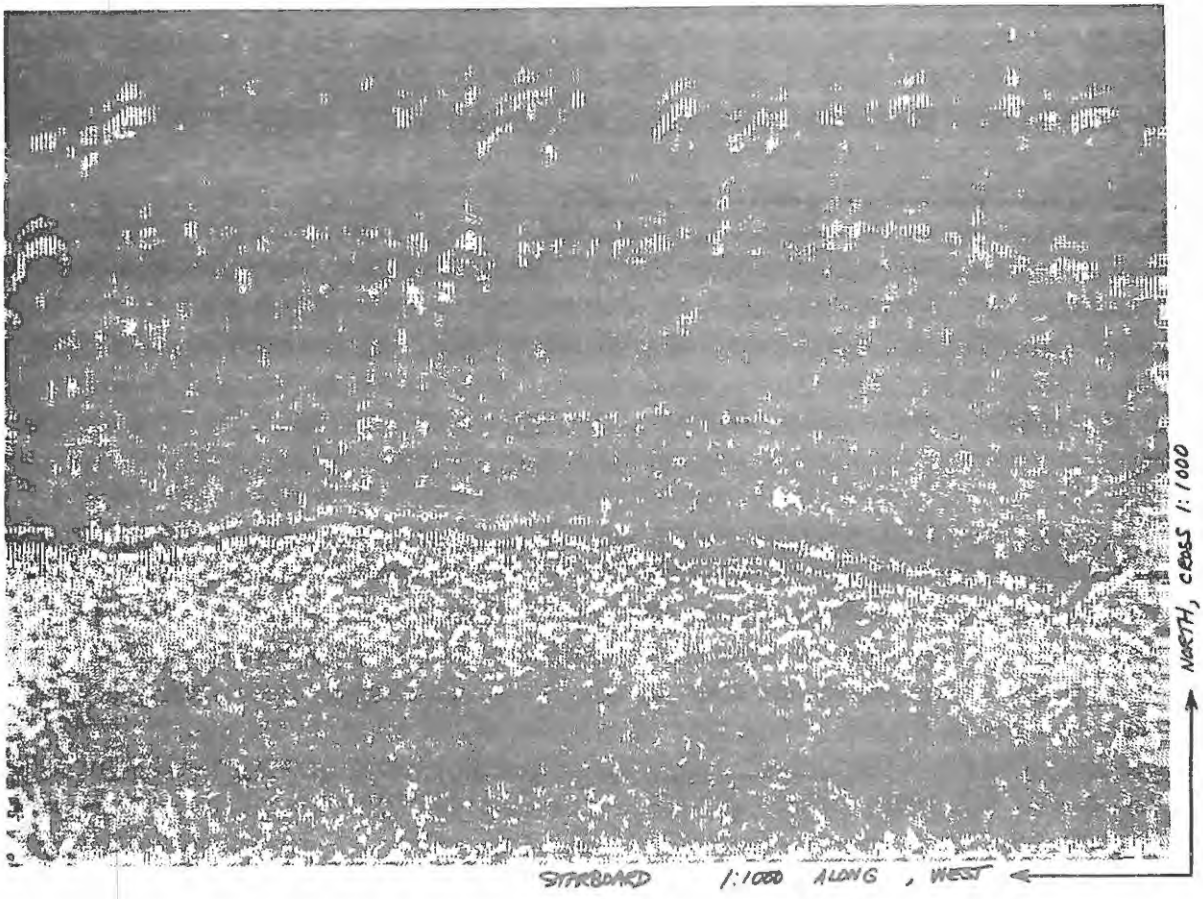


Figure 20. Test of Weiner - inverse filter to subimage of Figure 15 using a Gaussian point-spread function.*

*Note: 1:1000 is the hard copy scale. Cross track width is 13 inches.

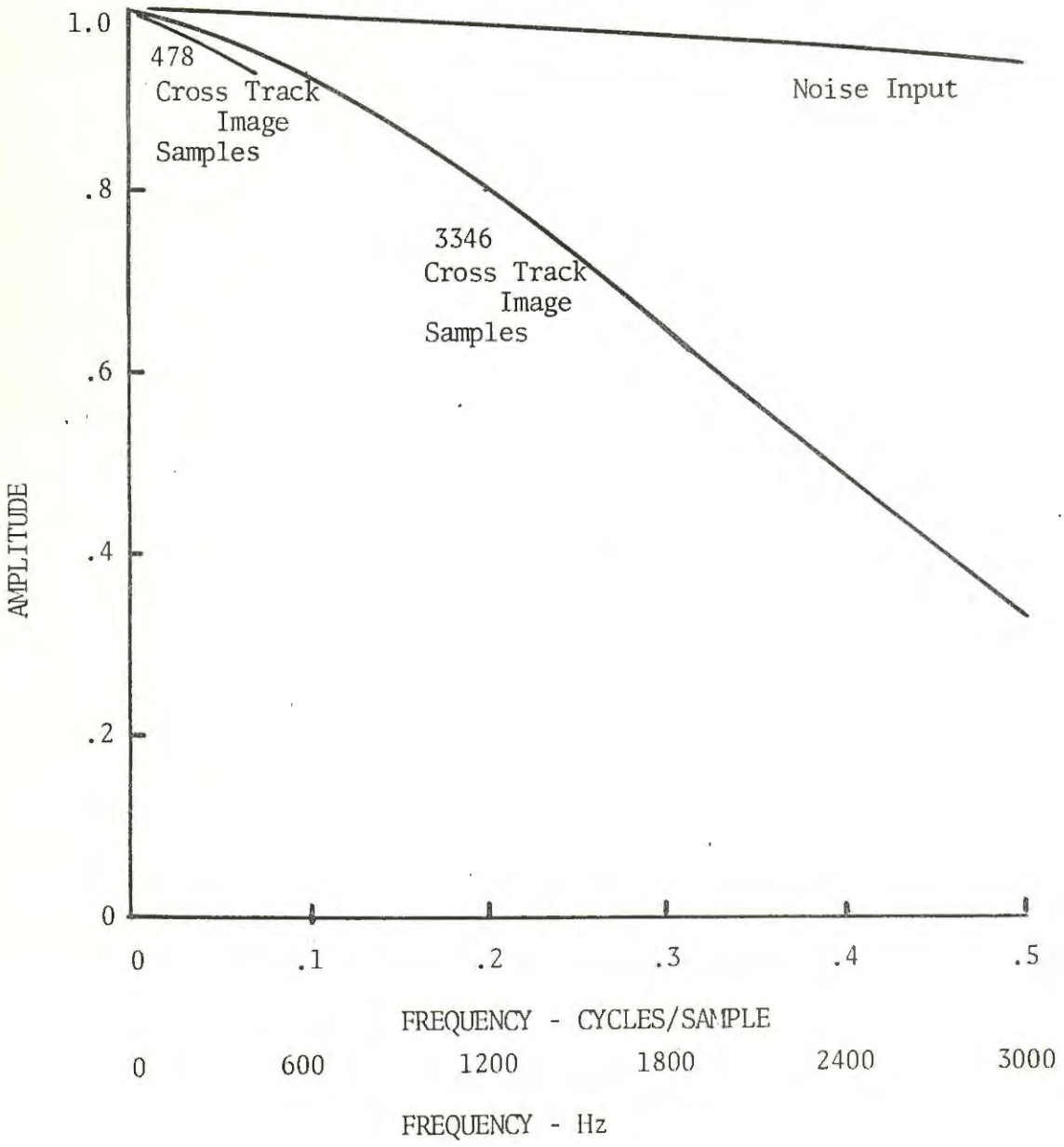


Figure 21. System modulation transfer function determined from the leading edge of the sonar synch pulse.

Nearshore Wave Power Generator

R. Seymour, *Scripps Institution of Oceanography, University of California, San Diego*

The project was undertaken to make available a wave power generator that could be used just outside the surf zone and which could be cheaply and easily installed by oceanographers to keep the batteries charged in their instruments. This would eliminate the need for battery changes or maintaining power cables through the surf zone and would improve data reliability. As proposed, this wave power generator would consist of a Savonius turbine mounted external to a submerged buoyant sphere which would be taut-moored to an anchor or the bottom. Seymour (1974) showed that such an arrangement of a float and tether would result in rapid and energetic oscillation of the float when excited by waves and that the average relative velocity between the float and the water would be high enough to allow useful work to be done by the system.

Reviewers of the proposal were unanimous in their concern for the effects of marine fouling on the efficiency of the turbine. In addition , just prior to the initiation of the project, experience by the Shore Processes Laboratory with propellor type current meters in a similar nearshore environment suggested that the turbine might require maintenance on nearly the same schedule as the unrecharged batteries they were to replace.

Therefore, the design approach was modified to eliminate the fouling problems. In effect, a second sphere was placed outside of the float and turbine and the annular space created was partially filled with an abiotic working fluid. The turbine, rather than being directly driven by sea water, is driven by the slosh of the working fluid in the annulus as the float system oscillates in response to the waves. It was clearly understood that the characteristic fluid velocities through the turbine would be substantially reduced, and the power output decreased, but this method was nonetheless selected to eliminate maintenance problems from fouling and corrosion.

Experimental program

The response of the fluid in the annulus (slosh) to a broadband motion of the float (oscillation) is highly nonlinear, but it was necessary to determine its approximate characteristics to allow the design of the hardware.

One important parameter is the undamped natural frequency of the slosh which provides a measure of that oscillation component which will be preferentially amplified. By suitable linearization an approximate expression was derived.

$$f_n=\frac{1}{2\pi}\left(\frac{g}{R}\frac{\sin A}{A}\frac{2R}{2R-H}\right)^{\frac{1}{2}}\ hz \qquad (1)$$

where

g= gravitational constant

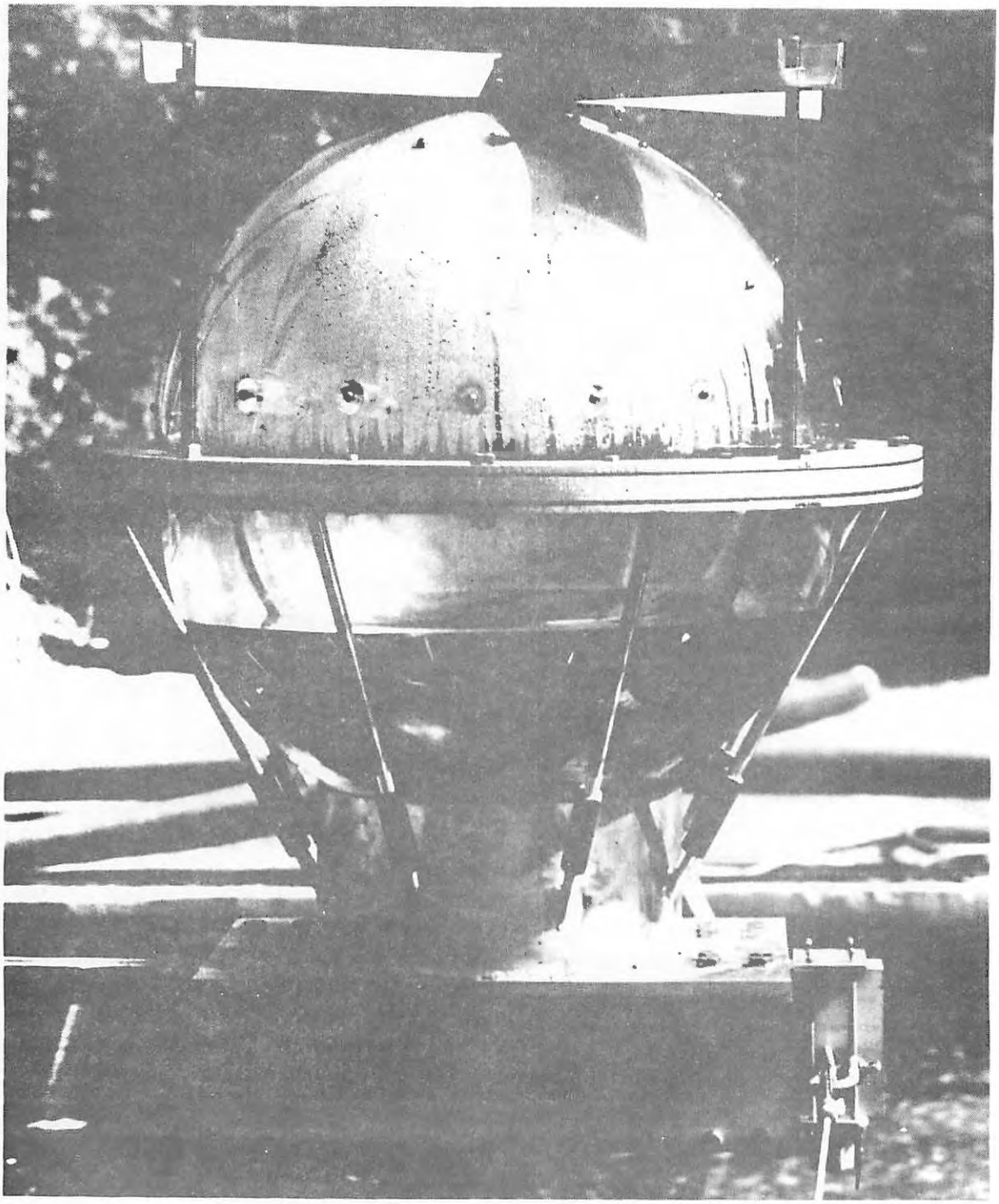
R= outer radius of the annulus

A= is the angle in radians measured between a downward pointing radius and a line connecting the sphere center to the working fluid surface

H= radial thickness of the annular space

Attempts were made to determine response functions analytically but the problem proved intractable and it became necessary to determine these empirically.

A large subscale model of the two sphere system was constructed from plexiglass hemipheres so that the fluid motion could be observed. The spheres were then oscillated by a hydraulically powered boom which was capable of broadband motions in response to the signal from a tape recorder. The general arrangement is shown in Figure 1. The oscillatory boom was equipped to produce a voltage proportional to its position. The position of the fluid interface in the annulus was measured by means of 96 digital contacts evenly spaced around a 180° vertical segment of the annulus wall. The number of wetted contacts was sampled at high speed and converted to a digital output.



SPHERE MOUNTED ON TOP
OF OSCILLATORY BOOM

Figure 1.

Both the boom position and the angular position of the fluid surface was sampled at 4 hz and stored on magnetic tape by a digital computer. From these records, spectra of both signals could be calculated and compared. Typical spectra are shown in Figure 2.

The same oscillating boom system was also used to measure the performance of the turbine. The boom was mounted above a water tank so that the turbine could be immersed. In the previous work, the spheres were oscillated with a motion characteristic of their response to waves. In the case of the turbine tests, the motion was characteristic of the observed annular fluid response. The turbine could be run under no load conditions or with a generator and gear train engaged. Turbine speed was measured by counting revolutions. Stall torques were measured by means of a spring scale.

Available power estimates

The power available from a Savonius in a unidirectional stream has been determined empirically to be

$$P = C_s \rho A V^3 \qquad (2)$$

where

ρ = fluid density

A = cross-sectional area

V = fluid speed

C_s = empirical efficiency factor = .0002

For broadband oscillatory flows, assuming the velocity is gaussian, it can be shown that the average power is given by

$$<P> = .0003\, \rho A\, (\sigma_\theta\, \omega R)^3 \qquad (3)$$

where

σ_θ = standard deviation of surface elevation angular displacement

ω = radian frequency of slosh

Using Eq. (3) it is possible to estimate the power available from a particular turbine if the slosh spectrum is known.

It can be seen from Figure 2 that the slosh spectrum is sharply peaked at the natural frequency. It is also obvious that σ_θ is physically limited by the size of R-- that is, the amplitude cannot exceed that which allows the fluid to cross over the top of the annulus. Further, the maximum cross-sectional area of the turbine, A, is a function of R and H. Assuming the maximum area turbine is used, that the slosh energy is concentrated at the natural frequency given by Eq. (1), that the standard deviation of slosh angle is approximately $\frac{\pi}{4}$ radians, it is possible to express a rough estimate of the maximum available power in terms of the dimensions of the annulus, R and H.

Figure 3 shows a plot of maximum turbine output as a function of various values of R and the ratio, $\frac{H}{R}$. For the design selected for evaluation in this project, H= 53 cm and $\frac{H}{R}$ = 0.32, the average output power is 2.5 watts, which is sufficient to meet many instrumentation needs.

Useful power estimates

The available power of Figure 3 is degraded by losses in the bearings and gearing and in the efficiency of the generator. These losses can be minimized by careful design, but within the capabilities of this project, the selection of generators was limited to commercially available models of the approximate size. A number of bicycle generators were evaluated for no load torque and output power/speed characteristics and the best was selected for test with the turbine.

The results of these evaluations are summarized in Table I which shows the speed of the turbine under two load conditions with simulated design slosh conditions.

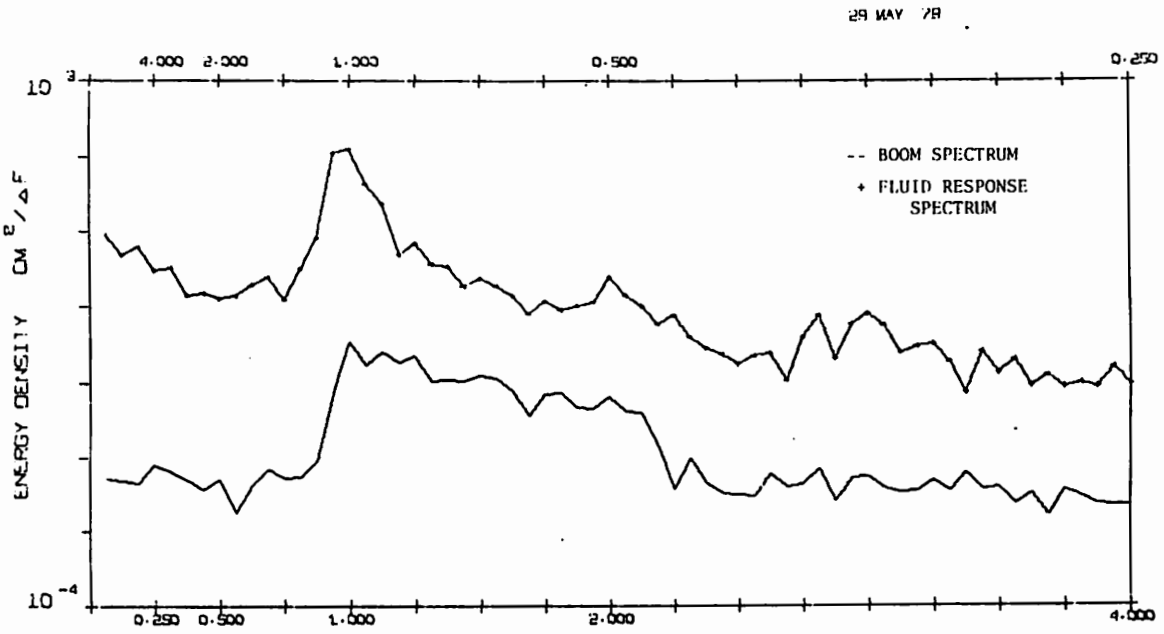


Figure 2.

Frequency (Hz)
Fluid slosh response to broadband driving force

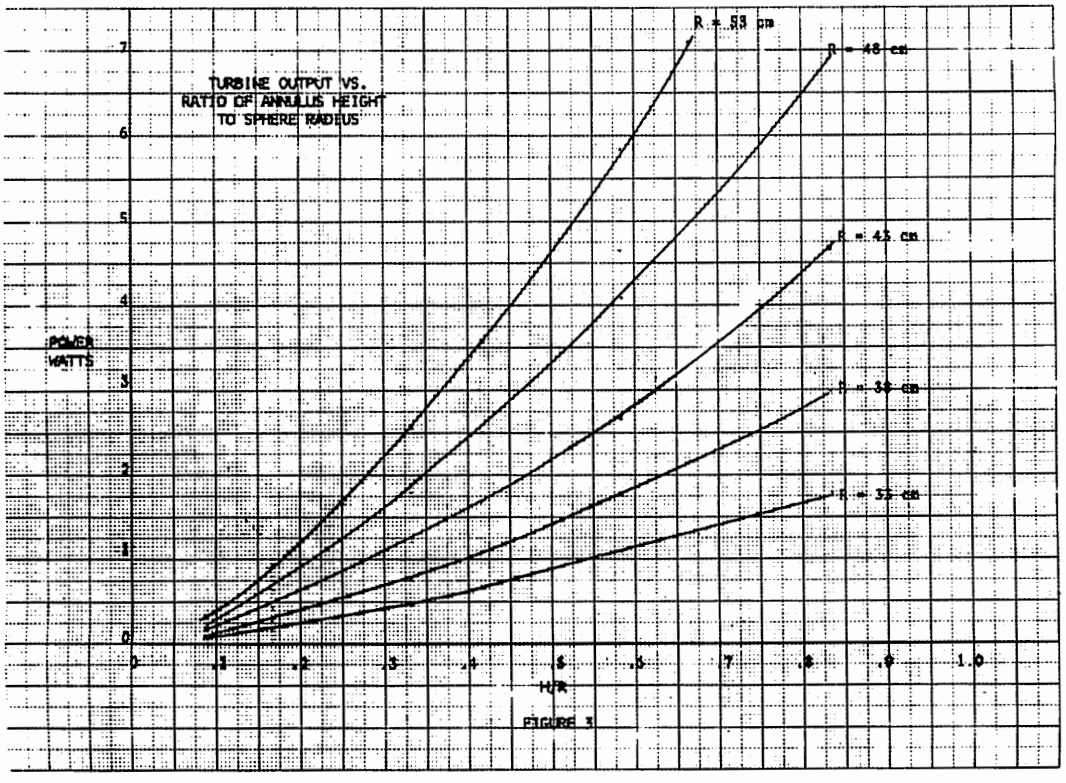


Figure 3

Turbine output vs. ratio of annulus height to sphere radius

Table I	
Turbine speed, RPM design conditions	
Generator Disengaged	Generator Engaged, No Electrical Load
46	13.5

The theoretical no slip average speed of the turbine under these conditions is 46 rpm so that it is clear that the turbine is performing properly under no load. The generator drag alone, without any useful work being performed, is seen to reduce this speed by 70%. Assuming the torque remains constant, this also means that the available power is reduced to 30% of the Figure 2 values. The actual efficiency of the generator will further degrade this, and the final electrical output is estimated to be only 10% of the Figure 2 value, or 0.45 watts for this design. This is an uneconomical result.

Observations and Conclusions

1. For the float size chosen, which represents a reasonable limit for simple installation using a small boat and divers, the potential electrical power current is adequate for many instrumentation requirements.
2. The actual electrical power obtainable using readily available generators was unacceptably low.
3. This turbine appeared to stall under load at low velocities. This could probably be improved by the use of a flywheel, perhaps in conjunction with a "double decked" turbine with the two four-bladed rotors phased by 45°.
4. The potential power of the system increases roughly as the cube of the float diameter. If costs remain proportional to system weight, this could indicate a nearly constant cost per watt.

References

Savonius, J. 1931. The Savonius rotor and its applications. ASME, Vol. 53, No. 5

Seymour, R. J. 1974. Resistance of spheres in oscillatory flows. Ph.D. thesis, University of California, San Diego, Scripps Institution of Oceanography.

Cooperating Organizations

U.S. Navy, Navy Facilities Engineering Command

U.S. Army Corps of Engineers

California Department of Boating and Waterways

Power Generator Inertially Coupled to Seawaves

Paul H. Lee and M. S. Manalis
University of California, Santa Barbara

The proposed effort was to design and construct a prototype of an inertially coupled seawave generator which produces modest amounts of power conveniently and reliably for the purpose of recharging batteries carried by buoys. A working prototype of this generator has been designed, built and tested under laboratory conditions. In these tests, the prototype generated electricity and showed that the long-range objectives of the program could be realized in a practical inexpensive device.

The design concept originally proposed was changed considerably as the program progressed. The most important change was to make the inertial mass a column of liquid. That same liquid could then serve as a self-sealing piston to compress the same pneumatic springs that were originally designed. Power is then removed from the moving liquid by a single-state turbine. The turbine drives an electrical generator at an unusually low angular velocity. This generator was an adaptation of a commercially available permanent magnet direct current torque motor.*

Figure 1 is a diagram of the inertially coupled seawave type that was built to test this concept. The figure shows the essential features of our design which are important to the success of its operation. First, the liquid oscillating vertically in the central tube must change both speed and direction on entering and leaving both the top and the bottom of the tube. These velocity changes can cause important losses in efficiency unless the terminating tube and wall contours are carefully designed. In the final simpler design shown here these losses are negligible.

As a second contribution to efficiency, the turbine blades change angle of attack during the cycle to drive the shaft in one direction only, independent of the liquid flow direction. This mechanism is shown in Figure 2. The turbine system could probably be further improved in future designs: The rotational speed could be made constant as well as undirectional over the cycle. Fixed straightening fins should probably be added above and below the energy extraction region to remove spin from the liquid leaving the region. Future work on this design should also include efforts to efficiently match the turbine to both the liquid drive and the generator load.

To account for pressure leaks by bubble transport or diffusion, a small external pump is needed to maintain the pressure (P_b) for long periods of time. This pump will require relatively little energy compared to the output of the device. In addition, pressure leaks can be reduced by applying a thin layer of oil or plastic over the liquid pool which is in contact with the high pressure pneumatic (P_b) spring.

An expression for the resonant frequency, ω_o, for the prototype was derived using the Lagrangian formulation** and can be written as

$$\omega_o = a\left[\left(\frac{2\rho g}{A} + \frac{\Gamma P_b}{V_b}\right)\frac{1}{M}\right]^{\frac{1}{2}} \qquad (1)$$

where

Γ = ratio of specific heats

a = area of central tube

A = area of liquid in the pools

V_b = pneumatic volume at pressure P_b

* Inland Motor, Kollmorgen Corporation, Radford, Virginia

** Goldstein, Herbert, *Classical Mechanics*, Addison-Wesley Publishing Co., Inc., 1959.

SCHEMATIC DRAWING OF INERTIALLY COUPLED GENERATOR PROTOTYPE

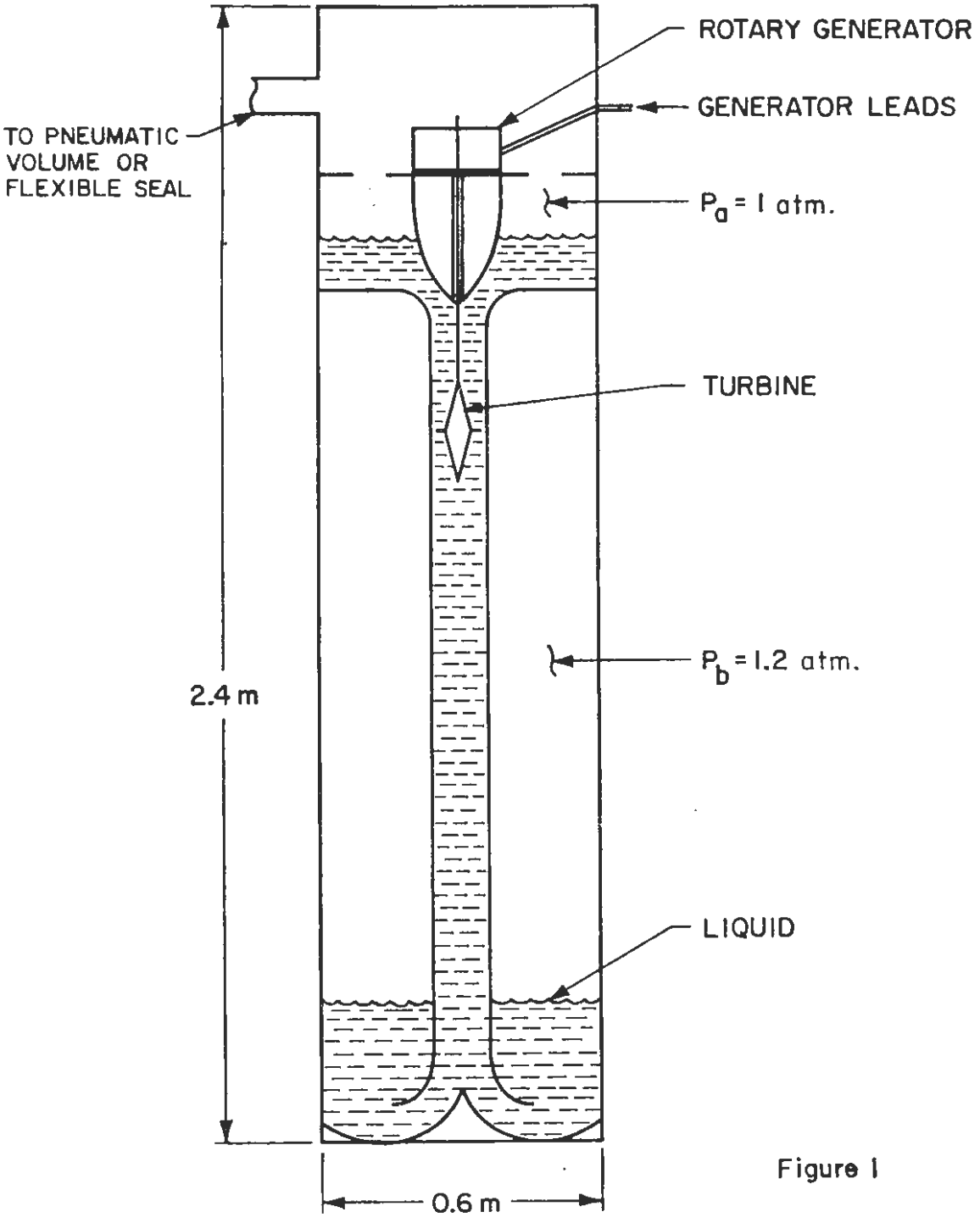


Figure 1

ρ = liquid density

g = acceleration of gravity

This expression was verified by experiments and yields a value of 1.6 rad sec^{-1} for the parameters given in Figure 1. The mass subject to acceleration, M is 10 kg. It can be seen from the above expression that the prototype design is tunable and thus the design can be optimized for a given sea state.

One of the advantages of this design concept is the full utilization of the available oscillator height. The maximum displacement of the liquid in the pools, Y, is given by

$$Y=\frac{a}{A}HQ \tag{2}$$

H is the sea wave amplitude and Q is a dimensionless parameter which gives the rate at which power is to be extracted from the oscillating liquid. The value of Q is in the neighborhood of 2. For typical sea states Y is of the order of 5 cm.

An additional advantage for this design concept is that the average power output is optimally flat over an octave of sea wave energy. This average power, P, is given by

$$P=\frac{MH^2\omega_o}{2Q}\beta G(\omega)\omega^6 \tag{3}$$

where

$$\beta\equiv\left[(\omega^2-\omega_o{}^2)+(\frac{\omega\omega_o}{Q})^2\right]^{-1} \tag{4}$$

$G(\omega)$ is function which describes the response of turbine generator system.

Water was the inertial liquid in these experiments. The use of heavier liquids promises an improvement in output power by a factor of two to three. Future liquids such as certain halogenated hydrocarbons or organo-metallic compounds can be chosen primarily for higher density, and secondarily, for lower frictional losses.

Acknowledgements

The authors acknowledge the private support of Mr. M. Maulhardt of Modesto, California. Discussions with Professor Roy S. Hickman of the Department of Mechanical and Environmental Engineering were very helpful and contributed significantly toward the success of this program.

Cooperating Organizations

Mr. M. Maulhardt, Modesto, California

Roy S. Hickman, University of California, Santa Barbara, Department of Mechanical and Environmental Engineering

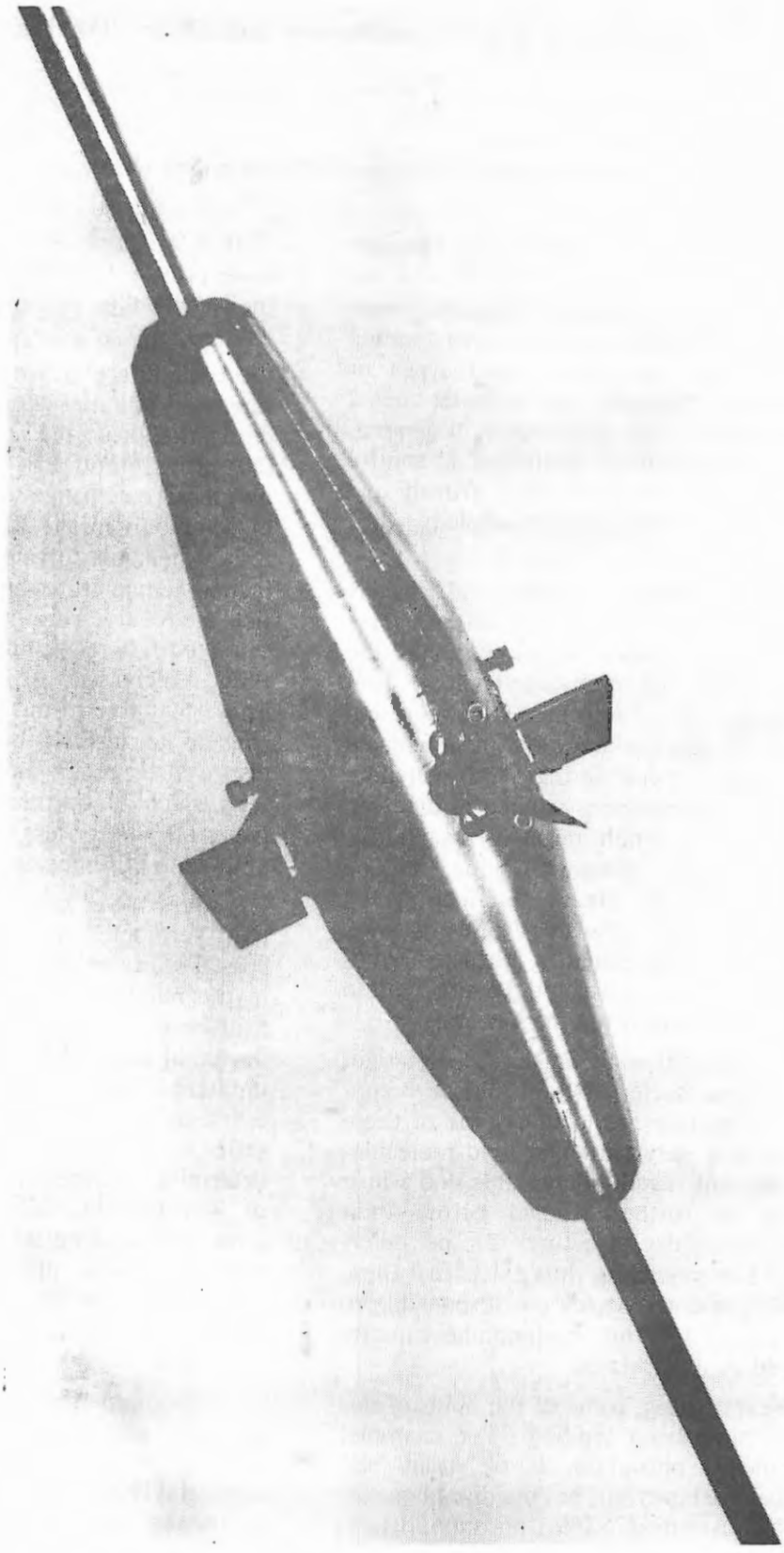


Figure 2. Photograph of the Turbine System.

Studies on Thermophilic Microorganisms Isolated From Undersea Hot Springs, Electric Power Plant Condensers and Ships' Heat Exchangers

Francisco V. Vidal and John Isaacs
Scripps Institution of Oceanography, University of California, San Diego

During the past year our research investigations, under the sponsorship of the UC Sea Grant College Program, were specifically directed towards understanding the physiology, distribution and types of thermophilic bacteria in seawater-cooled heat exchangers and in seawater in general, with the intention of designing a control methodology to prevent their growth and accumulation in seawater-cooled heat exchangers.

To date we have isolated and partially characterized ten strains of thermophilic bacteria, five of which we know inhabit the inside walls of seawater-cooled heat exchanger tubes. Another five represent potential invaders which have been isolated from submarine hot springs and nearshore seawater. All organisms studied to date can be classified as gram negative, facultative anaerobic rods. However, none can be classified under the already described genera listed in *Bergey's Manual of Determinative Bacteriology*. Consequently, these thermophilic marine isolates could be grouped to form a new genus of marine bacteria.

A detailed analysis of the lipids of several of our bacterial strains has been conducted. We have found that some of these bacteria have very particular lipid molecules which are not readily identifiable and which have to be further studied before their specific molecular structure can be determined. The possibility thus exists that these particular lipid molecules are responsible to some extent for the thermophilic capacity displayed by our isolates.

Nevertheless, some of the lipids of our bacteria have been typified. For example, the principal phospholipids of strain PB5 have been shown to be mainly phosphotidylethanolamine (75.0%), phosphotidylglycerol (16%) and diphosphotidylglyercol (3.5%). The methyl esters from phospholipids of strain PB8 were analyzed by gas chromatography and they consisted of: 16:1 (4.3% wt.), 16:0 (56.2%), 17:0 (<3.1%), 18:1 (30.2%), 19 (<3.1%), 20:1 (<3.1%), 22:0 (4.9%) and 24:0 (<3.1%). These data have proven valuable when used to aid in the classification of the organisms.

We have also determined that when the bacteria are grown at different temperatures and salinities there is an apparent random variation in the proportion and types of fatty acids produced. For example, we did not observe a change toward a higher degree of saturation in the fatty acids of our bacteria when the organisms were grown at higher temperatures, nor did we observe that the relative concentration of a particular saturated fatty acid, present at low temperatures, increased at high temperatures. These tentative results indicate that our isolates do not possess the adaptive mechanism displayed by other known thermophilic bacteria which allows them to regulate the synthesis of more or less saturated fatty acids as a function of temperature.

We have conclusively demonstrated that thermophilic bacteria commonly inhabit coastal seawater and that they are ubiquitous in the marine environment, at least in the nearshore realm. An experiment was conducted at the end of the Scripps pier, where unfiltered seawater was heated to 55° C and 82° C as it was made to circulate through a series of stainless steel pipes, in order to determine whether marine bacteria capable of withstanding such temperatures would grow and accumulate inside the pipes. It was determined that a considerably thick mass (>1 mm) of thermophilic organisms would develop and accumulate in less than a few hours.

This experiment actually duplicates, at a minor scale, what happens in a power plant which utilizes seawater to cool its condensers. The organisms that accumulated in the system were isolated by enrichment culture techniques and are now under investigation and cultivation in the laboratory. To date we have studied their morphology under the phase contrast and electron microscope, and found them to be very long thin filaments, greater than 70μ in length and

about 1-2μ in width. Several types are represented, some of which are yellow pigmented. All strains are gram negative and have an optimum temperature for growth between 55° and 65° C.

Another aspect of our research has dealt with the accumulation and uptake of arsenic by marine bacteria and yeast. We have demonstrated that marine bacteria and marine yeast are capable of assimilating and reducing arsenate to arsenite and of synthesizing arsenic containing macromolecules *in vitro*. These compounds have been identified as cacodylic and methyl arsonic acid. The ability of these organisms to reduce arsenate represents a unique mechanism of detoxification. All the arsenate incorporated is reduced to arsenite. Only a small fraction of the arsenite is used to form cacodylic and methyl arsonic acid, the rest is excreted as such back into the culture media.

The arsenic concentration in the oceans is relatively constant, while the concentration of phosphorus can vary considerably; it sometimes falls below the concentration of arsenic. Thus, whenever the ratio of the concentrations of arsenic to phosphorus in the ocean is relatively high, the organisms in question most probably assimilate more arsenic than phosphorus. They do so since they are incapable of distinguishing arsenic from phosphorus in uptake. These two atomic species are related and very similar to each other. It therefore appears that marine bacteria and marine yeast possess a unique mechanism of partial arsenic detoxification. However, this mechanism does not involve the transformation of toxic to non-toxic forms of arsenic.

Publications

Vidal, Francisco V., Victor M. V. Vidal and John D. Isaacs. *In prep.* Thermophilic marine microorganisms from coastal seawater, submarine hot springs and power plant heat exchangers.

Vidal, Francisco V. and K. H. Nealson. *In prep.* Taxonomy of marine thermophilic bacteria.

Vidal, Francisco V., J. H. Lasso and A. A. Benson. *In prep.* Biosynthesis of arseno-compounds by marine bacteria and yeast.

Cooperating Organizations

University of California, San Diego, School of Medicine

San Diego Veterans Administration Hospital

Mexican Federal Government, National Science Foundation

San Diego Gas and Electric Company

Marine Vehicle Safety Analysis

William C. Webster, *University of California, Berkeley*

A computer program was developed to predict turning trajectories for a medium sized cargo ship for a wide range of possible speed and rudder commands. The predictions were based on model tests of a Mariner *class vessel. Using these predicted trajectories, it was then possible to investigate methods for avoiding collisions between ships. The computer was made to simulate two similar ships on a collision course. It then systematically executed various maneuvers to determine if the ships would collide. By this technique it was possible to determine under what circumstances a collision is avoidable and what the best and worst possible maneuvers are in various situations. Computations were also made to determine the risk of collision if the positions of the ships are uncertain as, for instance, if they are operating with limited visibility. The effect of shallow water on ship controllability and the risk of collision was also examined. All of these results were compiled and summarized in a published report.*

Two main objectives were addressed by this research. The first was to predict by computer simulation the turning trajectories for a *Mariner* class ship based on previous towing tank results. The second was to use these computed trajectories to systematically analyze various potential collision situations to determine optimal maneuvers and to quantify the uncertainties and risks involved.

The program for computing trajectories was completed and the results were found to agree well with full scale trial results. Thus for this particular ship it was possible to compute and plot ship paths for a wide variety of rudder and speed commands. Figure 1 shows an example of some computed trajectories in both deep and shallow water.

A second computer program was written to compute critical ranges and optimal maneuvers for two ships on a collision course. The program assumes the two ships to be on a perfect collision course and, for a specified maneuver, determines the minimum separation distance the ships can attain and still be capable of avoiding collision by that maneuver. The combination of maneuvers with the smallest or largest critical range is then the best or worst maneuver combination respectively. Some sample results are shown in Figures 2 and 3. Included in these figures are critical ranges computed with the right turn rule in effect, restricting either ship from making a left turn.

Additional computations were made to determine the effect of uncertainties in ship position on the choice of optimal maneuver and the probability of collision. The ship position was assumed to have a normal probability distribution about the observed position. Based on this it was possible to compute the maneuver with the highest probability of being optimal and also the probability of collision for a given maneuver. These computations were performed for a wide variety of encounter situations.

The results of the analyses may be summarized briefly by the following conclusions:

1. The maneuvering simulation indicates that the *Mariner* has greatest directional stability in shallow water although for most rudder angles this ship turns more quickly due to greater rudder effectiveness.
2. The ship turns more quickly when power is increased rather than decreased.
3. Critical ranges for collision avoidance are less in shallow water than deep water.
4. The optimal maneuvers for collision avoidance are usually, but not always, maximum power and maximum rudder angle.
5. The probability of choosing the optimal maneuver is least, and the chances are greatest, for head-on encounters.

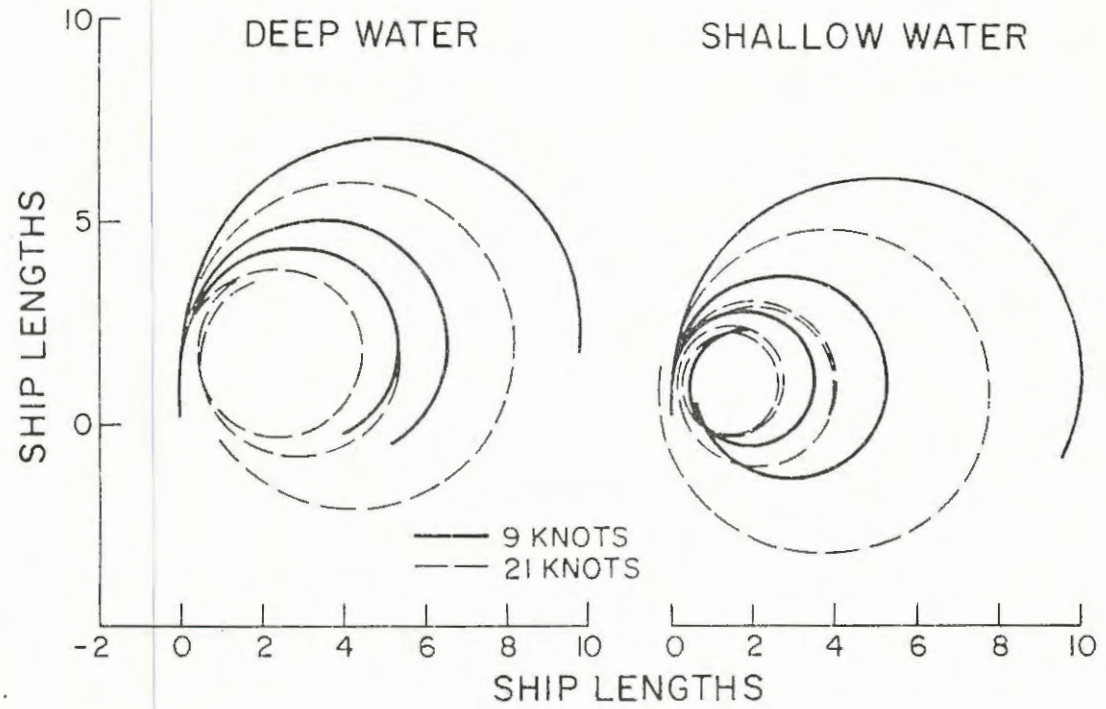


Figure 1. Turning trajectories measured in ship lengths for rudder angles of 12°, 24° and 36°.

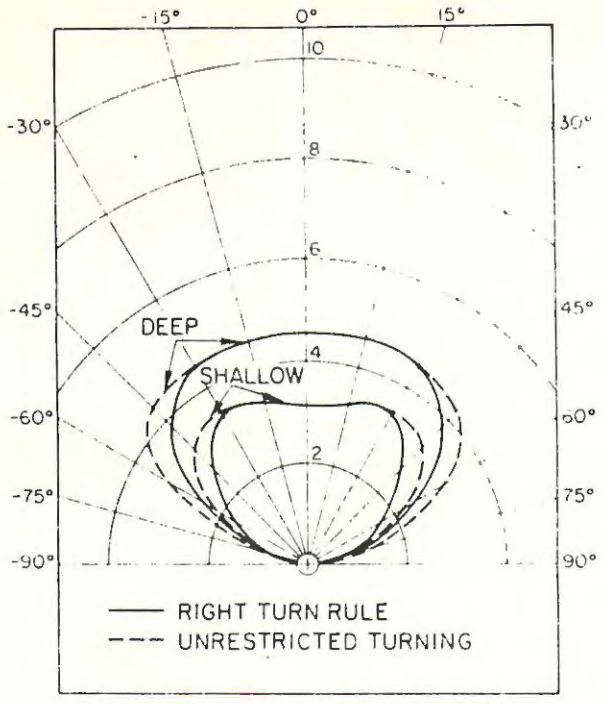


Figure 2. Critical range in ship lengths as a function of relative bearing angle, assuming both ships make the best maneuver.

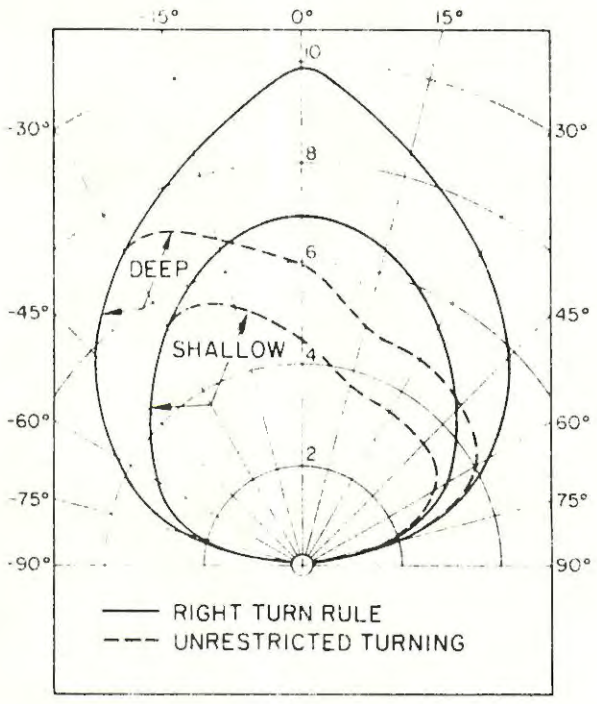


Figure 3. Critical range in ship lengths as a function of relative bearing angle assuming one ship makes the best maneuver and the other ship makes the worst maneuver.

The results of this research have been described in more detail in a paper entitled "Some aspects of ship maneuverability as applied to the problem of collision avoidance". This was published in the Proceedings of the Symposium on Aspects of Navigability of Constraint Waterways which was held in Delft, The Netherlands in April of 1978. The trainee for this project attended this symposium and made a formal presentation of these results to a large group of scientists and engineers who had gathered to exchange ideas on similar and related topics. During his stay in Europe, the trainee was afforded the opportunity to visit several ship model testing facilities and hydraulics laboratories, and to observe first-hand the techniques being used by other researchers in this field. Since model testing is an integral part of ship related research, this proved to be an invaluable educational experience.

Publications

Dillingham, J. T. and W. C. Webster. 1978. Some aspects on ship maneuverability as applied to the program of collision avoidance. Symposium on Aspects of Navigability, Delft, The Netherlands.

University of California

Sea Grant and IMR Series Publications

September 1, 1977 - September 30, 1978

Sea Grant. University of California Sea Grant College Program Annual Report 1976-77. Sea Grant Publication Number 61, IMR Reference No. 78-101. Robert Powell (ed.). 171 pages (1978).

Sea Grant. University of California Sea Grant College Program Directory 1977-78. Sea Grant Publication No. 60, IMR Reference No. 77-107. 20 pages. (October 1977).

Sea Grant. University of California Sea Grant College Program Directory 1978-79. Sea Grant Publication No. 66, IMR Reference No. 78-103. 26 pages. (November 1978).

Sea Grant. University of California and University of Southern California Programs. California's Sea Grant Program, A review. A Report to the Resources Agency Sea Grant Advisory Panel. UC Sea Grant Publication No. 63, USC Sea Grant Publication No. 1-78. (February 1978).

Sea Grant. University of California and University of Southern California Programs. California's Sea Grant Program; Summary of the Review Report, February 1978. UC Sea Grant Publication No. 64, USC Sea Grant Publication No. 2-78. (1978).

Sea Grant. University of California. California Ocean Research -- A Sea Grant Sampler. Sea Grant Publication No. 65. 43 pages. Spring 1978.

Seymour, Richard (Chairman, NSTS Workshop). Nearshore Sediment Transport Study Workshop on Instrumentation for Nearshore Processes, June 16-17, 1977, La Jolla, California. Sea Grant Publication No. 62, IMR Reference No. 78-102. 91 pages. (1978).

Trondsenilif and Walter J. Mead. California Offshore Phosphorite Deposits, an Economic Evaluation. Sea Grant Publication No. 59, IMR Reference No. 77-106. 188 pages. (1977).

University of California

Sea Grant Technical Publications

September 1, 1977 - September 30, 1978

Allen, P. G. and Warren E. Johnston. Research direction and economic feasibility: an example of systems analysis for lobster aquaculture. *Aquaculture* 9: 155-180 (1976).

Al-Shaibani, Khalid A., Robert J. Price, and W. Duane Brown. Enzymatic reduction of methyoglobin in fish. *J. Food Sci.* 42(5): 1156-1158 (1977).

Al-Shaibani, Khalid A., Robert J. Price, and W. Duane Brown. Purification of methyoglobin reductase from Bluefish Tuna. *J. Food Sci.* 42(4): 1013-1015 (1977).

Bailard, James A. and Douglas L. Inman. Analytical model of duct-flow fluidization. Proceedings, *Symposium on Modeling Techniques.* ASCE/San Francisco, California, September 3-5, 1975. Pages 1402-1421.

Barbour, Michael G. and Ann Johnson. Beach and dune. *In:* Terrestrial vegetation of California, Chapter 7. M. C. Barbour/Dr. Jack Major (Eds.). Pages 223-261 (1977).

Barbour, Michael G. and Theodore M. DeJong. Response of West Coast beach taxa to salt spray, seawater inundation, and soil salinity. *Bulletin of the Torrey Botanical Club* 104 (1): 29-34 (January-March 1977).

Blonz, Edward R. and H. S. Olcott. *Daphnia magna* as a bioassay system for histamine in tuna extracts. *Bulletin of the Japanese Society of Scientific Fisheries* 44(5): 517:519 (1978).

Botsford, L. W., A. M. Schuur, R. Shleses and H. E. Rauch. An economically optimum aquaculture facility. Proceed-

ings, *6th Annual Meeting, World Mariculture Society,* Seattle, Washington, January 27-31, 1975. Pages 407-420 (1977).

Bray, Richard N. and Mark A. Hixon. Night-shocker: predatory behavior of the Pacific Electric Ray *(Torpedo californica). Science* 200: 333-334 (April 21, 1978).

Byrd, Robert C. A laboratory study of the fluid-structure interaction of submerged tanks and caissons in earthquakes. Earthquake Engineering Research Center, College of Engineering, University of California, Berkeley, Report No. UCB/EERC-78/08. 149 pages. (May 1978).

Carroad, Paul A. and Raymond A. Tom. Bioconversion of shellfish chitin wastes: process conception and selection of microorganisms. *J. Food Sci.* 43: 1158-1161 (1978).

Cornet, Israel, D. Pirtz, M. Polivka, and Y. Gau. Effect of stray electric current on the corrosion of prestressed concrete in seawater. *10th Annual Offshore Technology Conference,* Houston, Texas, May 8-11, 1978.

Dayton, Paul K. Experimental studies of algal canopy interactions in a sea otter-dominated kelp community at Amchitka Island, Alaska. *Fish. Bull.* 73(2): 230-237 (1975).

Epstein, E. Genetic potential for solving problems of crops to salinity. *Pallant Adaptation to Mineral Stress in Problem Soils Workshop,* National Agricultural Library, Beltsville, Maryland, November 22-23, 1976.

Epstein, E. and J. D. Norlyn. Seawater-based crop production: a feasibility study. *Science* 197: 249-251 (15 July 1977).

Fisher, William S. and Richard T. Nelson. Therapeutic treatment for epibiotic fouling on Dungeness crab *(Cancer magister)* larvae reared in the laboratory. *J. Fish. Res. Bd. Canada.* 34(3): 432-436 (1977)

Flagg, V. G. Alternative management for yellowfish tuna in the eastern tropical Pacific. Center for Marine Studies, San Diego State University, Sea Grant Report. (1977).

Higgs, Martin D. and D. John Faulkner. 5α-Pregna-1, 20-Dien-3-One and related compounds from a soft coral. *Steroids.* 30(3): 379-388 (1977).

Higgs, M. D., D. J. Vanderah and D. J. Faulkner. Polyhalogenated monoterpenes from *Plocamium cartilagineum* from the British Coast. *Tetrahedron.* 33: 2775-2780 (1977).

Jenkins, Scott A. and Douglas L. Inman. Forces on a sphere under linear progressive waves. American Society of Civil Engineers, Proceedings *15th Coastal Engineering Conference.* Honolulu, Hawaii, July 11-17, 1976. Pages 2413-2427.

Love, Milton S. and Ralph J. Larson. Geographic variation in the occurrence of tympanic spines and possible genetic differentiation in the kelp rockfish *(Sebastes atrovirens). Copeia* 1: 53-59 (1978).

Love, Milton S. and Alfred W. Ebeling. Food and habitat of three switch-feeding fishes in the kelp forests off Santa Barbara, California. *Fish. Bull.* 76(1): 257-271 (1978).

McConnell, Oliver J. and William Fenical. Halogenated metabolites -- including Favorsky rearrangement products -- from the red seaweed *Bonnemaisonia nootkana. Tetrahedron Letters* 48: 4159-4162 (1977).

McEnroe, Frank J. and William Fenical. Structures and synthesis of some new antibacterial sesquiterpenoids from the gorgonian coral *Pseudoptero-gorgia rigida. Tetrahedron* 34(11): 1661-1664 (1978).

Moser, M. Myxosporida (Protozoa): The discrimination and maintenance of spore size and shape. *International Journal for Parasitology* 7: 389-391 (1977).

Moser, Mike and Elmer R. Noble. The genus *Myxoproteus* (Protozoa: Myxosporida) in macrourid fishes. *International Journal for Parasitology* 7: 253-255 (1977).

Moser, M. and E. R. Noble. Three genera of Myxosporida (Protozoa) in macrourid fishes. *International Journal for Parasitology* 7: 93-96 (1977).

Moser, M. and E. R. Noble. *Zschokkella* (Protozoa: Myxosporida) in macrourid fishes. *International Journal for Parasitology* 7: 97-100 (1977).

Mynderse, Jon S. and D. John Faulkner. Variations in the halogenated monoterpene metabolites of *Plocamium cartilagineum* and *P. violaceum*. *Phytochemistry* 17: 237-240 (1978).

Nelson, Keith and Dennis Hedgecock. Electrophoretic evidence of multiple paternity in the lobster *Homarus americanus* (Milne-Edwards). *American Naturalist* III(978): 361-365 (March-April 1977). Letters to the Editor.

Neushul, Michael. The domestication of the giant kelp, *Macrocystis*, as a marine plant biomass producer. *The Marine Plant Biomass of the Pacific Northwest Coast*, Robert Knauss (ed.): 163-181 (1978).

Pearse, John S., Daniel P. Costa, Marc B. Yellin and Catherine R. Agegian. Localized mass mortality of red sea urchin, *Strongylocentrotus franciscanus*, near Santa Cruz, California. *Fish. Bull.* 75(3): 645-648 (July 1977).

Ravi, B. N. and D. John Faulkner. Cembranoid diterpenes from a South Pacific soft coral. *Journal of Organic Chemistry*. 43: 2127-2131 (1978).

Rice, Robert H., Gary E. Means and W. Duane Brown. Stabilization of bovine trypsin by reductive methylation. *Biochimica et Biophysica Acta* 492: 316-321 (1977).

Scott, Stanley. Coastal planning in California: a progressive report. *Public Affairs Report*, a bulletin of the Institute of Governmental Studies, UC Berkeley, 19(3-4): 13 pages (June-August 1978).

Scheser, R. A. Development of Crustacean Aquaculture. *Proc. 10th European Symposium on Marine Biology*, Ostens, Belgium, September 17-23, 1974 *Volume 1: 455-471 (1975).*

Wick, Gerald L. Power from salinity gradients. *Energy* 3(1-G): 95-100 (1978).

Wick, Gerald L. and John D. Isaacs. Salt domes: Is there more energy available from their salt than from their oil? *Science*. 199: 1436-1437 (March 31, 1978).

Wickham, Daniel E. A new species of *Carcinonemertes* (Nemertea: Carcinonemertidae) with notes on the genus from the Pacific Coast. Proceedings, *Biological Society of Washington*. 91(1): 197-202 (1978).

Wolfe, Steven K., Daniel A. Watts and W. Duane Brown. Analysis of myoglobin derivatives in meat or fish samples using absorption spectrophotometry. *J. Agric. Food Chemistry*. 26(1): 217-219 (1978).

Activity Budget Sheet

	NOAA Grant Funds	Matching Funds
Marine Resources Development		
Aquaculture	376,806	557,629
Living Resources	85,788	76,037
Marine Biomedicinals & Extracts	119,240	59,628
Socio-economic & Legal Studies		
Marine Economics	29,875	21,181
Ocean Law	7,699	10,438
Marine Recreation	8,255	29,262
Socio-Political Studies	24,221	15,387
Marine Technology Research & Development		
Ocean Engineering	200,718	114,748
Resources Recovery & Utilization	59,592	75,292
Marine Environmental Research		
Research & Studies in Direct Support of Coastal Management Decisions	175,654	104,765
Ecosystems Research	76,344	49,192
Marine Education & Training		
Other Education (Sea Grant Trainees)	379,145	43,987
Advisory Services		
Extension Programs	421,085	214,081
Other Advisory	113,944	87,807
Program Management & Development		
Program Administration	205,638	205,602
Program Development	95,996	40,365
Total	2,380,000	1,705,401

Matching Funds Source 1977-78

Aquarium Museum Docents
California Cooperative Oceanic Fisheries Investigation
California Institute of Technology
Comprehensive Employee Training Act
Donations - various donors
Eureka Fisheries Inc.
Ford Foundation
Grader Fish Company
Hubbs/Sea World Institute
Humboldt Bay Fisheries Association
Humboldt State University
Humboldt State University Foundation
Kelco, a Division of Merck Inc.
San Diego Gas & Electric Co.
San Diego State University
San Diego State University Foundation
San Jose State University
Southern California Edison
Stanford University
State of California:
- California Resources Agency
- Department of Fish and Game
- Department of Navigation and Ocean Development
- Department of Parks and Recreation

Tavolek Laboratories
Tuna Research Foundation
University of California
University of San Diego
Zoecon Corporation

The Regents of the University of California

Edmund G. Brown, Jr.
Governor of California and
President of the Regents
Mervyn M. Dymally
Lieutenant Governor of California
Leo T. McCarthy
Speaker of the House
Wilson Riles
State Superintendent of Public Instruction
Donald G. Reithner
President of the Alumni Association of the University of California
Gene E. Pendergast, Jr.
Vice President of the Alumni Association of the University of California
David S. Saxon
President of the University
Cheryl F. Biles
Forrest A. Plant

Appointed Regents*
Edward W. Carter (1982)
Frederick G. Dutton (1978)
William K. Coblentz (1980)
Chairman of the Regents
Dewitt A. Higgs (1982)
Glenn Campbell (1984)
William French Smith (1986)
Robert O. Reynolds (1986)
Vice Chairman of the Regents
Dean A. Watkins (1984)
Joseph A. Moore (1990)
John H. Lawrence, M.D. (1988)
William A. Wilson (1988)
Gregory Bateson (1988)
Vilma S. Martinez (1990)
Verne Orr (1988)
John F. Henning (1989)
Stanley K. Sheinbaum (1989)
Yori Wada (1980)
Michael B. Salerno (1978)
Theodora Kroeber-Quinn (1978)

*Terms of Regents appointed by the Governor expire March 1 of the year named in parentheses, with names arranged in order of original accession to the Board. The student Regent (Michael B. Salerno) is appointed by the Board for a one-year term beginning July 1, and ending June 30 of the year named in parentheses.

Principal Officers of the Regents
Donald L. Reidhaar
General Counsel
Owsley B. Hammond
Treasurer
Marjorie J. Woolman
Secretary

Faculty Representative to the Board of Regents
William B. Frazer
(September 16, 1977 to August 31, 1979)
John S. Galbraith
(September 1, 1977 to August 31, 1978)

University of California Systemwide Administration

David S. Saxon
President of the University
Chester O. McCorkle, Jr.
Vice President of the University
Donald C. Swain
Academic Vice President
Archie Kleingartner
Vice President - Academic and Staff Personnel Relations
James B. Kendrick, Jr.
Vice President - Agriculture and University Services
Lowell J. Paige
Special Assistant to the President for Governmental Relations
Dorothy Everett
Assistant President - Coordination and Review
Beverly R. Liss
Assistant President - Campus and Internal Relations

Officers Emeriti

Charles J. Hitch
President of the University, Emeritus, and Professor of Economics, Emeritus
Clark Kerr
President of the University, Emeritus, and Professor of Business Administration, Emeritus
Claude B. Hutchison
Vice President of the University, Emeritus, and Dean of the College of Agriculture, Emeritus
Harry R. Wellman
Vice President of the University, Emeritus, Professor of Agricultural Economics, Emeritus, and Agricultural Economist, Emeritus
Robert M. Underhill
Vice President, Emeritus, and Secretary and Treasurer of the Regents, Emeritus
Thomas J. Cunningham
General Counsel of the Regents, Emeritus
Frank L. Kidner
Vice President - Educational Relations, Emeritus, and Professor of Economics, Emeritus
John A. Perkins
Vice President - Business and Finance, Emeritus, and Professor of Political Science, Emeritus
John E. Landon
Associate Counsel of the Regents, Emeritus
August Fruge
Director of the University Press, Emeritus

Chancellors

Albert K. Bowker
Chancellor at Berkeley
James H. Meyer
Chancellor at Davis
Daniel G. Aldrich, Jr.
Chancellor at Irvine
Charles E. Young
Chancellor at Los Angeles
Ivan Hinderaker
Chancellor at Riverside
William D. McElroy
Chancellor at San Diego
Francis A. Sooy
Chancellor at San Francisco
Robert A. Huttenback
Chancellor at Santa Barbara
Robert L. Sinsheimer
Chancellor at Santa Cruz

1977-1978
Institute of Marine Resources Advisory Council
William A. Nierenberg, Chairman

Members

Willard Bascom
Director, Southern California Coastal Water Research Project
1500 East Imperial Highway
El Segundo, California 90245

Claire T. Dedrick
Public Utilities Commission
350 McAllister St.
San Francisco, California 94102

The Honorable Hugo Fisher
San Diego Superior Court
Department 29
220 West Broadway
San Diego, California 92101

C. M. (Tod) Ghio
Ghio Seafood Products
5232 Lovelock
San Diego, California 92110

Arthur W. Hansen
Director, Consumer and Environmental Protection
Del Monte Corporation
P.O. Box 3575
San Francisco, California 94119

Francis J. Hortig
Consulting Engineer
Energy Resources
2216 Westboro
Alhambra, California 91803

James Joseph
Director of Investigations
Inter-American Tropical Tuna Commission
Southwest Fisheries Center
La Jolla, California 92037

Hayden A. Moore
President
ITT, Cable-Hydrospace Division
3040 Terminal
National City, California 92050

Allen E. Puckett
Executive Vice President
Assistant General Manager
Hughes Aircraft Company
Centinella Avenue and Teale
Culver City, California 90230

J. T. Riley
President, Kelco
Division of Merck & Co., Inc.
8355 Aero Drive
San Diego, California 92123

Brian J. Rothschild
Director, Office of Policy Development and Long-Range Planning
National Marine Fisheries Service
U.S. Department of Commerce, NOAA
Washington, D. C. 20235

John J. Royal
Secretary-Treasurer
Fisherman's Union ILWU Local 33
806 South Palos Verdes Street
San Pedro, California 90731

Philip N. Storrs
Senior Vice President
Engineering-Science Inc.
150 North Santa Anita Avenue
Arcadia, California 91006

James G. Wenzel
Vice President
Lockheed Missiles and Space Company
1111 Lockheed Way
Sunnyvale, California 94088

Elmer P. Wheaton
Retired Vice-President
Lockheed Missiles and Space Co.
127 Solana Road
Portola Valley, California 94025

***Ex Officio Members (1976-77)**

William A. Nierenberg
Chairman, IMR Advisory Council
Director, Scripps Institution
of Oceanography
University of California
La Jolla, California 92093

John D. Isaacs
Director, Institute of Marine Resources
University of California
La Jolla, California 92093

Richard W. Eppley
Associate Director, IMR
for Marine Productivity
University of California
La Jolla, California 92093

Joseph L. Reid
Associate Director, IMR
for Pelagic Resources
Director, Marine Life Research Group
University of California
La Jolla, California 92093

*Includes members of the IMR Executive Subcommittee for Sea Grant

IMR Executive Subcommittee for Sea Grant

James J. Sullivan, Chairman
Program Manager
Sea Grant College Program
University of California
La Jolla, California 92093

Victor C. Anderson
Deputy Director
Marine Physical Laboratory
University of California
La Jolla, California 92093

William T. Doyle
Associate Director
Institute of Marine Resources
Director, Center for Coastal Marine Studies
University of California
La Jolla, California 92093

Richard F. Ford
Director
Center for Marine Studies
San Diego State University
San Diego, California 92182

Jeffery Frautschy
Associate Director
Institute of Marine Resources
Coastal Resources and Sea Grant
University of California
La Jolla, California 92093

Robert Holmes
Department of Biological Sciences
University of California
Santa Barbara, California 92106

Theodore H. Kerstetter
Director, Marine Laboratory and
Sea Grant Coordinator
Humboldt State University
P.O. Box 624
Trinidad, California 95570

Anthony Orme
Chairman
Geography Department
1255 Bunche Hall
University of California
Los Angeles, California 90024

Bernard Schweigert
Associate Director
Institute of Marine Resources
Chairman, Department of Food Sciences
and Technology
University of California
Davis, California 95616

Gerald Wick
Assistant Director
Institute of Marine Resources
University of California
La Jolla, California 92093

Aquaculture Industry Advisory Committee

Steve Henderson, Chairman
International Shellfish Enterprises, Inc.
Moss Landing, California 95039

Nate Shafer
Pacific Ocean Farms
Carmel, California 93921

Daniel T. Cullen
President
International Shellfish Enterprises, Inc.
Moss Landing, California 95039

George Lockwood
Monterey Abalone Farm
300 Cannery Row
Monterey, California 93940

James McBeth
American Shellfish Corporation
Moss Landing, California 95039

John McMullen
Ab. Lab
Civil Engineering Laboratory
Port Hueneme, California 93043

Hugh W. Staton
California Marine Association
Cayucas, California 93430

Seafood Industry Advisory Committee

Robert Dean, Chairman
International Pacific Seafoods
616 Stanford Avenue
Los Angeles, California 90021

Maurice Camillo
California Seafood Institute
2677 Larkin Street
San Francisco, California 94109

Tom Elliott
Washington Fish and Oyster
185 Berry Avenue
San Francisco, California 94101

Tod Ghio
Ghio Seafood Products
5232 Lovelock Street
San Diego, California 92110

Lawrence Lazio
Tom Lazio Fish Company
No. 4, C Street
Eureka, California 95501

M. Loewe
Star Kist Foods, Inc.
582 Tuna Street
Terminal Island, California 90731

Ernest W. Peterson
Van Camp Seafood Company
11555 Sorrento Valley Road
San Diego, California 92121

Tom Tarantino
Tarantino Fish Company
Division of Puccini and Sons
Foot of Leavenworth Street
Fisherman's Wharf
San Francisco, California 94133

Jerry Thomas
Eureka Fisheries
Fields Landing
Eureka, California 95501

Nich Vitilich
Chesapeake Fish Company
535 Harbor Lane
San Diego, California 92101

Program Summary
1976-1978

Project Title/Project Leader	FY76	FY77	FY78
Program Management			
Management and Program Development (M/A-1, Sullivan)	O	O	O
Education/Training			
Sea Grant Trainees (E/G-2, Sullivan)	O	O	O
Model Course in Marine Planning (R/R-14, Burton)	N/C	-	-
Marine Education: Undergraduate Independent Research (E/UG-1, Doyle)	-	N	O
Advisory			
Ocean Education for the Public (A/PE-1, Wilkie *et al.*)	O	O	O
Marine Advisory Program (A/EA-1, Cummings)	O	O	O
Publications and Public Advisory Services (A/P-1, Frautschy)	O	O	O
Coastal Resources Research			
Physical Criteria for Coastal Planning (R/CZ-3, Inman/Winant)	C	-	-
Oceanographic Inventory of the Southern California Shelf (R/CZ-23, Fischer/Berry)	C	-	-
Management of Beach and Dune Vegetation (R/CZ-22, Barbour)	O	C	-
Diving Safety Research Project (R/CZ-25, Egstrom)	O	C	-
Management of Cumulative Impacts of Coastal Development (R/CZ-26, Dickert)	N/C	-	-
Issues of Coastal Governance (R/CZ-27, Lee/Scott)	N/C	-	-
San Francisco Bay Project: Reference Collection, Bibliography, Identification Keys and Specimen Depository (R/CZ-28, Lee)	N	C	-
Coastal Engineering Data Network (R/CZ-30, Isaacs)	-	N/C	-
Tilting Spar Directional Wave Sensor (R/CZ-40, Inman/Guza)	-	N/C	-
Coastal Wetlands Management: Biological Criteria (R/CZ-33A, Holmes *et al.*)	N	O	O
Coastal Wetlands Management: Effects of Disturbance on Estuarine Function (R/CZ-33C, Zedler/Mauriello)	-	N	O
Coastal Wetlands Management: Opening of Coastal Lagoons by Sand Fluidization (R/CZ-33D, Inman/Nordstrom)	-	N	C
Longshore Sand Transport Studies (R/NP-1O, Inman)	-	N/C	-
Model Coastal Ordinance Project (R/NP-1V, Motley)	-	N/C	-
Development of a California Coastal Wetlands Information Directory for Resources Management (R/NP-1W, Dickert/Pepper)	-	N/C	-
Marine Resource Evaluation of Humboldt and Del Norte Counties, California: Preliminary Investigations (R/NP-1X, Isaacs/Kerstetter)	-	N/C	-
Geology, Faulting, and Related Seacliff Erosion, San Dieguito River to Carlsbad, San Diego County, California (R/NP-1H, Shepard)	N/C	-	-
Fiscal Impact of Park Acquisition in Laguna Beach (R/NP-1L, Dickert)	-	N/C	-
Transportation Analysis in the Coastal Zone: Subregional Considerations for Local Coastal Plans (R/NP-1M, Dickert)	-	N/C	-
Thermal Variability in Coastal Waters in the Southern California Bight (R/CZ-31, Winant)	N	O	O
Internal Waves Over Shelf and Canyon (R/CZ-32, Cox)	N	O	C
Assessment of the Offshore Commercial Sand and Gravel Potential on the Central California Continental Shelf (R/CZ-37, Berry/Wilde)	N	C	-
Methods for the Management of the Cumulative Impacts of Coastal Development (R/CZ-26, Dickert/Twiss)	N	C	-
Coastal Governance in California (R/CZ-38, Lee/Scott)	-	N/C	-

Half Moon Bay Private Sector Impact Study (R/NP-1C, Goldman)	N/C	-	-
Development of Interpretive Methods and Materials for Marine Parks in Nothern California (R/MR-1, DeMartini)	-	N	C
The Potential Environmental Impact of the Japanese Algae, *Saragassum muticum* (R/R-4, Dayton)	N/C	-	-
Geological and Historical Analysis of Coastal Zone Environmental Hazards and Liability for Losses Caused by Them (R/CZ-43, Shepard/Hildreth)	-	-	N
Kelp Bed Mariculture and Resource Management (R/A-16, Neushul *et al.*)	N	R	C
Coastal Governance 1977-1978: First Steps in Implementing California's 1976 Legislation (R/CZ-41, Lee/Scott)	-	-	N/C
Coastal Zone Management: Methods for Plan Development, Evaluation and Monitoring of Local Programs (R/CZ-42, Dickert)	-	-	N/C
Aquaculture Research and Development			
Economics of Aquaculture (R/ME-1, Johnston)	C	-	-
Development of Aquaculture Systems (R/FA-4, Shleser)	C	-	-
Use of Thermal Effluent in Aquaculture (R/FA-17, Ford/Van Olst)	C	-	-
Salt-Tolerant Plants (R/FA-13, Epstein)	C	-	-
Development of a Commercial Aquaculture System for the Crab *Scylla serrata* (R/A-8, Harrison)	C	-	-
Protective Measures for Shellfish Aquaculture (R/A-15, Steenbergen)	N	O	C
A Genetic Program for Improvement of Carrageenan in Red Algae *Gigartina* (R/A-17, West)	N	R	-
California Aquaculture Law (R/A-13, Bowden)	N	O	C
The Development of the Science and Technology of Aquaculture (R/A-19, Hand)	-	N	C
Optimization of an Artificial Diet for Lobsters (R/NP-1D, R/A-20, Holtz)	N	C	-
Use of Thermal Effluent in the Culture of Crustacea and Fishes (R/A-21, Van Olst/Ford)	-	N	C
Biochemical and Genetic Control Applied to the Critical Stages in Culturing Abalone (R/NP-1A, R/A-25, Morse)	N	O	C
Surfperch Mariculture (R/R-9, R/A-23, Norris)	N	C	-
Aquaculture of the Purple-Hinge Rock Scallop (R/R-7, R/A-24, Phleger/Leighton)	N	O	C
Carrageenophyte Cultivation, Genetics, Population Dynamics and Development of Agar Substitutes (R/A-17, Doyle *et al.*)	-	R	C
Toward a Seawater-Based Crop Production (R/A-22, Epstein)	-	N	O
Astaxanthin from Yeast for Fish Diets (R/R-11, R/A-27, Lewis)	N	O	C
The Role of Diseases in Aquaculture: Preliminary Survey (R/NP-1E, Raggi)	N/C	-	-
Plant Pathogens of Aquaculture Systems (R/NP-1R, Goff)	-	N/C	-
Bioeconomic Modeling of the Freshwater Prawn *Macrobrachium* spp. (R/NP-1T, Johnston)	-	N/C	-
Food Conversion Efficiencies of Instar Dungeness Crab (E/G-2, Tulles)	-	N/C	-
Control of Reproduction in the Lobster (R/NP-1-7B, Talbot)	-	-	N/C
Fisheries Research And Development			
The California Market Squid Fishery (R/F-15, Recksiek/Frey)	O	O	C
Optimal Management of Sea Urchin Fisheries (R/F-18, Dayton)	O	R	-
Effects of Fishing Sea Urchins on the Marine Ecosystem (R/F-18, Connell)	O	R	-
Studies Toward the Optimal Management and Environmental Effects of Sea Urchin Fisheries (R/F-18, Dayton/Connell)	-	R/C	-
Studies of Fish Muscle Proteins and Fresh and Frozen Seafood Technology (R/ST-2, Brown)	O	C	-

Histamine Toxicity from Fish Products (R/F-22, Olcott *et al.*)	O	C	-
Methods of Quality Assessment in Fishery Products (R/F-23, Chang)	N	C	-
Limited Entry: An Assessment for California Fisheries (R/F-24A, Wyner/Harding)	N/C	-	-
Cause of the Decline in Dungeness Crabs in the San Francisco Bay Area (R/NP-1F, Horne)	N/C	-	-
Sand Bottom Community Structure and Artificial Reefs (R/R-5, Dayton)	N/C	-	-
A Study of the Santa Barbara Inshore Party Boat and Aspects of the Life History of the Olive Rockfish *Sebastes serranoides* (R/NP-1I, Ebling)	N	C	-
Development of Trapping Methods for Migratory Salmonid Smolts in Hatcheries (R/NP-1N, Kerstetter)	-	N/C	-
Optimal Leasing Agreements for Marine Resource Development (R/F-35, Quirk/Lewis)	-	N	C
The Effects of Food Availability on the Growth and Survival of California Jack Mackerel Larvae (R/F-44, Mullin/Lasker)	-	N	O
Investigation of Data for an Economic Study of the U.S. Pacific Albacore Jig Boat Fishery (R/NP-15, Holt)	-	N/C	-
An Ethnography of the San Pedro Wetfish Fishing Fleet (R/NP-1U, Velez)	-	N	C
Socio-Economic Aspects of Expansion of the California Swordfish Fishery (R/F-26, Holt)	-	N/C	-
Coordinated Management of the Pacific Coast Salmon Fisheries and Implications of Extended Jurisdiction (R/F-24, R/F-31, Moore *et al.*)	-	N	C
Protective Immunization of Anadromous Salmonids Against *Aeromonas salmonicida* and *Vibrio anguillarum* (R/F-29, Kerstetter)	-	N	C
Development of a Mechanism to Allow Release of Dungeness Crabs from Lost or Abandoned Pots (R/F-27, Jolly)	-	N	C
Endocrinology of Salmon Smoltification and Adaptation to Seawater (R/F-25, Bern)	-	N	C
Comparative Analysis of the Social and Political Systems of the Tuna Fleets of San Diego and Ensenada (R/F-30, D'Andrade/Bailey)	-	N	C
Development of Multispecies Management for Kelp Bed Resources with an Emphasis on Sea Urchins (R/F-36, Tegner)	-	-	N
Improved Marine Food Products and Marine Food Technology (R/F-32, Brown)	-	-	N
Amine Toxicity of Fish Products (R/F-43, Bjeldanes)	-	-	N
Design and Development of a Squid Processing Machine (R/NP-1J, R/F-33, Singh)	-	-	N
Bioconversion of Chitin Wates (R/F-34, Carroad)	-	-	N
An Economic Study of the U.S. Pacific Albacore Jig Boat Fishery (R/F-38, Holt)	-	-	N/C
Santa Barbara Inshore Party Boat Fishery: Emphasis on the Olive Rockfish (R/F-39, Ebling)	-	-	N/C
Re-establishment of Anadromous Fishes in Southern California (R/F-42, Van Olst/Ford)	-	-	N/C
A Multispecies Bioeconomic Fisheries Model Under Uncertainty (R/F-37, Just)	-	-	N/C
Experimental Abalone Enhancement Program (R/NP-1-7A, Tegner)	-	-	N
Limited Entry in the California Abalone Fishery: A Longitudinal Analysis (R/NP-1-7C, Cicin-Sain/Moore)	-	-	N/C

New Marine Products			
Seaweed Products: Application in Algae Control, Mariculture and Agriculture (R/MP-7, Fenical)	O	C	-
Antiviral Compounds from Algae (R/MP-12, Vedros)	N	O	C
Marine Natural Products Chemistry of Fouling Organisms (R/MP-10, Faulkner)	N	C	-
Development of Anticancer Substance from the Brown Seaweed *Dictyota* (R/NP-1G, Fenical)	N/C	-	-
Tissue Culture of *Macrocystis* and Related Seaweeds of Economic Importance (R/MP-13, Lewin/Fenical)	-	N/C	-
Marine Plants as a Source of Insect Growth Inhibitors (R/MP-14, Crews)	-	N	O
Pharmacological Evaluation Program (R/MP-15, Jacobs)	-	-	N
Marine Natural Products for Pharmacological Evaluation (R/MP-16, Faulkner)	-	-	N
New Agricultural Chemicals from Marine Organisms (R/MP-18, Fenical)	-	-	N
Antileukemia Compounds from the Brown Seaweed *Dictyota* (R/MP-17, Fenical)	-	-	N/C
Energy			
Wave Climate Modification in Harbors by Dynamic Breakwater (R/E-1A, Isaacs)	C	-	-
Biological Effects of Waste Heat Effluents of Coastal Power Plants (R/E-10, Smith/Hand)	C	-	-
Stray Electrical Current Hazards to Prestressed Concrete Construction in Seawater (R/E-12, Cornet)	N	O	C
Earthquake Loading on Large Offshore Structures in Deep Water: A Study for the Correlation of Analytic and Physical Models (R/E-14, Wiegel)	-	N	O
Seismic Hazards to the Development of Offshore Oil Resources (R/E-15, Prothero)	-	N	O
Power from Salinity Gradients (R/NP-1B, R/E-16, Isaacs)	N	O	C
Studies on Thermophilic Microorganisms Located from Undersea Hot Springs, Electric Power Plant Condensers and Ships' Heat Exchangers (R/NP-1P, R/E-21, Isaacs)	-	N	O
Placement of Underwater Mass Concrete by the Tremie Method (R/NP-1Q, Gerwick)	-	N	C
Identication of Sources of Oil Spills in the Santa Barbara Channel (R/R-8, Profio)	N/C	-	-
Marine Vehicle Safety Analysis (R/E-17, Webster)	-	N	C
Side-Scan Sonar Mapping and Computer-Aided Interpretation of the Geology of the Santa Barbara Channel (R/E-18, Luyendyk/Simonett)	-	-	N
Nearshore Wave Power Source (R/E-19, Seymour)	-	-	N/C
Power Generator Inertially Coupled to Seawaves (R/E-20, Lee/Manalis)	-	-	N/C
Rapid Response			
Rapid Response Capability (R/NP-1, Sullivan)	O	O	O

N = New Project
O = Ongoing Project
R = Restructured Project
C = Completed Project
T = Terminated Project

This Annual Report, as required by the National Sea Grant Program, is produced with funds from NOAA Office of Sea Grant, Department of Commerce, under Grant #USDC 04-8-M01-189, and the State of California Resources Agency. Additional copies may be obtained from:

Sea Grant College Program
University of California
Institute of Marine Resources
La Jolla, California 92093